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सी.एस.आई.आर-केन्द्रीय यान्त्रिक अभियान्त्रिकी अनुसंधान संस्थान, दुर्गापुर

BIENNIAL REPORT 2012 - 14

CSIR - CENTRAL MECHANICAL ENGINEERING RESEARCH INSTITUTE
DURGAPUR

द्विवार्षिक प्रतिवेदन
Biennial Report
2012 - 2014

सी. एस. आई. आर – केन्द्रीय यान्त्रिक अभियान्त्रिकी अनुसंधान संस्थान, दुर्गापुर

CSIR - Central Mechanical Engineering Research Institute, Durgapur

About CSIR-CMERI

The **CSIR-Central Mechanical Engineering Research Institute** is a public funded engineering research and development institution in Durgapur, West Bengal, India. It is a constituent laboratory of the Indian Council of Scientific and Industrial Research (CSIR). CSIR-CMERI is the only national level research institute in the field of mechanical engineering in India and is mandated to conduct cutting edge research in the broad area of mechanical engineering along with allied engineering disciplines.

CSIR-CMERI was founded in February 1958 under the endorsement of the CSIR for developing mechanical engineering technology on an indigenous basis, specifically for helping Indian industries. During its first decade, the CMERI mainly focused its efforts towards development of indigenous technology and import substitution. Currently, the Institute is making R&D efforts in the front-line areas of research such as Robotics; Mechatronics; Microsystems; Manufacturing; Thermal Engineering; Precision Agriculture; Cybernetics, Electronics, Drives & Control & Embedded Systems; Near Net Shape Manufacturing and Biomimetics. Besides conducting cutting-edge research, the Institute works towards different R&D based mission mode programs of the country to provide suitable technological solutions for poverty alleviation, societal improvement, energy security, food security, aerospace, mining, automobile and defense.

CSIR-CMERI has developed many products and processes, out of which 26 have been awarded prestigious national awards. CSIR-CMERI has a repository of more than 100 patents, many of which have been transferred to industries for commercial exploitation.

The institute is one of the nodal points of National Knowledge Network connectivity program under multi-gigabit pan-India network to share intellectual property and knowledge-base among premier R&D labs/institutes/universities of the country.

The Mechanical Engineering Research & Development Organization (MERADO) at Ludhiana, which had long served as an extension center of CMERI was established to concentrate on technology development and provision of expertise to around 65,000 small & medium scale industries concentrated in and around Ludhiana, Punjab. In the past, a major component of R&D carried out at this center has gone in towards the development of appropriate machinery for productivity enhancement in the agricultural and the post-harvest processing sectors. The CSIR-CMERI Centre of Excellence for Farm Machinery, a major take-off from the erstwhile MERADO is now concentrating on precision farming, multi-cropping and productivity improvement of available land that would lead to conservation of seed, water and fertilizer through the development of advanced farm machinery equipped with advanced sensors and systems for precision farming.

Institute Vision

To be an innovative and focused R&D Institute serving the customers and social needs and to become the best R&D organization in the field of Mechanical Engineering.

Institute Mission

To ensure satisfaction of customers regarding quality, delivery and cost of technology and services.

सी.एस.आई.आर–सी.एम.ई.आर.आई के बारे में

सी.एस.आई.आर-केंद्रीय यांत्रिक अभियांत्रिकी अनुसंधान संस्थान एक लोक वित्त पोषित अभियांत्रिकी अनुसंधान एवं विकास संस्थान है, जो दुर्गापुर, पश्चिम बंगाल, भारत में अवस्थित है। यह वैज्ञानिक एवं औद्योगिक अनुसंधान परिषद, भारत (सी.एस.आई.आर) की एक घटक प्रयोगशाला है। सी.एस.आई.आर-सी.एम.ई.आर.आई भारत में यांत्रिक अभियांत्रिकी के क्षेत्र में अनुसंधान करनेवाला राष्ट्रीय स्तर का एकमात्र संस्थान है तथा यह यान्त्रिक अभियांत्रिकी के संबद्ध विषयों के साथ यांत्रिकी के व्यापक क्षेत्र में अत्याधुनिक अनुसंधान करने के लिए अधिकारप्राप्त है।

सी.एस.आई.आर-सी.एम.ई.आर.आई की स्थापना फरवरी, 1958 में स्वदेशी आधारवाले खासकर भारतीय उद्योगों को सहयोग करने के लिए यांत्रिक अभियांत्रिकी तकनीकी को विकसित करने हेतु सी.एस.आई.आर के अनुमोदन के तहत की गई थी। अपने पहले दशक के दौरान, सी.एम.ई.आर.आई ने अपना ध्यान मुख्य रूप से स्वदेशी तकनीकी एवं आयात प्रतिस्थापना को विकसित करने पर केंद्रित किया। वर्तमान में, संस्थान रोबोटिक्स; मेकैट्रोनिक्स; माइक्रोसिस्टम्स; मैन्यूफैक्चरिंग; थर्मल इंजीनियरिंग; प्रेसिसन एग्रीकल्चर, साइबरनेटिक्स, इलेक्ट्रोनिक्स, ड्राईव, कंट्रोल ऐंड इम्बेडेड सिस्टम्स; नियर नेट शेप मैन्यूफैक्चरिंग एवं बायोमिमेटिक्स जैसे अनुसंधान के अग्रणी क्षेत्रों में अनुसंधान एवं विकास करने का प्रयास कर रहा है। अत्याधुनिक अनुसंधान करने के अतिरिक्त, संस्थान गरीबी उन्मूलन, सामाजिक विकास, ऊर्जा सुरक्षा, खाद्य सुरक्षा, अंतरिक्ष प्रौद्योगिकी, खनन, ऑटोमोबाइल एवं प्रतिरक्षा के लिए अनुकूल प्रौद्योगिकी समाधान प्रदान करने हेतु देश के विभिन्न अनुसंधान एवं विकास आधारित लक्ष्य निर्धारित कार्यक्रमों के प्रति कार्य कर रहा है।

सी.एस.आई.आर-सी.एम.ई.आर.आई ने कई उत्पादों एवं प्रक्रियाओं को विकसित किया है, जिसमें से 26 को सम्माननीय राष्ट्रीय पुरस्कार प्रदान किया गया है। सी.एस.आई.आर-सी.एम.ई.आर.आई के पास 100 से अधिक पैटन्ट का संग्रह है, जिनमें से कई को वाणिज्यिक अन्वेषण के लिए उद्योगों को हस्तान्तर कर दिया गया है।

संस्थान देश के प्रमुख अनुसंधान एवं विकास प्रयोगशालाओं/ संस्थानों /विश्वविद्यालयों में बौद्धिक सम्पदा एवं ज्ञान-आधार को साझा करने के लिए मल्टी-गिगाबिट पैन-इंडिया नेटवर्क के तहत नेशनल नॉलेज नेटवर्क कनेक्टिविटी प्रोग्राम के मुख्य बिन्दुओं में एक है।

लुधियाना स्थित यांत्रिक अभियांत्रिकी अनुसंधान एवं विकास संगठन (एम.ई.आर.ए.डी.ओ), जिसने लम्बे समय तक सी.एम.ई.आर.आई के एक हिस्सा के रूप में सेवा प्रदान की थी, की स्थापना पंजाब के लुधियाना और उसके आस-पास के अंचलों में करीब 65,000 लघु एवं मध्यम स्तर के उद्योगों के प्रौद्योगिकी विकास एवं विशेषज्ञत आवश्यकताओं पर ध्यान केंद्रित करने के लिए की गई थी। अतीत में, इस केंद्र में किए गए अनुसंधान एवं विकास के बड़े अवयव कृषि तथा फसल पश्चात् प्रसंस्करण क्षेत्रों में उत्पादन बढ़ाने के लिए उचित मशीनरी को विकसित करने के काम में आए। फार्म मशीनरी के लिए सी.एम.ई.आर.आई उत्कर्ष केंद्र सी.ओ.ई.एफ.एम, जो पूर्ववर्ती एम.ई.आर.ए.डी.ओ से अधिक प्रभावशाली है, अब प्रेसिसन फार्मिंग, बहु-फसली एवं उपलब्ध भूमि की उत्पादकता में सुधार करने पर ध्यान केंद्रित कर रह है, जो अत्याधुनिक सेंसरों के साथ सुसज्जित उन्नत फार्म मशीनरी को विकसित कर बीज, जल एवं उर्वरक का संरक्षण करेगा। वर्तमान में, इस केंद्र का मुख्य अनुसंधान एवं विकास जैव-ईंधन के विभिन्न स्रोतों के अन्वेषण एवं अपनी निष्कर्षण प्रौद्योगिकी को निपुण बनाने के प्रति केंद्रित है।

संस्थान की दृष्टि

यांत्रिकी एवं अभियांत्रिकी के क्षेत्र में सर्वश्रेष्ठ अनुसंधान एवं विकास संगठन के रूप में स्थापित होना तथा ग्राहक सेवा एवं सामाजिक आवश्यकतायों की पूर्ति में सक्षम नवोन्मेश केंद्रित शोध एवं विकास संस्था के रूप में स्थापित होना।

संस्थान का उद्देश्य

तकनीकी एवं सेवा के लागन एवं प्रदायगी तथा गुणवत्ता के संदर्भ में ग्राहकों की संतुष्टि सुनिश्चित करना।

CONTENTS

Engineering today is multidisciplinary: to claim that you are an engineer, you must earn experience in more than one field. Multidisciplinary work yields joy and satisfaction as one gets on finding innovative solutions to intriguing problems. Working on multidisciplinary research demands in-depth knowledge on the related fundamental subjects. Mechanical Engineering is the integral part of device design regardless of its application and complexity. Understanding science, conversion of the concepts and knowledge into technology and finally innovation forms the heart of progress of a nation.

Keeping the scenario in mind, CSIR-CMERI is entering into a paradigm to execute the projects under the national programme of 12th Five Year Plan. Two major responsibilities of CSIR-CMERI are: a mega project on Robotics & Micromachines and a large mission project on Autonomous Underwater Robotics. In both the areas, the responsibility is to develop cutting-edge electromechanical devices involving sensors, power sources, precision-kinematics, analog and digital electronics, software for navigation and control algorithms. The Supra Institutional Network Project (SINP) is yet another major task. The project is aimed at developing intelligent actuators, biomimetic tools, early detection of diabetic retinopathy, vibration control, magnetically levitated bearings, IPMC based microrobots, friction analysis, nano-tribology related lubricants, etc.

Participation in the project on Clean Coal Technology (TAPCOAL) spearheaded by CSIR-CIMFR is a significant drive of CSIR-CMERI scientists in the broader area of energy and power generation. The scientists in the Aerosystem Engineering group are working for a renaissance in new generation valves, novel hydraulic and pneumatic devices.

The group on Advanced Materials Processing is focusing on experimental research and development in nanomaterials processing for different functional applications like Dye Sensitized Solar Cell (DSSC), Nano-hybrid Materials for Tissue Engineering and Structural Nanocomposites for Cutting Tools. The group is also engaged in the development of Bio-Sensors for detecting organic contaminants. Some scientists are engaged in fabrication of nano-composite porous-filter for toxic pollutant removal from waste water. Scientists of the group are also working in the area of toxic and inflammable gas sensing by semi conducting metal oxide and multi-ferroic material for sensor development.

The activities in Electrical & Electronics have been remarkable over the last four years. They are thriving with their forthcoming venture in power-electronics for electric cars and newer control mechanisms for improved drives. The group is a major contributor in the TAPSUN project. Recently CSIR-CMERI scientists have been granted US patent on Portable Magnifying Instrument for Colposcopy (Patent No. US 8,422,130 B2). A major project has been funded by the Department of Science and Technology (DST) and CSIR for developing a mini-DMD (Direct Metal Deposition) machine. The project on Rheo-Pressure Die Casting has been a very successful joint venture of DST and CSIR-CMERI yielding several important scientific publications and an end-to-end process development.

Some significant developments have taken place in the area of microchannel flows involving novel utilization of gold-nano particles. The work on Reconfigurable Microfactory has been completed. The Five Axis Micro Milling Machine is ready for commercialization. As such, the Reconfigurable Microfactory and the Five-Axis Micro Milling Machine have been identified amongst the most significant CSIR products in the last 70 years. In this list of most significant products, AUV-150 (Autonomous Underwater Vehicle) and Voice Controlled Wheel Chair also found place together with CSIR-CMERI's traditional pride SWARAJ and SONALIKA tractors. During the 11th Five Year Plan period, CSIR-CMERI developed Serpentine Robots that are capable of entering inaccessible corridors for the purpose of disaster mitigation. On July 17, 2011, deep into the heart of the Bay of Bengal, buffeted by a choppy sea amidst inclement weather, the AUV-150 – an Autonomous Underwater Vehicle designed and developed by CSIR-CMERI, Durgapur, literally plumbed a sea depth of 150 m within its estimated mission time. This event marked the end of a protracted effort for obtaining self-sufficiency in the design development underwater robotic systems, for which the country had to depend solely on foreign sources. The project was sponsored by the Ministry of Earth Sciences, Govt. of India. IIT Kharagpur was a partner in this project. Such developments have to enter the next level of excellence during the 12th Five Year Plan period.

During the period of 12th Five Year Plan, activities in micro and nano technology would be extended to Dip-Pen Nanolithography and development of PDMS microfluidic chips. Some scientists are exploring Graphene based Bionic materials for neural interfaces. CSIR-CMERI was a partner of VECC Kolkata, for design and fabrication of Radio Frequency Quadruple (RFQ) LINAC at VECC. After successful execution of the responsibilities, CSIR-CMERI has been chosen a partner of the project entitled **Facility for Antiproton and Ion Research (FAIR)** being carried out at GSI Darmstadt, Germany. The co-ordination committee comprising the Department of Science and Technology (DST) and the Department of Atomic Energy (DAE) have formed a consortium of Indian stakeholders and CSIR-CMERI has been given the responsibility to play an important role in engineering design.

In addition to creating a massive impact on Farm Machinery and related components, the Extension Centre of CSIR-CMERI in Ludhiana has, for the first time in the country, developed a Mobile Bridge Inspection Unit (MBIU). The project was jointly funded by the Department of Science and Technology (DST) and CSIR. The Extension Centre in Ludhiana is expected to become a part of the Networking Institute for Manufacturing Technology (NIMT) during the 12th Five Year Plan period. CSIR-CMERI has been given the responsibility of incubating NIMT in collaboration with CSIR-NCL and CSIR-CEERI.

The Simulation and Modeling activities have drawn attention of the country due to its contribution to a major project of the Aeronautical Development Agency (ADA) and several cutting edge publications in the top tier journals including Physical Review Letters (PRL). The Simulation and Modeling Group is a major partner of CSIR-CIMFR in the exciting developments of underground coal gasification technology (Coal Gas Urja). During the 12th Five Year Plan period, the group has another major responsibility of simulating the motion of underwater vehicles at a sea depth of 1000m. Simulation activities have been extended to the analysis of self-organized nano-patterning of thin bilayers using Molecular Dynamics (MD).

Under the broad umbrella of 12th Five Year Plan projects, CSIR-CMERI scientists are participating in the project on Very High Power Microwave Tubes of CSIR-CEERI, BIOCERAM of CSIR-CGCRI, Extraction of Coal from greater depths of CSIR-CIMFR, Engineering of Disaster Mitigation and Health Monitoring of Safe and Smart Built Environment (EDMISSIBLE) of CSIR-CBRI, Development of Advanced Materials of CSIR-NPL, Development of Multifunctional Electrodes of CSIR-CECRI. Participation of CSIR-CMERI scientists also includes large mission projects of CSIR-AMPRI, CSIR-SERC (I-Heal), CSIR-CSIO (ASHA), CSIR-NEERI and CSIR-NISCAIR.

CSIR-CMERI is a stakeholder in CSIR's initiative to be associated with MSMEs for the prosperity of poorly-organized sectors. CSIR-CMERI scientists have already completed the task of design and development of semi-mechanized machine for incense stick making and polishing operations. An IC-Engine test bed has been made ready to provide training to the workers of the Ghaziabad Auto Cluster. A robotic intervention is also being planned for the Auto Cluster.

India is proud of some of the companies for their massive contributions to combat the technological denial regime. Public sector enterprises such as ECIL, BHEL, NTPC, SAIL, IOCL, etc. are definitely pride possessions of mother India. The CSIR Laboratories have to play a paramount role to support such companies in the era of globalization. The country has to depend more and more on innovation-driven techno-economical paradigm for the better livelihood of millions of Indians. CSIR-CMERI will shoulder these responsibilities. The Academy of Scientific and Innovative Research (AcSIR) is ready to do the required hand holding for generation of new knowledge. The synergy between AcSIR and CSIR will stimulate the developments faster and we will see a better performing CSIR-CMERI in the coming years.

Gautam Biswas

Pijush Pal Roy

आज के युग में अभियांत्रिकी बहुआयामी हो गई है-आज एक अभियंता होने के लिए एकाधिक क्षेत्रों में अनुभवी होना अनिवार्य हो गया है। बहुआयामी कार्य अनुभव से आनंद एवं संतुष्टि की प्राप्ति होती है क्योंकि व्यक्ति को नूतन पहेलियों जैसी समस्याओं के अभिनव समाधान खोजने के लिए प्रयासरत रहना होता है। बहुआयामी शोध कार्य में संबंधित मौलिक विषयों के गंभीर ज्ञान की प्रयोजन होती है। उपकरणीय अभिकल्प में उनके अनुप्रयोग और जटिलता की विभिन्नताओं को साथ ही यांत्रिकी अभियांत्रिकी इसका अभिन्न अंग है। विज्ञान को समझना, इसके सिद्धांतों तथा ज्ञान को प्रौद्योगिकी में परिवर्तित करना और उद्भावन राष्ट्र का उन्नति दिलाता हैं।

इस को ध्यान में रखते हुए, सी.एस.आई.आर-सी.एम.ई.आर.आई 12 वीं राष्ट्रीय पंचवर्षीय योजना के अंतर्गत परियोजनाओँ को निष्पादित करने हेतु प्रयासरत है। सी.एस.आई.आर-सी.एम.ई.आर.आई के दो महत्वपूर्ण दायित्व हैं - रोबोटिक्स एवं माइक्रोमैकेनिक्स और ऑटोनोमस अंडरवाटर रोबोटिक्स - जंहा एक वृहद लक्ष्य को प्राप्त करने हेतु परियोजना पर कार्य चल रहा है। दोनों ही क्षेत्रों में नेवीगेशन एवं कंट्रोल एल्गोरिद्मस, सेन्सर, पॉवर सौर्शेज, प्रेसीसन काइनेमेटिक्स, एनेलॉग एवं डिजिटल तथा इलेक्ट्रॅनिक्स, सॉफ्टवेयर सहित आधुनिकतम इलेक्ट्रो मैकेनिकल उपकरण विकसित करने का उत्तरदायित्व है। सुप्रा इंस्टीटयूशनल नैटवर्क प्रोजेक्ट भी एक बहुत बड़ा उत्तरदायित्व है। इस परियोजना का उद्देश्य इंटेलीजेंट एक्च्युएटर्स, बायोमिमेटिक उपकरण, डायेवेटिक रेटिनोपैथी की शीघ्र पहचान, कंपन नियंत्रण, मैग्नेटिकली लेविटेटिड बीयरिंग्स, आई.पी.एम.सी आधारित माइक्रोरोबटस, फ्रिक्शन एनेलाइसिस, नैनो-ट्राईबोलोजी से संबंधित लुब्रीकेंटस आदि विकासित करना है।

ऊर्जा एवं बिजली उत्पादन के बृहद क्षेत्र में सी.एस.आई.आर-सी.एम.ई.आर.आई के वैज्ञानिकों द्वारा स्वच्छ कोयला प्रौद्योगिकी (टैपकोल) परियोजना में सहभागिता करना सी.एस.आई.आर-सी.आई.एम.एफ.आर के नेतृत्व में उल्लेखनीय प्रयास है। एयरो-सिस्टम के वैज्ञानिक न्यू जेनरेशन वाल्वस, नोवल हाइड्रोलिक एवं न्यूमेटिक डिवाइसेस के नवयुग प्रवर्तन हेतु प्रयासरत हैं।

एडवांस्ड मैटीरियल्स प्रोसेसिंग ग्रुप विभिन्न प्रकार्यात्मक अनुप्रयोगों जैसे कि डाई सैसिटाइज्ड सोलर सैल (डी.एस.एस.सी), टिशु इंजीनियरिंग के लिए नैनो-हाइब्रिड, कटिंग टूल्स के लिए नैनोकंपोजिट्स, आदि के लिए प्रयोगात्मक शोध एवं विकासात्मक कार्यों पर अपना ध्यान केंद्रित कर रहा है। आर्गेनिक कंटेमिनेंटस की पहचान, बायो-सैंसर्स विकसित आदि करने के लिए भी काम चल रहा है। कुछ वैज्ञानिक अपशिष्ट जल से विषैले प्रदूषक दूर करने के लिए नैनो-कंपोजिट-पॉरस-फिल्टर का फैब्रीकोशन करने में लगे हुए हैं। समूह के वैज्ञानिक टॉक्सिक तथा इनफ्लेम्मेवल गैस सैंसिंग के क्षेत्र में संसूचक विकास के लिए सेमी कंडक्टिंग मैटल ऑक्साइड तथा मल्टी-फैरोइक पदार्थ पर भी काम कर रहे हैं।

पिछले चार वर्षों में विद्युत एवं इलेक्ट्रोनिक्स के क्षेत्र में विशेष उल्लेखनीय कार्य हुए हैं। इलेक्ट्रिक कारों के लिए नूतन नियंत्रण यांत्रिकी विकसित करने के काम भी चल रहा हैं। यह (TAPSUN) परियोजना में भी उल्लेखनीय योगदान कर रहा है। अभी हाल ही में सी.एस.आई.आर-सी.एम.ई.आर.आई वैज्ञानिकों को कोलपोस्कोपी (Colposcopy) पर अमेरिकी पेटेंट (Patent No.US 8,422,130 B2) पोर्टेबिल मैग्नीफाइंग इंस्ट्रूमैंट विकसित करने के लिए मिला है। एक मिनी डायरेक्ट मैटल डिपोजीशन मशीन विकसित करने के लिए विज्ञान एवं प्रैद्योगिकी विभाग (डी.एस.टी) एवं सी.एस.आई.आर से एक बहुत बड़ी परियोजना को अनुदान मिला है। रियो प्रेशर डाईकास्टिंग पर एक परियोजना डी.एस.टी एवं सी.एस.आई.आर-सी.एम.ई.आर.आई का संयुक्त सफल कार्यक्रम है जिससे अनेक महत्वपूर्ण वैज्ञानिक प्रकाशन जरनलों में प्रकाशित हुए हैं तथा आद्योपांत विकास प्रक्रिया संपन्न हुई है।

गोल्ड नैनो पार्टीकल्स के नोवल यूटिलाइजेशन का प्रयोग करते हुए माइक्रोचैनल फ्लोज के क्षेत्र में कुछ महत्वपूर्ण नूतन निष्कर्ष निकाले गए हैं। रिकानफिगरेबल माइक्रोफैक्टरी पर काम भी पूरा हो चुका है।

पांच अक्षीय माइक्रो मिलिंग मशीन व्यवसायीकरण के लिए तैयार है। यह एक विशेष प्रसन्नता की बात है कि पिछले 70 वर्षों में पांच अक्षीय माइक्रो मिलिंग मशीन एवं रिकानफिगरेबल माइक्रोफैक्टरी को सी.एस. आई.आर द्वारा विकसित उत्पादों में सबसे महत्वपूर्ण उत्पाद के रुप में पहचाना गया है। सर्वोत्तम उल्लेखनीय उत्पादों की श्रेणी की सूची में एयूवी-150 (आटोनोमस अंडरवाटर व्हीकिल) एवं वाइस कंट्रोल्ड व्हील चेयर ने भी सी.एस.आई.आर-सी.एम.ई.आर.आई के पारंपरिक गौरव स्वराज एवं सोनालिका ट्रैक्टरों के साथ अपना स्थान बनाया है। सी.एस.आई.आर-सी.एम.ई.आर.आई ने 11 वीं पंचवर्षीय योजना अवधि के दौरान आपदा राहत न पहुंच वाले स्थानों में भी प्रवेश करने में सक्षम सर्पेन्टाइन रोबोटस का विकास किया है। बंगाल की खाड़ी में 17 जुलाई 2011 को तूफानी मौसम की अस्थिर समुद्र में एयुवी-150-लगभग 150 मीटर गहराइ के भीतर अनुमानित समय में अपना मिशन को पूरा किया । यह घटना बहुत ही महत्वपूर्ण है जिसने देश को विदेशी शक्तियों से मुक्त कर प्रौद्योगिकी रुप से आत्मनिर्भर बना दिया। अब तक अंडर वाटर रोबोटिक्स सिस्टम डिजाइन विकसित करने के लिए विदेशी स्रोतों पर निर्भर रहना होता था। यह परियोजना पृथ्वी विज्ञान मंत्रालय, भारत सरकार द्वारा प्रायोजित थी और भारतीय प्रौद्योगिकी संस्थान खड़गपुर इसमें एक सहभागी था। इस प्रकार के विकास कार्यों को 12 वीं पंचवर्षीय योजना में उत्कृष्टता के अगले चरण पर पहुंचाने की तैयारी करनी है।

माइक्रो एवं नैनो टैक्नोलोजी में शोध कार्य — डिप-पैन-नैनोलिथोग्राफी एवं पी.डी.एम.एस माइक्रो फ्लूड़डिक चिप्स के विकास 12 वीं पंच वर्षीय योजना की अवधि तक विस्तारित किया जाएगा। कुछ वैज्ञानिक ग्राफेन आधारिक बायोनिक पदार्थों को न्यूरल इंटरफेस के लिए विकसित करने हेतु संभावनाएं तलाशने के काम में लगे हैं। सी.एस.आई.आर-सी.एम.ई.आर. आई रेडियो फ्रेक्वेंसी क्वाड्रपल (आर.एफ.क्यू) एल.आई.एन.ए.सी के फैब्रीकेशन एवं डिजाइन के लिए वी.ई.सी.सी, कोलकाता का एक सहयोगी रहा है। अपने उत्तरदायित्वों तथा दिए गए कार्यों को पूर्ण रुप से सौपने के बाद सी.एस.आई.आर-सी.एम.ई.आर.आई को जी.एस.आई डर्मस्टैड, जर्मनी द्वारा फॅसिलिटि फार एंटीप्रोटोन एवं आयन रिसर्च (FAIR) परियोजना के लिए सहयोगी चुना गया है। समन्वय समिति में विज्ञान एवं प्रौद्योगिकी विभाग तथा परमाणु ऊर्जा विभाग ने मिलकर एक संघटन बनाया है जिमसें भारतीय पक्षकारों तथा सी.एस.आई.आर-सी.एम.ई.आर.आई को शामिल किए गए हैं और अभियांत्रिकी डिजाइन में एक मइत्वपूर्ण भूमिका निभाने का दायित्व दिया गया है।

सिमूलेशन एवं मॉडेलिगं विभाग की कार्यकलापों ने देश का ध्यान आकृष्ट किया है। ए.डी.ए की एक बड़ी परियोजना से उभरते हुये गवेषणा पत्रों शीर्ष स्तरीय जरनलों — जैसे कि फिजीकल रिव्यु लैटर्स आदि में प्रकाशित हुये है। अंडरग्राउंड कोल गैसीफिकेशन टैक्नोलोजी (कोल गैस ऊर्जा) के उत्साहशील विकास कार्यक्रमों में सहयोग करने के लिए सिमूलेशन एवं मॉडेलिगं समूह महत्वपूर्ण भागीदार है। इस समूह को 12 वीं पंचवर्षीय योजना की अवधि के दौरान एक और महत्वपूर्ण परियोजना — सागर में 1000 मीटर गहराई में अंडरवाटर व्हीकिल्स की मोशन सिमूलेशन का दायित्व मिला है। सिमूलेशन क्रियाकलापों को स्वयं व्यवस्थित नैनो-पैर्टनिंग ऑफ थिन बाइलेयर्स के विश्लेषण तक मॉलीक्यूलर डायनेमिक्स का प्रयोग करते हुए विस्तारित किया गया है।

सी.एस.आई.आर-सी.एम.ई.आर.आई वैज्ञानिकगण 12 वीं पंचवर्षीय योजना के विशाल परिवेश में सी.एस.आई.आर-सी.ई.ई.आर.आई की अति उच्च शक्ति माइक्रोवेव टयूब्स; सी.एस.आई.आर-सी.जी.सी.आर.आई की वायोसेरम; सी.एस.आई.आर-सी.आई.एम.एफ.आर की एक्स्ट्रेशन ऑफ कोल फ्राम ग्रेटर डेप्थ्स; सी.एस.आई.आर-सी.बी.आर.आई के सुरक्षित एवं स्मार्ट वातावरण हेतु आपदा राहत एवं स्वास्थ्य मानीटरिंग अभियांत्रिकी; सी.एस.आई.आर-एन.पी.एल के एडवांस्ड मैटीरियल्स के विकास; सी.एस.आई.आर-सी.ई.सी.आर.आई के मल्टीफंक्शनल इलेक्ट्रोडस के विकास आदि परियोजनाओं में सहभागिता की है। सी. एस.आई.आर-सी.एम.ई.आर.आई वैज्ञानिकों ने सी.एस.आई.आर-ए. एम.पी.आर.आई, सी.एस.आई.आर-एस.ई.आर.सी (आई-हील), सी. एस.आई.आर-सी.एस.आई.ओ (आशा), सी.एस.आई.आर-एन.ई.ई.आर. आई एवं सी.एस.आई.आर-एन.आई.एस.सी.ए.आई.आर की बड़ी मिशन परियोजनाओं में भी सहभागिता कर रहे है।

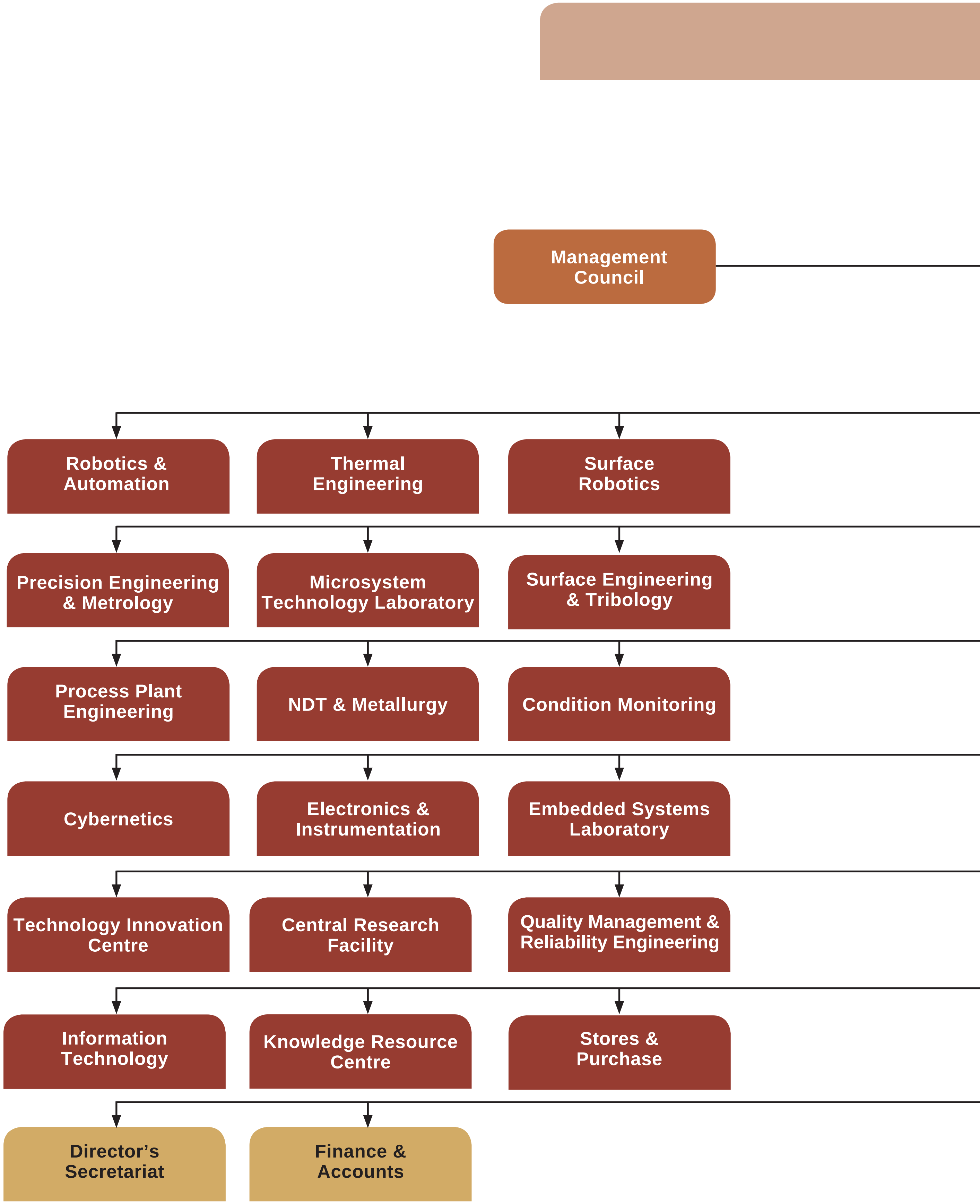
सी.एस.आई.आर-सी.एम.ई.आर.आई आर्थिक रुप से कमजोर-संगठित क्षेत्रों में समृद्धि हेतु सी.एस.आई.आर और एम.एस.एम.ई के संयुक्त प्रयासों में पक्षकार हैं। सी.एस.आई.आर-सी.एम.ई.आर.आई के वैज्ञानिकों ने पहले ही इनसेंस मेकिंग और पालिशिंग आपरेशन्स के लिए सेमी मैकेनाइच्ड मशीन की डिजाइन तथा विकास की प्राप्त किया है। एक आई.सी इंजन टैस्ट बैड को गाजियाबाद ऑटो-क्लस्टर के कर्मचारियों को प्रशिक्षण देने हेतु तैयार किया गया है। ऑटो-क्लस्टर के लिए एक रोबोटिक इंटरवेंशन की भी योजना तैयार की गई है।

प्रौद्योगिकी बंदिश युग में मुकाबला कर अपना महान प्रौद्योगिकीय विकास एवं शोध से योगदान देने वाली कुछ कंपनियों पर भारत देश को गर्व है। लोक क्षेत्र की कंपनियां, उपक्रम जैसे कि ई.सी.आई.एल, बी.एच.ई.एल, एन.टी.पी.सी, एस.ए.आई.एल, आई.ओ.सी.एल आदि ऐसे ही महत्वपूर्ण प्रतिष्ठान हैं जिन पर हमारी मातृभूमि भारत को गर्व है। सी.एस.आई.

आर की प्रयोगशालाओं का ऐसी कंपनियों को वैश्वीकरण के इस दौर में सहायता करने का महत्वपूर्ण दायित्व है। हमें राष्ट्र के करोड़ों भारतीयों के बेहतर जीवन स्तर हेतु अधिक से अधिक मौलिक चिंतन पर आधारित प्रौद्योगिकी–आर्थिक प्रतिमान स्थापित करने हैं। वैज्ञानिक एवं अभिनव शोध अकादमी (AcSIR) नई पीढ़ी के लिए शोध आधारित नवीनतम ज्ञान खोजने हेतु तत्पर है। वैज्ञानिक एवं अभिनव शोध अकादमी (AcSIR) तथा सी.एस.आई.आर का गठबंधन विकास कार्यक्रमों में और प्रगति करेगा तथा निकट भविष्य में हम सी.एस.आई.आर–सी.एम.ई.आर.आई की सहक्रियाओं द्वारा और नए कीर्तिमान स्थापित करने हेतु आशान्वित है।

गौतम विश्वास

पीयुष पाल रॉय



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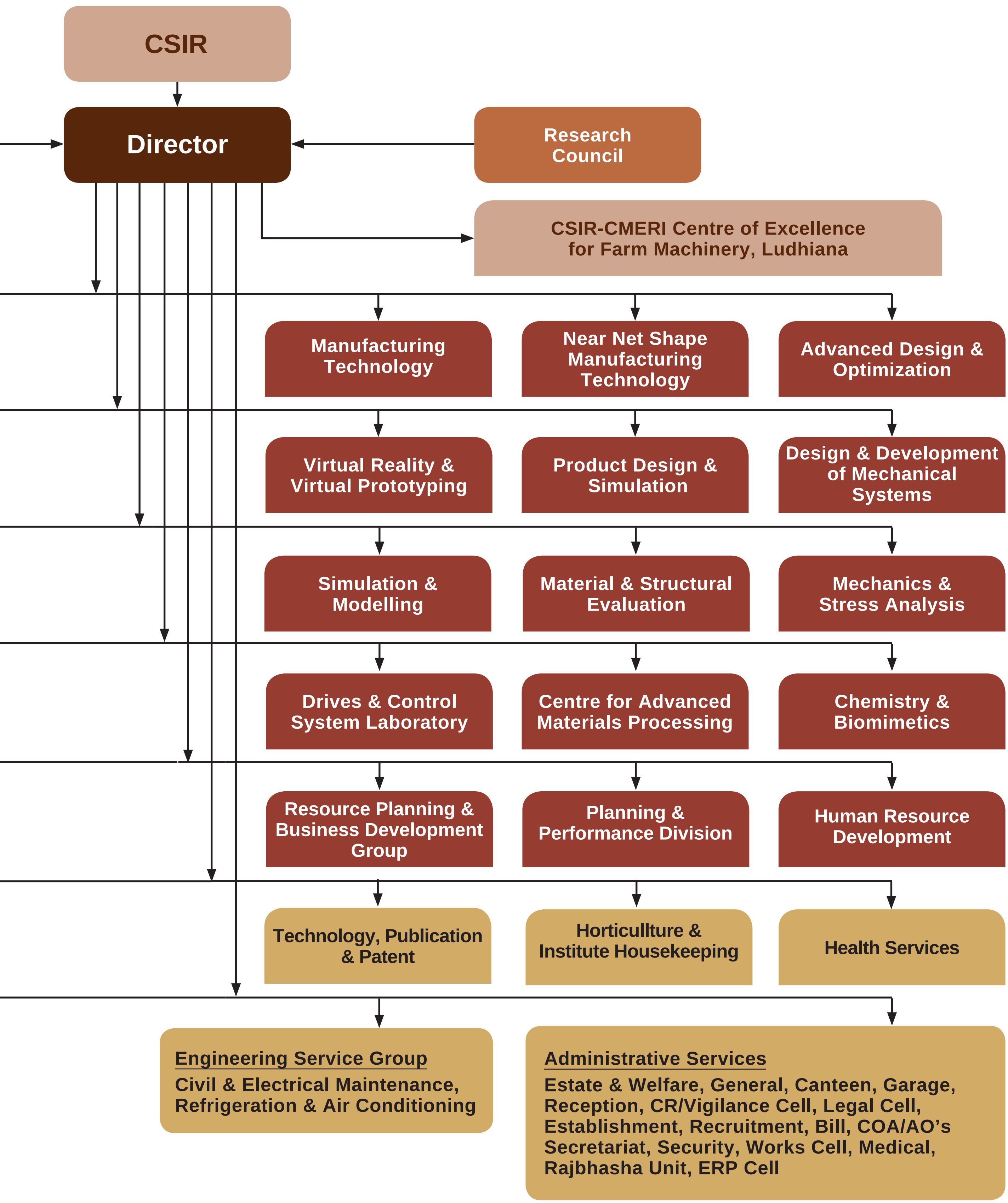

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January 01, 2012 – December 31, 2013

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January 01, 2014 – December 31, 2015

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Research Initiatives

- Computational Modelling of Transport Phenomena in High Energy Materials Processing Application: Large Eddy Simulation and Parallelization
- Simulation of Water Droplet Mobility in Gas Flow Channels of PEM Fuel Cell using the Lattice Boltzmann Method
- Design & Exploration of Nanocrystalline Multiferroic Materials
- Synthesis and Modification of Metal Oxides at Nano and Micron Length Scale for Gas Sensing and Dye Sensitized Solar Cell Applications
- Fabrication and Characterization of Flat Sheet Membranes
- Design and Development of Gold-Iron Oxide Based Smart Magnetic Nanosensor for Detection and Separation of Heavy Metal Ions
- Wire Drawing Die Wear Monitoring - Challenges and Achievements
- Appropriate Mechanization Project at the Durgapur Steel Plant
- Development of 100% Biofuelled Tractor
- Smart and Intelligent Actuator Based Micro Manipulation Systems for Robotic Micro Assembly
- Metal Injection Moulding
- New Initiatives at the Microsystem Technology Laboratory
- Synthesis of Single Layer Graphene and its Polymer Nanocomposites for the Fabrication of a High Performance Flexible Electrode

Computational Modelling of Transport Phenomena in High Energy Materials Processing Application: Large Eddy Simulation and Parallelization

The Importance, Objectives and Methodology

Laser assisted manufacturing processes such as laser cutting, laser drilling, laser cladding and laser surface alloying are considered to be the most modern processes of molten metal application, in which the work pieces are locally melted by an intense energy source (in this case laser), followed by solidification. The mechanical strength and microstructure of work pieces are strongly dependent on the thermal histories in the fusion zone and the nearby unmelted region. Further, fluid flow in the molten metal is known to have a considerable effect on the thermal histories and solidification processes. Thorough knowledge of the transport mechanism inside the laser molten pool – which leads to a final re-solidified microstructure – is thus required to predict the thermal behaviour of the process accurately.

Computational studies of fluid flow and heat transfer in high energy materials processing applications have been a subject of intense research for several decades. The majority of the earlier models in this regard are based on laminar flow theory. However, the flow for typically high power laser melting processes may be turbulent if the surface tension Reynolds number is greater than 100. Turbulence modelling in the context of phase change materials processing, in general, is a relatively recent practice. Most of the researchers in this field have preferred the k-ε model for its inherent simplicity. This has been primarily motivated by the fact that the Reynolds-averaged Navier-Stokes (RANS) equations represent transport equations for the mean flow quantities only, with all the scales of the turbulence being apparently modelled. The approach of permitting a solution for the mean flow variables greatly reduces the computational effort. If the mean flow is steady, the governing equations will not contain time derivatives and a steady-state solution can be obtained economically. A computational advantage is seen even in transient situations, since the time step is determined by the global unsteadiness in the mean flow rather than by the turbulent fluctuation scales. It should be understood that the k-ε model simply attempts to capture the turbulence by performing time or space averaging. Under certain conditions, this method can be very accurate; but it might not be very suitable for all transient flows since the averaging process wipes out most of the important characteristics of a time-dependent and large-scale coherent flow structure. Further, the k-ε model may not perform satisfactorily in recirculating flows, since it is based on the Boussinesq hypothesis that does not take into account the rotationality in motion and turbulent anisotropy. Unfortunately, no single turbulence model is universally accepted as being superior for all classes of problems. The choice of the turbulence model would eventually depend on considerations such as the physics encompassed in the flow, the established practice for a specific class of problem, the level of accuracy required, the available computational resources and the time available for the simulation. As such, most of the research currently taking place in the field of CFD concerns capacity of various mathematical models to be able to mimic real-life turbulent flows in a reasonably accurate and physically consistent manner. To that end, many models have been put forth to provide accurate solutions to these flows. Ideally, a direct numerical solution (DNS) would turn out to be the best choice in this respect due to its inherent capability to solve for all time and spatial scales associated with the turbulence. However, from a practical perspective, for most of the complicated CFD problems such as for laser assisted manufacturing processes, DNS is virtually ruled out since these are computationally too intensive. In practice, to resolve all spatial and temporal scales for such problems, the time and space resolutions would need to be extremely refined, resulting in a discretization that would take an extraordinarily long time to solve, even with the best of the computational facilities available these days.

Large eddy simulation (LES) provides an alternative, yet a more practical approach, in which the large eddies are computed in a time dependent simulation that uses a set of filtered equations. Filtering is essentially a manipulation of the exact Navier-Stokes equations to remove only eddies that are smaller than the size of the filter, which is usually taken as the mesh size. Since small eddies contain less turbulent kinetic energy, they have a more "universal" behaviour. Hence, they are more isotropic (based on Kolmogorov hypothesis) and are easier to be modelled. Like Reynolds averaging, the filtering process creates additional unknown terms that must be modelled in order to achieve closure. Statistics of the mean flow quantities, which generally are of engineering interest, are gathered during the time-dependent simulation. The attraction of LES is that by modelling less of the turbulence (and solving more) the errors induced by the turbulence model are greatly reduced. One might also argue that it ought to be easier to find a universal model for the small scales, which tend to be more isotropic and less affected by the macroscopic flow features than the large eddies. However, in a sense that LES computes at least the larger eddies participating in the overall transport process within the problem domain, it is expected to represent the physics of the problem in a manner mathematically more consistent than the commonly used RANS based models. In that respect, LES can be thought of as a reasonable compromise between some of the over-simplified turbulence models commonly employed in engineering analysis and the computationally over-intensive DNS approach.

Another important but often neglected aspect for such kind of computationally intensive flows is parallel processing for speeding up the turnaround time (i.e. the wall clock time) required to complete the task and to come up with a numerical prediction within a reasonable time frame. Chatterjee and Chakraborty (2006) have justified the necessity of parallel processing and have developed an efficient parallel algorithm in conjunction with the k-ε turbulence model for simulating a generic laser surface alloying process. Furthermore, Chatterjee and Chakraborty (2005) have also developed a LES based model pertinent to the phase change process modelling, which is restricted to heat transfer and fluid flow only without considering the mass transfer phenomenon. The mass transfer phenomenon essentially involves incorporation of an additional transport equation with the prevailing set of governing differential equations. This further complicates the situation and the simulation becomes computationally quite expensive.

Accordingly, the aim of computational modelling of transport phenomena in high energy materials processing application: large eddy simulation and parallelization is to perform a comprehensive three-dimensional computational study using the large eddy simulation (LES) model capable of addressing the coupled turbulent momentum and heat and species transport in presence of a continuously evolving phase-change interface and parallelizing the model subsequently for effective computational economy. In order to take into account the phase change aspects of the present problem, a modified enthalpy-porosity technique will be used which is consistent with the continuum approach adopted for the LES model. A typical high power laser surface alloying process will be simulated as a case study and the results would be validated against the available experimental results reported in the literature.

The problem considered in this study is a typical high power laser surface alloying process, the schematic of which is shown in Figure 1, where a continuous beam laser is moving with a constant scanning speed, u_{scan}, along the negative *x*-direction. The intense heat from the laser beam strikes the opaque surface of the base metal. For simulation purpose we consider iron (Fe) as the base material. Only a part of the heat available from the laser beam heats the surface of the work-piece and leads to the formation of a molten pool. As the substrate reaches the molten state, the absorbed energy induces a surface tension driven flow at the top surface. This occurs due to a very high temperature gradient caused by intense heating with the laser. It is important to note here that convection is the single most important factor in the laser molten pool. Though this convection is a combined effect of buoyancy and surface tension forces (Marangoni forces), the latter is found to dominate in the applications of laser surface alloying.

As the pool reaches a completely molten state, an alloying element is added to the pool in the form of a

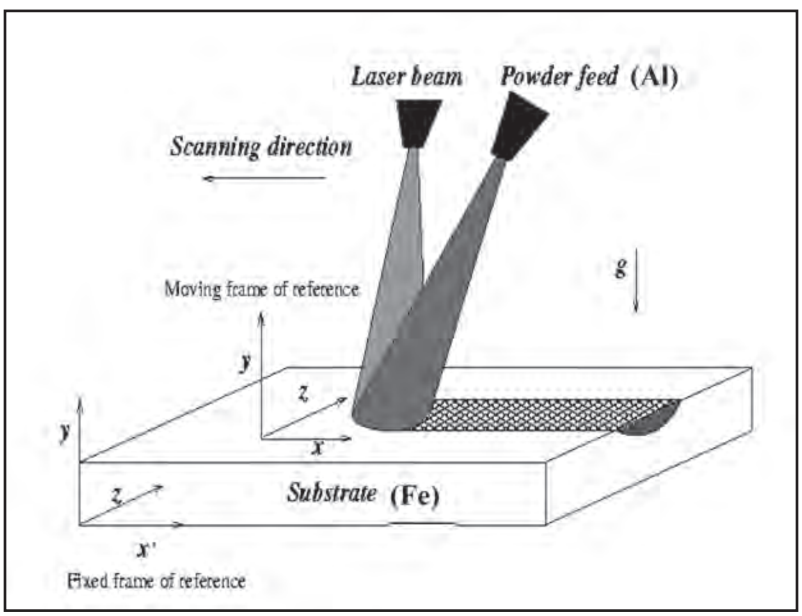


Figure 1: Schematic diagram of a typical laser surface alloying process

powder. We consider aluminium (Al) as the alloying material for simulation purposes. The powder melts and mixes with the molten base metal by convection and diffusion. As the laser source moves away from the location where the pool is already developed, resolidification of the zone occurs, leading to a final solidified microstructure. It is assumed that the alloying material is introduced in a molten state and exists as a dilute solute in the molten pool. Regarding the thermo-physical properties, thermo-solutal variation of thermal conductivity, viscosity and specific heat are taken into account. The molten metal is considered to be Newtonian and incompressible. The density variation owing to thermo-solutal effect is taken care of by Boussinesq approximation.

Some Representative Results

Temperature and velocity fields

The temperature field obtained from numerical simulations is presented in Figure 2. It is important to understand here that the molten pool shape and size is a consequence of the convection process in the pool. For this reason it is instructive to look at the velocity field in the molten pool. The velocity field obtained from simulation is presented in Figure 3. As the surface tension coefficient of temperature is negative in the present case, a fluid element located in the vicinity of the laser source will have a lower surface tension than another fluid element located further away from the source, both fluid elements being located on the top (free) surface. This differential of surface tension gives rise to a radially outward fluid flow at the top surface, as is evident from Figures 3(a) and 3(b). The forces which influence the laser molten pool dynamics are primarily the surface tension force, viscous force and buoyancy force. Amongst all these forces, surface tension force is predominant and the most important as it initiates the flow within the molten pool.

From the top view of the temperature field, it is observed that the isotherms are more or less spherical in nature. Such a pool shape is a consequence of the isotropic nature of eddy diffusion process in which energy is progressively transferred from the largest

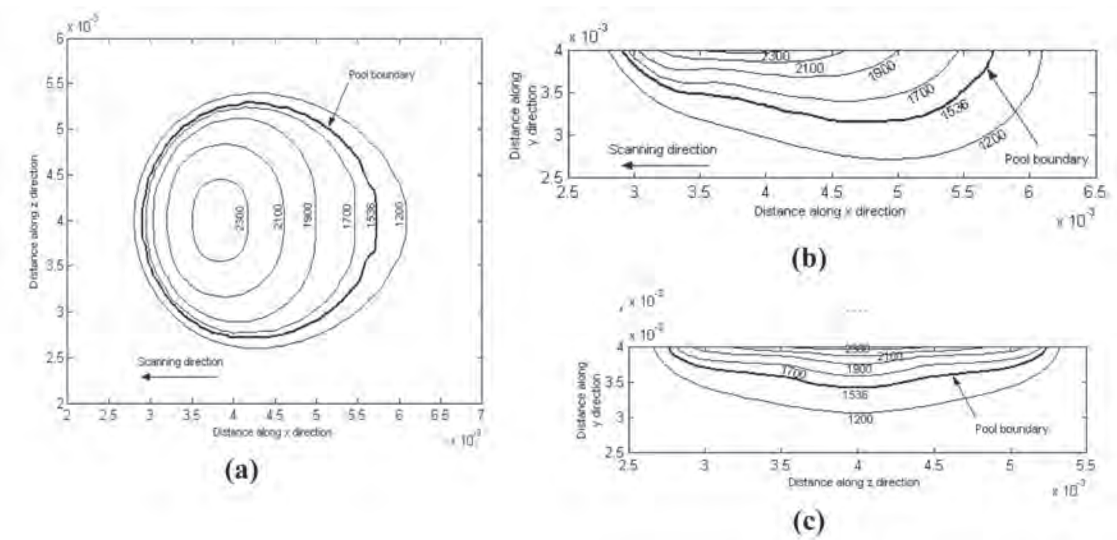
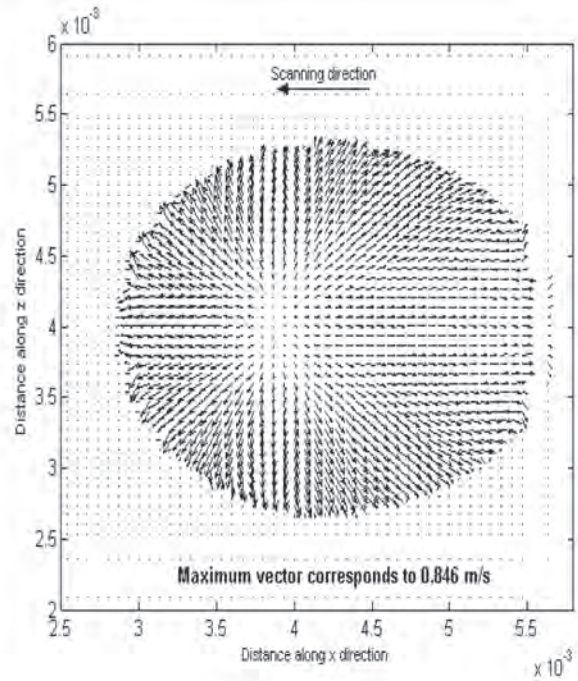
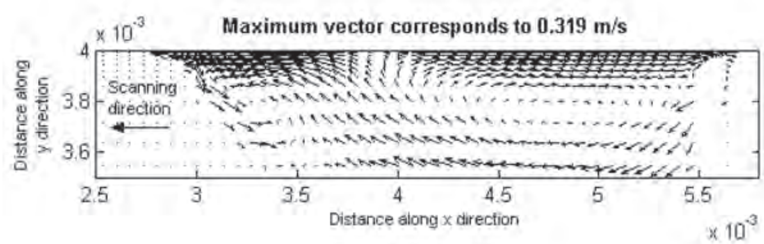


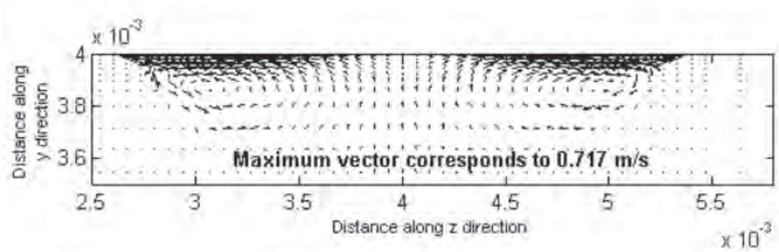
Figure 2: Mean temperature contour plots at 1 s: (a) top view, (b) at longitudinal mid plane, (c) at cross-sectional mid-plane. All the temperatures shown on the contours are in ^0C.



(a)



(b)



(c)

Figure 3: Instantaneous velocity vector plots at 1 s: (a) top view, (b) at longitudinal mid-plane, (c) at cross-sectional mid-plane

to the relatively smaller eddies through interaction between fluctuation velocity components by means of energy cascading. Such effects cannot be captured so elegantly by employing RANS (Reynolds Averaged Navier-Stokes) based turbulent flow models. Further, the net energy available to the pool is transported along the longitudinal and sidewise directions by the Marangoni advection due to the fluid flow, along with the thermal diffusion process. The downward advection of heat is small compared to the longitudinal and span-wise advections because of the small magnitude of downward velocity component as compared to magnitudes of longitudinal and spanwise components. However, due to an enhanced mixing process on interaction between participating eddies the mean advection strength goes down, which results in a decrease in the longitudinal and sidewise advection strengths. On the other hand, an enhanced diffusion process tries to increase the dimensions of the pool in all possible directions. The resultant pool geometry is a consequence of these two counteracting effects. Additionally, thick hydrodynamic boundary layers are formed due to increased momentum transport on account of turbulence (Figure 3).

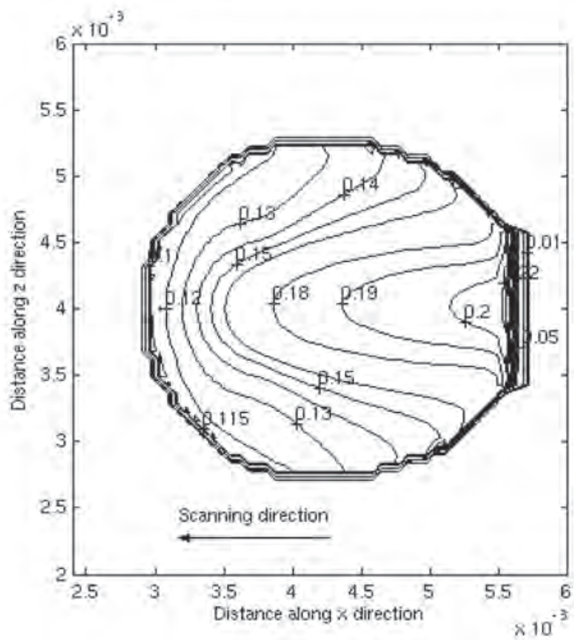
Composition field

The concentration distribution of aluminium in the molten pool is presented in Figure 4. It can be seen that the concentration of the solute is higher near the solidification front and gradually decreases toward the alloying front. At the alloying front, dilution of species takes place due to addition of fresh molten base metal. On the other hand, since the solubility of the solute in the solid phase is less than that in the liquid phase for the present case, preferential solute rejection takes place from the solidified material back into the molten pool at the solidification front. The rejected solute is transported back into the centre of the pool from the solidification front by the advective effect of recirculating molten metal in the pool along with the mass diffusion. The enhanced effective mass diffusivity leads to localized homogenization in the solute concentration field across the scanning direction, resulting in much flatter shapes of iso-concentration lines [approximately normal to the scanning direction along the centre line; Figure 4(a)] with negligible concentration gradients perpendicular to scanning direction, as one looks from the top. Further, the solute rejected at the solidification front diffuses towards the centre of the pool. This effect is manifested by higher penetration of iso-concentration lines near the solidification front [Figure 4(b)]. This has far-ranging consequences in the sense that the species concentration distribution in the vicinity of the solidification interface eventually gives rise to the final microstructure of the resolidified alloy. It can also be observed that due to reduced mean advection strength, a mean advection of alloying material transport from the solidification front to the middle of the pool is reduced. This is evident in the longitudinal view of concentration contours presented in Figure 4(b).

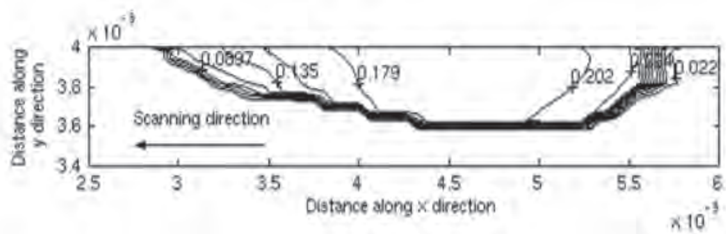
Further, there is an efficient diffusive mixing of rejected solute from the solidification front and dilute fluid emanating from the alloying front. This results in considerable reduction in average solute concentration along the vertical depth of the turbulent pool [Figure 4(c)].

Sub-grid scale turbulence

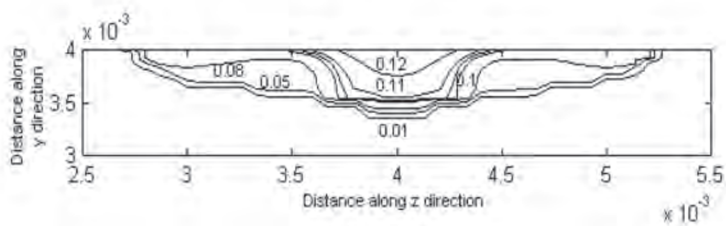
Figure 5 shows a contour plot of the sub-grid scale turbulent kinetic energy in the molten pool. It is observed from Figures 5(a-c) that the turbulent kinetic energy attains a maximum value near the solid/liquid interface. At the solid/liquid interface, the temperature gradients are higher than the rest of the domain. Consequently, the local velocity gradients are also higher. Since the production of sub-grid turbulent kinetic energy is proportional



(a)



(b)



(c)

Figure 4: Mean species distribution plots at 1 s: (a) top view, (b) at longitudinal mid-plane, (c) at cross-sectional mid-plane

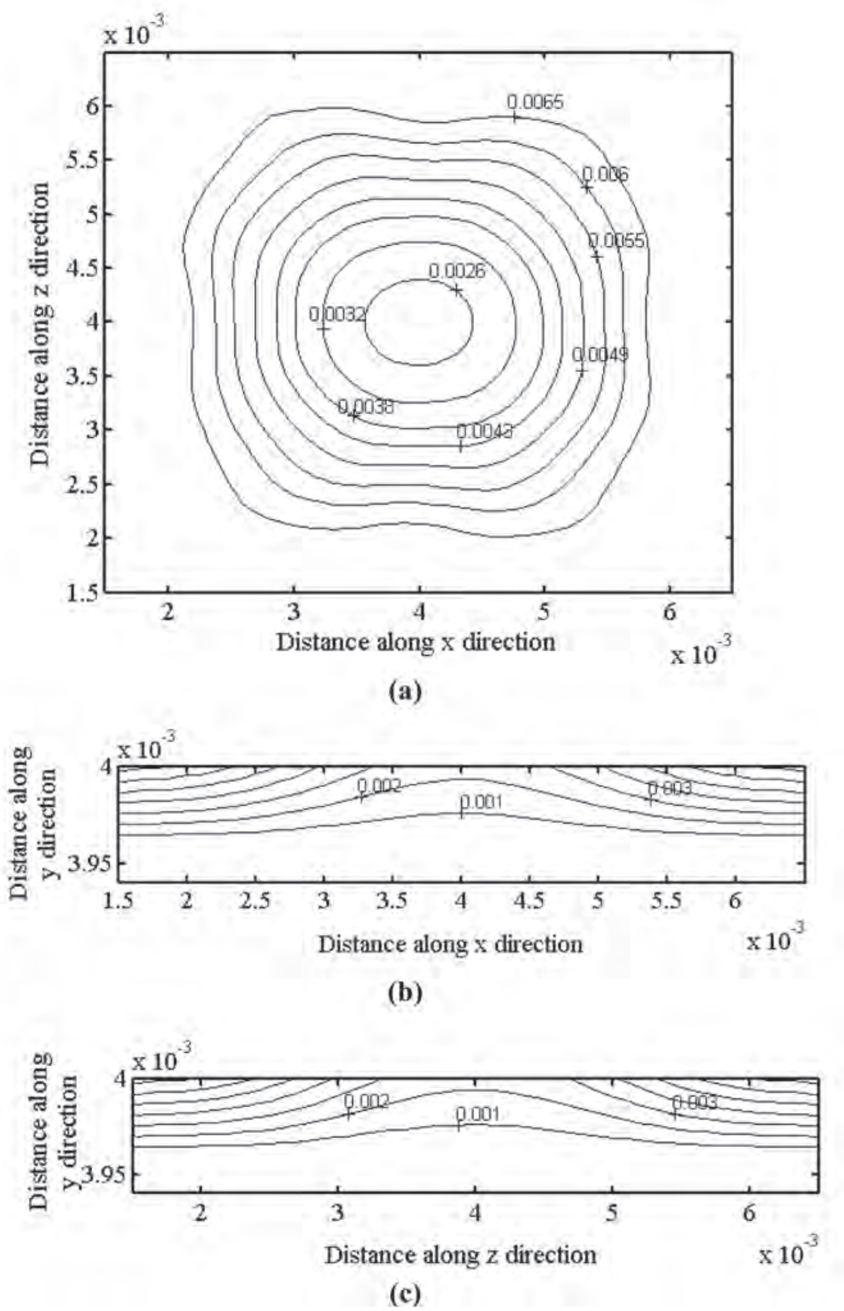


Figure 5: Sub-grid turbulent kinetic energy plots at 1 s: (a) top view
(b) at longitudinal mid-plane
(c) at cross-sectional mid-plane
All the values shown on the contours are in m^2/s^2

to the filtered velocity gradient, the sub-grid scale turbulent kinetic energy generation is a maximum near the solid/liquid interface. The dissipation is considered to be important since it provides a direct measure of the energy emanating from the system. In the context of LES, in addition to the resolved scale dissipation that accounts for the direct loss of energy from the resolved scale to dissipation, sub-grid scale dissipation also takes place, the latter accounting for the net transfer of energy from the resolved scales to the sub-grid scales and eventually to heat. This can physically be elucidated as follows. The largest resolved turbulent eddies interact with and extract energy from the mean flow through vortex stretching. The presence of mean velocity gradients in sheared flows – as captured by an LES – distorts the rotating turbulent eddies. In absence of substantial dissipative effects on account of a high Reynolds number based on large eddy length scales, angular momentum of the large eddies remain approximately conserved. This implies that the larger eddies are forced to elongate (i.e., decrease in cross section) with increase in the rotational rate, as they extract kinetic energy from the mean flow. This process creates motion at smaller transverse length scales (sub-grid scales), and also at smaller time scales. Smaller eddies are themselves stretched strongly by somewhat larger eddies, and more weakly by the mean flow. In this manner, kinetic energy is progressively transmitted to smaller and smaller eddies through a mechanism known as 'energy cascading'. This leads to a situation in which all fluctuating properties of the turbulent flow contain energy over a wide range of frequencies or wave numbers, giving rise to an energy spectrum of turbulence. The smallest scale motion that can occur under these circumstances, however, is dictated by viscosity. At these scales, a sub-grid scale modelling suggests frequencies of the order of 10 kHz, and viscous effects tend to become more important on account of small Reynolds numbers (Re <1). Work needs to be done against the action of the viscous stresses so that the energy associated with eddy motion is dissipated and converted into thermal internal energy. It is important to note here that whereas the structure of the largest eddies (resolved scale) is highly anisotropic, smaller eddies tend to exhibit greater degrees of isotropy due to stronger diffusive actions. Consequently, the enhanced isotropic diffusivity values manifested through sub-grid scale modelling effectively ensure that various turbulent length scales are represented with consistency.

From a mathematical perspective, the resolved scale dissipation and the corresponding sub-grid scale dissipation in dimensionless form can be represented as $\varepsilon^{RES} = \left(2/\mathrm{Re}\right)\bar{S}_{ij}\bar{S}_{ij}$ and $\varepsilon^{SGS} = 2\nu_t\bar{S}_{ij}\bar{S}_{ij}$, respectively, where Re is the Reynolds number. Hence, the ratio of the sub-grid to resolved scale dissipation becomes $\varepsilon_{SGS}/\varepsilon_{RES} = \nu_t/\left(1/\mathrm{Re}\right)$. Figures 6 and 7 respectively show the isocontours of the sub-grid scale dissipation at the top surface and the ratio of the sub-grid to resolved scale dissipation plot on a line parallel to the *x*-axis at the middle of the top *x-z* plane. It is revealed from these figures that unresolved small scales account for substantial dissipation. It can be noted here that an enhanced strain field associated with stagnation point flow near interfaces also contributes to significant dissipation, typically somewhat away from the centre of the pool.

Effects of process parameters

Simulations are carried out for different sets of process parameters in order to analyse the effects of effective heat input, laser scanning speed and powder feed rate on the geometry and dynamics of the alloyed pool.

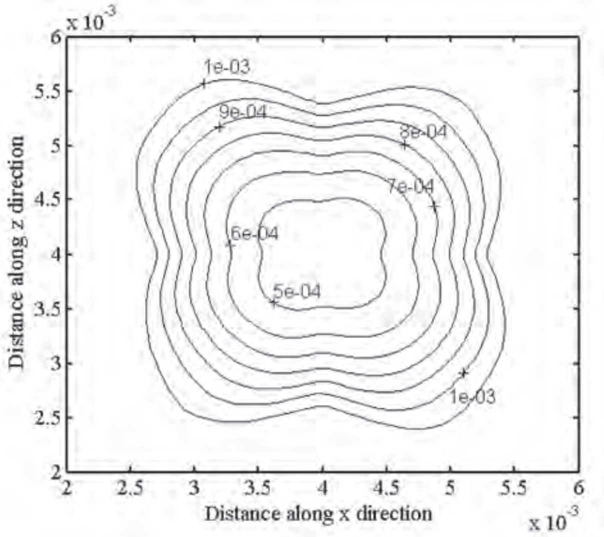


Figure 6: Contour of sub-grid scale dissipation at 1 s on the top surface. All the values shown on the contours are in m^2/s^2

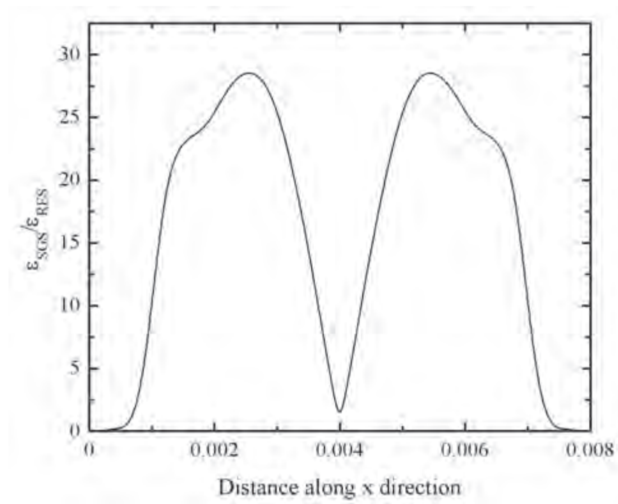


Figure 7: Ratio of sub-grid scale dissipation to resolved scale dissipation plot on a line at the middle of the top surface at 1 s

Effects of effective heat input

Figure 8 shows the variation of maximum velocity, temperature in the pool, pool aspect ratio and maximum cooling rate, with effective heat input. It is observed that the maximum velocity as well as the maximum temperature increases with the effective heat input whereas the pool aspect ratio and the maximum cooling rate decrease correspondingly. Higher amount of heat on the top surface of the pool induces a very high thermal gradient, which in turn induces a high shear stress resulting in a strong surface tension driven (Marangoni) flow. The maximum velocity increases as a consequence [Figure 8(a)]. As the evolution of the thermal field is dictated by the nature of the velocity field, the maximum temperature also rises due to combined conductive and convective effects [Figure 8(b)]. It is observed from the numerical simulations that the width of the pool does not change appreciably with the variation of the heat input (once the size of the heat source is fixed). By contrast, the depth increases more rapidly with increase in heat input. Hence, the aspect ratio increases with decrease in effective heat input [Figure 8(c)]. Cooling rate is an important parameter in determining the microstructure of the resolidified material. At higher cooling rates, the microstructure becomes refined, since substantial time is not available for the grains to grow during the resolidification process. With an increase in effective heat input, the size of the pool increases, and consequently the distance from the laser tip to the solid front increases. As a result, the molten metal has more time to cool down. Thus, the cooling rate decreases with an increase in effective heat input [Figure 8(d)].

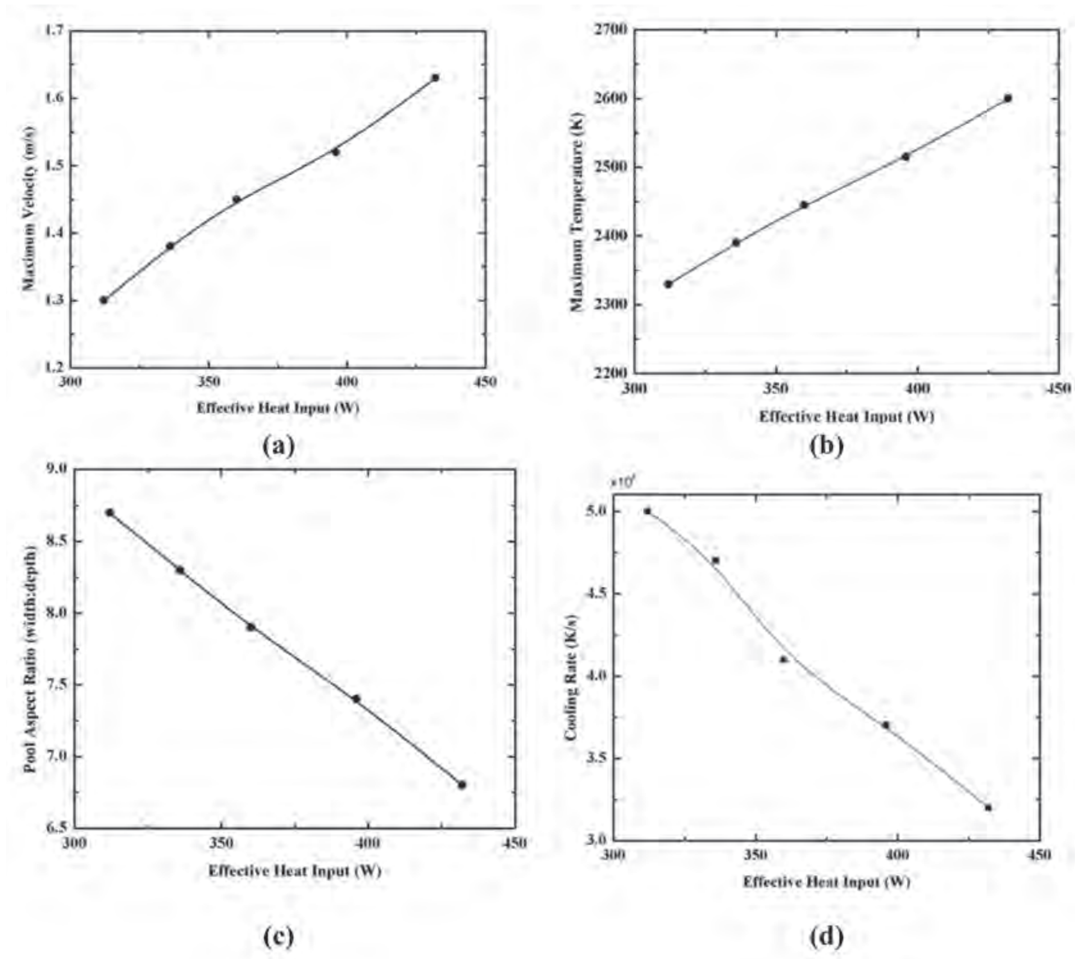


Figure 8: Variation of (a) maximum velocity, (b) maximum temperature in the pool, (c) pool aspect ratio and (d) maximum cooling rate with effective heat input (u_{scan} = 0.017 m/s, η = 0.15, m_f = 0.02 gm/s)

Effects of scanning speed

Figure 9(a) depicts the variation of the pool aspect ratio with the scanning speed. Although the width of the pool does not change appreciably with the variation of the scanning speed, it is observed from the numerical simulations that the depth of the pool increases rapidly with decrease in scanning speed. Hence, the aspect ratio increases with increase in scanning speed. The variation of the maximum cooling rate with the scanning speed is shown in Figure 9(b). With an increase in scanning speed, the pool size becomes smaller and the distance from the laser tip to the solidification front also decreases. As a result, the molten metal has less time to cool down. Accordingly, the cooling rate increases with increase in scanning speed.

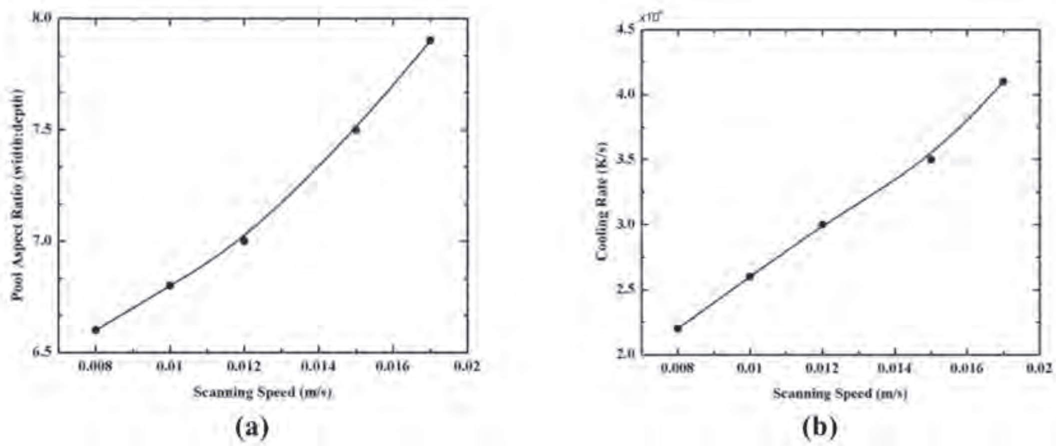


Figure 9: Variation of (a) aspect ratio of the pool and (b) maximum cooling rate with scanning speed (P = 2.4 kW, η = 0.15, m_f = 0.02 gm/s)

Effects of powder feed rate

The variation of maximum solute concentration (in terms of mass fraction of aluminium) with powder feed rate is shown in Figure 10. Since aluminium is lighter than iron, the effective density of the mixture reduces. This increases the mass fraction of aluminium in the molten pool.

Parallel performance

The parallel performance is adjudged in respect to the following four important parameters:

- ✓ Speed-up (S), $S = T_s/T_p$, where T_s and T_p are the execution times for the sequential and parallel computations
- ✓ Efficiency (E), $E = T_s/(N_p T_p)$, where N_p is the number of processors
- ✓ Global iteration number (G), which is the number of iterations required for obtaining a converged solution, and
- ✓ Communication overhead (C), which is the ratio of the communication time and the execution time for parallel simulation.

The parallel performance is investigated by changing N_p from 1 to 4, 8, 12 and 16. The numerical results obtained are found to be same for different numbers of processors which ensure correctness of the domain decomposition strategy and data communication among the parallel nodes.

Three different grid distributions are selected to show the effect of grid size on parallel performance: 59×25×59, 69×35×69 and 79×45×79. For a particular grid size, the speed-up is found to increase with an increase of N_p and the corresponding efficiency is found to decrease (Table 1). This behaviour can be explained from the response of the global iteration number and communication overhead. The iteration numbers for obtaining a converged solution is not much affected by the number of processors, as is evident from Table 1. This is because of the fact that the local flow properties at a particular grid point are mostly affected by the neighbouring grid flow properties and the rest of the domain is virtually not required. Nevertheless, it is found that the global iteration number slightly increases with an increase of N_p. In a parallel simulation, data communication among the processors is required. As the number

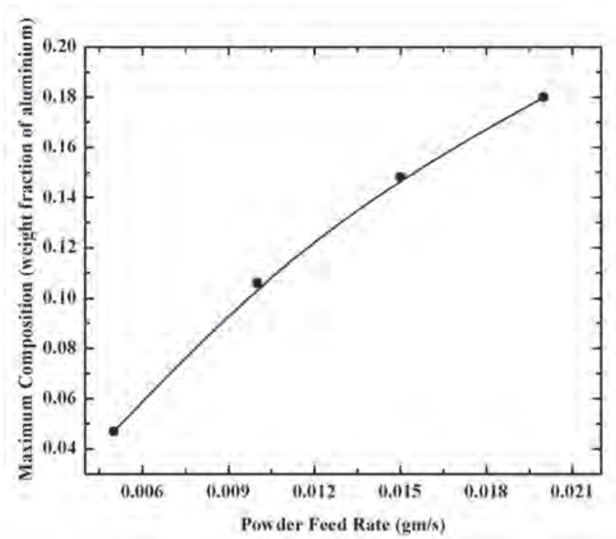


Figure 10: Variation of maximum solute concentration in the solidified alloy (in terms of mass fraction of aluminium) with powder feed rate (u_{scan} = 0.017 m/s, P = 2.4kW, η = 0.15)

Table 1: Parallel performance results, GA, GB and GC represent three different grid sizes, viz. 59×25×59, 69×35×69 and 79×45×79 respectively

N_p	*S*			*E*			*G*			*C*		
	GA	GB	GC	GA	GB	GC	GA	GB	GC	GA	GB	GC
1	1	1	1	100	100	100	32	32	32	0	0	0
4	2.2	3	3.8	55	75	94	34	35	37	6	2	0.8
8	4	5.6	6.8	49	70	86.5	37	39	42	10	3	1
12	5	8	9.6	43	66.67	80	39	40	43	14	4	1.1
16	6	9.2	11	37.5	57.5	68.75	40	41	44	16	5	1.2

of processors increase, the communication time also increases, resulting in a considerable increase in the communication overhead. Higher iteration number and communication overhead result in a slow increase of speed-up and rapid reduction of efficiency with N_p.

In so far as the effect of grid size is concerned, the speed-up and efficiency are found to decrease and the communication overhead is found to increase, as the total number of cells decreases, whereas the grid size is found to have little influence on the global iteration number. As the grid resolution decreases, the number of computational cells belonging to the interface boundaries increases in a node, which result in an increase in the communication overhead. This, in turn, is responsible for the degradation of the parallel performance with respect to speed-up, resulting in a consequent decrease in efficiency.

Comparison with other model predictions and experiments

The results obtained from the present LES simulation is compared with the corresponding laminar flow model (Sarkar et al., 2002) and k-ε turbulence model based results (Chakraborty et al., 2004) in Table 2. It can be seen that the laminar model predicts higher values of maximum velocity, temperature and species concentration in the domain in comparison to the turbulence model estimations. This is physically obvious, since with a lower net diffusive strength, there is always a chance that laminar flow assumptions may over-predict the values of local flow, heat and mass transfer quantities. With a more realistic accounting of energy cascading mechanisms and subsequent dissipation over diffusive length scales, the LES model predicts values of maximum velocity, temperature and species concentration that are even less in comparison to the corresponding k-ε model predictions. Such predictions from the LES based model eventually turn out to be more realistic than other commonly used mathematical models. This can further be justified from experimental results reported in the literature (Chakraborty et al., 2004) as depicted in Figure 11. The figure gives the interface composition of the solidified layer along

Table 2: Comparison of various simulation results

	Maximum temperature (K)	Maximum velocity (m/s)	Maximum composition
Laminar Model	2500	2.35	0.25
k-ε Model	2370	1.85	0.22
LES Model	2300	1.15	0.22

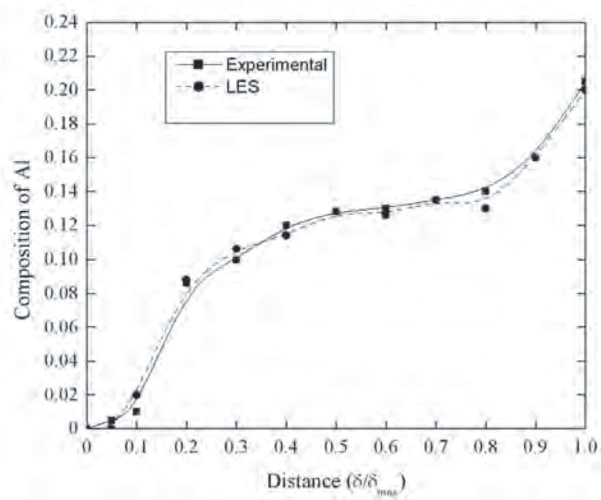


Figure 11: Composition of solidified layer along the depth of the pool

the depth of the pool. The composition of aluminium is observed to be maximum at the top surface, and decreases gradually towards the substrate. It is clearly seen that the present LES simulation result is consistent with the experimental results which is a strong validation of the proposed model.

Summary

A large eddy simulation model is presented for the coupled momentum, heat and solute transport with continuous evolution of solid-liquid phase boundaries typically encountered in high energy materials processing applications. A conventional laser surface alloying process has been considered as a typical case study where the turbulent transport can actually be realized. The evolution of the velocity, temperature and composition fields along with the turbulence quantities are predicted for the process. The LES model based results are compared with the corresponding laminar flow model and k-ε turbulence model based results and available experimental results. The comparison establishes that the LES prediction is much closer to the experimental results in comparison to other models. The robust LES code is subsequently vectorized in anticipation of improved computational performance. The number of processors is varied with different grid sizes. For all cases, it is found that the speed-up increases slowly and the efficiency decreases with the number of processors. It should, however, be stressed that the application of LES to industrial flow process simulations is still in its infancy. This is mainly because of the large computer resources required to resolve the turbulent eddies. Most successful LES has so far been done using high-order spatial discretization, with great care being taken to resolve all scales larger than the inertial sub-range. The degradation of accuracy in the mean flow quantities with poorly resolved LES is not well documented. In addition, the use of wall functions with LES is an approximation that requires further attention. Further, the effects of important process parameters such as laser power, scanning speed, and powder feed rate on the molten pool transport are analyzed in detail. Significant differences can be observed between results obtained from the simulations with turbulent transport and without turbulent transport (laminar simulation) for the same set of process parameters. It is observed in general that the enhanced diffusive mixing in turbulent transport ultimately results in relatively reduced maximum values of mean velocity, temperature and solute mass fraction in comparison to those obtained from the corresponding laminar simulations.

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Simulation of Water Droplet Mobility in Gas Flow Channels of PEM Fuel Cell using the Lattice Boltzmann Method

Proton Exchange Membrane (PEM) fuel cell is emerging as a viable alternative for zero-emission power sources in automotive and backup power applications. One of the key issues in this regard is water management, which has direct ramification on the cell performance. To avail the high proton conductivity, the water generated on the cathode side is used to hydrate the membrane but excessive water may cause flooding in the reaction zone, gas diffusion layer (GDL) and flow channels which, in its turn, reduces the oxygen supply in the reaction zone. At low operating temperatures in PEM fuel cells, water vapor condensation starts easily and liquid water droplets accumulate within the flow channels, thus affecting the chemical reactions and degrading the fuel cell performance. Water management is therefore one of the critical issues to improve cell performance.

The aim of the research work was to develop a rigorous mathematical model based on the multiple relaxation lattice-Boltzmann method for effectively simulating mobility of water droplets within gas flow channels of PEM fuel cell. The major objectives were:

- ✓ Simulation of the water droplet movement using FLUENT
- ✓ Simulating a real-life water/air flow in gas flow channel of PEM fuel cell
- ✓ Thorough study on the effects of surface wettability, inclined angle, sliding angle and inlet air velocity

The modeling and simulation of gas flow channels using LBM/FLUENT for water droplet mobility can help manufacturers to design the bipolar plate with precise dimensions so as to obtain higher current density and higher efficiency of PEM fuel cells. This eventually can lead to better design of bipolar plate, resulting in an ultimate benefit to the industry.

As has been mentioned earlier, water management is one of the critical issues in proton exchange membrane (PEM) fuel cells, and proper water management requires effective removal of liquid water generated in the cathode catalyst layer, typically in the form of droplets through cathode gas stream in the cathode flow channel. Theoretical and numerical studies on water management in GDL/gas flow channels have been performed by several researchers in the past.

Water droplet surface attachment with flow channels greatly depends on the contact angle, i.e. surface wettability properties of the channel. An inclusive study on the effect of surface wettability properties on water droplet movement in flow channels has been conducted numerically. The numerical study has been done using different conventional CFD solvers.

A serpentine flow channel of a PEM fuel cell, which has a square cross section of 1mm x 1mm and a wing length of 8 mm and which employs three such wings is chosen as the computational domain (Figure 1).

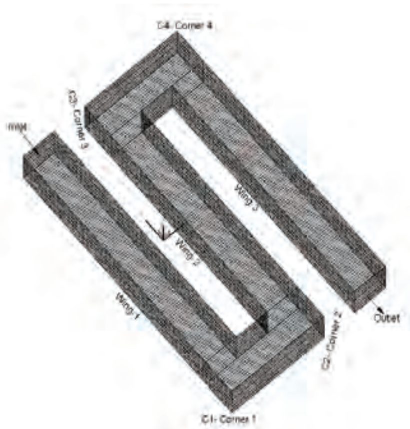


Figure 1: The schematic diagram of the serpentine gas flow channel.

The connecting length of two wings is 1mm. Water generated in the reaction zone of the cathode reaches the flow channels in the form of a droplet.

In the present numerical study, the droplet is kept either at the center of the bottom wall or a little away along the -z axis of the flow channel and at the center of the top wall along +z axis. For the sake of simplicity, it is assumed that:

a) Only a single droplet is being considered
b) The droplet is introduced at time, t > 0
c) The motion of gas (air) and water is considered to be an incompressible Newtonian flow
d) Two phases are separated by the interface having a constant surface tension coefficient
e) There is no phase change for both air and water, and
f) The density of air and water are considered at the room temperature

The following governing equations are solved to study the water droplet transport in single flow channel:

Continuity equation:

$$\frac{\partial \rho}{\partial t} + \nabla.(\rho \vec{v}) = 0 \qquad (1)$$

Momentum equation

$$\frac{\partial}{\partial t}(\rho \vec{v}) + \nabla.(\rho \vec{v}\vec{v}) = -\nabla p + \nabla.\left[\mu\left(\nabla \vec{v} + \nabla \vec{v}^{T}\right)\right] + \rho \vec{g} \qquad (2)$$

where $\vec{v}$ is the velocity vector, ρ is the density of the fluid, p is the pressure and $\rho\vec{g}$ is the gravity force. The above two equations govern the motion of both air and liquid water in the flow channel. The liquid droplet may deform while moving in the channel and its instantaneous surface is determined by the Volume-of-Fluid (VOF) method.

Table 1: A list of all the conditions investigated along with results obtained

Case. No.	Max. velocity at center of channel inlet, U_{max} (m/sec)	Reynolds Number (Re)	Contact angle for channel surface (θ^0)	Droplet average speed	Droplet transport time (Sec)
Droplet is introduced at the center on bottom wall of flow channel $(x=-0.001\text{m}, y=0.0\text{m}, z=-0.0005\text{m})$					
1	12.5	428	140	0.6808	C4-0.0235
2			150	0.6916	**0.034700**
3			160	0.7777	C3-0.018
4	10	342	140	0.4285	C2-0.014
5			150	0.5797	**0.041400**
6			160	0.6648	**0.036100**
7	7.5	257	140	0.2857	C2-0.021
8			150	0.3000	C2-0.020
9			160	0.4444	C4-0.036
Droplet is attached off the center on the bottom wall of flow channel $(x=-0.0012\text{m}, y=0.0\text{m}, z=-0.0005\text{m})$					
10	12.5	428	140	0.3809	C1-0.0105
11			150	0.5714	C1-0.0070
12			160	0.8027	**0.029900**
Droplet is attached at center of the top wall in the flow channel $(x=-0.001\text{m}, y=0.0\text{m}, z=0.0005\text{m})$					
13	12.5	428	140	0.7430	**0.032300**
14			150	0.7619	C4-0.021
15			160	0.7777	C3-0.018

Initially $(t=0)$ all velocities and the gauge pressure in the channel are set as zero. At time $t>0$, a no-slip boundary condition is applied to all the channel walls. The air flow at the inlet is considered as fully developed with a parabolic velocity profile having the maximum velocity at the center of the inlet. The channel surface wettability is adjusted by setting different contact angles at the wall. The gravity force is considered along the negative z-direction. The pressure at the channel exit is maintained zero; thus the pressure at the channel inlet increases when the droplet is introduced into the channel in presence of air flow.

To investigate the water droplet transport in a serpentine flow channel of a PEM fuel cell, different hydrophobic properties, inlet air velocities and droplet positions are considered in the present 3-D simulation. Water produced in the reaction zone of the cathode is transported into the flow channel through GDL. The droplet is kept either at the center or a little off-center of the bottom wall of the flow channel and at the center of the top wall. The center (0, 0, 0) of the computational domain is taken at the middle of wing 1 and wing 2. A total of 15 cases are simulated to examine the water droplet transport under following conditions:

- ✓ The droplet is introduced at the center of bottom wall (x = –0.001m, y = 0.0m, z= –0.0005m) for three different inlet boundary conditions (7.5 m/s, 10 m/s and 12.5 m/s) and three contact angles (140^0, 150^0 and 160^0).
- ✓ The droplet is placed off-center of the bottom wall (x = –0.0012m, y = 0.0m, z= –0.0005m) for a maximum inlet velocity of 12.5 m/s and three contact angles (140^0, 150^0 and 160^0).
- ✓ The droplet is attached to the top wall (x=–0.001m, y = 0.0m, z= –0.0005m) for maximum inlet velocity of 12.5 m/s and three contact angles (140^0, 150^0 and 160^0).

The droplet shape depends on material properties like contact angle, viscosity and surface tension. Inertial force, shear force and pressure differences start to deform the droplet when a fluid is forced to pass over a stationary droplet. The forces due to surface tension and adhesion play important roles to maintain the droplet spherical and affix it to the surface. Since the study is conducted at room temperature, a constant value of surface tension coefficient between air and water (σ= 0.0734 N/m) is used. Standard values of density and viscosity of air and liquid water are also used in all cases. The droplet has a radius equal to one quarter of the channel width.

All the conditions investigated along with the results obtained are enlisted in Table 1. The hemispherical droplet having a radius of 0.00025m is introduced at the center of bottom wall (x = –0.001m, y = 0.0m, z= –0.0005m) for the first 9 cases (Case no. 1-9). In the next 3 cases (Case no. 10-12), the study has been carried out for off-the-center of the bottom wall position (x = –0.0012m, y = 0.0m, z= –0.0005m). In this case, the hemispherical droplet is placed towards the left wall of the first wing. A droplet of the same size is attached to the center of the top wall (x = –0.001m, y = 0.0m, z= –0.0005m) for the last 3 cases (Case no. 13-15). In all cases, the parabolic inlet velocity profiles with a maximum velocity (7.5 m/s, 10 m/s and 12.5 m/s) at the center of the inlet are applied. On the basis of droplet diameter, density and viscosity of air, the computed Reynolds numbers are listed for all cases. A wide range of surface wettability properties (140^0, 150^0 and 160^0) are considered to study the effect of hydrophobic property of walls on droplet transport. The average droplet speeds are calculated approximately on the basis of the distance covered by the droplet and time taken by the droplet to reach the destination. Due to less contact area for high values of contact angles, the average speed is more compared to the other two contact angles. With a high contact angle (160^0) and even at the minimum considered inlet velocity (7.5 m/s), the droplet is detached from the bottom wall and reaches the top wall, whereas with a small contact angle (140^0) and maximum considered inlet velocity (12.5 m/s), the droplet is always attached to either the bottom wall or the side walls of the flow channels. Due to a smaller contact angle (140^0), the contact area of the droplet and wall is more compared to the other two contact angles; hence more surface tension force is applied for this case. However, with a maximum inlet velocity (12.5 m/s), sufficient lift force is not developed for detaching the droplet from the bottom wall of the channel with contact angles of 140^0. The highlighted values in the last column of Table 1 indicate the time required for the droplet to escape from the serpentine flow channel and other values indicate the time required to reach the droplet at the corner position mentioned. It is also observed that the minimum droplet removal time is found for Case no. 12 and maximum removal time is observed for Case no. 5 in Table 1.

Figure 2 shows the 3-D view of droplet transport for different hydrophobic surface properties with a maximum inlet velocity of 10 m/s at different time instants. The droplet is introduced at the bottom wall center of wing 1. It takes the position at corner 2 (C2) for the contact angle 140^0 [Figure 2(a)] and the time taken by the droplet to reach C2 is 0.014sec. Due to low drag force at the corner and the presence of recirculation, the droplet remains completely stuck there till the entire simulation time of 0.05sec.

The droplet escapes from the serpentine flow channel for contact angles of 150^0 and 160^0. Due to less contact area of water and the surface of the wall, the lift force dominates over the force due to surface tension and the droplet detaches from the bottom wall and then touches the top wall of the channel in both cases.

The droplet collides with the side wall of wing 2 and moves forward. Finally it escapes from the serpentine flow channel at time t = 0.0414sec for contact angle of 150^0 whereas it takes comparatively less time for contact angle of 160^0.

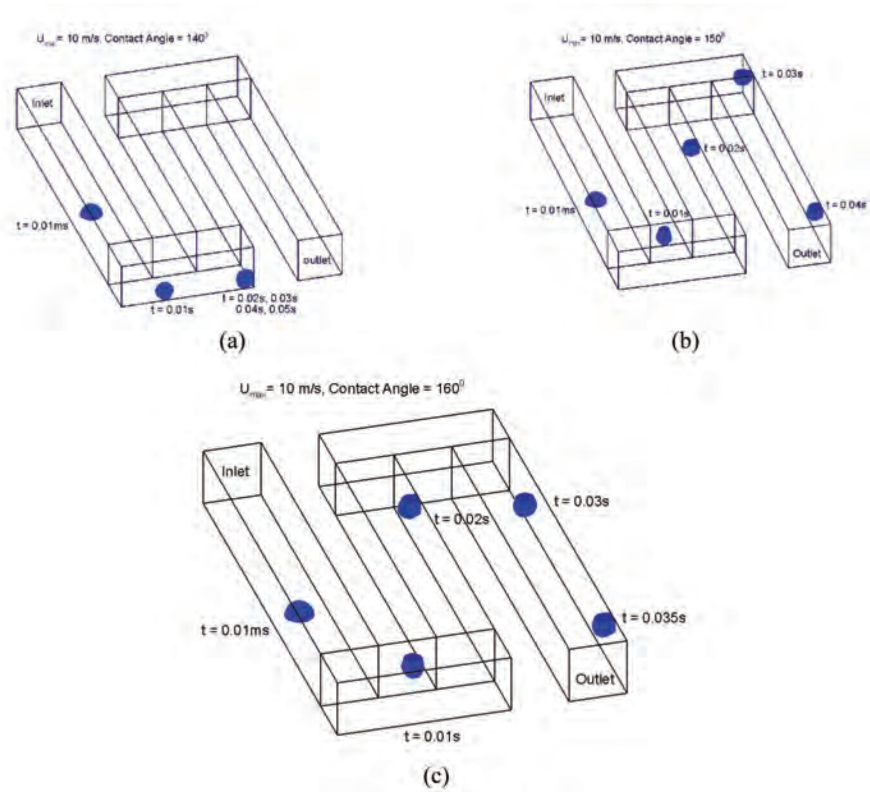


Figure 2: Droplet transport (center of bottom wall) at different instants on hydrophobic surfaces for the maximum inlet velocity 10m/sec

In Figure 3, the 3-D view of droplet positions are shown for different hydrophobic surface properties with the maximum air velocity of 12.5 m/sec at the center of the channel inlet at different time instants. The droplet is introduced at a position off-center from the middle of the bottom wall of wing 1 (x = –0.0012m, y = 0.0m, z= –0.0005m).

Three contact angles (140^0, 150^0 and 160^0) are considered to study the effect of the position of the droplet on the droplet transport. In Figure 3(a), the droplet positions are shown for the contact angle of 140^0. Due to off-center position, it moves towards the right side wall of wing 1 due to unequal pressure force and adheres to the side wall very quickly. Finally, it reaches a corner position C1 at time 0.0105 sec. The same phenomena have been observed for higher contact angles of 150^0 [Figure 3(b)].

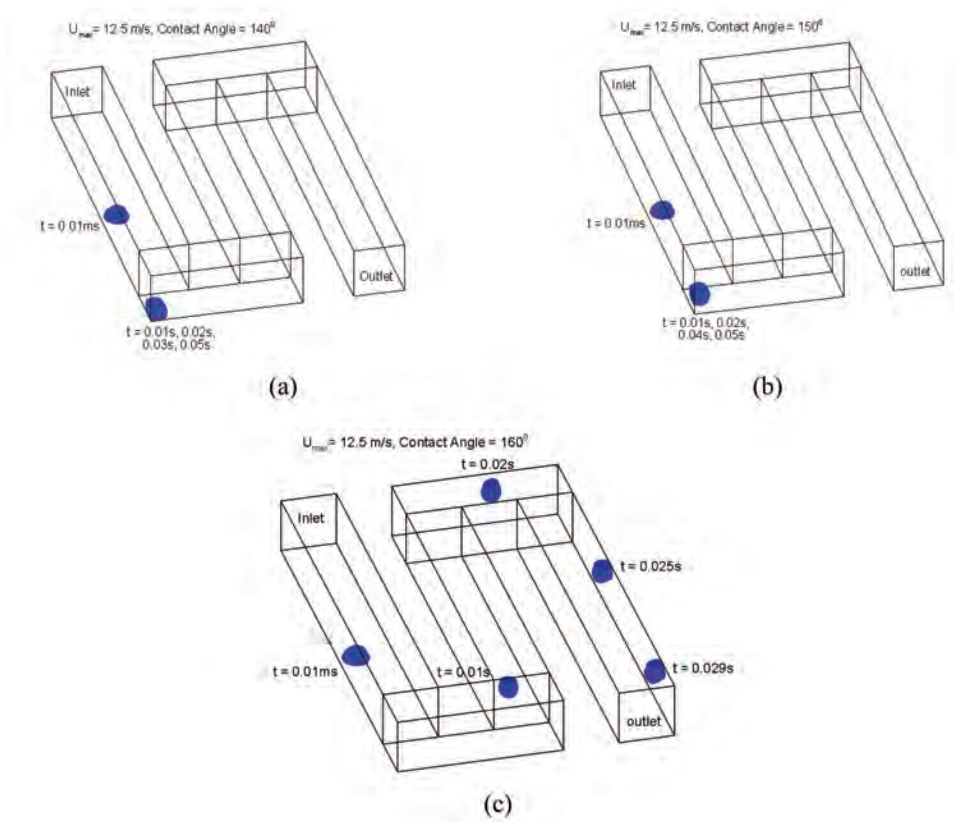


Figure 3: Droplet transport (off-center position) at different instants on hydrophobic surfaces for the maximum inlet velocity 12.5m/sec

With contact angle of 150°, the droplet detaches from the bottom wall and floats in air. Finally it reaches the side wall of wing 1 due to unequal pressure force and adheres at C1. For the super hydrophobic surface property of a contact angle of 160° [Figure 3(c)], the droplet is lifted up quickly and moves forward as a floating body, finally to collide with the front wall near C1. Thereafter it touches the top wall and changes the moving direction gradually from the right side wall to the left side wall. Subsequently it collides again with the right wall of wing 2. For this case, it moves forward while touching the top and the one side wall. Finally, the droplet is completely swept out from the flow channel at time t = 0.0299 sec.

The droplet positions at different time instants are shown in Figure 4. The same size droplet is introduced at center of top surface (x = –0.001m, y = 0.0m, z= –0.0005m) of wing 1. The parabolic velocity profile with maximum velocity 12.5 m/s is applied at the inlet of the serpentine channel. The surface wettability properties are maintained by imposing proper values of the contact angles. The droplet positions at five time instants are shown for the contact angle of 140^0. At time t = 0.01ms, the droplet holds almost at the starting point. Due to high contact area that results in higher surface tension force, it does not detach from the top surface throughout the entire simulation. At time t = 0.02 sec, the droplet looks bigger because of deformation

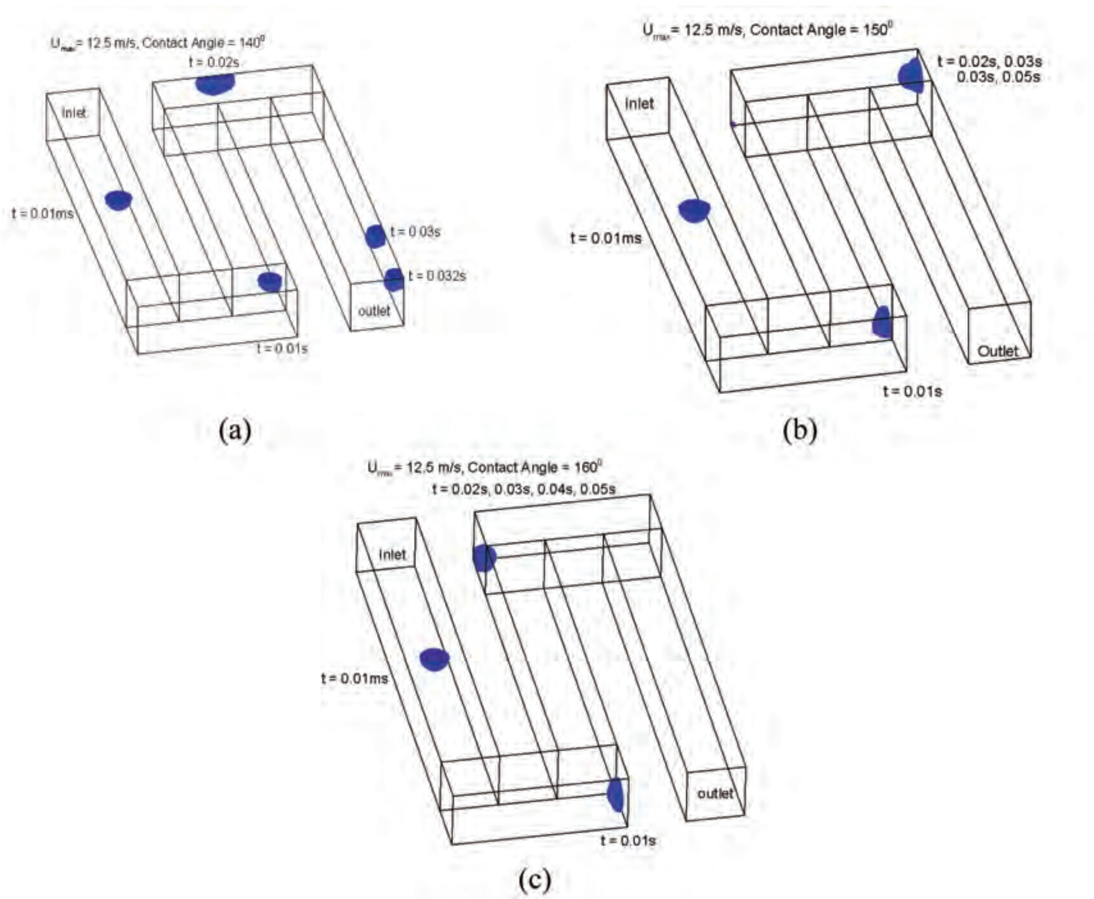


Figure 4: Droplet transport (top surface) at different instants on hydrophobic surfaces for the maximum inlet velocity 12.5m/sec

of the droplet with high thrust force. Finally, it escapes from the channel at time t = 0.0323 sec. However, it is trapped once again for other two cases (Case no 14 and Case no 15 in Table 1). Due to the gravitational force, the droplet detaches from the top surface and moves forward as a floating body throughout the entire wing 1 for the contact angle of 150^0 [Figure 4(b)].

The droplet touches the wall again and moves forward. Finally, at time t = 0.021 it sticks at the corner 4 (C4) and remains at the same corner until the end of simulation. It is to be noted that due to high impact collision of water droplet at the end of wing 2, a small part of droplet is separated and stuck at C3. In Figure 4(c), the droplet comes to the bottom wall very quickly. The droplet detaches again from the bottom wall and moves forward. At time t = 0.0125, the droplet touches the left wall of wing 2 and moves forward. Then it is finally trapped at C3 because surface tension force dominates over drag force at the corner.

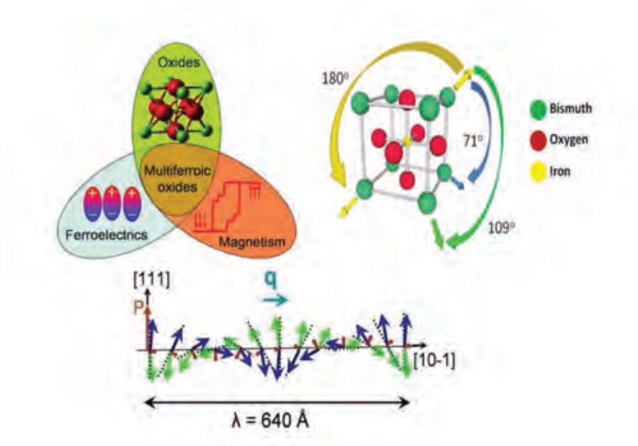
Conclusion

To understand the fundamental phenomena of a water droplet transport in serpentine gas flow channel, a comprehensive three dimensional numerical simulation was carried out by using the commercial CFD package FLUENT. A total of 15 cases for different combinations of channel surface wettability, droplet positions and air flow conditions were studied to investigate the characteristics of water droplet transport in the flow channel. The droplet movement is significantly affected by the channel surface wettability, air flow conditions and the initial droplet position. As expected, the average droplet speed is higher for higher values of the contact angle. However, the high contact angle (160^0) surface wettability property is not suitable for water management in PEM fuel cell channel. In case of the median position of the droplet on the bottom wall with maximum inlet velocity (12.5 m/s), the preferable contact angle is 150^0. In case of a parabolic velocity profile with maximum inlet velocity of 10 m/s at the center of the inlet, the effective surface wettability property is 160^0. The droplet is not removed for any kind of surface properties with parabolic velocity profile having maximum velocity of 7.5 m/sec at the center of the inlet. The droplet is completely removed from the flow channel only with a contact angle of 160^0 and for a maximum inlet velocity of 12.5 m/s off-center position of the droplet on the bottom wall. The opposite trend is observed in case of droplet attachment at the top wall of wing 1 in the flow channel. In this case, the preferable surface wettability property is 140^0. Therefore, super hydrophobic surface property depending upon the inlet velocity and droplet position is required to design the flow channels of PEM fuel cell.

Design & Exploration of Nanocrystalline Multiferroic Materials

Introduction

Ferroelectromagnetic materials such as multiferroics exhibit both ferroelectric and ferromagnetic properties simultaneously in the same phase. Additionally, they exhibit the phenomenon called magnetoelectric coupling, i.e. magnetization induced by an electric field and vice versa. Multiferroic materials therefore have potential application in magnetic and ferroelectric devices. Among the multiferroic materials, perovskite $BiFeO_3$ (BFO) has attracted much attention recently due to its relatively higher ferroelectric Curie ($T_C \approx 830^0C$) and Neel ($T_N \approx 370^0C$) temperatures, which are advantageous for various applications. BFO is basically an electro-ceramic composed of bismuth, iron and oxygen. Multiferroicity in BFO appears due to the presence of $6s^2$ lone pair of electrons in Bi3þ ions and (anti) ferromagnetism is due to the availability of unpaired d-orbital electrons. It has a rhombohedrally distorted perovskite structure with space group R3c.



Increasing demands for high-density storage media, stable nanoscale memory elements, quest for creating smaller and more powerful devices with less power consumption as well as fundamental discoveries in the field of spintronics have led to renewed interest in exploring the coupling between magnetism and electric polarization of BFO. One of the major problems for BFO is the large leakage current due to the presence of small amounts of Fe^{2+} ions and oxygen vacancies in the sample which hinders its practical applications. To tackle the leakage current issue of BFO, several research groups have attempted to dope with +3 valence lanthanide ions [La^{3+}, Nd^{3+} or Sm^{3+}] at the A site of BFO (ABO_3). The doping has resulted in the reduction of leakage current density and the improvement of ferroelectric properties of BFO to some extent.

The weak macroscopic magnetization is another main barrier for device applications of BFO. Hence improving the magnetic properties constitutes another challenging task. Several studies have reported the enhancement of magnetic properties by transition metal ion substitution, or forming solid solutions with other ferroelectrics such as $BiFeO_3$–$BaTiO_3$ solid solution. However, the modified $BiFeO_3$ system still shows antiferromagnetism or very weak ferromagnetism. In contrast, multiferroics in nanocrystalline form shows ferromagnetic properties due to braking of spin cycloid. The multiferroic properties can therefore be enhanced either by doping or tailoring the microstructure.

Keeping in view the importance of BFO, it appears interesting to investigate how the multiferroic properties can further be enhanced by applying some approach to realize device application. Tailoring the size in nanometer range is proposed, along with identification of different dopants/co-dopants for the achievement of enhanced multiferroic properties in BFO.

Objectives

The principal objectives of this project were:

(1) Identification of new multiferroic materials and clarification of the mechanisms leading to the unusual properties of this class of materials

(2) Preparation and characterization of nanocrystaline rare-earth orthoferrite / multiferroic materials having double ferroic behaviour

(3) Study of the coupling between magnetic and ferroelectric ordering with particles size

(4) Determination of new materials having large magnetoresistance ratio which also exhibit magneto-dielectric behavior

(5) Detailed study of the electrical transport mechanism (by measuring of dc and ac conductivity, dielectric response, dc magnetoconductivity and frequency dependent magnetoconductivity at different temperatures).

Methodology

Synthesis of Nanomaterials

Initially, different types of multiferroic materials including rare earth orthoferrite in nanocrystalline form shall be synthesized by using hydrothermal route. This shall be followed by doping these materials with selected transition metals to improve their properties. Simultaneously, suitable chemical techniques shall be identified for synthesis of the materials.

Study of the multiferroics properties

The magnetic properties of the synthesized nanomaterials shall be studied in detail by using Vibrating Sample Magnetometer (VSM). Thereafter, the ferooelectric behaviour of the same materials shall be studied using LCR meter.

Study of the magnetoresistance and magnetocapacitance properties

Electric polarization (PE) hysteresis loop in presence of magnetic field of the different nanocrystalline multiferroic samples shall be measured to study the coupling behaviour between magnetic and ferroelectric orders, along with a detailed study of the magnetoresistivity of the different samples.

Analysis of the data with suitable model

The measured data shall be analysed by using suitable theoretical models in an effort to understand the basic science involved.

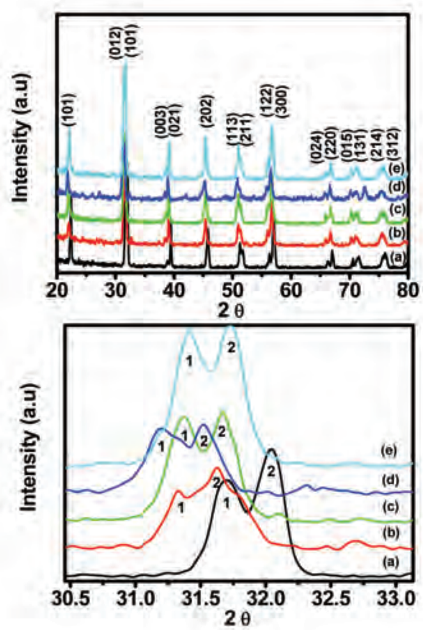
Applications of the developed materials

Efforts shall be undertaken to demonstrate some prototype application using these nanocrystalline materials.

Highlights of ongoing work

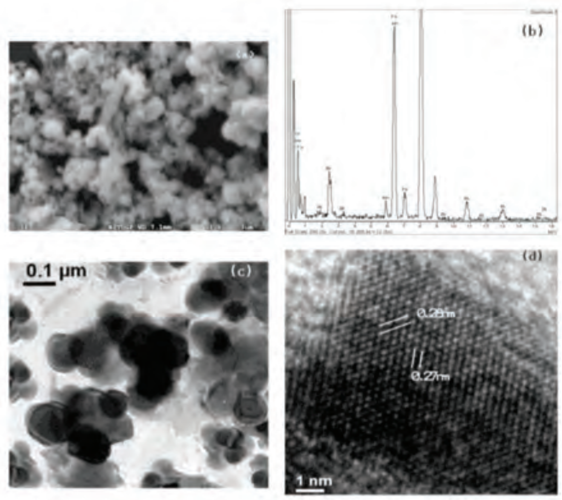
X-ray diffraction pattern of nanocrystalline $BiFeO_3$ doped with different concentrations of neodymium has been studied. Absence of any extra peak in the pattern confirms the growth of single phase $BiFeO_3$. Effect of Nd doping is clear from the peak shifting.

The representative scanning electron microscope (SEM), tunneling electron microscope (TEM), energy dispersive x-ray spectrum (EDX) and high resolution tunneling electron microscope (HRTEM) photographs of x=0.1 (10 %) Mn-doped $BiFeO_3$ nanoparticles are presented below. It is clear from both the SEM and TEM micrographs that the shapes of the particles are not spherical. They are also agglomerated in nature. Assuming the bigger dimension, the average size of the sample as estimated from TEM image has been found to be 34 nm. EDX spectrum, taken from SEM micrograph confirms the presence of Bi, Fe and Mn in the sample.

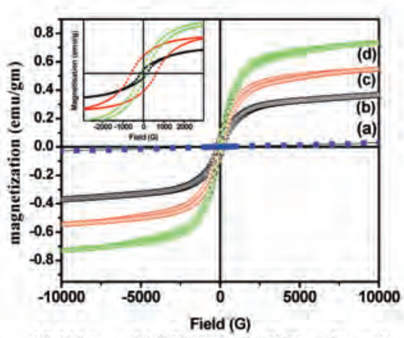


XRD pattern of (a) $BiFeO_3$
(b) $BiFe_{0.99}Nd_{0.01}O_3$ (c) $BiFe_{0.97}Nd_{0.03}O_3$
(d) $BiFe_{0.95}Nd_{0.15}O_3$, (e) $BiFe_{0.93}Nd_{0.07}O_3$

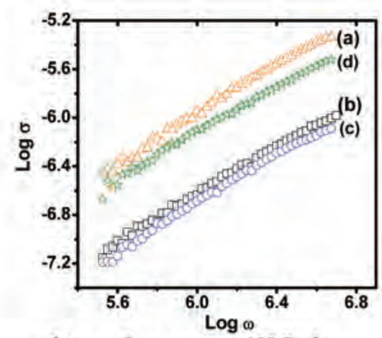
Closer view of (a) $BiFeO_3$
(b) $BiFe_{0.99}Nd_{0.01}O_3$ (c) $BiFe_{0.97}Nd_{0.03}O_3$
(d)$BiFe_{0.95}Nd_{0.15}O_3$, (e) $BiFe_{0.93}Nd_{0.07}O_3$



Enhancement of magnetic moment and resistivity by virtue of lanthanum doping is clearly delineated in the above graphs.



M-H loop of (a) $BiFeO_3$ (b) $BiFe_{0.99}La_{0.01}O_3$ (c) $BiFe_{0.95}La_{0.05}O_3$ (d) $BiFe_{0.90}La_{0.10}O_3$. Inset shows the expande loop for clarity.



Log ω – log σ curve at 100 C of (a) $BiFeO_3$ (b) $BiFe_{0.99}La_{0.01}O_3$ (c) $BiFe_{0.95}La_{0.05}O_3$ (d) $BiFe_{0.90}La_{0.10}O_3$.

Expected Deliverables

- ✓ Nanomaterials with enhanced multiferroic properties.
- ✓ Prototype device.

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Synthesis and Modification of Metal Oxides at Nano and Micron Length Scale for Gas Sensing and Dye Sensitized Solar Cell Applications

Introduction

The fascinating optical, electronic, magnetic, thermal, mechanical and chemical properties of metal oxides have made them useful in diverse applications including – but not limited to – microelectronics, magnetic applications, high-density data storage, drug delivery, catalysts, imaging, rechargeable lithium batteries, solar cells, sensors, catalysis, etc. For these applications, the morphology of metal oxides plays a significant role in modulating their performances. At CSIR-CMERI, initiatives are undertaken to synthesize metal oxides in various morphologies (both in nano-length and micro-length scales) using simple and cost effective wet chemical synthesis route. The volatile organic compound (VOC) sensing characteristics of the synthesized semiconducting metal oxide based sensors are being investigated by varying the operation of the sensors and concentrations of the VOCs. In a parallel study, the performance of metal oxide based photo-anodes is also being studied for dye sensitized solar cell application.

Cost effective synthesis and modification of metal oxides

A variety of metal oxides (e.g. ZnO, TiO_2, Fe_2O_3, etc.) and their cation modified counterparts are being synthesized in micro and nano length scales using simple and cost effective wet chemical and hydrothermal synthesis route. For these metal oxides, the influence of respective morphologies on the gas sensing and photovoltaic performances is being analysed. The modulation of electrical properties of the metal oxides is often recommended to achieve promising chemi-resistive gas sensing and dye sensitized solar cell performances. To tune the electrical properties of the metal oxides, conducting polymer (e.g. polyaniline) and graphene based metal oxide composites are being synthesized. Figure 1 shows the Field Emission Scanning Electron Microscope (FESEM) images of synthesized hierarchical assembly of micro/nano zinc oxide [(a) and (b)], flower like structure of zinc oxide (c), nano-crystalline thin film of titania (d), nano-particles of iron oxide (e) and iron oxide-polyaniline composite (f). The Transmission Electron Microscope (TEM) image of the synthesized titania nano particles is shown in Figure 2 (a). The lattice fringe pattern of the titania particle is clearly observed in High Resolution Transmission Electron Microscope (HRTEM) image shown in Figure 2 (b). The TEM image of the synthesized reduced graphene oxide and the zinc oxide-graphene composite is shown in Figures 2 (c) and (d) respectively.

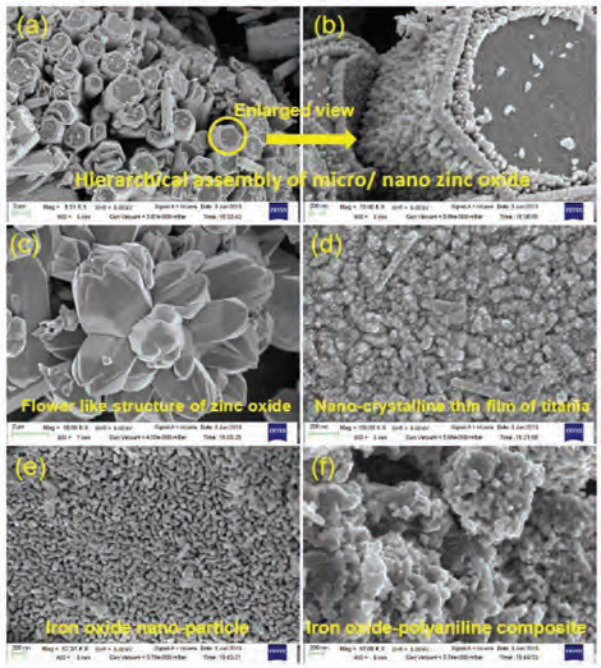

Figure 1: FESEM images of the synthesized materials. Details of the materials are mentioned in the respective figure

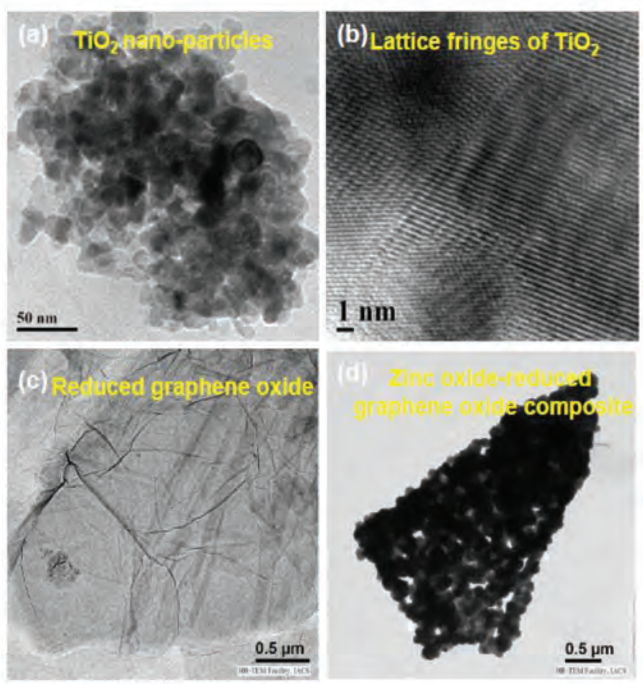

Figure 2: TEM images of the synthesized materials. Details of the materials are mentioned in the respective figure

Chemi-resistive type volatile organic compound sensing

The detection and monitoring of volatile organic compounds (VOCs) are important since some of them act as breath biomarkers for human health (e.g. the amount of acetone in breath can detect the diabetic status) and several of these are generated by the degradation of food and biochemical products. VOCs are widely used either as solvents or as chemicals in various industries. The presence of VOCs in air at high concentration may trigger the enhancement of the pollution level and disrupt the terrestrial ecosystems. Semiconducting metal oxide (SMO) based chemi-resistive sensing elements are popular as low cost and efficient sensors for detecting low concentration of VOCs.

The principle of SMO sensor is based on their resistance change while exposed to volatile organic compounds (e.g. acetone and ethanol). When the sensing elements are kept in air at elevated temperature, oxygen is chemi-adsorbed by accumulating electrons from the sensor surface. The chemi-adsorption of oxygen over these sensing elements can be represented as follows [Equations 1 (a)-(b)].

$$O_2 + e \rightarrow O_2^- \qquad 1(a)$$

$$O_2 + 2e \rightarrow 2O^- \qquad 1(b)$$

Depending on the operating temperature of the sensor, oxygen may chemi-adsorb on the sensing surface either in molecular (O_2^-) or in atomic forms (O^-). Reducing gases coming in contact with the surface adsorbed oxygen becomes oxidised, leaving the electron to the conductance band of the sensing material. The typical reactions for acetone and ethanol with chemi-adsorbed atomic oxygen are presented in Equations 2 & 3 respectively. Acetone and ethanol are oxidised into carbon monoxide or carbon dioxide and leave the sensor surface during recovery [4-5].

$$C_2H_5OH + 6O^- \rightarrow 3H_2O + 2CO_2 + 6e^- \qquad (2)$$

$$CH_3COCH_3 + 8O^- \rightarrow 3CO_2 + 3H_2O + 8e^- \qquad (3)$$

The sequential sensing phenomenon (response as well as recovery) and the corresponding change of sensor resistance during detection of acetone over chemi-resistive type SMO sensors have been illustrated schematically in Figure 3. Due to the chemi-adsorption of oxygen, the surface of the sensing element becomes electronically depleted. Consequently, the mobility of electrons through the sensor surface is impeded, which increases the resistance of the sensor. The oxidation of acetone on the sensor surface releases the electrons back to the sensing element, thereby decreasing the resistance of the sensor. When the sensor is further exposed to air, the adsorbed oxidised products (CO and CO_2) begin to fade away from the sensor surface and oxygen is chemi-adsorbed simultaneously. The concurrent chemi-adsorption of oxygen over the sensing element recovers its resistance.

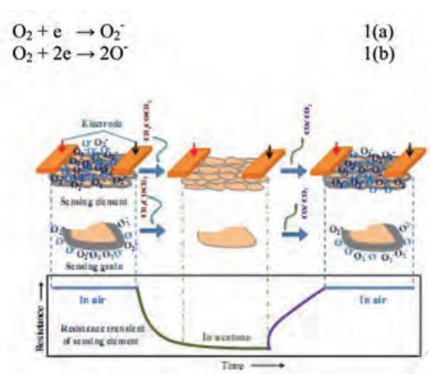

Figure 3: Schematic mechanism for the sensing of acetone over chemi-resistive semiconducting metal oxide sensors

The VOC sensing characteristics of the prepared sensing elements are measured using static flow gas sensing measurement set-up developed in the laboratory. The set-up is equipped with a temperature controller and a source meter interfaced with a PC through GPIB interface and operated through LabTracer 2 software. The photograph of the total set-up and the sample holder is shown in Figure 4.

Figure 5 (a) shows the typical response and recovery resistance transient of spinel ferrite based sensor (operated at 300^{o}C) for sensing ~ 50 ppm of acetone. For sensing ~ 50 ppm of acetone and ethanol vapours, the percentage variation of response with the sensor operating temperature (300^{o}-375^{o}C) has been shown in Figure 5 (b). As shown in the figure, the sensor is more sensitive towards acetone than ethanol.

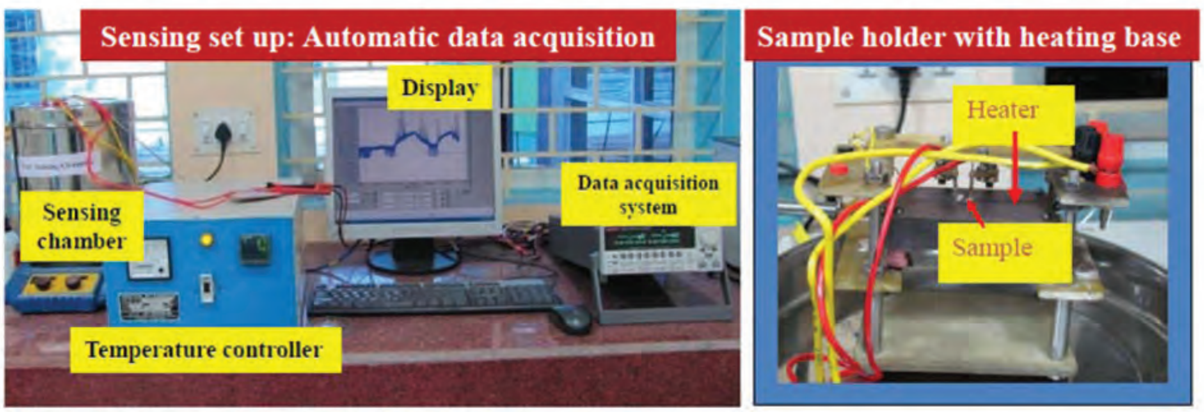

Figure 4: Photograph of the developed VOC sensing measurement set-up and sample holder

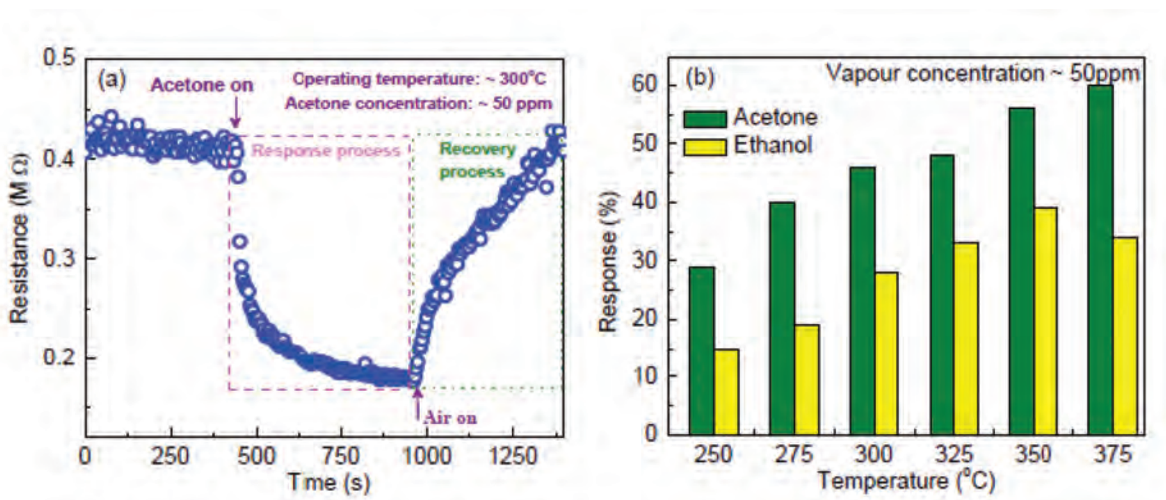

Figure 5: (a) Resistance transient of the spinel ferrite sensor for detecting acetone (b) Percentage Variation of response with sensor operating temperature

Metal oxide based photo-anode for dye sensitized solar cell application

Recently, dye-sensitized solar cells (DSSCs) have attracted much attention as a source for renewable energy. The fairly accepted solar to electric conversion efficiency of these DSSCs is not yet attainable repeatedly. The underlying reasons that limit the reproducible performance of metal oxide (e.g. TiO_2, ZnO, etc.) photo-anode based DSSCs is not clearly understood. Research is being undertaken to investigate the solar cell performances of such photo-anodes through the modification of their structure, morphology, thickness and electrical properties.

In a DSSC the most influencing component is the photo-anode which actually serves the purpose of collection and transportation of excited photoelectrons from the dye to the conducting substrate via a metal oxide layer. To demonstrate the role of the photo-anode in the conduction of photo excited electron, the principle of dye sensitized solar cell has been illustrated schematically in Figure 6. When exposed to sunlight, the dye molecules become photo-excited and inject electrons into the conduction band of the metal oxide electrode. The original configuration of the dye is subsequently restored by electron donation from the electrolyte. The quick regeneration of the dye by the electrolyte intercepts recombination of the electrons injected into the conduction band, thus allowing the electrons to flow to the conducting surface of the anode. The electrolyte is regenerated at the counter electrode when the circuit is completed through an external load [6]. The photo-excitation, transportation and regeneration of electrons in DSSC are sequentially described in the figure.

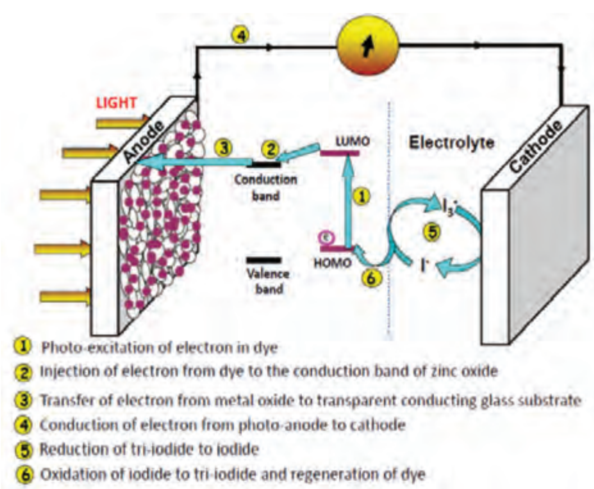

Figure 6: Operating principle of dye sensitized solar cell

The metal oxides (e.g. TiO_2, ZnO and their composites) based photo-anodes are being prepared on conducting glass substrate either in thin or thick film architecture. The dye sensitized solar cells are being prepared by sandwiching the photo-anode, Dye (N3/N719), electrolyte (iodide/tri-iodide solution) and counter electrode (platinized glass substrate).

The photo current (I)-voltage (V) characteristics and incident photon to current conversion efficiency (IPCE) measurements are being carried out using an automated set-up equipped with a solar simulator. The photograph of the set-up is shown in Figure 7.

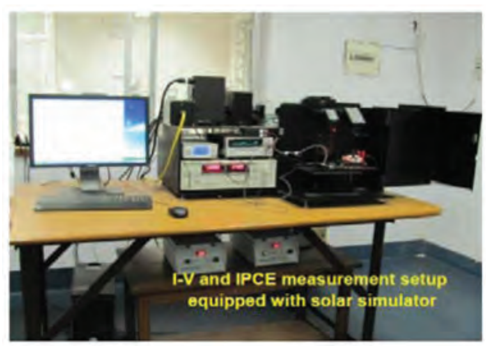

Figure 7: I-V and IPCE measurement set-up

Figure 8 shows the I-V curves of the developed ZnO based DSSC. The I-V tests have been repeated thrice to validate the results. The estimated photovoltaic parameters (short circuit current density (J_{SC}), open circuit voltage (V_{OC}), fill factor (FF) and photo-current conversion efficiency (η) in three repeated tests are summarised in the inset of Figure 8. The estimated power conversion efficiency of the developed solar cell with an active area of 0.49 cm^2 is found to be in the range of ~4.1-6.1%.

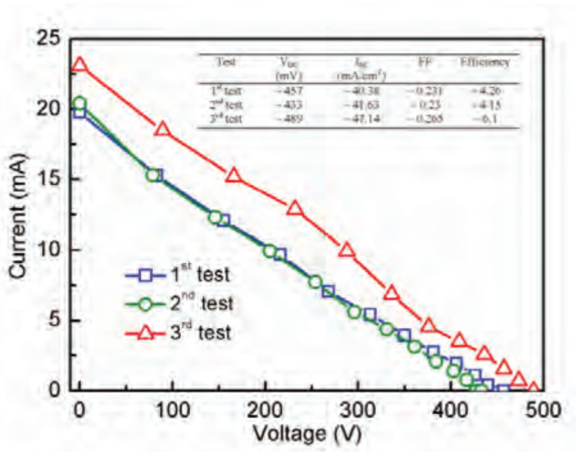

Figure 8: I-V characteristics of the developed dye sensitized solar cell. Inset summarizes the photovoltaic parameters

Summary

Metal oxides are being prepared in micro/ nano length scale using simple and cost effective wet chemical and hydrothermal synthesis route. The synthesized materials are being investigated in terms of their volatile organic compound sensing characteristics. Parallel experiments are also being carried out to investigate the performance of the prepared metal oxide based photo-anodes for dye sensitized solar cell applications. Till date ~10 ppm acetone and ethanol has been detected by the synthesized metal oxide sensors. Using ZnO based photo-anode the solar to electric conversion efficiency has been achieved upto ~6%.

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Fabrication and Characterization of Flat Sheet Membranes

Introduction

Electrochemical cells play a very important role in converting chemical energy directly to electrical energy by means of electrochemical redox reaction. Lithium-ion batteries are particularly popular these days due to their high energy density, absence of memory effect and excellent electrochemical performance which makes such batteries an excellent choice for powering various portable consumer electronic devices such as mobile phones, cameras, laptops, etc. Lithium-ion batteries are attracting extensive interest from researchers who envisage a growing market for energy storage. In the recent scenario, high energy density lithium ion rechargeable batteries are in large demand both for consumer electronic products as also for plug-in hybrid electric vehicles. The performance of Lithium-ion batteries depends mainly on the choice of electrodes, electrolyte and the separator used. Separator for lithium-ion batteries must have a sufficiently small pore size and narrow pore size distribution to suppress self-discharge and internal short-circuits of cell.

Separator (Microporous Membrane)

The separator, a critical component present in lithium-ion batteries for prevention of physical contact of the positive and negative electrodes while permitting free ionic transport within the cell, does not in itself contribute to any electrochemical reaction; still, its properties have an effect on the energy density, power density, cycle life and safety of the battery. The separator is permeable and retain electrolyte to maintain the desired ionic conductivity. In Lithium-ion batteries, the performance of the membrane is determined to function as an ion permeable micro-porous barrier.

The reaction occurring in the cathode and anode materials are as follows:

$LiCoO_2 \leftrightarrow Li_{1-x}CoO_2 + xLi^+ + xe^-$ (forward for charge, reverse for discharge)

$C + xLi^+ + xe^- \leftrightarrow Li_xC$ (forward for charge, reverse for discharge)

During discharge, the positively charged lithium ion flows in a conducting electrolyte routed through a separator to the cathode, leaving negatively charged electrons on the anode. This flow direction is inverted during charging.

Research Issues

The designated function of the separator is to prevent thermal runaway condition of the Li-ion battery during electrical abuse. In the event of a current demand far exceeding the safe limits, the separator starts melting at an appropriate time, thereby shutting down the separator pores, resulting in tough reduction of the current flow. Research is focused on improving conventional Lithium ion battery technology in regard to the cost, durability, dimensional stability, specific capacity, cyclability and inherent safety. Proper selection of suitable separator is more important for achieving good battery performance with respect to cycle life and safety. Favorable condition for novel separator fabrication must be identified and inorganic fillers should be used to improve performance and thermal behavior of lithium rechargeable batteries.

In keeping with this mandate for improvement of performance and thermal behavior, research is being undertaken to fabricate microporous membranes (separator) for application in Li-ion batteries. Material synthesis techniques have been optimised so as to control the membrane microstructure with improved thermal stability. Issues with polymer properties like the solvent property, homogeneity of the prepared slurry and membrane properties including porosity, pore-size distribution should be duly accounted for while preparing the membrane as this can be revealed in the cyclic experiments and electrochemical performance study.

In general, separators in lithium-ion batteries are made of polyolefins, primarily polyethylene (PE) and/or polypropylene (PP). These polyolefin based separators find widespread use and exhibit many advantages, but have poor thermal shrinkage. To overcome the defects of polyolefin membranes, polyvinylidenefluoride (PVDF) based membranes are being considered as alternative separators for lithium-ion batteries because of the excellent miscibility PVDF exhibits with the liquid electrolyte. PVDF based membranes can withstand higher temperatures due to their crystalline nature and chemical stability. In our study, PVDF membranes of high porosity are fabricated by phase inversion technique. This involves mixing the additives to the base polymer to form a solution, followed by extrusion of this solution on a glass plate to form a film of desired thickness and extraction of the membrane in a non solvent. The fabricated separator sample is shown in Figure 1(a). Inorganic filler materials are also used to improve thermal stability

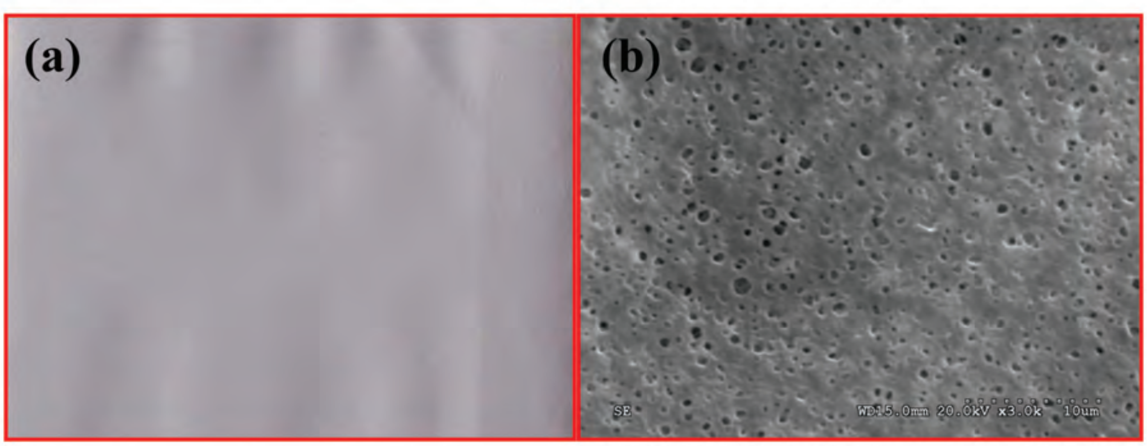


Figure 1: Fabricated separator sample (a) and SEM micrograph of the fabricated separator (b)

of the separator. To obtain optimized performance, the composition of filler material and the solvent used for fabricating the separator were varied, and the electrochemical performance of the fabricated separator was investigated.

Dimensional Stability and Morphology

The fabricated separator was tested for thermal shrinkage using the vacuum oven method. Shrinkage test was carried out to observe the structural integrity of the sample by subjecting the membrane to a temperature of 150ºC for 1 hour at a pressure of 1 torr, which exhibited dimensional shrinkage of less than 5%. This procedure employs measuring the initial sample dimensions (3cm x 3cm) and then placing the sample in vacuum oven at 150ºC for one hour. The final dimensions are measured and the shrinkage is then calculated for change in dimensions. The shrinkage pertaining to the fabricated separator was calibrated against a commercially available standard PE separator. Shrinkage test illustrates that the commercially available membrane shrinks by 47% after heat treatment, whereas the fabricated separator with and without presence of inorganic fillers shows a shrinkage value of 2% and 8% respectively. This test provides a clear indication of the thermal stability of fabricated separator. DSC analysis is performed to investigate the thermal property of the fabricated separator (endothermic peak 158°C). Electrolyte loading and contact angle variation against electrolyte on commercial membrane and fabricated membrane was further investigated, which shows excellent wettability.

The fabricated membrane was analysed for microstructure using scanning electron microscopy (SEM) for micro structural analysis. Figure 1(b) presents the SEM microstructure (10 µm) of the fabricated separator which shows uniform distribution of pores throughout the whole membrane area.

The fabricated separator with optimized PVDF/NMP ratios had uniform pore size distribution after phase inversion. Once characterization was completed, the separator was placed in between two electrodes in an electrolyte to prevent physical contact between the electrodes so as to ensure unhindered passage for the lithium ions.

Electrochemical Performance

Electrochemical performance of the fabricated separator was determined using a computer controlled potentiostat / galvanostat system with FRA for charge-discharge measurement, EIS measurement and rate capability studies. The coin cell was carefully fabricated in an argon filled glove-box using Lithium metal as the anode, fabricated separator and $LiFePO_4$ as the cathode and subjected to cycle testing at room temperature. $LiPF_6$ 1 M, 1:1 by weight mixture of ethylene carbonate and dimethyl carbonate was used as the electrolyte. The cathode, separator and anode were crimped together using a crimping tool inside a glove box with O_2 and H_2O levels less than 0.5 ppm to fabricate the CR2032-type coin cell. Fabrication facility is shown in Figure 2.

Figure 2: Separator fabrication facility and performance testing

Specific capacity is calculated based on the active materials present in the electrode. Figure 3 shows the charge-discharge profile of the second cycle in the voltage range 3V - 4.3V at a current density of $17 mAg^{-1}$ corresponding to the C/10 rate. Discharge capacity stabilized after a few cycles of charge-discharge. The fabricated separator exhibits very good electrochemical performance. This fabricated membrane is promising for application in lithium ion batteries with high safety and good electrochemical performance.

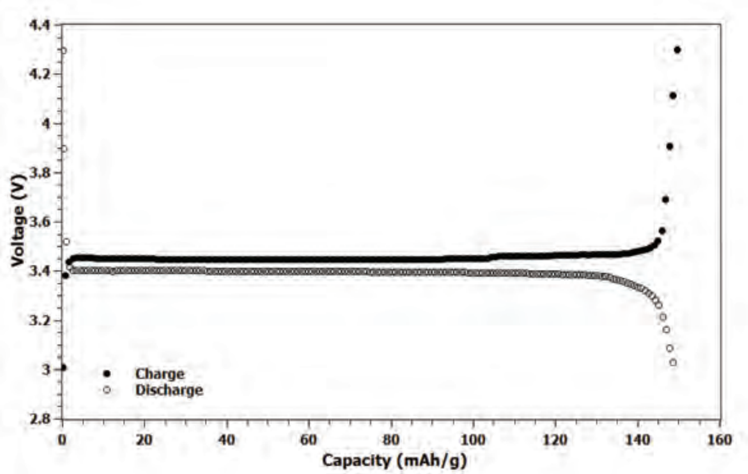


Figure 3: Charge-Discharge profile of fabricated separator sample in CR2032-type coin cell during the 2^{nd} cycle.

Summary

Desirable characteristics of fabricated separator include enhanced wettability, dimensional stability at elevated temperature and chemical resistance. Through the aforementioned exercise, a simplistic approach has been demonstrated to appreciably enhance the thermal stability of the fabricated separator by incorporating inorganic nano fillers (SiO_2). Fabricated membranes were analyzed for their wettability, thermal stability and electrochemical performance, which exhibited excellent miscibility with the liquid electrolyte desirable for developing better lithium ion rechargeable batteries. Effort is being made to investigate advanced materials and develop separators with even better electronic insulation, uniform pore size distribution, mechanical strength and good electrochemical performance.

Design and Development of Gold-Iron Oxide Based Smart Magnetic Nanosensor for Detection and Separation of Heavy Metal Ions

Introduction

Monitoring the tracer level of heavy metal ions such as lead (Pb^{2+}), copper (Cu^{2+}) and arsenic (As^{3+}) in environmental and biological systems is essential since exposure to these can trigger toxic effects in humans through the alteration of cellular activities and resulting in the development of serious disorders including cancer. For example, the accumulation of high levels of Pb^{2+} can cause irreversible brain damage in children aged between one and five years. The biochemically essential metal ion Cu^{2+} can cause serious human affliction such as Wilson's disease probably by its active involvement in the production of reactive oxygen species. Copper can also turn on the angiogenesis process in humans, thereby aiding the development of malignant tumors. Abnormally high levels of copper have been detected in the serum levels of many cancer patients where growth factors bind to copper in order to perform angiogenesis. Copper-binding molecules (ceruloplasmin, heparin) are non-angiogenic when free of copper, but become angiogenic when bound to copper. The most dangerous metal is arsenic, because exposure to As^{3+} can cause skin problems, skin cancer, cancers of the bladder, kidney and lung, diseases of the blood vessels of the legs and feet, high blood pressure and reproductive disorders and possibly diabetes also. Natural arsenic contamination is a major concern in many countries of the world including Bangladesh, India, Thailand, China, Argentina, Chile, Mexico and the US. Therefore, the development of safe and effective techniques for the real-time detection of the heavy metals such as copper, lead and arsenic is an important goal for clinical toxicology, water contamination control and food and pharmaceutical processes.

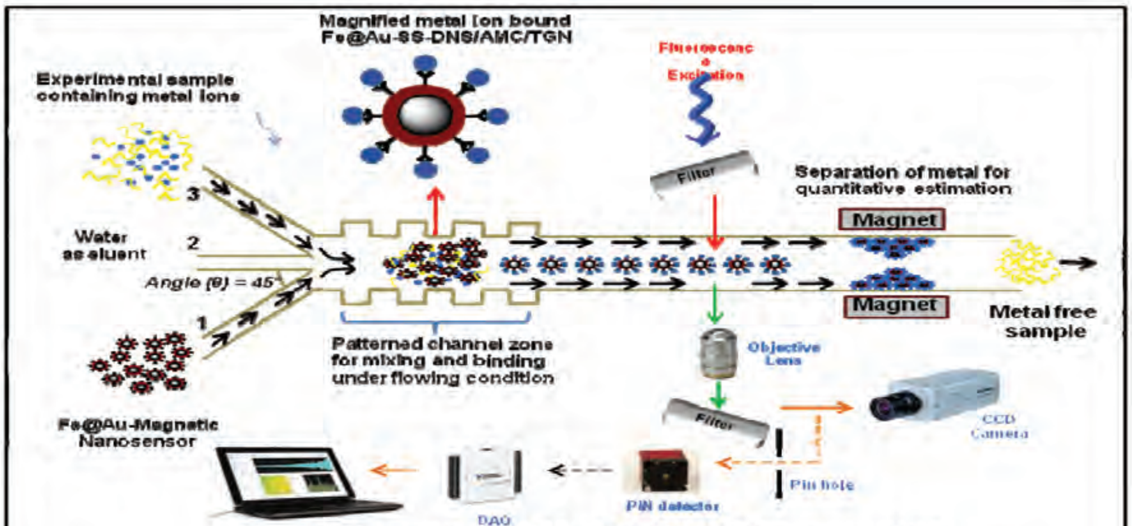
Hypothesis and Current Trends

Currently, the most common methods for the detection of toxic metal ions include atomic absorption spectroscopy (AAS), inductively coupled plasma mass spectrometry (ICP-MS) and anodic stripping voltammetry. These instrumentally intensive methods require extensive sample preparation. Therefore, a simple and inexpensive method for detection and separation of the metal ions is desirable in real-time monitoring of environmental, biological and industrial samples. To responsd to this challenge, the MST Group is carrying out extensive research for the development of magnetic nano-sensors based on core-shell Fe@Au-nanomaterials, Fe@Au-SS-DNS, Fe@Au-SS-AMC, and Fe@Au-SS-TGN to offer a viable solution with high sensitivity and rapid separation ability for the detection and quantification of specific metal ions (Cu^{2+}, Pb^{2+} and As^{3+}) in environmental and biological samples. Nanoparticle-based sensors are particularly valuable in this context, because miniaturization to nano-dimensions can provide selective and immediate response to metal ions since all the receptors for the metal ions are exposed to the large nanoparticle surface-sample interface. Moreover, the use of magnetic nanoparticles through a magnetic field offers additional benefits to successful detection such as concentration and removal of trace amounts of specific analytes. Therefore, nanosensors based on receptor-cum-fluorescent probes that bind metal ions reversibly but selectively with concomitant fluorescence signal transduction and followed by magnetic separation is desirable and worthwhile. The need for dual performances in terms of tracer level metal ion detection and quantification by a single sensor in aqueous medium led the researchers to initiate the current research program.

The planned Fe@Au-SS-DNS, Fe@Au-SS-AMC and Fe@Au-SS-TGN magnetic nanosensors are expected to possess multiplexing capabilities by incorporating thousands of receptor-cum-fluorescent agents in conjunction with the magnetic core, thereby yielding a simultaneous and diverse sensing cum separation modality for heavy metal ion detection and quantification. Such dual performance based technologies can easily be employed in basic laboratory assays as also adapted for in-field measurements through portable devices so as to evolve commercial indicators for household use. Moreover, the project will explore interests in biomedical applications where such nanosensors can be introduced into microfluidic devices by means of an external magnetic field for low-volume immunoassay detection of metal ions in experimental samples (e.g. monitoring the level of Cu^{2+} ion in blood serum in many types of progressive cancers or As^{3+} ion in urine of arsenicosis patients). The proposed magnetic nanosensors therefore have potential use in medical diagnosis and therapy under clinical settings.

Research Plan

This study proposes to utilize the unique optical and electronic properties of nanometer-sized particles which cannot be achieved by traditional materials or methods. The research plan is based on the expertise of the researchers of the MST Group in developing functionalized nanomaterials and subjecting these to various biological fields. In working towards this goal, fluorescence based magnetic nanosensors, Fe@Au-SS-DNS, Fe@Au-SS-AMC and Fe@Au-SS-TGN with an intrinsic fluorescent signal will be synthesized to indicate the presence of toxic metal ions. The versatile synthetic approach will be employed in preparing fluorescence based metal ion chelating ligands, Dansyl-C6-SS (DNS-SS), Coumarin-C6-SS (AMC-SS) and Thioguanine-C6-SS (TGN-SS) which will be immobilized on the surface of magnetic Fe@Au-PEG nanoparticles. The high density of fluorescence units on the surface would initiate several photophysical processes leading to a lesser response time with significant signal amplification, which is highly desirable in sensors to achieve extremely low detection limits. The fluorescent emissions of dansyl, coumarin or thioguanine units are sensitive to its environment and change as metal ion binding occurs, thereby signaling the presence of such metal ion binding. Moreover, the magnetic properties of the nanoparticles will be useful for the quantification of metal ions by the process of extraction from the experimental samples. These nanosensors will be used in microfluidic devices for process controlled and low-volume immunoassay analysis of metal ions



Scheme 1. Application of Fe@Au-SS-DNS/AMC/TGN in microfluidic device for the detection and quantitative estimation of metal ion.

in various experimental samples as shown above in Scheme 1.

Conclusions

The present research activity, which has been supported by the Department of Biotechnology, Government of India, will contribute to significant knowledge-based platforms for various nanosensor fabrications where the signal of specific entity would be visibly seen for toxic metal ions, proteins and bacteria upon binding. There is no doubt that nanomaterial based devices would solve many important problems encountered in traditional measuring techniques and open new areas of modern analysis. The importance of nanotechnology research has already been established as a proof of concept in environmental, clinical, agricultural, food or defense sectors. Despite the enormous potentials compared to conventional laboratory techniques, numerous problems still remain to be solved. Most of the nano-scaled materials show excellent performances under laboratory set-up, but often fail to demonstrate their efficiency and robustness in real sample monitoring. Another limitation is the poor reproducibility between synthesized nanomaterials and their targeting ability in complex environments. Future research programmes may provide answers to these problems by building scientific networks for the production of useful materials with specific properties for applications in medicine and environmental analysis.

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Wire Drawing Die Wear Monitoring - Challenges and Achievements

Introduction

Wire drawing machines are important equipment for manufacturing metal wires whose main function is to reduce the size of wire rods into fine wires pressing through wire drawing dies. Generally, a wire whose diameter is to be reduced is made to pass through a hole of a smaller diameter and plastic deformation results in reduced cross section while the volume remains unchanged. The process is generally carried out at room temperature; however, the process is also used at elevated temperatures.

The health of the die used in wire drawing process plays a key role in productivity improvement as well as in maintaining the quality of the wires. One of the main reasons for die failure in wire drawing industries is wear. Die wear affects the tolerances of formed wires and cost of processes. The only way to control failures due to die wear is to monitor the condition of the die.

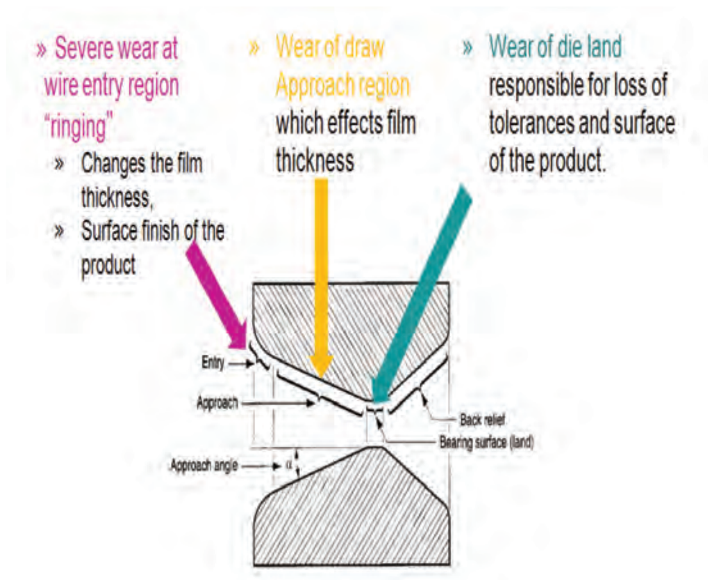


Figure 1: Wear Zones of a Wire Drawing Die.

Challenges in Die Wear Monitoring

✓ Traditional monitoring using optical microscope requires stoppage of machine and results in production loss. An indirect method is therefore needed.

- ✓ No software is available commercially for wear monitoring.
- ✓ Harsh environment conditions in production plant.
- ✓ Robust working conditions like high speed, temperature.
- ✓ Deciding judiciously on locating of sensors, since this plays a major role in gathering effective data.

What is Acoustic Emission

Acoustic emission (AE) is defined as radiation of mechanical elastic waves produced by a material due to the dynamic local rearrangement of its internal structure. Possible causes of the internal structural changes are crack initiation and growth, crack opening and closure, dislocation movement, elastic and plastic deformation of surface asperities, etc. It is a known fact that material surfaces are not perfectly smooth, and even highly polished surfaces possess some degree of roughness. When two such surfaces come in contact with each other at asperities, or when there is a relative sliding between the two, continuous formation and rupture takes place at these asperity junctions. The deformation and rupture of these asperity junctions during sliding results in high frequency stress waves known as AE. These AE signals are characterized by parameters which contain information on physical phenomena causing AE and these are sensitive to the changes in the conditions of the sliding surfaces.

How Acoustic Emission can be used for Die Wear Monitoring

The die wear can be monitored in real time by using the acoustic emissions generated during the wire drawing process. By monitoring AE characteristics like Root Mean Square (RMS) and Cumulative counts, one can judge the condition of the die and the process can immediately be halted to prevent the manufacturing of any out-of-specification product. A single wire diameter measurement at the end of the spool cannot guarantee that all the wire inside the spool is within the specifications, and this in itself necessitates the development of online wear monitoring system using indirect measurement techniques for wire drawing process. Indirect monitoring systems offer great benefits not only by reducing the labour costs but also by saving significant amount of raw material.

Root Mean Square (RMS) is a statistical measure of the magnitude of a varying quantity. The RMS value of a signal is a measure of its power content. Mathematically

$$RMS = \sqrt{\frac{1}{N}\sum_{n=1}^{N}[x(n)]^2}$$

Where N is the number of samples taken within the signal and x(n) is the amplitude of the signal for the n^{th} sample.

Counts involve counting the number of times the amplitude exceeds a preset voltage level (threshold level) in a hit/event and gives a simple number characteristic of the signal.

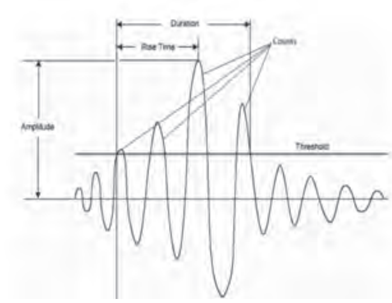


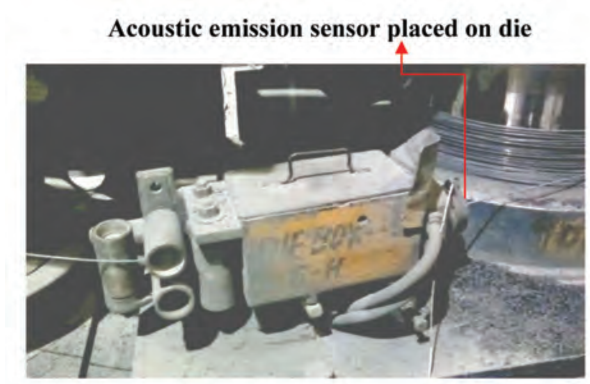
Figure 2: Acoustic Signature

Solution Provided by CSIR-CMERI

Online die wear monitoring system is crucial to reduce production costs as well as downtime in industrial machines, and an online die health monitoring system has been developed by CSIR-CMERI to facilitate this. This system can detect and analyze AE signals relating to asperity contacts in sliding surfaces, and the corresponding health condition is displayed on a computer screen. Statistical analyses are carried out to characterize the AE signals and to identify the changes in signals from the sensors. A wide range high frequency response sensor is mounted on the stationary surface to capture AE signals. The signals are then transmitted to the signal conditioning device, further to the data acquisition system and finally to the computer display. An integrated approach is taken in using Matlab and Labview software for data acquisition and analysis of the AE signals. Labview software platform is used to develop a user-friendly graphical user interface (GUI) and for data collection; this data is processed by a Matlab code developed to analyze the signals.

Industrial Trials

Industrial trails were conducted in the ISWP plant of Tata Steel, Jamshedpur. The AE data was acquired by placing the sensor on the die holder as depicted in the figure. The sensor position was chosen by carrying lead break tests and it was found that the sensor can capture the AE signal with good signal strength even when placed on the die holder. Another advantage is that the frequency range of AE signals generated during sliding process is very high [100Khz-2Mhz] when compared to machine vibrations, so this will neglect all the vibrations generated by the machine as well as other heavy machinery used in the plant. The captured Acoustic emission data is processed to obtain characteristics of AE signal. The RMS shows a steady increase as the wear of die progresses in keeping with the cumulative counts. A significant variation in the characteristics of AE for a die wear of 10 microns was manifested, which shows that this monitoring technique is very sensitive to changes in die wear or improper lubrication.



Conclusion

This article demonstrates the feasibility of using Acoustic emission (AE) signals as an online indirect measuring technique to monitor the health of wire drawing die. The significant features of the user-friendly GUI are its ability to graphically display the characteristics of AE which is influenced by die wear. The observations from the industrial trails are quite interesting and are consistent with the wear of die. This investigation motivates us further to develop a portable hand held device which can assess the health of die.

Appropriate Mechanization Project at the Durgapur Steel Plant

Task

Design & development of a mechanical or an electromechanical system for holding and shifting of red hot forged wheels in the Wheel and Axle Plant at the Durgapur Steel Plant.

Problem Definition

- ✓ Hot Forged Wheel Transfer
- ✓ Hot wheel temperature 800^{O} - 950^{O}C (approximate)
- ✓ Continuous presence of two people at ground floor is required to engage the EOT crane grippers
- ✓ Working environment is hazardous and high temperature leads to fatigue of ground floor operators
- ✓ Manpower requirement: 2/shift

Abstract

Earlier, hot railway wheels were transported within the Wheel and Axle plant of DSP using a device made of three metallic soft MS brackets (Figure 1). The end of brackets carried MS hooks, which were placed under the edge of hot wheels. The brackets were operated with the help of an EOT crane and two ground operators. Very frequently, at least twice a week, the bracket hooks were deformed and required repair work. There was also the risk of the hot wheels falling down from the holding device during transportation.

The DSP assigned the task to CSIR-CMERI of developing an automatic mechanical gripper for holding and shifting red hot wheels in the Wheel and Axle Plant. Accordingly, a mechanical gripper was designed at CSIR-CMERI. The gripper was designed using mechanical links and a special type of cam mechanism placed nearer to the cam follower mechanism resembling a retractable ballpoint pen but having no spring. The details of actual design along with material specifications were prepared based on strength and thermal analysis of each component. The device can be operated with the help of an EOT crane for translational movement and proper location of the gripper. The device then holds or releases wheel stacks automatically on the shop floor. The scaled down functional prototype of gripper

was built and the desired function was validated satisfactorily at the laboratory level before actual implementation. The design was handed over to DSP for implementation. The final device (Figures 4 & 5) has been manufactured by DSP through their ancillaries and implemented successfully in the Wheel and Axle Plant. This device is under continuous operation in the plant since 1st April, 2013 eliminating requirement of additional ground operator in the shop floor for handling the wheels, leading to cost benefit and better safety of the Wheel and Axle Plant.

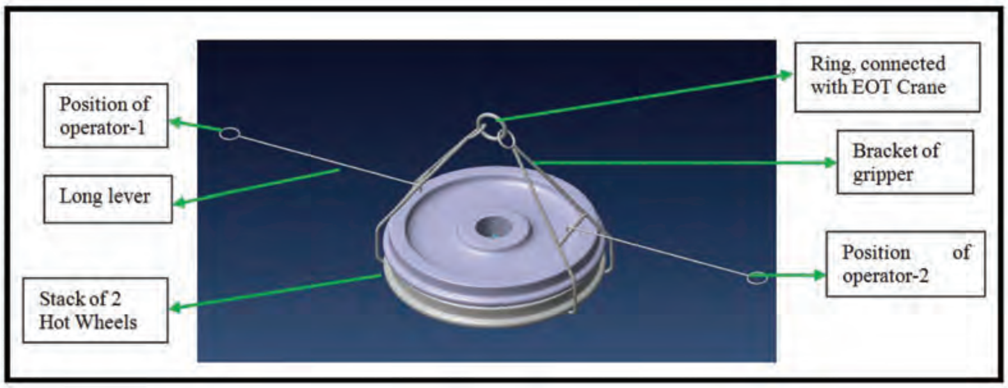


Figure 1: Earlier system of handling hot wheels with the help of EOT crane and 2 additional ground operators

Figure 2: 3D CAD model of device

Figure 3: Scaled down prototype for design validation, showing its desired function

Figure 4: Final device in the Wheel and Axle Plant, lifting the hot wheels

Figure 5: Final device transporting the hot wheels in Wheel and Axle Plant of DSP

Milestones achieved

- ✓ Conceptual design
- ✓ Detail drawing
- ✓ Scaled down prototype
- ✓ Actual device successfully implemented at the Wheel and Axle Plant of DSP
- ✓ Successful operation of device since implementation
- ✓ Manpower reduction in each shift
- ✓ Increase in productivity

Development of 100% Biofuelled Tractor

The Project was sanctioned by the Department of Science & Technology, Government of India with budgetary support of Rs. 32.54 lakh. Shortage of petroleum products and their rising international prices has drawn interest towards the exploration of alternate fuels. Moreover, attention is being given to emission control. Among different alternate fuels, Biodiesel has proven to be the best candidate. In India, tractors are versatile prime movers in farms as well as on roads which run on diesel. But there is no tractor available in the market as on date compatible to run on 100 % Biodiesel. This project has aimed towards running an indigenous tractor for long duration on B100 in collaboration with M/s International Tractors Limited, Hoshiarpur.

The objectives of the research were:

- ✓ Study of existing Sonalika 35 hp tractor
- ✓ Modification of the engine hardware for running on B100
- ✓ Endurance test of Sonalika DI–35 on diesel and B100 (both on test bed & field)
- ✓ Study of the engine after the test
- ✓ Incorporation of any other hardware changes, if required
- ✓ Demonstration of B100 fuelled tractor

Minimum modification of the engine and allied systems to suit with B100 has been done for trial runs. One 35 hp, 3 cylinder, Direct Ignition Sonalika tractor (engine) has been tested on B100 on test bed to assess its performance. The engine has run on B100 on test bed with modified engine for 800 hours without any complications. It has shown equally comparable performance in terms of power developed, thermal efficiency, bsfc, etc. as compared to diesel. The Biodiesel required for the long duration test has been produced from CMERI developed semi-continuous Biodiesel plant (600 litre/day capacity) and all the fuel properties have been tested to meet BIS/ASTM standards.

Presently the tractor with modified engine is being run in field condition to assess its performance. Once developed, this will be **India's first Indigenous Tractor to run on B100.**

Following modifications/ changes have been incorporated in the engine to suit with B100:

Fuel Characteristic	Effect	Failure Mode	Proposed Change / preventions
Fatty acid methyl ester (FAME)	Causes some elastomers including nitrile rubber to soften, swelling	Fuel leakage	Biodiesel consumed within 6-8 weeks after production because after 8 weeks softening of elastomers takes place; viton materials have been used. Additive (F2- 21) added to biodiesel to increase shelf life
Free methanol in biodiesel	Corrodes Aluminium & Zinc, Low flash point	Corrodes FIE	Proper washing of biodiesel has been done. Anti corrosion coatings provided
Biodiesel Process Chemicals	Sodium & Potassium Compound	Blocked Nozzles	Proper washing of biodiesel has been done; pressure to be raised to 750 bar; nozzle dia increased to 0.25 – 0.30 mm
Free Glycerin (Mono or Di-Glycerides)	Corrosion of non ferrous metals, Soaks cellulose filters	Filter clogging, Injector Choking	Redesigning of Injector and FIP has been done. Fuel filter has been changed to centrifugal type; multiple filters provided
Free water in mixture	Corrosion, Increases conductivity of fuel	Sludging	Proper removal of water after processing of biodiesel has been ensured. $CuSO_4$ packed column introduced at the fuel inlet.
Free fatty acid	Provides an electrolyte and hastens corrosion of Zn, Salts of organic acids compound formed	Corrosion of FIE, Filter plugging, Sediments on parts	Efficient process has been used to convert 99.99 % FFA into FAME; anti corrosion coatings provided
High Viscosity at low temperature	High stress on components, Generates excessive heat in rotary pump	Pump seizure, Early life failures	Redesigning of Injector and FIP done. Fuel filter changed to centrifugal type. Turbo charging done for preheating of fuel.
Acid (Formic/Acetic)	Corrodes metal parts	Corrodes FIE	Fuel filter changed to centrifugal type; anti corrosion coatings provided
Polymerization products	Deposits especially from fuel mixes	Filter plugging, Lacquering formation in hot areas	Fuel filter changed to centrifugal type; anti corrosion coatings provided
Trace material in lubrication oil	Cylinder liners, piston rings, valves and gear wear	Fuel leakage	Bimetallic Bearings has been used for eliminating copper wear ($AlSn_20$).
Dilution of lubricating oil	Excessive wear of piston rings, head, cylinder liner	Engine becomes heated	SAE 10W 40 used
Excessive NOx emission	Environmental impact	Crosses the limit of standards	Introduction of de NOx catalyzer or catalytic converter to be done

Smart and Intelligent Actuator based Micro Manipulation Systems for Robotic Micro Assembly

Introduction

An emerging technology of micro system facilitates the assembly operation of very small mechanical/electronic components using miniature actuators like piezoelectric and ionic polymer metal composite (IPMC), etc. These actuators are capable of performing the functional task of miniature parts in automation such as grasping and micro manipulation, etc. For achieving these tasks, the micro manipulator is an essential tool in an industrial level for developing automation. The automation is to assist the human operator in picking up microscopically small components, holding them and placing them in the right position. These improvements enhance product quality, reliability and decrease the product cost. In this aspect, handling and manipulation tasks demand a flexible, light weight and cost effective product. In order to develop the microsystem technology, CMERI is focusing towards new design of micro gripping systems with an integrated micro manipulator which offers flexibility in handling of peg and its manipulation in a large work space. The development of piezo actuator based micro manipulation system is an application part of the Supra Institutional Network Project (SINP) on **Intelligent Devices and Smart Actuators**.

Objective of the project

The main objective of this project is to design and develop the piezo/IPMC actuator based micro manipulation system. For this purpose, new designs are attempted and their characteristics are identified.

Salient achievements

Under this project, the following activities have been carried out and their achievements have been highlighted:

1. **Development of piezoelectric actuator based micro gripper for robotic micro assembly**

   In order to execute the sequential pick & place and peg-in-hole assembly operations of robotic assembly in 3-D environment, a manipulator needs at least 3 degrees of freedom (DOF) and a micro gripper which can adjust the orientation of the peg, rotational motions and to execute the assembly. Therefore, a novel three

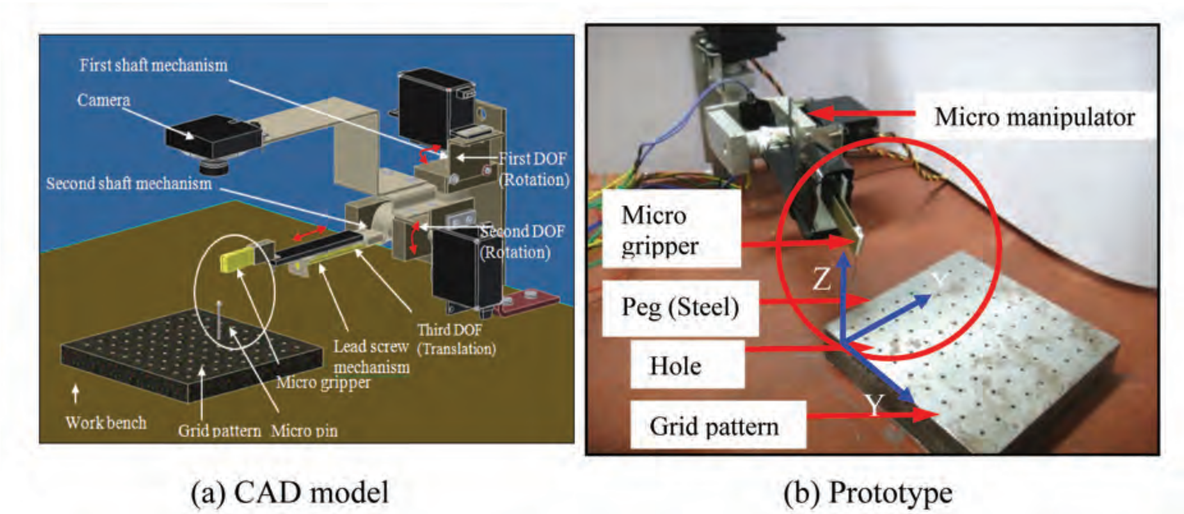
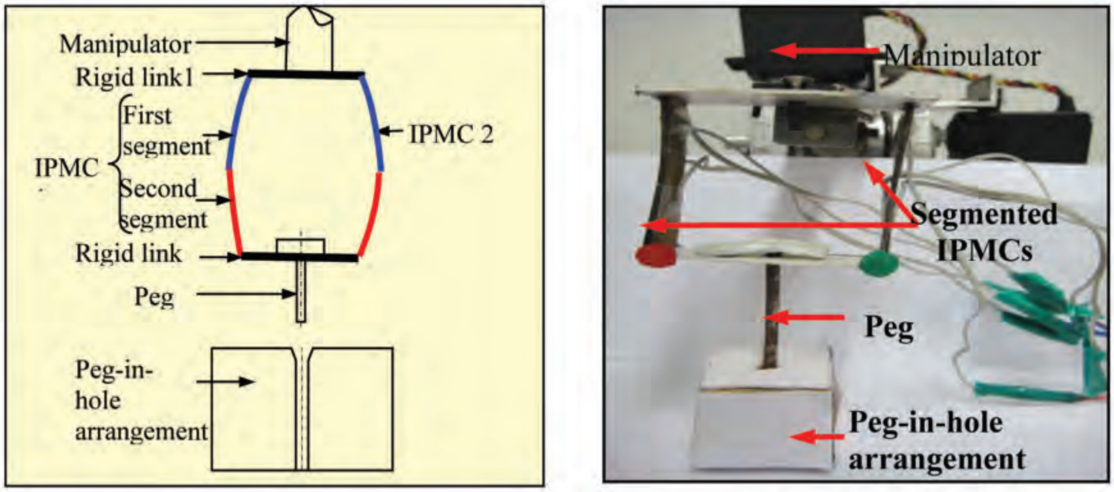


Figure 1: Piezoelectric actuator based micro gripper for robotic micro assembly

DOF micro manipulator was designed, whose schematic CAD model is shown in Figure 1(a). The micro manipulator consists of two shaft mechanisms to achieve two rotational motions and one lead screw sliding mechanism to provide the translational motion. A micro gripper is fitted at an extreme end of the lead screw mechanism by a retrofit fastener arrangement so that the micro gripper can be used as an integral part during assembly with micro manipulator. This micro gripper needs compliance for dexterous handling. Due to this reason, the micro gripper is constructed using bimorph piezo actuators/benders. In this micro gripper, two bimorph piezo strips are used as two fingers. These fingers are operated at 0-60 V. One piezo actuator based finger bends on one side and the other finger produces the opposite behavior. These fingers thus bend in opposite directions for holding the micro components like micro pin/peg, etc. and perform the robotic assembly. A camera is also mounted on top along with a computer for visualizing the robotic micro assembly operations like pick & place and peg-in-hole assembly so that vision based feedback is provided to the system. A grid pattern is also designed for robotic micro assembly where the size of the grid pattern (100 mm×100 mm) is considered as a square pattern because the distance between one hole and the next is taken as 10 mm. Thus, robotic micro assembly can be performed with 81 hole positions using piezo actuator based micro gripper in a large workspace (100 mm×100 mm).

2. Development of active 4 DOF based RCC wrist using segmented IPMCs for robotic peg-in-hole assembly

The objective of this work is to design and develop an active 4 DOF based Remote Compliance Centre (RCC) wrist using two segmented IPMCs for micro assembly. A new design of segmented IPMC based RCC wrist is proposed as shown in Figure 2(a). This RCC consists of two rigid links and two segmented IPMC strips. The two rigid links are mounted on the top and bottom supports. A peg is held by the lower rigid link during insertion. Each IPMC strip is cut at the



(a) Schematic diagram (b) Prototype

Figure 2: Active 4 DOF based RCC wrist using segmented IPMCs

centre position by a CO_2 laser cutting process so that it behaves like a two DOF based IPMC. These IPMCs adjust the lateral and angular alignments during peg-in-hole assembly. If the center lines of the peg and the hole are parallel but not coaxial, it is called a lateral misalignment. Whereas, if the center lines of the peg and the hole intersect during mating, it is called angular misalignment. During assembly, both types of misalignments may occur simultaneously. This kind of RCC can compensate both for lateral and angular misalignment actively by providing voltage to the four IPMC segments. Therefore, this kind of RCC is called as 4 DOF based RCC for robotic assembly. The major advantages of such mechanism are that RCC wrist consists of only one four-bar mechanism and precise assembly can be achieved by individually controlling any one segment of the IPMC link. A prototype of an active 4 DOF based RCC wrist using two segmented IPMCs is developed and manipulation task is demonstrated as shown in Figure 2(b).

3. Design and control of an IPMC artificial muscle finger for micro gripper using EMG signal

The objective of this work is to design and control IPMC based artificial finger for micro gripper. In this work, an IPMC based micro finger is actuated by controlled electromyography (EMG) signal as shown in Figure 3. The EMG signal is taken from human index finger via the EMG sensor. This signal is pre-amplified before transferring to IPMC for achieving the large bending behaviour of IPMC. The bio-mimetic actuation behaviour of IPMC is studied by movement of index finger muscles through long tendons. The stability analysis of EMG signal from human index finger is carried out by providing a PID control system. Experimentally, it is observed that the IPMC finger can hold a load of upto 100 mg when IPMC finger is activated through EMG via human muscles and an IPMC based finger for micro gripper is demonstrated as shown in Figure 4.

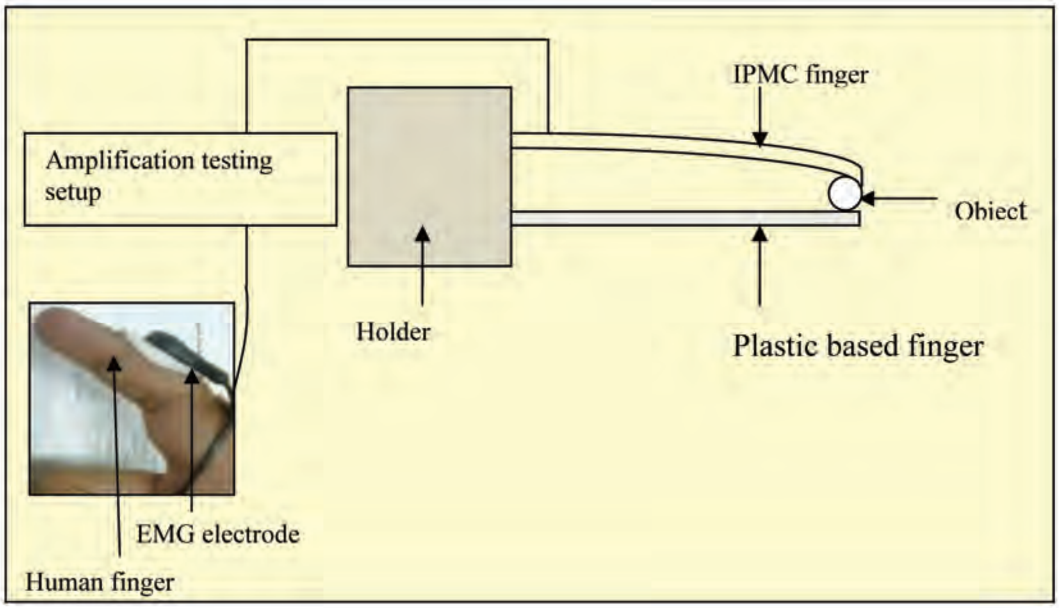
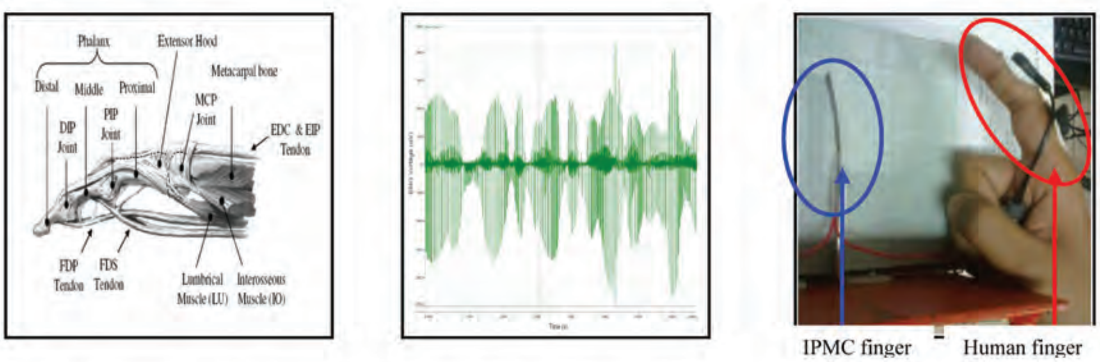


Figure 3: Layout of IPMC based micro gripper driven by EMG signal



(a) Index Finger (b) EMG signal (c) Activated state of finger

Figure 4: Behavior of IPMC finger for micro gripper using EMG

4. Development of multi micro manipulation system using piezoelectric actuator based micro grippers for robotic micro assembly

In order to design the multi micro manipulation system for robotic micro assembly, four micro-manipulation systems (MMS) are placed on a single work bench as shown in Figure 5. Each MMS is placed on specific rails which are positioned at equal distances and which are perpendicular to each other. These rails are constructed for providing the lateral motion of MMS towards picking and placing of the object from one hole position to another. Each MMS is identical in shape and size and has 3-DOF for attempting the pick & place and peg-in-hole assembly in 3-dimesional space. These MMS can perform the operation of robotic assembly in sequential or random manner through automatic or joystick controls. Each MMS consists of a mobile mechanism, shaft mechanism, lead screw mechanism and a micro gripper. The base of the mobile mechanism has dimensions 90mm×62mm×16mm and are made of aluminum. Two wheels along with two servo motors are added to the base frame so that lateral motion can be attempted. A shaft is constructed using aluminum which is rotated by another servo motor in the shaft mechanism. This mechanism provides up-down motion during handling of the peg. A lead screw mechanism is built using lead screw and stepper motor for to and fro motion in linear direction for picking and placing the object. The stepper of lead screw mechanism is housed in the shaft mechanism for connectivity between the two. A micro gripper is fitted at the end of the lead screw mechanism for grasping and holding the object. This gripper is constructed using two bimorph piezoelectric actuators which are operated at 0-60 V. Each piezoelectric actuator has dimension of 45mm×11mm×0.6mm. For placing the object, a grid pattern (7×7 holes) is designed so that the MMS can attempt the pick and place and peg-in-hole assembly in the desired work space. A camera is mounted at the top of work bench through a support frame which is used for visualizing the robotic assembly operations in a desktop computer.

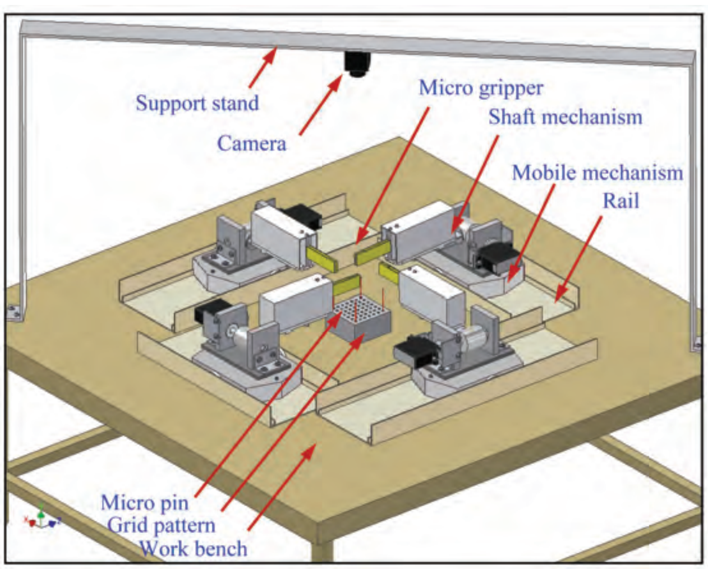


Figure 5: Micro manipulation system using piezoelectric actuator based micro grippers for robotic micro assembly

Metal Injection Moulding

Metal Injection Moulding (MIM) is a fast-growing manufacturing process which combines the flexibility of injection moulding with the strong structural integrity of sintered metal powder. The process makes possible manufacturing of metal parts which are stronger, denser and more capable than other manufacturing processes in production of complex geometric shapes. This process begins with a very consistent feedstock. Metal Injection moulding is a high volume technology that can produce details as fine as 0.25 mm on a regular basis and also create geometries that are unattainable by conventional processes such as stamping, screw machining, or even standard powder metallurgy. The processing steps in MIM are: (1) Preparation of Feedstock: Polymers and lubricant are mixed to the fine metal powder to produce a "feedstock" which is the initial raw material of MIM process. Feedstock is then converted into small pellets for easy feed; (2) Moulding: The pellets are fed through a hopper into the screw conveyor of injection moulding machine where they are converted into a viscous mass with the help of heat and shear action of screws. The viscous mass is then injected inside the mould cavity to produce complex geometry green compact; (3) Debinding: Polymers and lubricants are gradually extracted from green compact through a process called "debinding"; (4) Sintering: Debound components are sintered in between 1300^{0}C-1380^{0}C to produce final products. It has been found that the densities of sintered parts are in between 95% and 98%, almost as high as that of wrought metals. Despite the shrinking which varies

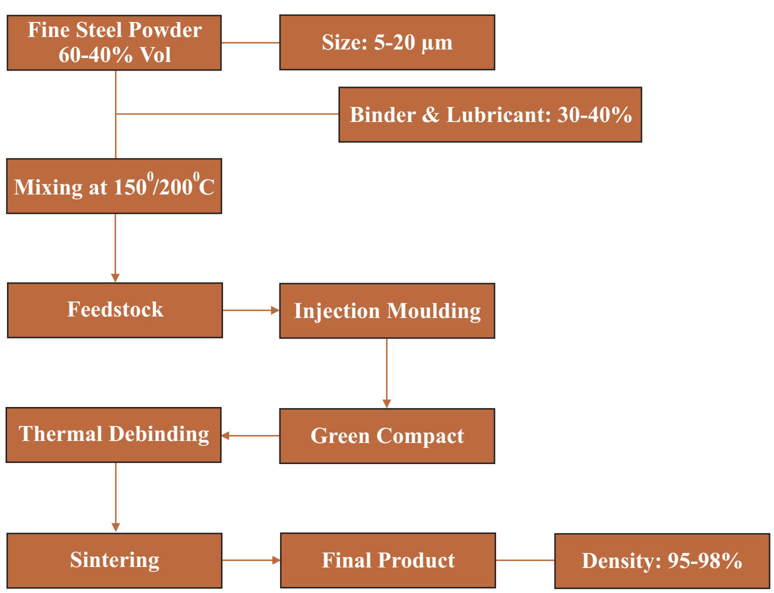


Figure 1: Process route for manufacturing of components by MIM

from 12%-15%, closer and more accurate tolerances can be achieved with injection moulded metals. This is because the plasticity of the feedstock and the nature of the closed injection mould allow greater design freedom than other conventional methods. Figure 1 shows the process route for manufacturing of MIM components. The higher densities of injection moulded parts provide much higher strength and other superior mechanical properties.

The entire process route of MIM process has been developed at CSIR-CMERI – starting from initial raw material for the process to the final product – and the components developed will be sent to the interested companies for commercialization and field trial. The components developed are: (a) Extractor and (b) Trigger for the Ichapur Rifle Factory (under Ministry of Defence); Scissors to the indigenous manufacturers of surgical instruments (namely from M/s Glowtronics India Pvt. Ltd., Coimbatore).

Experimental details

1. **Manufacturing of Metallic die/mould for metallic components/tensile specimen**

   After getting drawing of the components, solid model of the components was developed. Solid model helps in ascertaining the gating system of the die. For a tensile specimen, after finalizing the dimensions of the tensile specimen as per ASTM Standard E-8, and taking $L_0/\sqrt{A_0}$ ratio as 4.5 (as per ASTM), solid model of the tensile specimen was developed. A systematic approach was adopted to develop a MIM mould with mould design parameters such as shrinkage values, proper gating and ejection system required for the manufacturing of green compacts. The supplier of the feedstock provided the binder content of the feedstock. From the knowledge of percentage of binder content it was possible to ascertain the shrinkage factor of the feedstock.

   During the manufacturing of the mould, 15% shrinkage is considered. Single cavity mould is prepared. The mould material is EN-24. Figure 2 shows engineering drawing of the tensile specimen with 15% shrinkage allowance. Figure 3 shows solid model of (a) extractor, (b) trigger, (c) upper and lower arm of scissors and (d) assembly of scissor.

Figure 2: Component Geometrical drawing after taking 15% shrinkage

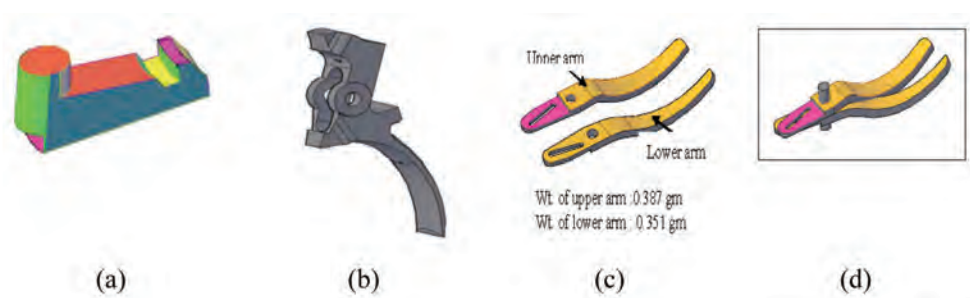


Figure 3: Solid model of (a) Extractor, (b) Trigger, (c) upper and lower arm of scissors and (d) assembly of scissor

2. Preparation of Feedstock

(i) Imported feedstock of 4140,316L,420

The experimental work was carried out initially by taking feedstock of 4140,316L,420 feedstock from Advanced Metalworking Works Inc., Carmel, USA. Figure 4 and Figure 5 shows the SEM photograph of imported feedstock and distribution of iron particles respectively.

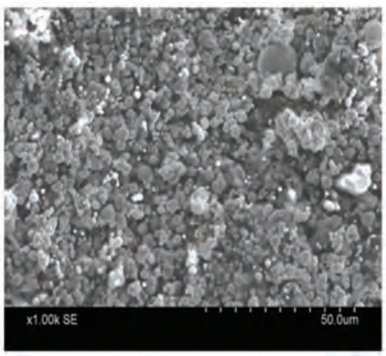


Figure 4: Imported Feedstock

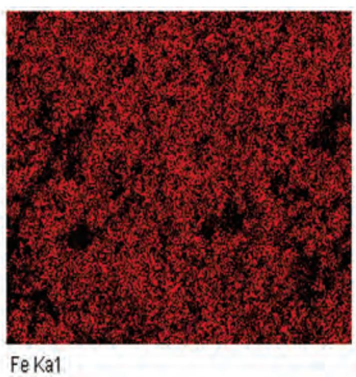


Figure 5: Distribution of iron particles

(ii) Formulation of Indigenous Feedstock of 4140

The indigenous feedstock was developed by mixing of fine powder of 4140 steel powder having the mean particle size less than 10 micron and organic binder consisting of LDPE, PW wax and stearic acid. The viscosity of LDPE, PW Wax and stearic acid is given in Table 1. The properties of the powder is shown in Table 1: The feed stock of 4140 was prepared by mixing powder of 4140 steel with binder in the volume ratio 60:40. The feedstock was prepared by continuous stirring of metal powder and binders in a sigma blade mixer, During mixing the temperature of the mass was maintained at 120^0-150^0C. By removing the lump of feedstock from the mixer, it was cooled and then granulated into feedstock. Figure 6 and Figure 7 shows the SEM micrograph of indigenous feedstock and distribution of iron particles in indigenous feedstock respectively.

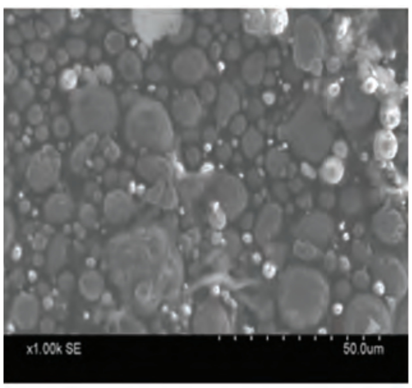


Figure 6: SEM Micrograph of Indigenous Feedstock

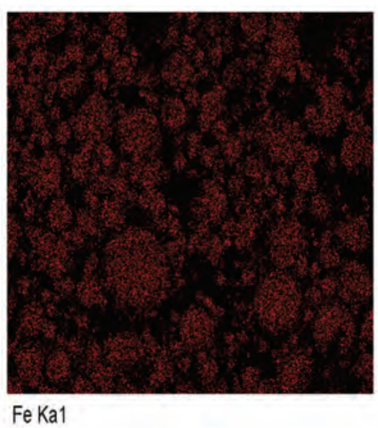


Figure 7: Distribution of Iron particles in indigenous feedstock

3. Manufacturing of green compacts in Injection Moulding Machine

The standard mould along with mould cavity of the product is assembled in an Injection Moulding Machine. During moulding feedstock pellets are converted in the form of paste in an injection moulding machine under the application of heat. The feedstock in the form of paste is injected inside the mould cavity under pressure. While there are many variables that control MIM process, mould filling is the most critical phase for manufacturing of component. Sink marks, voids, weld line and density variations are among the consequences of improper specification of moulding variables and tool design. These defects cannot be repaired in the next subsequent steps of product development. The success of moulding depends not only on the rheology of the mixture but also on the design of the mould cavity and the choice of the process parameters of injection moulding like injection temperature, filling time, etc.

Manufacturing of green compacts was carried out by using a 30 ton Plastic injection Moulding Machine. The injection performs two basic functions. First, it melts the feed-stock and deposits this melt in front of the screw in the barrel. The second function of the injection end is to inject the melt into closed mould. Table 1 shows the injection parameters of tensile specimen, trigger and scissors.

Density of the Green Tensile specimen/compacts of different components varies from 4.5 to 5 gm/cc. Figure 8 shows green (a) Tensile specimen, (b) trigger, (c) extractor and (d) laproscopy scissors.

Table 1: Parameters for Injection molding of feed stock

SI. No.	Product	Material	Injection Pressure pal	Locking Pressure psi	Injection Time see	Cooliig Time sec	Nozzle Temperature °C	Zone I	Zone II	Zone III
1.	Tensile Specimen	4140 Indigenous	20	80	10	30	50-90	70-80	115-120	120-140
2.	Tensile Specimen	4140 Imported	20	80	10	30	40-50	80-120	90-1 00	120-170
3.	Tensile Specimen	316L	20	80	10	30	45-55	80-145	100-130	120-130
4.	Tensile Specimen	420	20	80	10	30	45-50	80-1 SO	100-150	125-140
5.	Trigger	4140 (imported)	20	80	10	20	45-50	100-120	160-165	175-180
		4140 (indigenous)	20	80	10	20	45-50	65-70	80-90	100-120
6.	Scissors	420 (imported)	20	80	10	20	45-50	150-170	135-145	115-125

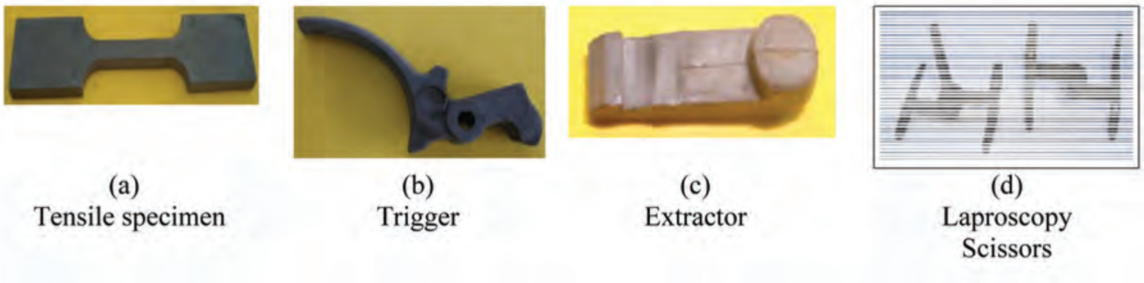


Figure 8: Photograph of green compacts

4. Debinding

Removing the binder without disrupting the particles is a delicate process and it is achieved in several small steps. Initially the binder holds the particles together. When the binder is heated it softens and is unable to withstand shear stresses from gravity, thermal gradients or internal vapour pockets. Hence to retain compact shape an inherent particle-to-particle friction is needed. The binder must be extracted from the pores as a fluid (liquid or vapour) without distorting or contaminating the compact.

Volatile binder is removed step by step by thermal degradation and evaporation and debinding temperature used was based on the Thermogravimetric Analysis (TGA) curve. The TGA analysis indicates the changes in weight as a function of temperature over time. These changes usually occur as a loss in weight, but a gain in weight can be seen if the sample goes through an adsorption (i.e oxidation). TGA curve helps to control furnace atmosphere, heating rate and debinding temperature.

(i) Thermal debinding of imported feedstock

The moulded components were placed on a ceramic tray using fine ceramic powder as the wicking media. A suitable combination of the three parameters – furnace atmosphere, heating rate and debinding temperature – produces a defect-free part. Wicking process that extracts the binder through capillary action has several advantages as it provides additional support, better thermal uniformity, reduction in gas partial pressure gradients at the surface of the part and homogeneous wicking out of the binder throughout the part. Green bodies are in the fluid state at the very beginning of debinding. In addition, the thermal expansion of the liquid binder induces hydraulic pressure in the capillaries which enhances binder removal rate.

(ii) Debinding of indigenous feedstock

Since multi-component thermoplastic binder has been designed, two step debinding process has been followed. Paraffin wax and stearic acid has been removed by solvent debinding and polyethylene has been removed by thermal debinding. The solvent used here is n-hexane. It is seen that if 80% of paraffin wax and stearic acid is removed from the component there will be no distortion during thermal debinding.

5. Sintering

Sintering, the final procedure in Metal Injection Moulding, is an irreversible step incapable of curing defects introduced in compacts during mixing, moulding or debinding. The debinding and presintering upto 1000^{0}C is done in a chamber type debinding furnace and sintering is performed in a high temperature tubular sintering furnace using inert atmosphere. The debound components were placed inside an alumina tube on a refractory base. The outlet of the debinding furnace and the ceramic tube of alumina tube of the sintering furnace is connected with an inert gas cylinder. Sintering is indicated by the density achieved in the MIM components. After debinding, components are often near 60% dense, while the final density approaches 93% to 99%. Proper tool design and close tolerances require reproducible and homogeneous shrinkage. Since shrinkage is inversely dependent on the green density, it is desirable to maintain a high and uniform powder packing density. A high packing density system can be obtained through selection of equiaxed (near spherical) particles with graded particle sizes or broad particle size distributions. Surface diffusion is often dominant at lower sintering temperature. Slow heating consumes the driving force for sintering without densification of the compact. It is suggested for rapid heating at low temperatures followed by slow heating in the intermediate temperatures where densification is active while grain growth is retarded, with a final short term high temperature hold.

Table 2, Table 3, Table 4 and Table 5 shows the rate of heating, rate of cooling and holding time at different temperatures that were followed during experiments for the feedstock of 4140 imported, 4140 Indigenous, 316L imported and 420 imported after optimization by Taguchi method.

Table 2: Rate of heating, rate of cooling and holding time for 4140 imported feedstock

Heating	
550^{0}C-1000^{0}C	2^{0}C per minute
1000^{0}C	Holding – 60 minutes
1000^{0}C-1280^{0}C	5^{0}C per minute
1280^{0}C	Holding – 45 minutes
Cooling	
1280^{0}C-1000^{0}C	5^{0}C per minute
1000^{0}C	Holding – 60 minutes
1000^{0}C-200^{0}C	5^{0}C per minute
200^{0}C – room temperature	Furnace cooling

Table 3: Rate of heating, rate of cooling and holding time for 4140 indigenous feedstock

Heating	
550^{0}C-1000^{0}C	20^{0}C per minute
1000^{0}C	Holding – 60 minutes
1000^{0}C-1250^{0}C	70^{0}C per minute
1250^{0}C	Holding – 60 minutes

Cooling	
1250^{0}C-1000^{0}C	50^{0}C per minute
1000^{0}C	Holding – 60 minutes
1000^{0}C-200^{0}C	50^{0}C per minute
200^{0}C – room temperature	Furnace cooling

Table 4: Rate of heating, rate of cooling and holding time for 316L imported feedstock

Heating	
550^{0}C-1000^{0}C	2^{0}C per minute
1000^{0}C	Holding – 60 minutes
1000^{0}C-1340^{0}C	7^{0}C per minute
1340^{0}C	Holding – 45 minutes
Cooling	
1340^{0}C-1000^{0}C	5^{0}C per minute
1000^{0}C	Holding – 60 minutes
1000^{0}C-200^{0}C	5^{0}C per minute
200^{0}C – room temperature	Furnace cooling

Table 5: Rate of heating, rate of cooling and holding time for 420 imported feedstock

Heating	
550^{0}C-1000^{0}C	2^{0}C per minute
1000^{0}C	Holding – 60 minutes
1000^{0}C-1380^{0}C	5^{0}C per minute
1380^{0}C	Holding – 45 minutes
Cooling	
1380^{0}C-1000^{0}C	5^{0}C per minute
1000^{0}C	Holding – 60 minutes
1000^{0}C-200^{0}C	5^{0}C per minute
200^{0}C – room temperature	Furnace cooling

Table 6: Density achieved by immersion method of different feedstock, 4140 Structural Steel (imported), 4140 Structural Steel (indigenous), 316L Stainless Steel (imported) & 420 Stainless Steel (imported)

	Material			
	4140 Structural Steel (Imported)	4140 Structural Steel (Indigenous)	316L Stainless Steel (Imported)	420 Stainless Steel (Imported)
Density (gm/cc)	7.6	7.39	7.78	7.89

The final densities of the sintered samples were tested by the immersion method. The densities achieved are given in Table 6. Figure 9 shows the sintered (a) tensile specimen (b) extractor (c) trigger and (d) scissors.

(a) Tensile specimen (b) Extractor

(c) Trigger (d) Scissors

Figure 9: Sintered components

New Initiatives at the Microsystem Technology Laboratory

During 2012-2013, the Microsystems Technology Group undertook a clutch of new initiatives. The ability of micro fabrication techniques to create structures and patterns on microscopic and sub-microscopic length scales on multi materials triggered the development of miniaturized devices and systems used in diverse areas. The Microsystems Technology Group successfully demonstrated the following:

1. Engineering of antibacterial surfaces directly over the solid surfaces
2. Pantograph based micro-machine to create nano-scale patterning

The Microsystems Technology Group further demonstrated the feasibility of designing patterned geometries to impart hydrophobicity to the surface that restricts bacterial colonization. Figure 1 demonstrates the number of bacterial colonies restricted over laser patterned surface compared to the smooth surface. Over and above, bacteria-specific or device specific micro-nano patterned surfaces have been developed and proven in commercial applications where these can find wide usage in a variety of industrial areas. This would have significant potential in reducing hospital acquired infections (HAI).

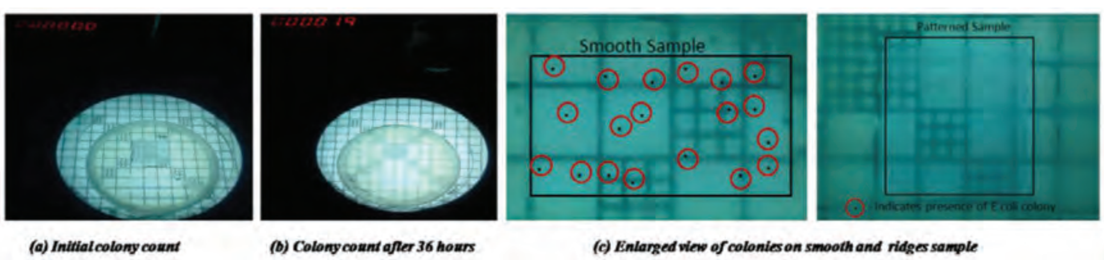


Figure 1: Restricted colonization of E coli bacteria over micro patterned surface

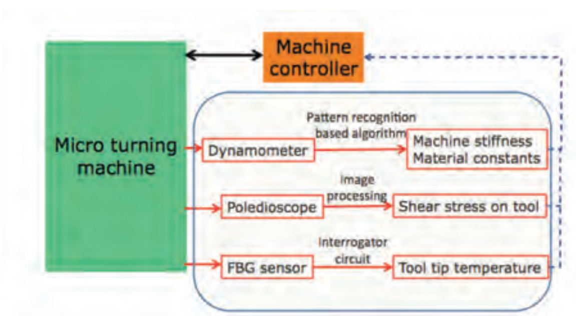
Currently, creating complex shaped (three dimensional) patterns directly over solid surface over a relatively larger area is a major challenge; the processes such as lithography, focused ion beam machining are too expensive and slow to meet batch production requirements. The Microsystems Technology Group has successfully developed a pantograph mechanism based micro machine prototype that creates patterns in the submicron scale through scratching over polymer and metallic surfaces (Figure 2). This machine has been designed to overcome the limitations of current AFM based nano-scratching and would be useful for batch production as well as for large area nano-patterning.

Figure 2: Micro machine with pantograph mechanism for nano-scratching

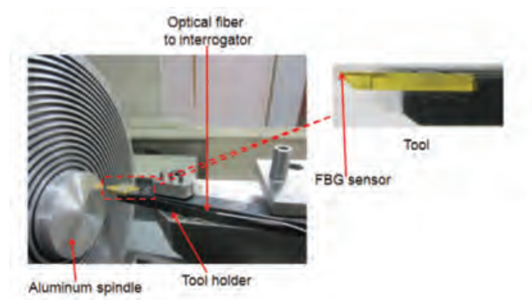
Micro Nano Process Control

The MST Group has developed a multisensory approach for dynamic process monitoring in the micro turning machine. The work deals with use of multiple sensors in an integrated way to monitor the micro turning process so that accuracy and precision of the process can be achieved and longevity of the machine and tool can be enhanced. Micro turning is used in industries for production of micro parts like motor shafts, fine needles and ultra reflective mirrors for lasers and optical applications. Ensuring accuracy, alleviating cutting tool damage and preserving surface integrity of the work in the process is a crucial task.

Three sensors – namely dynamometer, poledioscope and fiber Bragg grating sensors (FBG) – are used to generate dynamic stiffness, tool stress and tool tip temperature respectively. The procured signals were processed in order to monitor the micro turning process.



Schematics of research conducted



A micro tool with FBG sensor

Figure 3: Dynamic process control instrumentation developed for micro turning operation

Novel Nanoscale materials and their Micro-fluidic applications in Chemical and Biomedical sciences

The members of the MST Group are currently involved in design and development of nanoscale materials, devices and study of their applications in various chemical and biomedical sciences. The research focuses on, (i) rational design and synthesis of highly complex nanostructures with precisely controlled chemical composition, physical morphology and dimension; (ii) fundamental investigation of the novel opto-electronic and magnetic properties and (iii) exploration of new technological opportunities arising in these new nanoscale structures. A strong emphasis has been given on the smart integration of multi-composition, multi-structure and multi-function at micro-nanoscale, and by doing so to create a new generation of integrated systems with unique functions to overcome the barriers of traditional technologies. The following sections briefly describe some specific potential research areas based on nanoscale devices and integrated systems.

Nano–Sensors: A nano–sensor integrates one or more sensing operations in a single device. The system can provide fast result and easy operation. Nanoparticle-based devices offer many advantages by reducing analysis time, improving detection limits and allowing real time monitoring of relevant target species with high precision and accuracy. Functionalized nanoparticles typically possess manifold receptor sites, having structural and chemical features suitable for analyte recognition and binding, and a readout mechanism that provides significantly amplified electrochemical, optical and spectroscopic signals through a small device. The research focus is on the development of a nanoparticle-based magnetic sensor which will produce signals for specific targets such as toxic metal ions, proteins, bacteria, etc. upon binding. The technology could successfully be used in microfluidics and biotechnology. The grant-in-aid project has already been initiated where an attempt has been made to introduce this technique in microfluidic devices for process controlled and low-volume assays (Figure 4), which may allow for quick and accurate in-field environmental analysis of toxic metal ions such as arsenic, lead, etc. This research project has been funded by the Department of Biotechnology, Government of India.

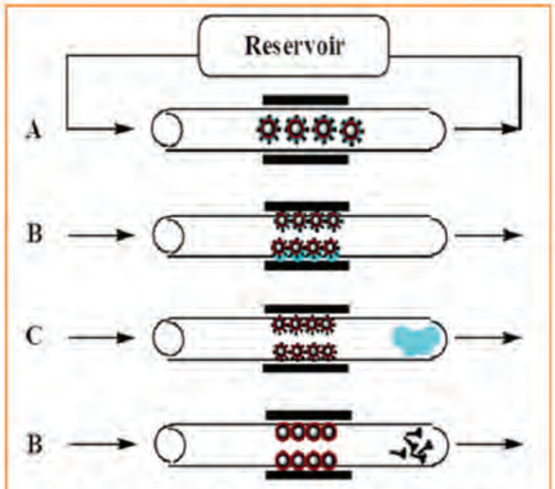


Figure4. Schematic diagram of microfluidic network for magnetic extraction. (A) Sample mixture containing magnetic nanoparicles is introduced into the channel; (B) Magnetic nanoparticles with analytes of interest are retained by the magnets; (C) Unwanted components are eluted; (D) Retained analytes are extracted by stronger eluent.

Figure 4

Drug Delivery Systems: The drug delivery in fluidic networks such as the blood circulatory systems of human body is vital. To know how these drug molecules travel as they are injected into the blood vessel and delivered to the desired sites, the blood circulatory system can be mimicked by straight or curved microchannels with or without patterned surfaces on the channel wall to demonstrate the delivery of a potential drug (Figure 5). The researchers at MST Lab are currently concentrating on demonstrating the *in-vitro* use of Thioguanine (TG) as cancer therapeutic carried by gold nanoparticles (GNP-TG) to kill tumour cells (CTC) suspended in a biologically relevant medium. In this context, the ongoing study includes a patterned micro-fluidic system that consists of biologically relevant components as sheath fluid to mimic the human cancerous cells and different nanoparticles as central trajectory to mimic the drug injected into the blood capillaries. The travelling paths of the nanoparticles through transverse diffusion and the interactions with biological components at the interfaces are of interest of this research. The presence of curvy structured walls provides a high degree of lateral transport within the channel and rapid mixing of two confluent streams undergoing laminar flow. The effect of Reynolds number (Re) has been investigated in terms of the experimental mixing indices. It appears that the proposed channel patterns offer required interaction when Re is >10. The technique can be simplified as typical particle-laden flows in microchannels and some experiments have been carried out as proof-of- concept to illustrate the drug delivery mechanism. This research is being pursued as an institutional project.

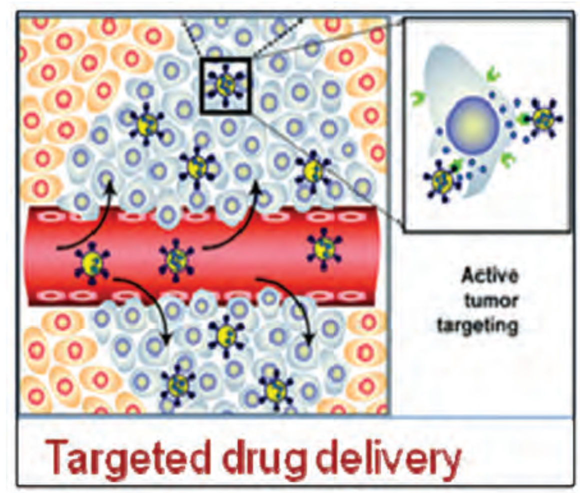


Figure 5

Membraneless micro-bio fuel cell with self pumping mechanism

The MST Group undertook experimental studies for the generation of self oscillatory potential in patterned micro fuel cell channels to demonstrate the mechanism behind self oscillations present in nature such as flapping wings of insects and butterfly, human ears, chemical reactions, etc. (Figure 6).

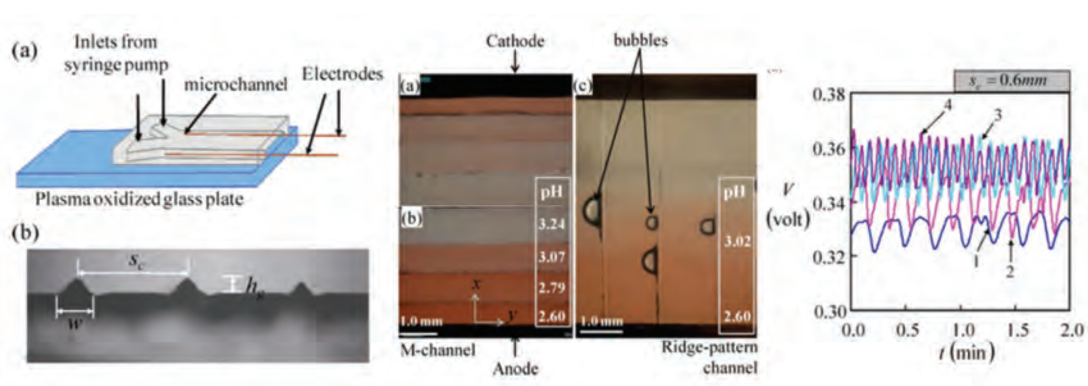


Figure 6: Showing the membraneless microfuel cell channel with patterned surface for the generation of oscillatory potential. The pH gradient shows the reason for the above phenomena

Dynamical interaction of nanoparticles in patterned microchannels

Hydrodynamic focusing of silver nano particles by hydrogen peroxide as sheath fluid in a three inlet micro-channel is investigated experimentally which undergoes a chemical interaction at the liquid-liquid interface for generation of silver ion precipitate. The precipitate can be used as electrode for the fuel cell application for its performance enhancement (Figure 7).

In addition, clustering of nanoparticles in micro channels is being studied to understand agglomeration of drug molecules around the disease affected sites present inside the body for effective treatment (Figure 8).

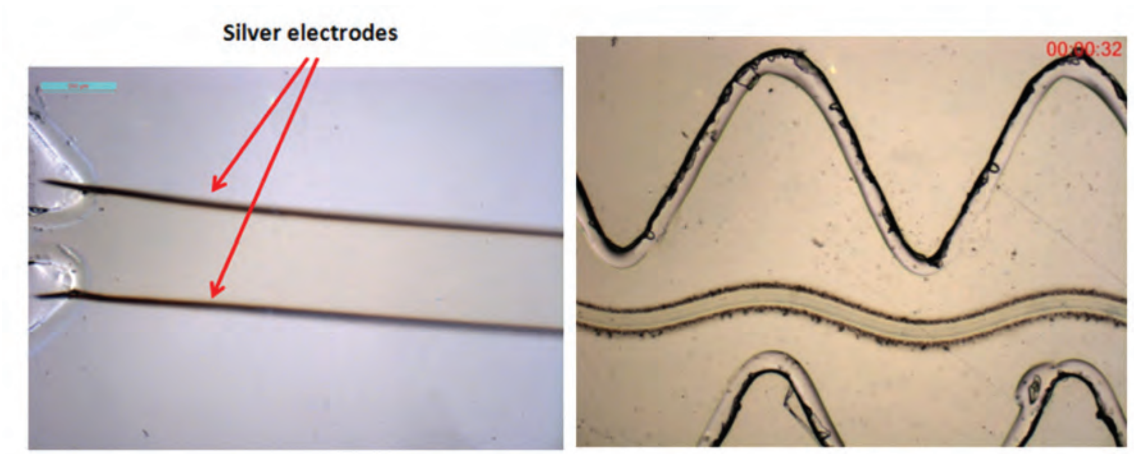


Figure 7: In-situ formation of silver electrode by nanoparticle deposition in straight and curved micro channels

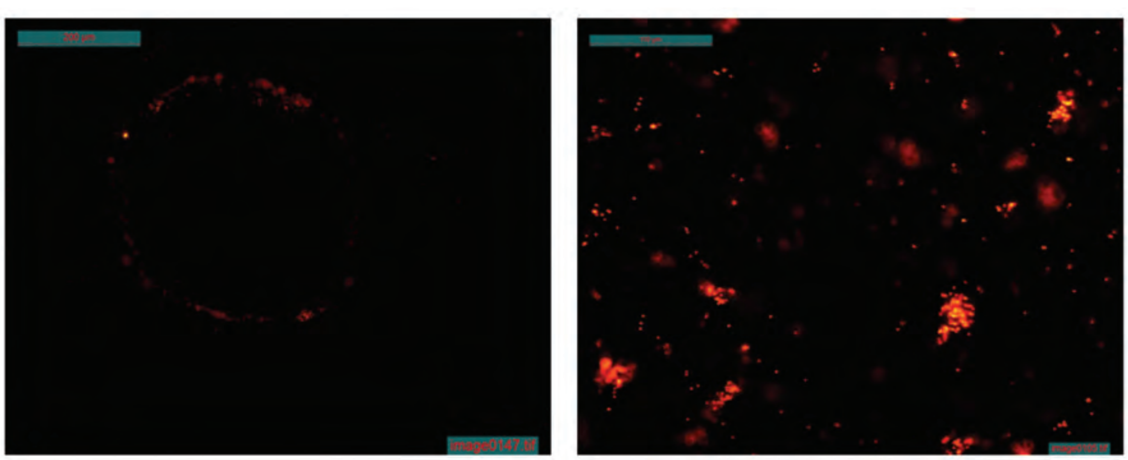


Figure 8: Showing the clustering of nanoparticles in microchannel consisting of patterned and smooth surfaces

Dewetting induced nano structure formation of confined bilayer system

When two immiscible liquid layers are confined in between two surfaces, the liquid-liquid interface show some kind of instability. The nature of instability depends on the two factors: surface tension force and van der Waals interactions. The first factor tends to stabilize the interface whereas the second one destabilizes it. When the films are sufficiently thin (<10nm), the van der Waals force becomes dominant and the instability grows leading to partial dewetting of some layers which produces some holes and droplets in nano dimension. This phenomenon is investigated using both molecular dynamics and continuum simulations (Figure 9).

Calculation of diffusivity of ink molecules for dip pen nanolithography using molecular dynamics

Dip pen nanolithography is a technique for creating nano structures on different substrates. It uses an AFM tip as a pen and some long chain thiol as ink molecules for creating the nano structures. For designing and modelling the DPN process, diffusivity values of long chain thiols are important. Diffusivity of two such ink molecules are calculated using molecular dynamic simulations using the Mean Square Displacement method based on Einstein's relationship.

$$D = \frac{1}{6N} \lim_{t\to\infty} \frac{d}{dt} \sum_{i=1}^{N} \left\langle \left| r_i(t) - r_i(0) \right|^2 \right\rangle$$

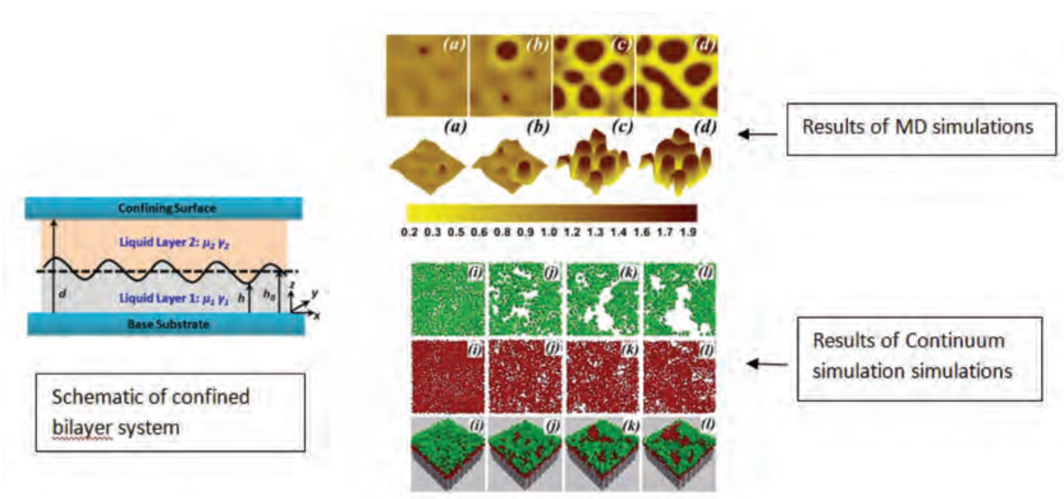


Figure 9: Comparative results obtained Molecular Dynamics and CFD based simulations

Metal-Ceramic Nano-Composite Coating by Electrolytic Deposition

Metal-ceramic nanocomposites can possess a combination of properties from the parent constituents into a single material. Research shows that there also is the possibility of new properties which are unknown in the parent constituent materials. Development of new nanocomposites by using various materials is a highly demanding area for advanced applications such as synthesis of functionalized super hydrophobic/ hydrophilic and anticorrosive surfaces. The Metal-Ceramic nanocomposites are synthesized using the electro-deposition of ceramic nano-particles along with deposition of reducing metallic species from an aqueous media giving a composite coating. The SEM micrographs show certain patterns. The preferential growth of the (111) planes are prominent in case of co-electrodeposition as an effect of specific process parameters. EDS and XRD analysis of the coatings confirmed the incorporation of the Ceramic particles (Figure 10).

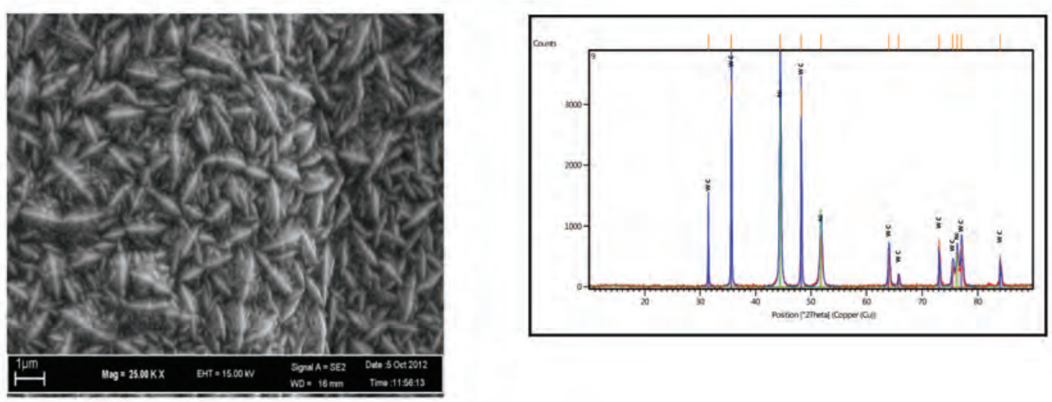


Figure 10: SEM and XRD micrographs electrodeposited Ni-WC Composite surface

Synthesis of Single Layer Graphene and its Polymer Nanocomposites for the Fabrication of a High Performance Flexible Electrode

Introduction

Flexible electronics have attracted significant attention in the area of energy storage device (i.e., supercapacitors or Li-ion batteries) due to compactness and the property of easy integration on flexible chips with other wearable electronic components. The development of high power density, long cycle life, mechanically robust and highly efficient electrode materials are highly demanding. Technologies for the development of electrode materials with sufficient inherent flexibility are, however, quite inadequate. Recent works have illustrated that mechanical flexibility and energy storage performance of graphene-based materials are superior as compared to the conventional nano-structured carbon materials. Flexible, high energy density and long life cycle supercapacitor electrode materials for the storage of electrical energy are being experimented with at CSIR-CMERI and reasonable success has been achieved. The foregoing brief summarises the achievements of CSIR-CMERI in this regard.

Objectives

- ✓ Development of graphene/metal oxide composites
- ✓ Preparation of surface modified graphene
- ✓ Structural and morphological investigation of the graphene-based hybrid materials
- ✓ Investigation of electrochemical performances of the composite materials
- ✓ Development of experimental prototype supercapacitor and electrochemical performance

Approaches/Experiments

Preparation of reduced graphene oxide (RGO)/Co_9S_8 composites: Graphite oxide was prepared through the chemical route achieved through appropriate modification of the Hummer's method. For composite preparation, cobalt chloride ($CoCl_2.6H_2O$) and urea were dissolved in an aqueous dispersion of GO. Two pieces of nickel foam and the reaction mixture were transferred into a 100ml Teflon-lined stainless steel autoclave with proper sealing and heated at 95°C for 7 hours. The nickel foams coated with black mass were thoroughly washed with DI water and dried under vacuum for 20 hours at 60°C. In the second step, ~ 1 ml of 0.2 M Na_2S solution was added to 80ml of distilled water in a Teflon-lined stainless steel autoclave of 100ml capacity. Precursor coated nickel foams were introduced to the autoclave and heated at 120°C for 2 hours in a hot air oven and designated as CSRGO1. Two other Co_9S_8/RGO composites were prepared by changing the amount of GO and the samples were designated as CSRGO2 and CSRGO3 respectively.

Preparation of reduced graphene oxide (RGO)/ Fe_3O_4 composites: A series of RGO/Fe_3O_4 composites (FRGO1, FRGO2 and FRGO3) were prepared by hydrothermal method. The detailed experimental procedure and GO to $FeSO_4.7H_2O$ ratios have been described in the research article published in the journal *RSC Advances*.

Preparation of surface modified RGO: Surface modified RGO was prepared by the non-covalent covalent surface modification of GO by sulfanilic acid azo-cromotrop at 70°C followed by the reduction of modified GO at 100°C using hydrazine monohydrate as reducing agent.

Fabrication of supercapacitor device: Supercapacitor electrodes were prepared using the composites of 75 wt. % of graphene hybrid, 10 wt. % PVDF and 15 wt. % carbon black dispersed into 10 ml DMF. The hybrid materials were casted on to the nickel foam (or stainless steel) (with 1 cm diameter) and dried under vacuum. Supercapacitor assembly was used to study the performance of practical device in two electrode system.

Results & Discussions

Structural characterization: X-ray diffraction (XRD), Fourier transform infrared (FT-IR) spectroscopy, X-ray photoelectron spectroscopy (XPS) and Raman spectroscopy were employed to investigate the structural features of the graphene materials. FT-IR and XPS were used to confirm the reduction and functionalization of GO present in the hybrid materials.

Morphological characterization: Field emission scanning electron microscopy (FE-SEM) and Transmission electron microscopy (TEM) were used to examine the distribution of graphene sheets in the composites. The appearance of paper-like, ultrathin and wrinkled surfaces confirmed the existence of RGOs in the composites.

Mechanical flexibility test: The electrodes for supercapacitor devices were prepared by casting onto a 0.05 μm thick stainless steel sheet. The electrodes were found to be quite flexible and their electrochemical performances remained unchanged even after bending/twisting.

Electrochemical performances: The electrochemical performances of the devices were evaluated by cyclic voltammetry (CV), charge-discharge and electrochemical impedance spectroscopy (EIS) analysis. The specific capacitance of Fe_3O_4, FRGO1, FRGO2 and FRGO3 were found to be 73, 519, 782 and 553.8 F g^{-1}, respectively at a current density of 3 Ag^{-1} (Figure 1a). The retention in specific capacitance of FRGO2 was recorded as ~100% after 1000 CD (Figure 1b). The energy density of Fe_3O_4, FRGO1, FRGO2 and FRGO3 were found to be 3.65, 25.95, 39.1 and 27.15 $WhKg^{-1}$ respectively at a power density of 1800 Wkg^{-1} (Figure 1c). It is therefore evident that the energy density of the composite electrodes always remained higher as compared to the Fe_3O_4-based supercapacitor.The energy densities of the CSRGO1, CSRGO2 and CSRGO3 were found to be 32.2, 68.6 and 49.1 $WhKg^{-1}$ respectively at a power density of 1319 WKg^{-1} and the results were found to be significantly higher than that of pure Co_9S_8. The specific capacitance of CSRGO3 and CSRGO2 electrodes were retained ~ 98 and 96% after

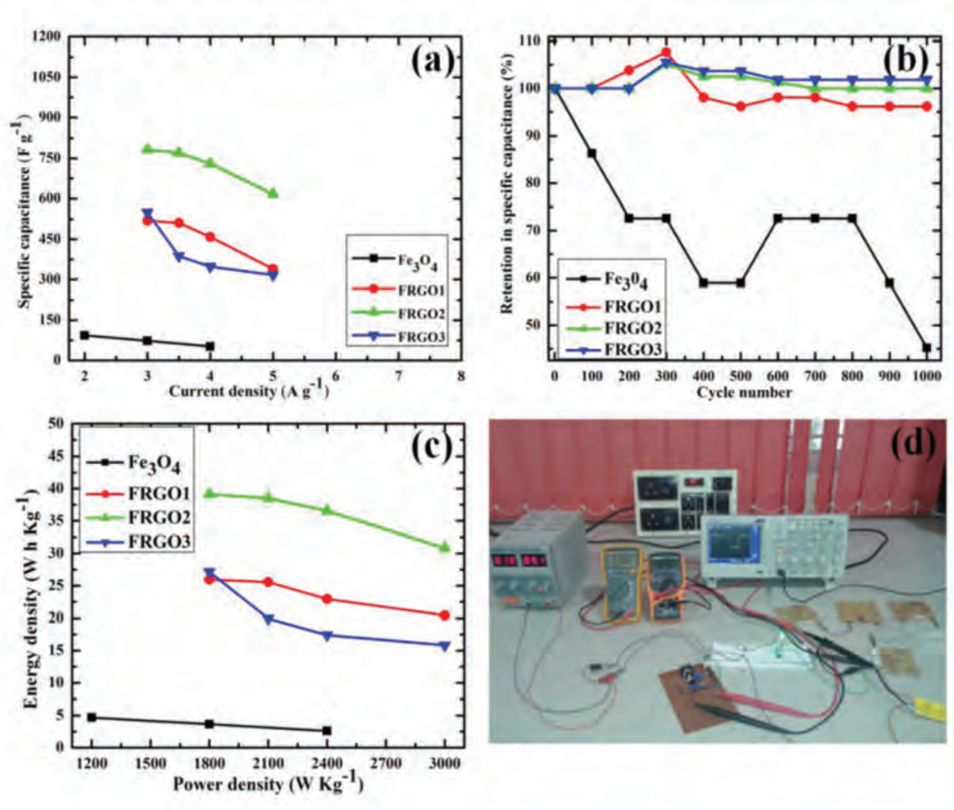


Figure 1: (a) Variation of specific capacitance with current density for Fe_3O_4, FRGO1, FRGO2 and FRGO3, (b) Electrochemical cyclic stability up to 1000 charge-discharge cycles, (c) Variation of energy density with power density and (d) Series connection of four supercapacitor devices giving ~3.1 V.

1000 cycles. The low electrochemical cyclic stability of CSRGO1 may be ascribed to the dominating pseudocapacitive nature, while the EDLC was dominated in the CSRGO3 and CSRGO2 composites. Four CSRGO2 supercapacitor devices were connected in series and achieved a voltage in excess of ~ 3.1 V (Figure 1d) was achieved. The charging time was only 45 s and two LEDs (Green and Red) glow for ~ 50 s.

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Looking Ahead

- Variable Impedance Actuation and Biomimetics: Toward Soft and Human Friendly Robots
- Design and Development of Biomimetic Frog Robot for Multimode Locomotion
- Biorobotic Swimming: a Tendon Driven Pectoral Fin Mechanism

Variable Impedance Actuation and Biomimetics: Toward Soft and Human Friendly Robots

Introduction

New generation human friendly robots are no longer rigid; they have become soft in terms of introduction of considerable flexibility at the actuated joints, at the links and on outer coverings. Introduction of flexibility and variation of intrinsic passive impedance is becoming essential in enhancing ability and performance of actuation systems in safety-critical applications involving physical-human-machine-interaction. Unlike conventional actuated machine joints, there exists flexibility in the transmission between the prime-mover shaft and the actuated joint shaft. In variable stiffness/impedance actuation, this joint compliance varies according to the need of task execution. In physically interactive tasks by machine with operators, the human safety is of prime importance. A joint can be made safe against accidental impact hazards of fast moving machine parts by attenuating the reflected inertia through the compliance. Hazard due to impact is a function of effective inertia and relative velocity of the impacting body. Thus, during a task execution, when positional accuracy is more demanding, the joint can be made stiff at low velocity, whereas during gross motion with high velocity, the joint can be made compliant, maintaining operator's safety intrinsically against accidental impact. This requirement leads to variability in stiffness and in turn impedance – giving rise to the concept of *Variable Impedance Actuation*. This article describes the development of such a Variable Impedance Actuator and illustrates the underlying principles for the design of nonlinear transmission elements. The present development is highly motivated by biological principles. The difficult area of online estimation of transmission and joint impedance is addressed.

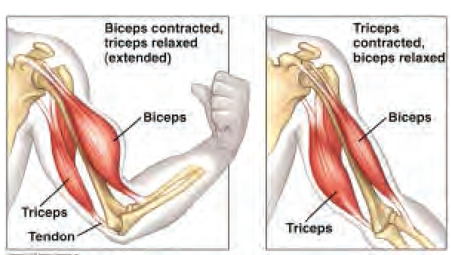


Figure 1: Agonist-antagonistic muscle actuation

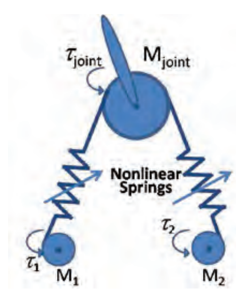


Figure 2: Agonist-antagonistic realization using nonlinear passive transmission for simultaneous control for motion and stiffness variation.

Actuator inspired by musculoskeletal actuation

Stiffness/impedance variation is omnipresent in every task execution in biological actuation systems. There are two things to perform – actuate for motion control and simultaneously act for impedance variation. Animal world achieves this by the ubiquitous agonist-antagonistic musculoskeletal actuation system (Figure 1). Getting inspired by this, an actuator is developed with agonist-antagonistic realization, where two motors are used at the same time for simultaneous control of motion and stiffness of the joint. This simple antagonistic realization for stiffness variation requires a *nonlinear* elastic transmission for each motor attached to the actuated output joint shaft (Figure 2). Like biological systems, this stiffness/impedance variation is achieved *passively*. Design of this nonlinear transmission is again inspired by the *passive* properties of biological muscle.

Nonlinear transmission possessing a passive property of biological muscle fibre

Muscles are identified with two distinct behaviours – active and passive (without stimulation). Muscle fibres are found to be progressively stiffer on stretching passively. It has been reported in literature that the *derivative of muscle stress with respect to Lagrangian strain is proportional to the muscle stress*. This particular functional behaviour has motivated the design of the nonlinear elastic characteristic of the transmissions. To possess muscle-like passive property, the force-displacement characteristic of the mechanical transmission is derived to follow an exponential behaviour, such that

$$Fs = F_0 + k_1 e^{k_2 x}$$

where, Fs is the transmission force, F_0 a force offset, x the transmission deformation and k_1, k_2 are constants. Defining $F_\sigma = F_0 + k_1 e^{k_2 x}$, and stiffness, $\sigma = \frac{\partial F_\sigma}{\partial x}$, following important property is obtained

$$\text{Stiffness} \propto \text{Force}$$

This particular property of the designed elastic element (spring) of the transmission makes possible the estimation of stiffness (impedance) and its control much easier. Estimation and control of stiffness (impedance) requires the knowledge of transmission force and displacement (velocity), which are obtained by using force and displacement sensors (encoders). The physical realization of the exponential function is achieved by using an exponential cam surface and a linear spring-loaded cam-follower mechanism. In assembly, two such cam profiles are used with two followers, loaded by a single linear spring. The assembly is shown in Figure 3.

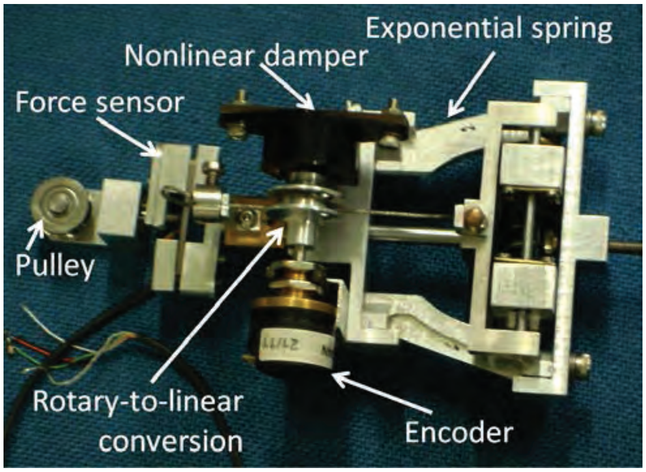


Figure 3: Photograph of the transmission assembly. The rotary damper is assembled by the use of a rotary-to-linear conversion. An encoder is used to measure the displacement through the same rotary-to-linear conversion.

A nonlinear damping element is added in parallel along with the elastic element. The passive damping element bears a variable *damping-rate* with velocity, characterized by the following odd function of velocity

$$F_d = d_0\, sgm(\dot{x}) + d_1\dot{x} + d_1\dot{x}^3$$

where, d_0 is the Coulomb friction in the velocity direction, d_1 & d_2 are constant coefficients and $\dot{x}$ is the time derivative of displacement (velocity). Neither the *stiffness*, nor the *damping-rate* are dependent on the constant force-offset and inherent Coulomb-friction respectively, which reduces estimation complexity of the impedance components.

The complete assembly of the nonlinear transmission is shown in Figure 3, showing the presence of exponential spring, damping element, encoder and force sensor. *Calibrated* and *Estimated* elastic characteristic as well as the damping characteristic of one of the transmission are reported in Figure 4. Estimation algorithm employs a first order *Extended Kalman Filter* technique.

Estimation of transmission impedance using Extended Kalman Filter

The property of transmission stiffness bearing an *affine* relationship with elastic force has been advantageously exploited in the estimation of stiffness (and damping rate). The Extended Kalman Filter (EKF) implementation utilizing this linearity property does not require the full model of the transmission. However, the mass-spring-damper model of the transmission can be expressed implicitly in terms of the constant parameters as

$$F = f\,(x, \dot{x}, \ddot{x}, m, F_0, k_1, k_2, d_0, d_1, d_2)$$

and a brute force estimation may attempt to identify the model parameters in estimating the impedance components. Instead, in this report, the impedance components are directly estimated without identifying the full transmission model.

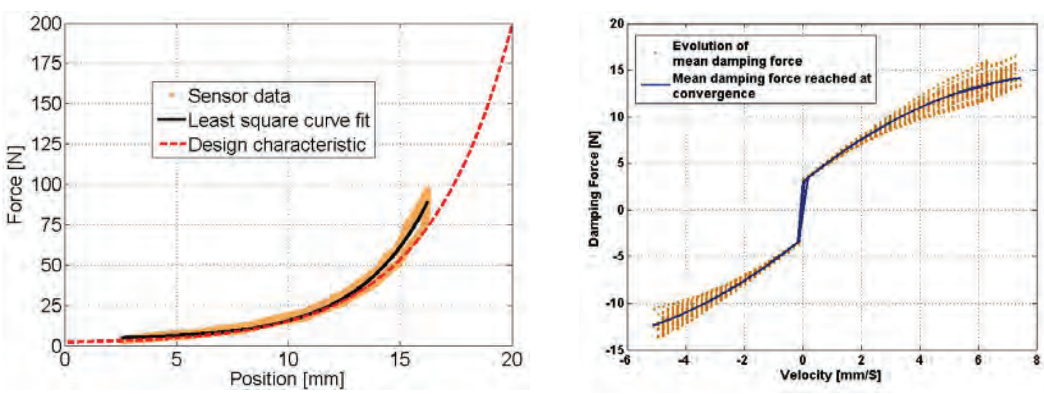


Figure 4: (Left) Exponential Elastic Characteristic of one of the transmissions. (Right) Damping characteristic of the same. Presence of Coulomb friction has been clearly identified. d_2 is estimated to be negative, complying with damper manufacturer's data sheet.

Mechanical impedance consists of

$$Generalized\ Stiffness, \quad \sigma(t) = \frac{\partial f}{\partial x},$$

$$Generalized\ Damping, \ D(t) = \frac{\partial f}{\partial \dot{x}}, \text{ and}$$

$$Generalized\ Inertia, \quad M = \frac{\partial f}{\partial \ddot{x}}$$

Using the linearity property in exponential elasticity,

$$\dot{\sigma}(t) = k_2\sigma(t)\dot{x}(t), \text{ and}$$
$$\dot{D}(t) = 6d_2\dot{x}(t)\ddot{x}(t)$$

The above variable stiffness and variable damping dynamics are used in formulating the first order EKF algorithm for estimating $\sigma(t)$, $D(t)$ along with the generalized inertia. The generalized inertia is the intrinsic mass felt during operating the transmission. Nevertheless, the formulation requires information of the time derivative of transmission force, which is obtained employing a first order filter on the force sensor data. The EKF estimation procedure takes force and force rate as input and position as EKF measurement. It is important that the noise in-built in the sensor data be *white* in order to implement the EKF estimator. Error models of the sensors are obtained through extensive experiments and the sensor noise are found to be white in position (encoder), force and force rate measurements.

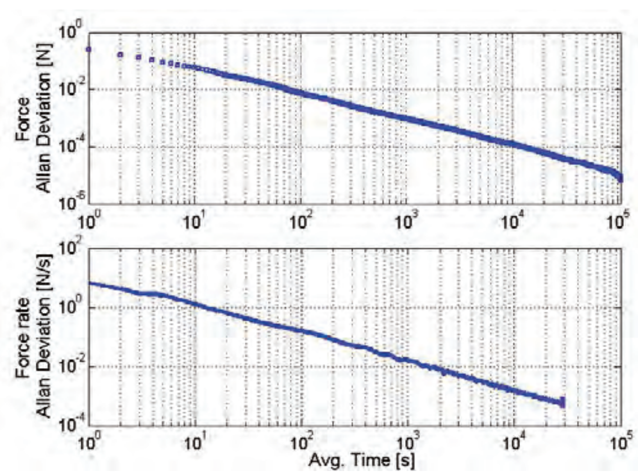


Figure 5: (Top) Allan variance of force sensor data. A slope of -1 indicates more or or less *white* nature of noise. (Bottom) Similar *white* nature of noise is observed in force-rate data

Good convergence was observed in both states (position, velocity and accelerating) and impedance (*generalized stiffness, damping rate and inertia*) estimation. Tracking and convergence result for impedance of one of the transmissions are reported in Figure 6 and Figure 7 respectively.

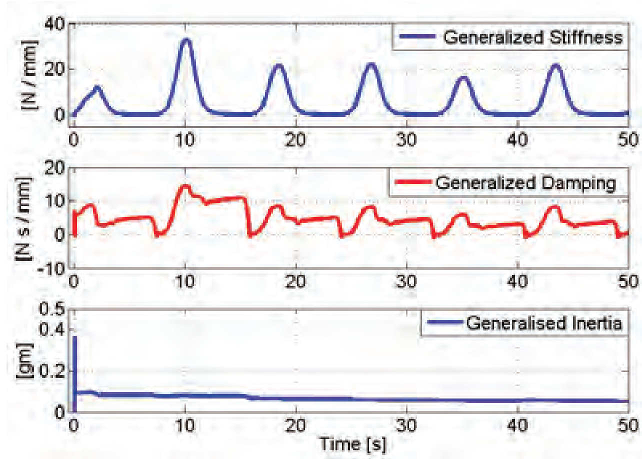


Figure 6: Tracking of generalized stiffness, damping rate and inertia

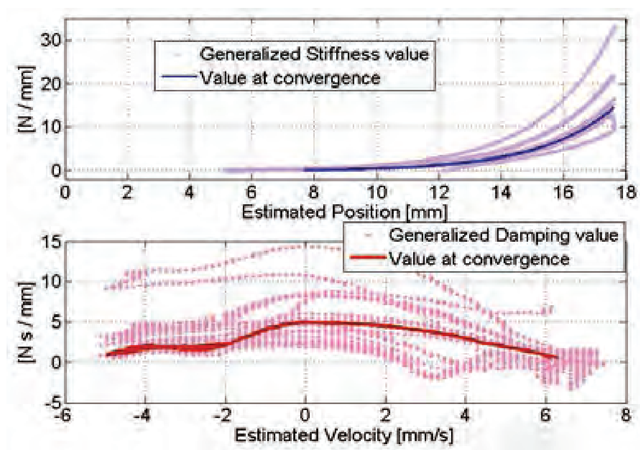


Figure 7: Estimation of stiffness and damping characteristics at convergence

	Transmission-1			Transmission-2		
At convergence	k_2	d_2	m	k_2	d_2	m
Mean	0.2711	-0.1089	0.3755	0.1673	-0.1170	0.2295
Variance $\times 10^{-4}$	0.7638	0.9851	1.053	0.8743	0.6098	0.7124

Figure 8: Estimated values of k_2, d_2 and m at convergence of the two transmissions in antagonism.

A Variable Impedance Actuator

A Variable Impedance Actuator is assembled with the simple antagonistic realization utilizing the damped elastic transmissions described above. The actuator joint consists of a joint shaft driven by a capstan pulley, which in turn is actuated by two positive drive tendons. Steel wire ropes are used as tendons. Tendons are pulled by two geared dc motors. On each side of the antagonistic arrangement, the nonlinear transmission element is interposed between the motor pulley and the capstan pulley in series with the tendon. Tendon on each side is routed through idle pulleys in such a way that the force sensed by the force-sensor on the pulling rod (Figure 3) is twice the tendon tension. The whole flexible joint assembly is illustrated in the photographs of Figure 9 and Figure 10.

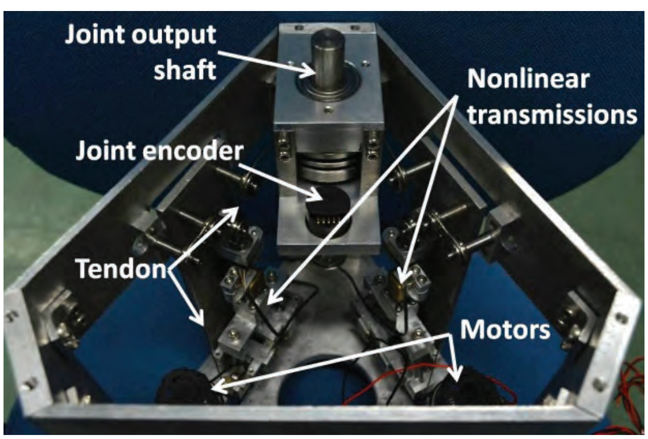


Figure 9: Assembly of the Variable Impedance Actuator

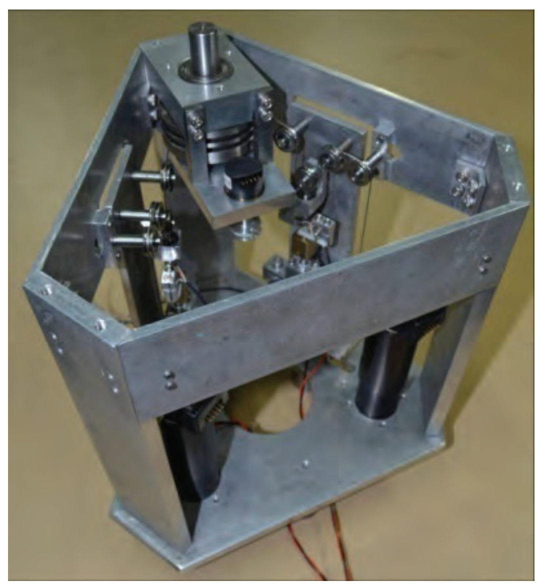


Figure 10: Partial assembly of the Variable Impedance Actuator showing the nonlinear transmissions.

The joint impedance is computed from the estimated impedance values of each of the transmissions using the respective force and position sensing. Estimated parameters (k_2, d_2 and m) of each transmission at convergence are shown in Figure 8. There are differences in the parameters mainly due to the difference in the spring rates of the linear springs used in the mechanism, which are obtained from local market and partly due to differences in manufactured components. Each tendon is considered as a linear spring in series with the nonlinear lumped mass-spring-damper system in modelling the entire transmission. At equilibrium and in absence of any external load, net joint-stiffness is estimated as

$$K_\theta = R^2 \sum_{i=1}^{2} \frac{\sigma_{non\ i} K_{tendon\ i}}{\sigma_{non\ i} + K_{tendon\ i}},$$

where R is the capstan pulley radius, $\sigma_{non\ i}$ is the stiffness of the i^{th} nonlinear transmission, and $K_{tendon\ i}$ is the stiffness of i^{th} tendon, i = 1, 2.

Similarly, the net joint damping rate is given by $D_\theta = \frac{1}{2}(D_2 + D_2)R^2 + D_{joint}$, where, D_{joint} is the constant damping present at the joint bearing. The net joint inertia due to only the transmissions is given by $M_\theta = \frac{1}{2}(M_2 + M_2)R^2 + J_{joint}$, where J_{joint} is the link inertia and $M_i = m_{Si}$, i = 1, 2 are the constant generalized inertias of the transmission. This inertia does not include the attenuated component of the reflected motor inertia and the generalized transmission inertia is normally much less than the link and reflected rotor inertia.

It is further to be noted that *stiffness* is an intrinsic property of a flexible system. The *input dependent* stiffness in an antagonistic flexible system is a property which lies in the *null-space* of the antagonistic forces (this does not include stiffness change due to external load). In other words, input dependent stiffness is related to the *internal force* components of the antagonistic system. The tendon-force-sensor readings can be decomposed into a force component causing the motion of the joint (no external torque) and an internal force. Again, using the stiffness-force linearity of an exponential elastic function, the stiffness of the transmission and in turn the joint can readily be estimated.

Design and Development of Biomimetic Frog Robot for Multimode Locomotion

Introduction

Nature has solved for the animal world the problem of moving around in some wonderful ways. Legs, wings, and fins have all evolved over time. But all have one thing in common. Animals have to travel as economically as possible. No creature that wastes energy survives the unforgiving hand of natural selection. Solutions for many of the modern problems are hidden in nature. Nature is the inspiration for many of the researchers and engineers. We must be able to improve our own technology by looking at natural legged locomotion (walking, running, jumping), swimming and flying. In nature, several animals and insects use jumping locomotion in rough terrains as it provides faster and efficient traversal through rough terrain.

Many locomotion principles from nature have been adapted in robotics. There are several species which are capable of multimode locomotion such as walking, swimming and flying, etc. Frogs are such a species capable of jumping, walking and swimming. Multimode locomotion is important for robots to work in unknown environments. There are many robots which have been developed for application specific purpose. Many conventional robots can work in a single working condition. But when the task demands locomotion in various terrains and also under water or any semi aquatic hazardous environment, design of the robotic system becomes a challenge. Multimode locomotion is important for autonomous mobile robots to operate in totally unknown environments. One such approach for developing a robotic system with multimode locomotion is to mimic the motion of semi–aquatic frog because many anatomical characteristics of frogs – particularly their long and powerful hind limbs – are very helpful for multimode locomotion.

For centuries, biologists and engineers have borrowed ideas from nature because nature gives useful hints about the functionality and design of systems. Frogs are widely known as good multimode locomotors. Webbed feet helps frogs to swim efficiently in water. Living frogs propel in water by the coordinated motion of their hind limbs, achieving good propulsive efficiency and manoeuvrability. The hind limbs of frogs are lengthy and powerful which can generate large ground reaction force during take-off.

Jumping Locomotion

Jumping locomotion is useful for ground robots as jumping provides high speed movement with enhanced energy efficiency. It also helps in overcoming obstacles relatively larger than their body sizes. A jumping sequence can be mainly divided into four phases as (i) take-off, (ii) flight, (iii) landing, and (iv) preparing for the next phase.

Frog's hind limbs are heavily muscled and lengthy to generate the required force to take-off from the ground. But with existing conventional actuators it is not possible to achieve similar locomotion as these fail to generate large amounts of force in short periods of time. It may be possible to mimic the behaviour of the frog legs with help of artificial muscles which are actuated by pneumatic power sources; but pneumatic actuators have their own limitations in this context. As pneumatic power sources are bulky, these can not placed on-board the robot. Keeping the pneumatic power source off-board is not a good solution as it restricts the workspace of the robot and the main purpose behind the design of the robot may lose its meaning. In our previous work, a method of jumping by using a four-bar spring/linkage mechanism integrated with spool winding and ratchet release mechanism was proposed.

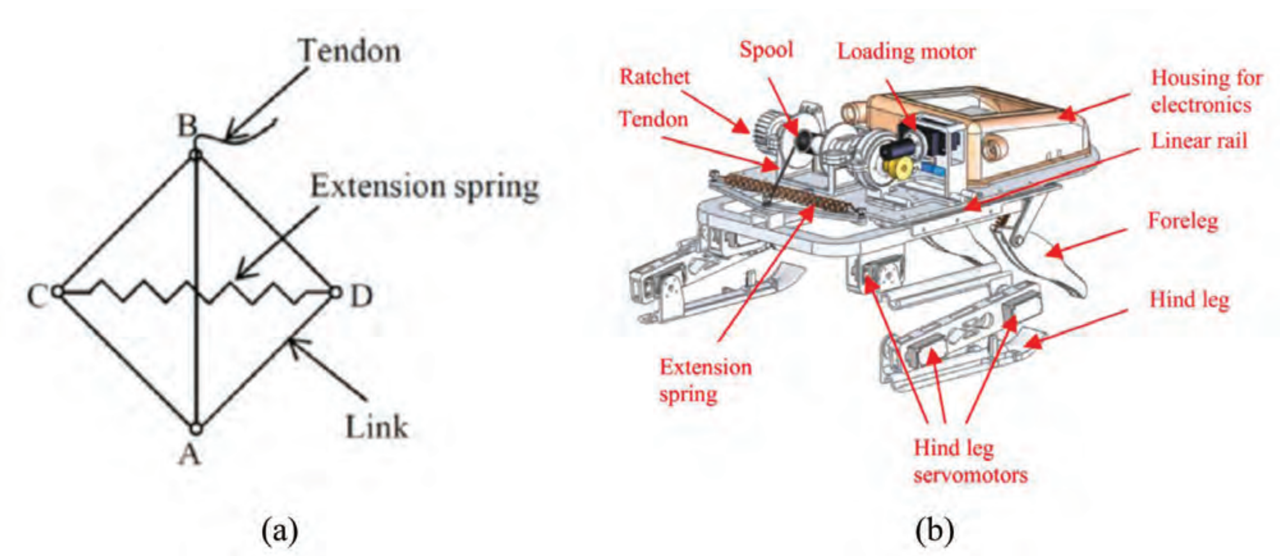


Figure 1: (a) Four-bar spring/linkage mechanism, (b) A CAD model of the jumping frog robot

Swimming Locomotion

For better understanding of the link between morphology and performance of actual frog locomotion in water, experiments are performed and cine films are recorded. Such cine films have led to exploration of aquatic locomotion of frog and trajectories of joints of the hind limbs. Through this experiment joint behaviour and morphological aspects of swimming frog is extracted. Furthermore, species that are both excellent swimmers and jumpers potentially have musculoskeletal compromises. Snapshots of one synchronous gait cycle are extracted from the cine-films. By analyzing the relative positions of the hind limb joints in the sequential frames changes in the joint angles are calculated (Figure 2).

A multi-body dynamic co-simulation (Figure 3) has been performed utilizing the calculated kinematic data to obtain drag and added mass forces (Figure 4) acting on the webbed foot of the frog during the propulsion phase.

With the observations made on biological frogs, we have designed a robotic leg with webbed foot to

Figure 2: Extracted frames of frog for one swimming cycle

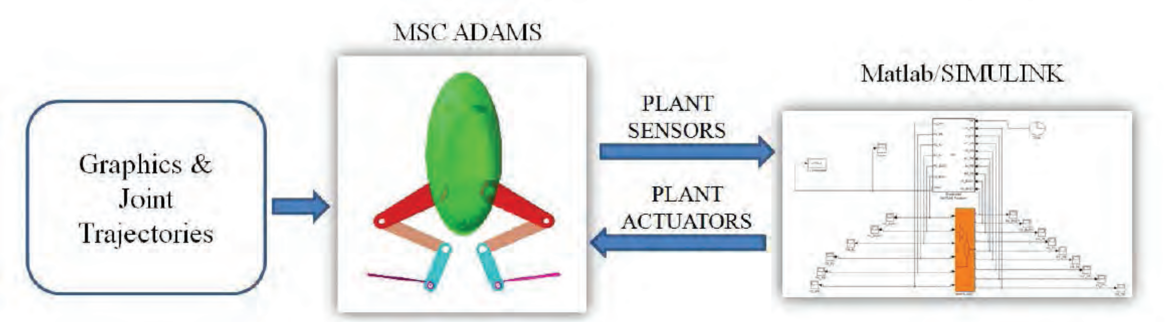


Figure 3: Block diagram describing the interaction of MSC ADMAS - Matlab/SIMULINK during co-simulation

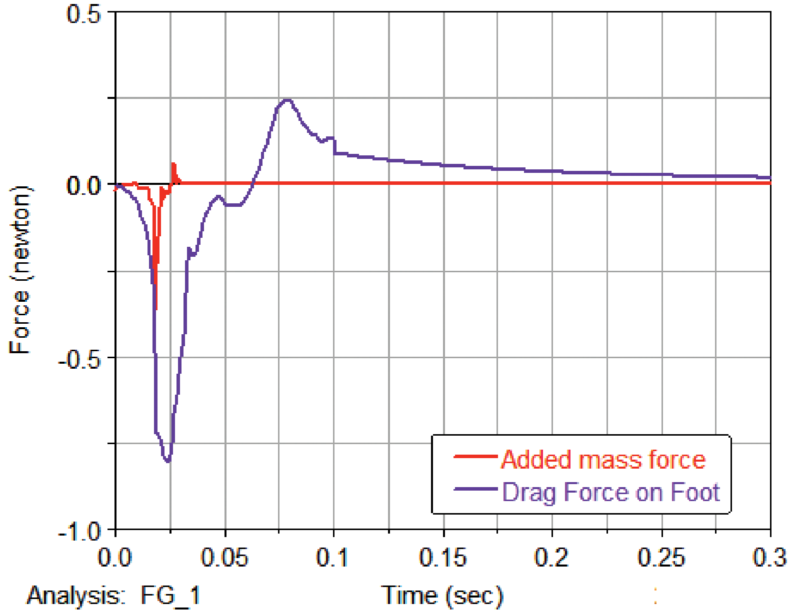


Figure 4: Drag and added mass forces acting on the webbed foot of the frog during the propulsion phase

mimic the swimming kinematics of a living frog. In reality, biomimetic robots may not afford the redundancy as biological species do because of the limitation of the existing actuators, weight and other constraints.

Webbed feet are responsible for generating the thrust force needed to propel the frog in water. These webbed feet expand to generate the maximum thrust force and fold to minimise the negative drag force during the swimming cycle. For efficient swimming, this phenomenon has to be adopted. In a living frog, the hind leg has a total of 7 DOF as shown in Figure 5 and it is attached to a flexible webbed foot for generating thrust force. It is very difficult to incorporate all the DOFs in a mechatronic system. Thus, while designing such a biomimetic mechatronic system, minimizing the total effective DOFs is required and this is achieved by choosing a suitable mechanism and/or by coupling the joints wherever it is possible. Again, placing the motors on the webbed feet or leg joints may result in poor efficiency due to heavy limbs. Thus the major challenging task is to design robust webbed feet and leg without placing actuators on joints in order to avoid high inertial effects and bulkiness. Tendon driven joints seem to provide a promising solution to the aforesaid problem.

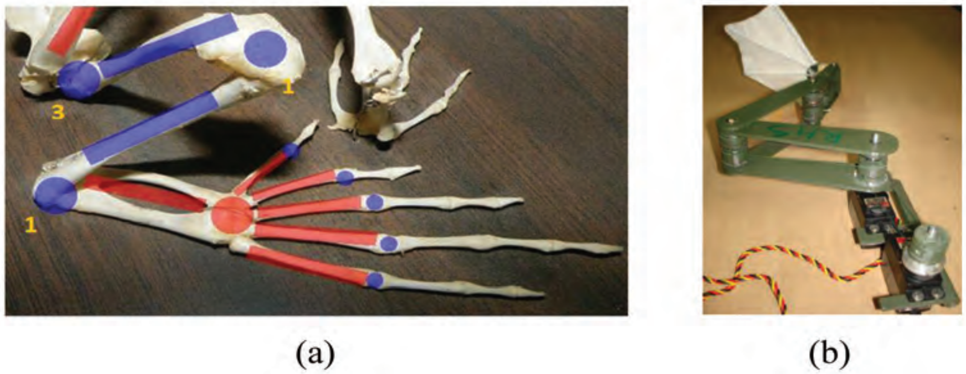


Figure 5: (a) Skeleton of a frog leg, (b) Prototype of the hind limb with webbed foot

a. Webbed Foot Design

There are total five phalanges connected to the base plate with revolute joints. All the phalanges are connected by a flexible web material. The movement of the webbed foot is coupled with the other joints of the leg with help of tendon-pulley arrangement.

b. Leg Design

Each hindleg is designed to have 3 link segments, which resemble three bone segments (femur, tibia-fibula and tarsal) of an actual frog, connected with the webbed foot. Frogs have 3 degrees of freedom (DOF) at the hip joint, 1 DOF at the knee and 1 DOF at the ankle. It is obeserved that frog legs move in a plane while swimming. Though the hip joint of living frogs has 3 DOF, it uses only 2 DOF of hip joint while swimming. But for jumping and walking, it uses 2 DOF at the hip joint. As mentioned earlier, a biomimetic robot can not afford the redundancy as biological species do; we have therefore designed the robotic frog with 1 DOF at the hip joint neglecting the hip rolling motion for swimming as if the leg moves on a plane. The knee and ankle joints have 1 DOF respectively. A cam-follower mechanism located at the ankle joint pulls the tendon to expand the web of the foot during the propulsion phase.

Forelegs of frogs are short and have minimum role in swimming but they provide support to crawl and while landing. Here, we have designed the foreleg to have 2 DOF, driven by two servo motors.

c. Mechanism to Support Multimode Locomotion

It has been obseved that the hindlegs of frogs move in the frontal plane during swimming motion whereas terrestial movements are accomplished with the movement of legs in the sagittal plane. We introduced an additional DOF for transforming the hindleg configuration from aquatic to terrestrial locomotion mode changing their plane of movement as shown in Figure 6(b).

d. Body Design

Frogs have short and stout bodies. Streamlined head and trunk supports efficient swimming. The body design is streamlined in shape and helpful for swimming. Figure 6c shows the isometric and top views of the CAD model of a swimming frog robot having hindlegs. All the dimensions are chosen thrice the corresponding dimensions of a living frog. The body is made symmetrical about the snout to the vent.

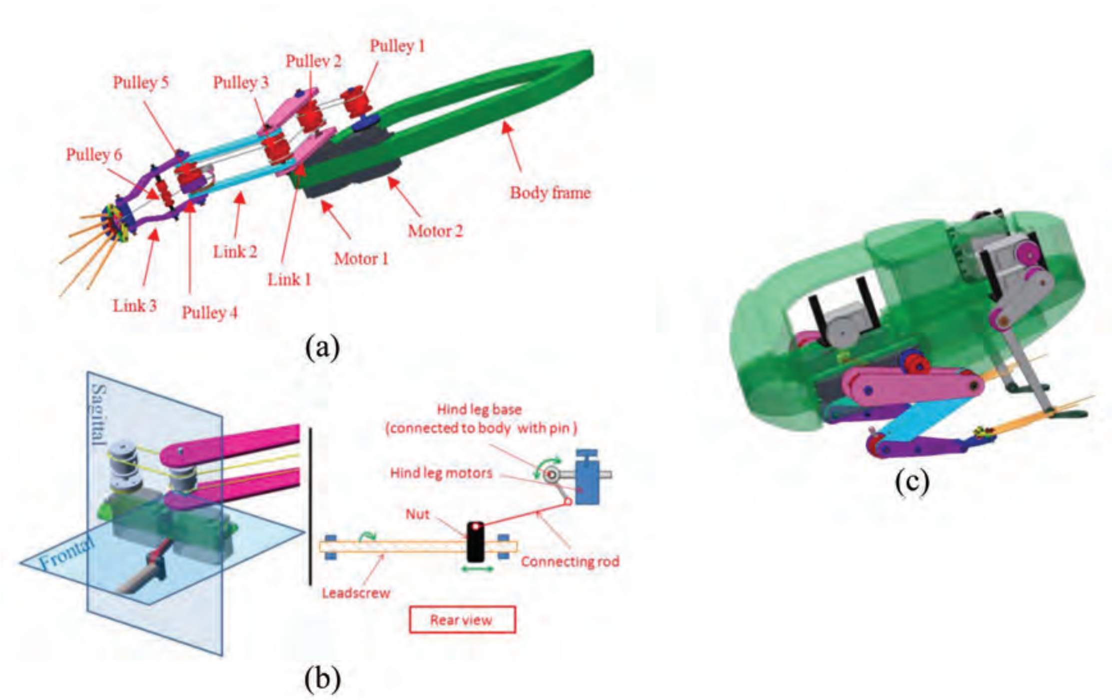


Figure 6: (a) Depicting the hindleg design, (b) Leg turning mechanism to change the mode of locomotion, (c) A CAD model of the complete design

Summary

In this work, experiments are conducted to study the different aspects of a live swimming Indus Valley Bullfrog. It is observed that jumping/crawling movements involve leg motions mainly on the sagittal plane whereas swimming locomotion involves leg motion in the frontal plane. Frogs use drag based propulsion for swimming. Propulsive forces are also generated by the hindleg with webbed feet. The kinematic and morphological data of a swimming frog were obtained with the help of cine-film records. Joint trajectories for one swimming cycle were extracted, which was helpful for the design of the robotic frog and modeling for the characterization of thrust forces. Different limbs of the robotic frog were designed from the morphological data. Hindlegs and forelegs are designed inspired by the musculoskeletal system of a frog. For the movement of hindlegs, we introduced two coupled motions for the four joints by means of a tendon-pulley arrangement. We also designed the webbed feet to support swimming. One additional DOF is also incorporated for changing the hindlimb configuration from the aquatic to the terrestrial locomotion mode. The foreleg design is simple with the two segments with two DOF. On the basis of design work presented above a prototype of robotic frog has been fabricated.

Biorobotic Swimming: a Tendon Driven Pectoral Fin Mechanism

Introduction

Gathering knowledge of vast oceanic resources, monitoring aquatic environment, enhancing security through surveillance, aquatic life observation and many other applications are increasingly demanding deployment of small, simple, energy efficient autonomous underwater vehicles which cause minimum disturbance in the surrounding environment and leave minimum signature. In such applications, manoeuvrability of the vehicle is of more importance than speed. Ability of making quick change in states (say, from hovering state to brisk movements) demands small size and low inertia of the vehicle. Small fishes like coral reef fish (Labriform) show excellent abilities of intricate manoeuver, hovering and brisk movement.

Conventional AUVs (cruise type) are usually designed for high speed and are intended for general purpose applications, and carry a variety of payload sensors and a large power source for long mission time. They are large, massive and propelled by thrusters leading to poor manoeuvrability and limited agility. Most of the conventional AUVs are designed with a torpedo shape, which exhibit low efficiency at low speed operation. Some AUV designs employ passive rigid fins (control surfaces) for lift generation and surge stability. Rigid and passive fins lead to inefficiency at low speed movements and severely limits the vehicle's manoeuvrability. To overcome the manoeuvrability limitation, some designs employ thrusters at each degree-of-freedom of the vehicle. However, this adds to the energy requirement significantly.

In view of above and in search of an alternative actuation method for vehicles with high manoeuvrability at low speed and high agility, the research community worldwide has started exploring biomimetic fin actuation. Swimming actions of fish result from *body and/or caudal fin* (BCF) and *median and/or paired fin* (MPF) movements. While BCF movements can achieve greater thrust and accelerations, MPF motions (paired *Pectoral fins*, in particular) are important for executing high and low speed manoeuvres, enhancing high speed stability, brisk movements (agility) and even enabling backward movements (Figure 1).

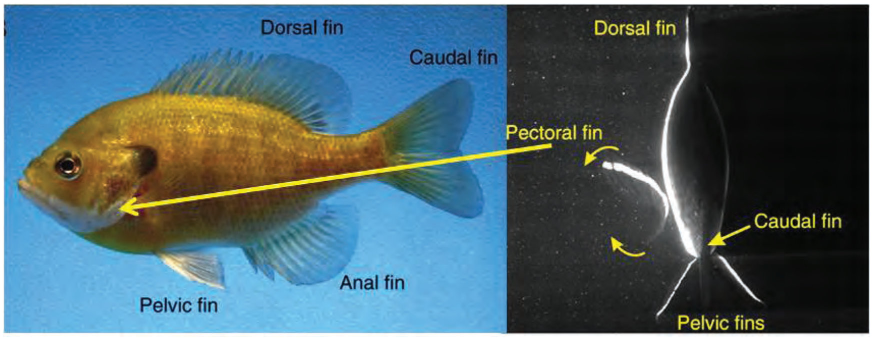


Figure 1: Labriform fish: median and paired fins (including pectoral fins)

This report describes an attempt to develop a reduced order, scaled up, biomimetic replica of a pectoral fin. A mathematical hydrodynamic model of a flat fin has been presented using blade-element. The flexibility of tendon-driven actuation is utilized in the design, keeping all the prime movers away from the moving fin and eliminating backlash and intermittent play. This article presents only an introduction to a rigorous activity taken up in CSIR-CMERI toward developing a biologically inspired actuator for underwater propulsion.

Pectoral fin morphology and motion primitives

The pectoral fin, like other fins, consists of several fin rays, movements of which in different combinations result in different action-modes of the fin. Pectoral fin musculoskeletal structure includes the pectoral skeleton, a row of four radials that form a base support for the fin and a fibrocartilage region upon which each fin ray rotates. A series of fin rays with rotational bases on the fibro-cartilage pad are actuated by a set of muscles. A simplified anatomy of a pectoral fin is shown in Figure 2.

Fin rays show a complex motion and replicating them in machine needs design of an immensely involved mechanism and subsequent synthesis. By observing the phases of motion of the pectoral fin of a Labriform species, some motion primitives are identified: (i) *rowing* and *flapping* by the whole fin as a single entity (modelled by a flat plate), (ii) *feathering* by the fin (flat plate), (iii) *cup* and *sweep* motion (individual fin-ray bending), and (iv) *undulatory motion* (individual fin-ray bending). These basic motions are illustrated in Figures 3a

Figure 2: Skeletal anatomy of the pectoral fin

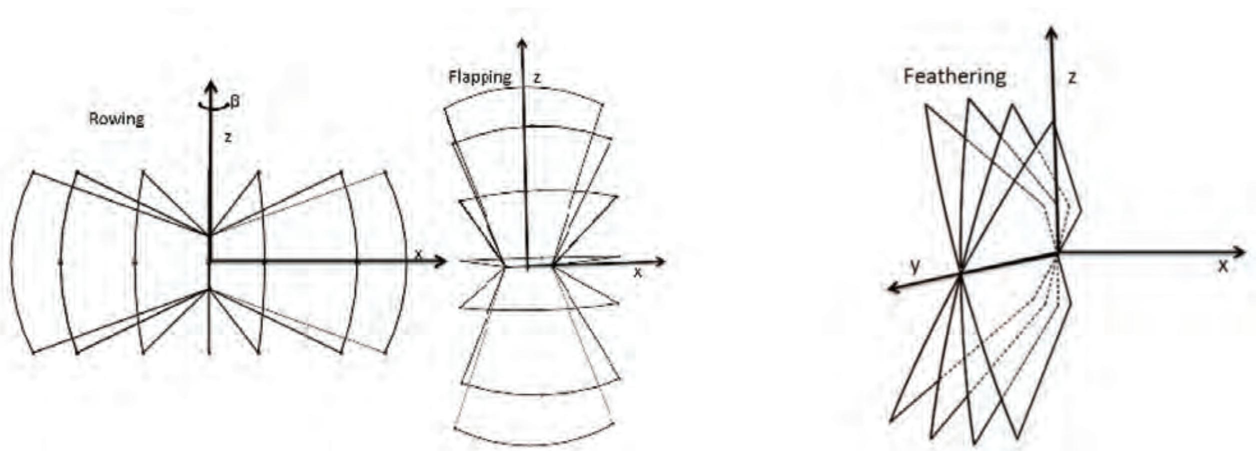


Figure 3a: Identified action primitives by a pectoral fin. (Left and Middle) Rowing and flapping motions are generated by moving the whole fin about one edge of the fin. (Right) Feathering is generated by the whole fin through roll motion

and 3b. In order to reduce the complexity of the involved mechanism, a reduced order mechanism is designed to generate the basic motions as identified above. Combinations of the motion primitives can lead to the complex motion, generating the needed movements and in turn forces in all directions.

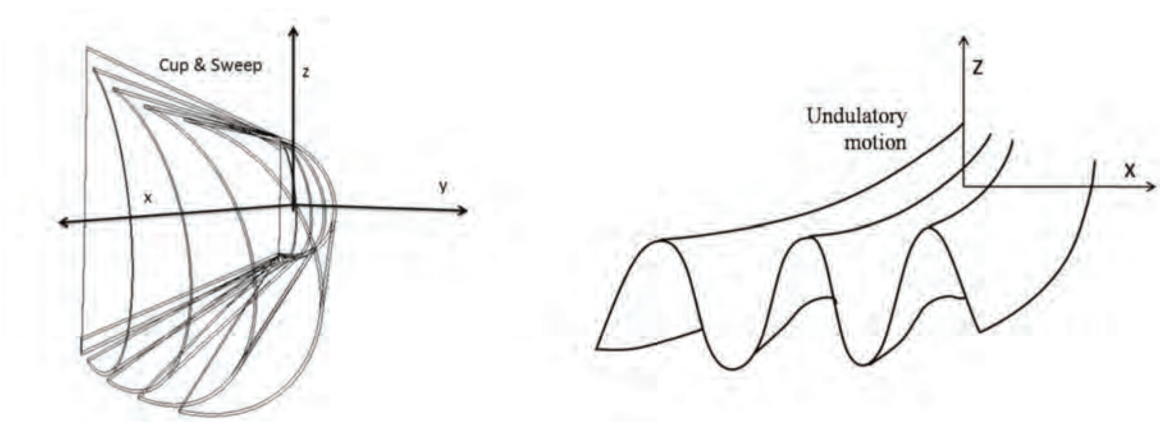


Figure 3b: (Left) Cup formation needs involvement of bending of individual fin rays. (Right) Undulatory motion is generated through oscillatory motion of individual bending of the fin rays with phase differences

Fin and fin-ray mechanisms

The basic fin design consists of four fin rays. A pulley is integrated with each fin ray for its bending motion which is obtained by two positive drive tendons. Range of bending motion is in degrees. Each fin ray has another *abduction/adduction* motion (Figure 4). The abduction/adduction of all the fin rays is coupled through a pinion-gear train mechanism. The input pinion is again actuated by a pulley, driven positively by two tendons. Transmission of all the tendon motions from the fin ray to the remotely mounted base motors are achieved through a tendon-sheath system. All the fin rays are assembled on a fin base. The gear-train responsible for coupled abduction/adduction movement of fin rays is mounted on this fin-base. Four fin rays and the fin base form the fin. The whole fin assembly has another two degrees of freedom through a differentially driven roll and pitch motion. The gear-train and roll-pitch assembly are illustrated in Figure 5. Two positive tendon drives actuate the differential mechanism. Thus, the developed biorobotic fin gets a total of seven degrees-of-freedom, five in the fin rays and two in the fin base, enabling all the basic four motions, namely, drag based rowing, feathering, cup motion and fin undulation. Assembly of the fin is shown in Figure 6, along with webbing (using fabric).

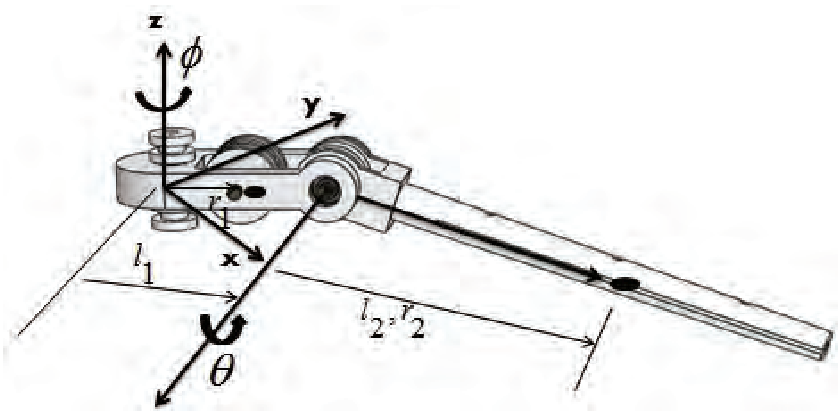
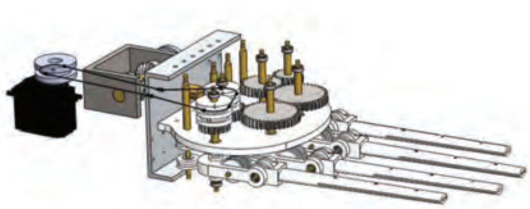


Figure 4: Schematic of fin ray mechanism design, showing the degrees of freedom.



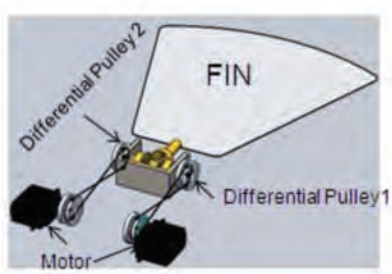


Figure 5: (Left) Gear train for coupling among the abduction/adduction of fin-rays and the drive. (Right) Flat plate approximation of the fin. Rowing, flapping and feathering actions are generated by pitch and roll motions of the differential.

Figure 6: (Left) Photographic view of assembly of fin-ray mechanism prototype. (Right) Webbing on fin-rays in one prototype.

Hydrodynamic modelling using Blade Elements

In order to estimate different torque/force requirements to actuate the fin rays and the overall fin in generating the desired lift, drag and propulsion, a hydrodynamic model of the fin is developed using blade element technique. The model is then simulated and validated with experimental results available in literature (Figure 7 shows the blade elements used in simulation modelling). In one exemplary simulation, following time varying oscillatory drag (rowing) and feathering motions are given to the rigid flat plate model of the fin:

$$\beta_r = \beta_{r0} - \beta_{ra} \cos(\omega_{fin} t)$$
$$\alpha_{fe} = \alpha_{fe0} - \alpha_{fea} \cos(\omega_{fin} t + \Delta\alpha_{fe}),$$

where, β_r denotes the rowing angle and α_{fe} the feathering angle, subscripts 0 and α are for initial angle and amplitude respectively; $\omega_{f\ in}$ is the frequency and $\Delta\alpha_{fe}$ is the phase difference between the motion of rowing and feathering. Figure 8 reports the different simulated coefficients C_X, C_Y, C_Z, along X, Y, Z directions, along with experimentally obtained values from literature.

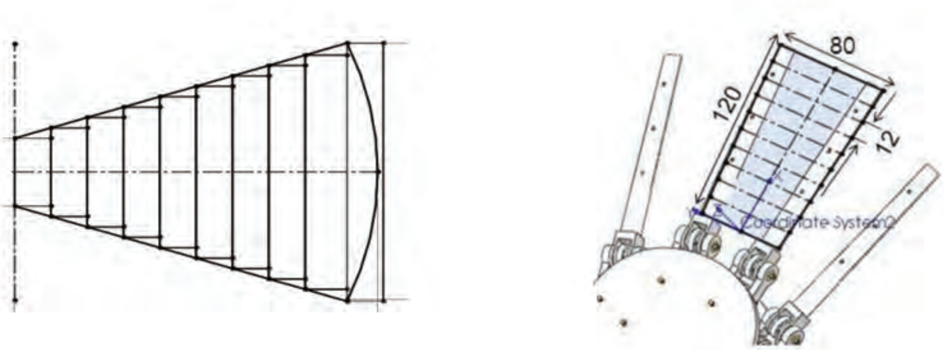


Figure 7: Blade elements used in hydrodynamic modelling of the fin. (Left) Entire fin as a flat plate. (Right) Approximate modelling of fin-ray and webbing as flat plate.

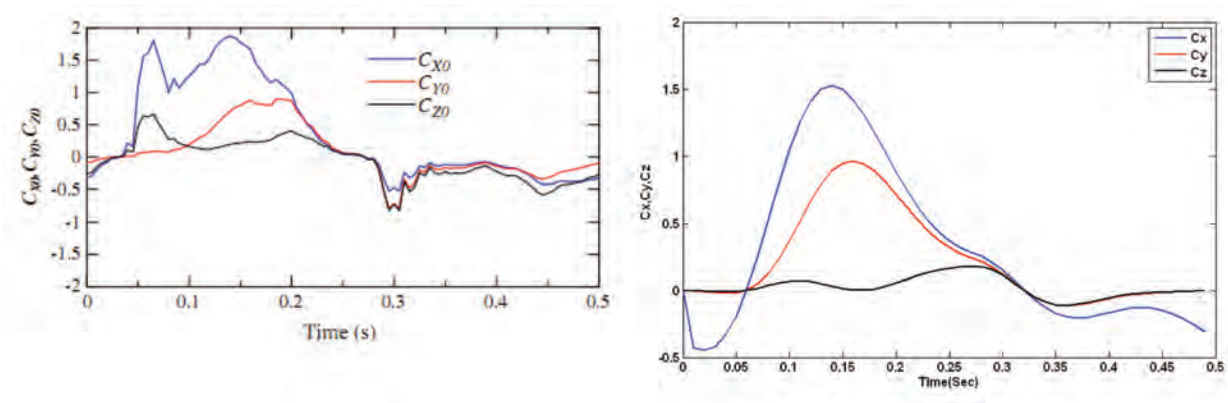


Figure 8: (Left) Hydrodynamic force coefficients obtained experimentally for motion sequence mentioned above in still water with $\beta_r = \beta_{ra} = \alpha_{fea} = 30$ deg, $\alpha_{fea} = -30$ deg, $\Delta\alpha_{fe} = 60$ deg and $\omega_{f\,in} =$ 2 rad/S. (Right) The coefficients obtained by Blade element modelling of the fin for the same motion sequence in still water.

Creation of New Facility

- Central Research Facility (CRF) at CSIR-CMERI
- Test Facilities for Special Purpose Valves for use in Civilian Aircraft
- Low Speed Wind Tunnel Facility

Central Research Facility (CRF) at CSIR-CMERI

Introduction

The Central Research Facility (CRF) at CSIR-CMERI has been formed to cater to in–house research needs as well as for facilitating research and development in academic institutions and government and private institutions or industries with advanced/sophisticated equipment. The sole objective behind formation of the CRF is to promote easy usage of modern equipment under a single roof. Most prestigious organizations abroad have well equipped Central Research Facilities as it is well established that the individual researcher cannot always maintain expensive instruments required for individual research work. Hence, the concept of forming a centralized research facility has developed over the years. The capability of such facilities are enhanced periodically. This helps other researchers to carry out their work without much hindrance. The CRF receives feedback from the researchers from time to time and upgrades the facilities in order to support cutting edge research.

Objective of the CRF

1 To provide facilities of sophisticated analytical instruments/ devices to external organizations for R&D purpose

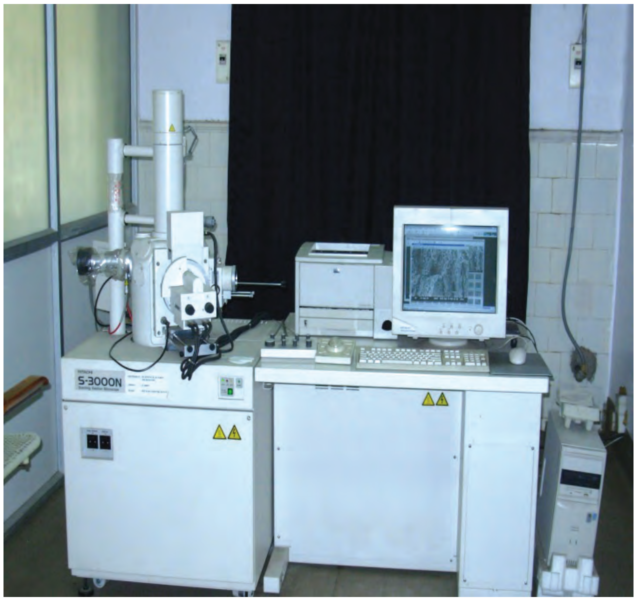
2 To acquire and develop capability for basic preventive maintenance through design of condition monitoring plan of the facilities

3 To organize short term training/courses/workshops on theoretical aspects and application of various instruments and analytical techniques.

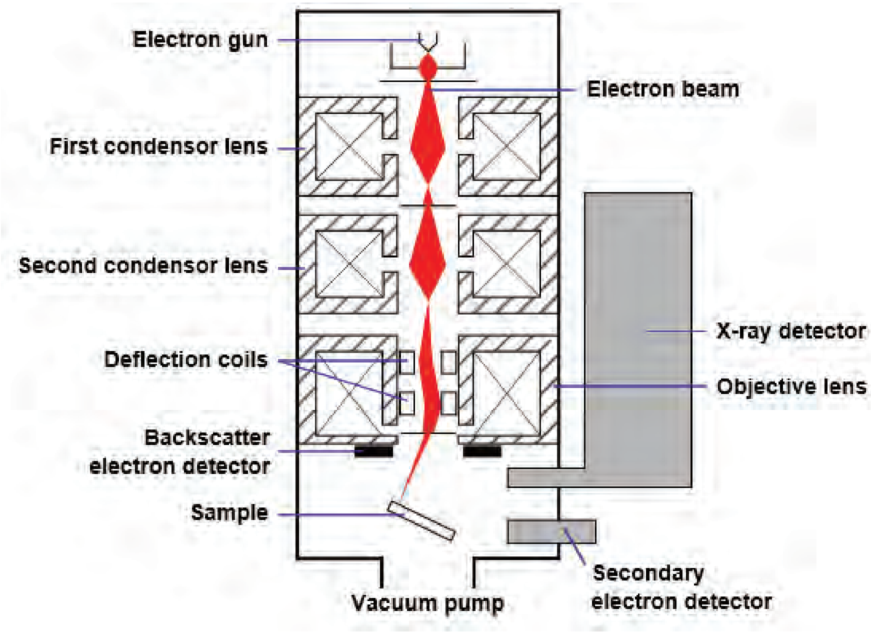
The following are the list of equipment/facility available at the Central Research Facility

1. **Scanning Electron Microscope (Model No. S3000N, Hitachi Ltd.) with attached EDS (Thermo Scientific, UK)**

   A **Scanning Electron Microscope** (**SEM**) is a type of electron microscope that produces images of a sample by scanning it with a focused beam of electrons. The electrons interact with atoms in the sample, producing various signals that can be detected and that contain information about the sample's surface topography and composition. The electron beam is generally scanned in a raster scan pattern, and the beam's position is combined with the detected signal to produce an image. Specimens can be observed in high vacuum, in low vacuum, and (in environmental SEM) in wet conditions. The most common mode of detection is by secondary electrons



Photograph of SEM with EDS system



Working principle of SEM

emitted by atoms excited by the electron beam. The number of secondary electrons is a function of the angle between the surface and the beam. On a flat surface, the plume of secondary electrons is mostly contained by the sample, but on a tilted surface, the plume is partially exposed and more electrons are emitted. By scanning the sample and detecting the secondary electrons, an image displaying the tilt of the surface is created.

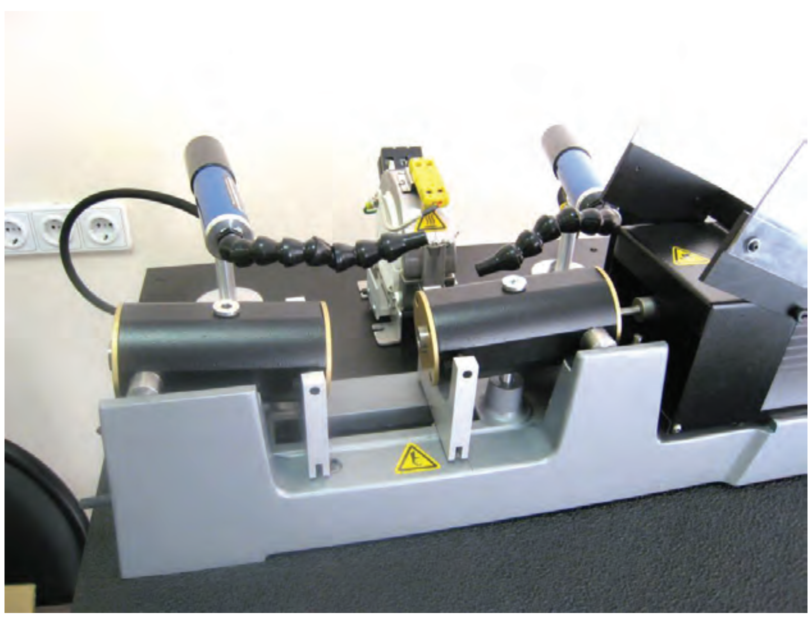
2. Rotating Beam Fatigue Testing Machine (Model R R Moore, Instron)

Theory of Operation

Based on the rotating beam principle, the specimen functions as a simple beam symmetrically loaded at two points. When rotated over half a revolution, the stresses in the fibers originally below the neutral axis are reversed from tension to compression and vice versa. Upon completing the revolution, the stresses are again reversed so that during one revolution the test specimen passes through a complete cycle of flexural stress (tension and compression).

Features

- ✓ Standard machine operates at an adjustable speed of 500 to 10,000 RPM
- ✓ An easy-to-read digital cycle counter with magnetic pickup device provides an accurate display of completed cycles in display increments of 1 cycle per count up to 99,999,999 counts.

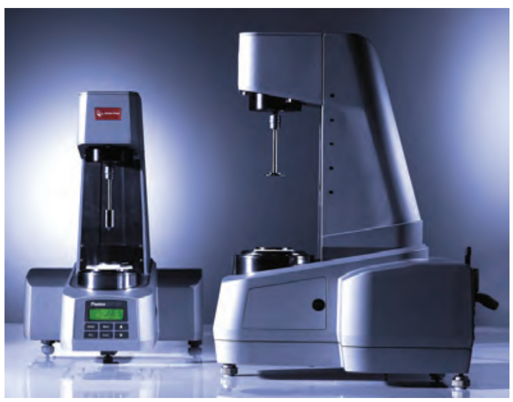


Rotating Beam Fatigue test system
(Make: Instron, UK)

3. Rheometer (Model Anton Par 501)

A **Rheometer** is a laboratory device used to measure the way in which a liquid, suspension or slurry flows in response to applied forces. It is used for those fluids which cannot be defined by a single value of viscosity and therefore require more parameters to be set and measured than is the case for a viscometer. It measures the rheology of the fluid.

There are two distinctively different types of rheometers. Rheometers that control the applied shear stress or shear strain are called rotational or shear rheometers, whereas rheometers that apply extensional stress or extensional strain are extensional rheometers. Rotational or shear type rheometers are usually designed as either a native strain-controlled instrument (control and apply a user-defined shear strain which can then measure the resulting shear stress) or a native stress-controlled instrument (control and apply a user-defined shear stress and measure the resulting shear strain) with integrated temperature devices provide **unrivalled temperature control from –150°C to up to 1000°C.**



Rheometer (Make: Anton Par, Germany)

High Definition Field Emission Scanning Electron Microscope SIGMA HD

4. Field Emission Scanning Electron Microscope (Model: Sigma HD, Carl Zeiss, Germany) with attached EDS (Make: Oxford, UK) and In-situ Straining Stage (Make: GATAN, UK)

SIGMA HD offers high resolution, fast imaging and easy sample navigation for nanoscale analysis of wide range of materials. This sophisticated and versatile instrument will definitely boost the research activities in CSIR-CMERI. This FESEM has an attached EDS along with in-situ straining stage for carrying tensile/compression studies of materials inside the microscope. This electron microscope has a resoltion of 0.1 nm at 15 kV with an magnifying capability upto 8,00, 000 X. This is equipped with advanced detectors (ASB, In-lens SE, four quadrant BSE) that makes it unique in every sense required for cutting edge research.

Apart from the above, the following instruments are planned to be integrated in the CRF

1. Powder X-ray Diffractometer
2. DSC-DTA-TG
3. UV-Vis-NIR
4. Atomic Force Microscope (AFM)
5. Servo Hydraulic Testing System
6. Optical Microscope with Image Analyzer

Test Facility for Special Purpose Valves for use in Civilian Aircraft

In today's technologically competitive world, countries which have their own aircraft industry are in an advantageous position. Many developing countries are now designing and building civilian aircraft to achieve economic growth and competence in the field of high-tech engineering. Development of aero industry in these countries will create fierce competition among the aircraft manufacturers for selling their products in the growing Asian market. India has made rapid inroads in this area by developing the SARAS. It is worthy to mention here that in an aircraft, the systems/sub-systems alone comprises almost 30% of the overall cost. At present, our civil aircraft development program is solely dependent on using costly imported systems/subsystems. Systems developed using off-the-shelf components used in other aircraft do not exactly match the requirements of aircraft designed in India and necessitates additional developmental cost for carrying out necessary modifications. This causes the prices to shoot up and, more importantly, involve extended delivery schedules. It is therefore difficult to develop a cost competitive aircraft indigenously after paying hefty prices for the bought-out items. Though it is prudent to use proven and certified systems initially for a newly designed aircraft, development of these items within the country is imperative for reducing the overall cost during series production. Development of systems, sub-systems and equipment is also very important along with the capability to design and build the complete aircraft in order to make significant progress in the area of civilian aircraft development.

The price of the aircraft is the ultimate determining factor for sale, which essentially depends on the quantum and price of the bought-out items. It is thus of significant benefit if these items can be procured at a cheaper rate by developing them locally. Every new aircraft manufacturer is now trying to source the systems/subsystems from within their own territory to make their aircraft competitive and this is true even for the developing nations like Brazil and China.

The reason why Indian companies were unable to manufacture these systems was the absence of an indigenous civil aircraft development program before SARAS, non-availability of know-how for constituting critical components and absence of suitable testing facility. High-temperature and high-pressure valves are among such critical components in an aircraft Environmental Control System (ECS). Similar critical components for an aircraft fuel system are highly reliable valves having redundant drives. Due to intense competition among international manufacturers, the technology for design and development of aircraft valves remains strategic and there is no possibility of acquiring the technology from outside sources. Considering this, CSIR-CMERI has taken up the challenge of designing the following three critical aircraft valves from first principle under the 10th Five Year Plan (FYP).

1. Pressure regulating and shut-off valve (PRSOV)
2. Ball type motorized fuel shut-off valve (FSV)
3. Butterfly type non return valve (NRV)

Testing of the valves for its acceptance to perform the intended function and qualification for airworthiness is an integral part of the developmental process. This essentially requires design and establishment of an elaborate test rig having necessary provision for altitude simulation. As a part of the aircraft valve development programme, CSIR-CMERI had also undertaken to set up a state-of-the-art valve development & performance testing facility for all kinds of civilian aircraft under the 11th FYP Major Laboratory Project.

An elaborate rig has been designed for testing various pneumatic valves and fuel flow control valves used in civilian aircraft. The design of the test facility is unique in the country and is suitable for carrying out research on designing various types of aircraft valves. The rig has incorporated all testing requirements for the PRSOV, FSV and NRV according to their Acceptance Test Procedures (ATPs) and further possesses the flexibility to test other types of valves through necessary minor modification/reconfiguration. The test facility can also accommodate some of the tests stipulated in the Qualification Test Procedure (QTP), which is inherent in the process of the valve development to ensure necessary performance of the valves. The QTP guideline is based on the "*Environmental Conditions and Test Procedures for Airborne Equipment*" published by RTCA Inc, USA and used worldwide by the aircraft manufacturers. The test procedures are designed as per its latest revision *RTCA-DO160G*.

Salient features of some components of the test rig

1. **Compressed Air System (Maximum Pressure: 10 Bar, FAD: 12.5 m^3/min)**

   a. Quality of supplied air: ISO 8573-1 Class 0 certified by TUV

   Reason for Class 0 (oil free) quality air requirement is that during endurance tests of aircraft valves, pressurized hot air at 360°C has to be passed through the valves continuously for a long period (7-10 days approx.). At that high temperature the lubricant oil present in the compressed air burns and deposits carbon particles on the valve surface, which degrades the quality of the test valves.

   b. Utilization of heat of compression to save electrical energy

   During different high temperature tests, the compressed air has to be heated by its passage through an electric heater. The energy consumption rate of the heater depends on the initial air temperature. In order to minimize the energy requirement, it has been decided to utilize the natural heat generated during the compression of air by tapping hot air from the compressor before the aftercooler, thereby reducing the recurring electrical cost.

   c. Pressure Dew Point of the supplied air: -70°C

   During the altitude simulation testing, the air inside the test chamber is to be cooled to a temperature of -55°C. If the dew point of the supplied air is above this, ice formation takes place inside the test chamber. This creates a problem in maintaining the test chamber ambient condition as well as hampers the monitoring of the valve performance inside the chamber by reducing the visibility.

2. **High Pressure Pneumatic System (Maximum Pressure: 30 Bar)**

Burst pressure tests of pneumatic valves according to the Federal Aviation Regulation (FAR 25) is carried out in the test facility which is equipped with a 7.5kW air compressor with a 1800L SS lined MS reservoir. The SS lining is only 2.5mm thick whereas the outer MS pipe thickness is around 14mm. This uniqueness in design has led to huge cost saving without sacrificing any design requirement. This vessel has been designed and fabricated as per ASME code, Section VIII, Division 1 for pressure vessels and inspected by M/s DNV, Kolkata during the entire fabrication process beginning from material procurement to the final pressure testing.

3. **Closed Loop Air Heater System (Maximum Pressure & Temperature: 10 Bar & 360°C)**

A closed loop controlled system capable of supplying air at any set temperature and pressure within the range of aero engine bleed in the test facility ensures continuous supply of hot air through the test valve at the required temperature and pressure. The system consists of a custom built air heater with a sophisticated and robust heater drive. The drive controller along with its logic is designed to consume minimum power and has all the protections for preventing coil overheating or burning. The air heater vessel has been designed and fabricated as per ASME code, Section VIII, Division 1 for pressure vessels and inspected by M/s DNV, Kolkata during the entire fabrication process beginning from material procurement to the final pressure testing.

4. **High Flow at Low Pressure (Maximum Flow: 50 m^3/min, Maximum Pressure: 10 kPa)**

The system is capable of providing high air flow at a very low pressure. It consists of a 15kW roots blower, a 2000L SS vessel, butterfly valve, ball valves with pneumatic actuator, safety valve and pressure gauge. Variable flows can be created by controlling the motor speed of the roots blower using a variable voltage variable frequency (VVVF) drive. The VVVF drive is coupled to the master control system and depending on the test requirement, the frequency and hence flow can be controlled.

5. **Vacuum System for Altitude Creation (-1,000 ft to 50,000 ft)**

The test facility accommodates a robust and accurate vacuum system with ultimate vacuum level up to 1 kPa absolute pressure in order to simulate the altitude conditions inside the test chambers. This in tandem with the compressed air system regulates the test chamber ambient through a fast and accurate vacuum regulator valve.

6. **ATF Cooling & Heating Systems (Minimum & Maximum Temperatures: -45°C & +60°C)**

Three environmental test chambers suitable for creation and maintenance of any altitude from -1000ft. to 50000ft. have been developed in the test facility. Each is configured for conducting a suitable test fluid through the test valves according to their ATPs. All chambers are provided with observation portholes that employ 1ft. thick toughened glass in two layers separated by a vacuum layer so that the portholes can withstand the differential pressure when high altitude conditions are simulated inside the chamber and to provide necessary thermal insulation from the ambient. There are provisions for mounting the test valves in horizontal, vertical and upside-down attitudes. The test chambers have been fabricated using SS-304 material and tested for vacuum. The chambers are fitted with nozzles on the cylindrical surface to connect pressure gauges, thermometers, pressure and temperature transducers, different pressure and electrical feed through, vacuum break valve, rupture disc, flow meters, etc.

Separate closed loop controlled altitude simulation system is provided individually for all three test chambers to create different environmental conditions in the chambers simultaneously. According to the RTCA DO 160F standard for testing of airborne equipment, the air pressure inside the test chambers needs to be varied from 109kPa absolute pressure (corresponding to -1,000 ft height) to 10kPa absolute pressure (corresponding to 50,000 ft height) and temperature inside the chambers has to be varied from +90°C to -55°C. Pressure and temperature can be controlled simultaneously to establish any set altitude within the chamber. In addition to this, variation of altitude at any rate to simulate different ascent/descent rates of aircraft can be simulated. The system includes custom designed vacuum control system, multiple electrical cartridge based air heating system, custom designed cryogenic cooling system, air motor operated circulation system, control valves, pressure & temperature transducers, etc.

a. Cascaded Refrigeration System for ATF Cooling

A cascade refrigeration system to cool around 400L of ATF in the tank up to -45°C in 4 hours from the ambient temperature has been designed and developed. The system can be programmed to maintain any set temperature of ATF in the tank within the range of 0°C to -45°C. To cool ATF inside the tank, the fluid is initially circulated through a special type of SS Welded Plate Heat Exchanger (PHE) of the cooling system at 10 lpm and then at 5 lpm to maintain the set temperature. Conventional Cu Brazed PHE is not used in the system as ATF has some known compatibility issues with Cu and Ni and may corrode the brazing in the long run.

b. Indirect hot water based heating system for ATF heating

The facility has a hot water based ATF heating system to continuously supply hot water at 80°C for primary heating of the ATF in the tank to a desired set temperature. Fine tuning of the temperature of ATF flowing through the test valve is achieved by circulating hot water through a specially designed heat exchanger fitted with the pressure vessel. Any desired set temperature of ATF within the range of 0°C to +60°C – both at the tank and in the upstream of the test valve – can be achieved by controlling the flow of hot water in a closed loop. This indirect heating of highly inflammable ATF (auto ignition temperature 210°C) through water (whose temperature can reach up to 100°C only) makes the system extremely safe and reliable.

7. **Real Time Control & Data Acquisition System**

A high performance data acquisition & sophisticated real time control system to achieve the necessary testing accuracy according to the guidelines of international standard RTCA DO-160F constitutes part of the test facility. Components of the test rigs are located in three different rooms and have around 20 independent closed loop control cycles. Each of these cycles has its own control and accurate data acquisition system for measuring pressure, temperature, flow, vacuum, humidity and solenoid operations. Since these are distributed across the laboratory, a real time operating system based deterministic & distributed control has been chosen. This makes the test facility highly flexible to accommodate a wide variety of test cycles for different designs of test valves. It has an easy-to-use graphical programming tool using NI LabVIEW software for quick design of test cycles. The system is reconfigurable and capable of implementing custom timing, triggering, signal processing and control of the input-output modules.

8. **Measuring Instruments**

Accurate and high precision measuring instruments with high repeatability under standard testing conditions have been installed in the test facility. All these instruments have output signals in the range of 4-20mA that can be fed to the master control system to monitor, examine and plot data of different testing variables.

9. **Standard Testing Condition**

A Variable Refrigerant Flow (VRF) HVAC unit has been installed in the laboratory to provide standard testing ambience and also to ensure repeatability of results. These instruments shall be calibrated at the standard testing condition only so that the accuracy of the results can be maintained.

10. **Unattended Testing Capability**

The whole test facility is developed in a manner that facilitates program test through the master control software which can run into days without any human intervention and relevant experimental data is stored in the computer for subsequent processing. In case of any untoward incident, the system shuts down automatically and can be restarted only through human intervention.

Test Condition Limits at the test facility

Environment Condition Limits:

Pressure	10 kPa abs to 110kPa abs (Equivalent to Altitude of -1,000 ft to 50,000 ft)
Temperature	-55°C to 90°C.

Pneumatic Testing Condition Limits:

Pressure	up to 30 Bar
Temperature	up to 360°C

Hydraulic Testing Condition Limits (for ATF):

Pressure	up to 16 Bar
Temperature	-45°C to 60°C

Present planned tests that would be carried out in the test facility

1. Performance testing of PRSOV at different attitudes which includes sub-assemblies as well as the complete valve unit under different engine bleed air conditions.
2. Performance testing of FSV at different attitudes.
3. Ultimate pressure test of PRSOV as per QTP.
4. Endurance test of PRSOV as per QTP (simulation of 65,000 flights x 1.155 flying hours).
5. Altitude test of PRSOV as per QTP including operating low temperature test and operating high temperature test (temperature variation rate at 5°C/min).
6. Performance Tests of FSV assembly (with & without actuator) e.g. static pressure test; leakage test, external; leakage test of valve seat; thermal relief setting; etc.
7. Valve operation test at rated voltage, at high voltage and at low voltage.
8. Performance testing of FSV at different attitudes.
9. Testing of FSV at different altitudes; operating low temperature test and operating high temperature test (temperature variation rate at 5°C/min) as per QTP.
10. Endurance test and burst pressure test of FSV as per QTP (simulation of 20,000 flying hours).
11. Basic performance testing of NRV as per ATP including static pressure test; quantitative leakage test, opening pressure test; performance test for pressure loss at rated flow.
12. Performance testing of NRV at different attitudes.
13. Testing of NRV at different altitudes; operating low temperature test and operating high temperature test (temperature variation rate at 5°C/min) as per QTP.
14. Endurance test and burst pressure test of NRV as per QTP (simulation of 45000 flying hours).

Contribution to Economy / Society

- ✓ Majority of the systems/sub-systems/components used for Indian built aircrafts are imported. Our manufacturing industries do not have the knowledge for designing such items and there is no chance of acquiring these technologies from the established vendors in the near future. Development of these items by Indian industry is absolutely necessary in order to compete with new entrants from other developing countries like Brazil, China, etc. as also for strategic reasons. Access to a sophisticated test facility is essential for development of aero components. Accordingly, the challenge to indigenously design an appropriate testing facility for testing of indigenously developed aircraft valves was taken up by CSIR-CMERI. In future, this will encourage Indian industries to develop aircraft valves within the country.
- ✓ The test facility has been designed to meet the necessary testing requirements of aircraft valves as per latest version of international standard RTCA DO160G. It is suitable for carrying out research on aircraft valve design from first principles. Augmentation of the rig for meeting test requirements of other valves used in civilian aircraft is also possible.
- ✓ The indigenous test facility so created will help in carrying out research on aircraft valve development from the first principles. The

advantage of designing and developing aircraft valves from scratch is that necessary modifications to suit the requirement of any other aircraft can be carried out easily. Use of indigenous test facility will definitely lead to the development of aircraft valves in the country at a cheaper rate and within a relatively short time frame.

- ✓ There are very few companies in the country engaged in research on airworthy product development. The designed test facility for this purpose is unique in the country and quite sophisticated. The laboratory has been inaugurated by DG CSIR on 26th February 2012. CSIR-CMERI has initiated discussion with M/s Larsen & Tourbo who have already visited the laboratory for exploring the possibility of carrying out testing of their developed components. In future, it will definitely raise the brand equity of CSIR-CMERI among the industries.

Low Speed Wind Tunnel Facility

A low turbulence open circuit subsonic wind tunnel facility with a test section area of 0.3m×0.3m has been created in CSIR-CMERI for aerodynamic studies and turbulence research. Wind tunnel is a device used for generating a controlled flow of air of user's interest in the test section. It is used in many engineering and environmental applications as a key tool in understanding the problems associated with aerodynamic and transport phenomena. Different types of wind tunnels exist around the world based on specific requirements (High Reynolds number, free flight, spin, stability, 2D, smoke, automobile, climatic, aeroacoustic, water, etc.) and each has its own sphere of application.

The subsonic wind tunnel facility created in CSIR-CMERI is a general purpose tunnel that is expected to find use in a wide range of applications spanning fundamental research to model testing. The Wind Tunnel Facility has a provision for changing the free-stream turbulence intensities (TI) and has a TI substantially less than 1%. The facility has an overall length of 8.2m. The settling chamber entrance area is 1.36m×1.36m. A square honeycomb (cell area of 0.03m×0.03 m) and three screens of different sizes (wire meshes of 0.019m×0.019m, 0.013m×0.013m and 0.007m×0.007m) are placed inside the settling chamber for breaking down the large-scale turbulent structures present inside the lab into small scale eddies. This is essential to reduce the low amplitude fluctuations inside the test section and minimize the turbulence intensity.

The wind tunnel has a contraction section with a contraction ratio of 11 which further decreases the size of eddies ($v'_2 = v'_1 \left(A_2/A_1 \right)$) convected into the test section. The length of the contraction section is 1m. Three sides of the old test section were covered with wood and one side was covered with glass. The length of the test section is 1.3m which helps in studying the wake behaviour and the decay of grid turbulence. Three sides of the test sections are covered with perspex sheet and the front is covered with glass. This helps in placing the laser sheet and the camera in both horizontal and vertical directions for flow visualization. Appropriate provisions are incorporated at the bottom and the top sides of the test section for fixing the models and manipulating the probes. The length of the diffuser is 1.2m and it has diversion angle of 4º. The diffusion ratio is 2. A wire mesh is attached to the exit of the diffuser to avoid accidental collision of models and probes with the suction fans. Two suction fans are placed inside a constant area duct in a shaft. The diffuser and the constant area duct are separated by a rubber tubing to avoid motor vibration from being transmitted to the test section. The constant area duct is attached to a second diffuser of a high divergence angle to minimize the pressure loading on the suction fans, as also for increasing its efficiency. The velocity in the test section is varied and velocity fluctuations controlled using a variable frequency drive (VFD). The maximum velocity in the test section is 35m/s. The laboratory testing conditions are maintained and varied with the help of air conditioners and dehumidifier. The local temperature and pressure are measured using analog barometer and a digital thermometer from SATO.

Figure 1 shows the wind tunnel test section with a model of an auto rickshaw scaled down to one twentieth of its original dimensions for studying the wake characteristics using the velocity measurements and flow visualization. The test section velocity is measured using a 4-in-1 micro manometer and a static Pitot tube. Turbulent fluctuations and wake characteristics are obtained using a four channel hot wire anemometry system. Miniature cross wire (2D), three wire (3D) and flush mounting probes are used for measuring the grid turbulence, energy exchange between small and large scale structures, decay of TI and shear stress acting on the wall. The analog data is acquired and digitalized using a multipurpose PCI 6143 16 bit 250 kS/s, 8 analog input channels, simultaneous card and a special purpose NI PXI 4462, 24 bit, 200 kS/s, 4 analog input channels, simultaneous card. A dedicated NI PXIe-1062Q chassis (8 slots) with NI PXIe-8133 controller is used for data acquisition and analysis. Data acquisition takes place with the help of LABVIEW 2011 software.

Figure 1: Wind tunnel facility with instrumentation for flow visualization and wake measurements

Flow visualization is performed with the help of a 2W continuous green DPSS laser (532nm). The laser beam intensity is adjusted and the laser sheet obtained using a cylindrical glass rod. The spreading (divergence) of the sheet is adjusted using different sizes of glass rods. A high flow rate fog generator (Phantom 1.1kW, Pea Soup, UK) is used for seeding the smoke particle in the flow. The smoke particle illuminated by the laser sheet is captured using a high speed camera (PCO 1200hs). The pressure distribution around the model is measured using a 16 channel Electronic Differential Pressure scanner (16HD-1901020006). At present the effect of free stream turbulence (FST) on flow past circular cylinder, decay of grid turbulence and the characterization of synthetic jet are being studied in the wind tunnel. The current facility will be enhanced in future for more quantitative studies by adding Stereo Particle Image Velocimetry (SPIV from TSI India) and a six component balance (AEROLAB, USA) for whole field velocity and vorticity calculation and the forces and moments acting on the vehicles.

Other Activity Facets

- Erudite Lectures By Eminent Faculty & Scientists
- Foreign Deputation of CSIR-CMERI Personnel
- Outside Training Schedules Attended by CSIR-CMERI Personnel
- HRDC Ghaziabad Training Programmes
- In-House Training Programmes Organised for CSIR-CMERI Personnel
- Workshops / Seminars / Conferences Attended by CSIR-CMERI Personnel
- Higher Qualification Attained
- Awards and Accomplishments
- Journal Publications: 2012
- Journal Publications: 2013
- Journal Publications: 2014 (Upto March)
- Chapter Contribution to Books
- Conference Papers: April 2012 – March 2014
- Dateline
- Scientific Manpower as on 31.03.2014
- Indo-German Winter Academy 2012
- Indo-US Workshop on “Fabrionics for Healthcare”
- National Seminar on “Advanced Functional Materials” (NSAFM-2013)
- CoEFM Developed Indigenous MBIU Technology Demonstrated to the Director General, CSIR
- Workshop on “Rheo Pressure Die Casting Technology”
- Activities of the TePP Outreach cum Cluster Innovation Centre (TOCIC)
- Performance Indices

Erudite Lectures By Eminent Faculty & Scientists

Sl.	Name	Topic	Date	Programme
1	**Ms. Deepanwita Chattopadhyay,** MD & CEO, IKP Knowledge Park, Hyderabad	Strategies to Foster Innovation & Entrepreneurship	03.04.2012	Innovation, Entrepreneurship & Government Supports
2	**Dr. Ramanuj Banerjee,** Scientist, DSIR, Ministry of Science & Technology, Government of India	Promoting Innovation through TePP of DSIR	03.04.2012	
3	**Dr. Suman Chakraborty**, Professor, Mechanical Engineering Department, IIT, Kharagpur	Effect of a Micro-confined Fluidic Environment: Droplets, Cells and Beyond …..	16.04.2012	Invited Lecture
4	**Dr. Subhash C. Mishra,** FNAE, FIE(I) Professor, Department of Mechanical Engineering, IIT, Guwahati	Thermal Characterization of a Radiating-Conducting System with and without Non-Fourier Effects	16.04.2012	Invited Lecture
5	**Prof. Nil Ratan Bandyopadhyay**, Director, School of Material Science & Engineering BESU, Shibpur	Impending Paradigm Shift in Engineering Science & Technology and Future Challenges	11.05.2012	Technology Day Celebration
6	**Prof. Tapas Chakraborty**, Department of Physical Chemistry, IACS, Kolkata	Sunlight Driven Chemistry Acetone in our Atmosphere		
7	**Dr. Sourav Haldar**, Centre for Cellular & Molecular Biology, Hyderabad	Organization and Dynamics of Membrane and Membrane-bound Peptides		
8	**Prof. Harish Hirani**, IIT, Delhi	Innovation in Maintenance		
9	**Dr. Deepak Sharma**, Senior Applications Engineer from TSI India	TSI's Measurement Solutions for Fluid Mechanics Experimental Research	16.05.2012	Invited Lecture
10	**Dr. Saikat Mandal**, Scientist, CSIR-CGCRI, Jadavpur	Designed Nanostructured Materials: Chemical Approach to Nanomaterials	22.05.2012	Invited Lecture
11	**Dr. William T. Townsend**, CEO of Barrett Technology Inc., USA	Robotic–Manipulator Application and Technology Without Barriers	18.07.2012	Invited Lecture
12	**Prof. Sanjay Kumar Biswas**, Department of Mechanical Engineering, IISc, Bangalore	Layered Particle Tribology	24.07.2012	Invited Lecture
13	**Prof. P. Nithiarasu,** College of Engineering, Swansea University, UK	Patient-specific Modelling of Flow, Heat Transfer and Endothelial Dysfunction of a Carotid Artery	02.08.2012	Invited Lecture

Sl.	Name	Topic	Date	Programme
14	**Dr. Dibyendu Bhattacharya,** Institute of Chemistry, Academia Sinica, Taipei 115, Taiwan	The Chemistry of Transition Metal Complexes related to Chemical and Electrochemical Energy Systems	05.09.2012	Invited Lecture
15	**Prof. Amitabha Ghosh**, RC Chairman, CSIR-CMERI, Durgapur	Revisiting Newton's Laws: Possible Modification and Amazing Astronomical and Cosmological Consequences	13.09.2012	Invited Lecture
16	**Prof. Asutosh Sharma**, IIT, Kanpur	Directing Self-organization in Thin Films to Sub-100 nm Scales: Fabrication of Nanolens and Ordered Nano-arrays	24.09.2012	70th CSIR Foundation day Celebration
17	**Prof. Anirvan Dasgupta**, IIT, Kharagpur	Vibration Assisted Transport & Manipulation	24.09.2012	
18	**Prof. B.V.S.S.S. Prasad**, Mechanical Engineering Department, IIT, Madras	1) Fluidized Bed Technology and Gasification 2) Secondary Air Systems in Gas Turbine - Turbine Blade Cooling	05.10.2012	Invited Lecture
19	**Dr. Debjyoti Banerjee**, Associate Professor, Department of Mechanical Engineering, Texas A&M University, USA	Nano Devices For Enhanced Thermal Energy Storage, Cooling and Sensing	06.12.2012	Invited Lecture
20	**Prof. Karl Strauss**, Technical University of Dortmund, Germany	Lecture on Simulation of Dense Particle Flow in Fluidized Beds with the Discrete Element Method	12.12.2012	11th Indo-German Winter Academy
21	**Prof. (Dr.) S. Mittal**, IIT, Kanpur	Aerodynamics of Cricket Balls and Feather Cocks		
22	**Prof. (Dr.) U. Rüde**, FAU Erlangen	Challenges in Computational Engineering		
23	**Prof. (Dr.) S. Chakraborty**, IIT, Kharagpur	Simulation of Flow Phenomena		
24	**Prof. Ryssel**, FAU Erlangen	Introduction to Course 3: Silicon Technology		
25	**Prof. (Dr.) S. Mishra**, IIT, Guwahati	Lattice Boltzmann Method and its Applications	13.12.2012	
26	**Prof. (Dr.) V. Buwa**, IIT, Delhi	Simulation of Multi-Phase Flows	15.12.2012	
27	**Prof. Amitava Das Gupta**, IIT, Madras	MEMS Technology and Applications - An Overview		
28	**Prof. (Dr.) G. Biswas**, CSIR-CMERI, Durgapur	Computations of Falling Drops and Rising Bubbles	16.12.2012	
29	**Prof. (Dr.) U. Rüde**, FAU Erlangen	Future Directions of Computational Science and Engineering		

Sl.	Name	Topic	Date	Programme
30	**Prof. Ryssel**, FAU Erlangen	Towards Electromobility	16.12.2012	11th Indo-German Winter Academy
31	**Prof. (Dr.) K. Gustavsson**, KTH Stockholm	Large Scale Simulations of Fiber Suspensions	17.12.2012	
32	**Prof. (Dr.) U. Rüde**, FAU Erlangen	Studying in Germany (for students of all courses)		
33	**Prof. Ajoy Kumar Ray**, Vice Chancellor, BESU, Shibpur	Cervical Scanner-Early Diagnosis of Cervical Abnormality	23.12.2012	Indo-US Workshop on Fabrionics for Healthcare
34	**Dr. Tapan Mukerji**, Biomedical Devices of Kansas, USA	Changes in Medical Device Industry & Corporate Outlook – A Paradigm Shift		
35	**Prof. Suman Chakraborty**, IIT, Kharagpur	Paper–Based Microfluidics: the Future of 'LAB-ON-A-CHIP' Applications		
36	**Prof. Debajyoti Banerjee**, Taxas A&M University, USA	Bio-microfludics and Scanning Probe Lithography Platforms for Nano-Manufacturing		
37	**Dr. Nripen Chanda**, CSIR-CMERI, Durgapur	Smart Integrated Biodiagnostic Systems for Healthcare Applications		
38	**Prof. Santanu Kr. Karmakar**, BESU, Shibpur	Biotribology – its Relevance in Healthcare		
39	**Prof. G.K. Ananthasuresh**, IISc, Bangalore	Tuning the Stiffness of Compliant Grippers for Characterizing Soft Cell and Hard Rocks	24.12.2012	
40	**Prof. Sree Sivakumar**, IIT, Kanpur	Directed Assembly of Nanoparticles using Click Chemistry		
41	**Prof. Chirosree Roy Chowdhury**, BESU, Shibpur	Silicon Micro/Nano Pore Impedance Biosensors: Prospects and Challenges		
42	**Prof. Subhasish Bhaumik**, BESU, Shibpur	Foot Steps of Gripping Techniques in Bio-Medical Applications		
43	**Prof. Rabibrata Mukherjee**, IIT, Kharagpur	Potential Application of Soft Lithographically Patterned Surfaces in Biological Applications		
44	**Dr. Tapas Kulia**, DST Inspire Fellow, CSIR-CMERI, Durgapur	Enzymatic Detection of Glucose using Water Soluble Poly-Ether-Ether-Ketone Functionalized Graphene		
45	**Dr. Naresh Chandra Murmu**, CSIR-CMERI, Durgapur	Preliminary Studies on Dip-Pen Nanolithography		
46	**Prof. Monidipa Ghosh**, NIT, Durgapur	Dendritic Cell-A Double-Edged Sword for Immunotechnology		

Sl.	Name	Topic	Date	Programme
47	**Prof. (Dr.) Chinmay Bhattacharya**, Defence Institute of Advanced Technology, Pune	Fast Fourier Transform	26.12.2012	Invited Lecture
48	**Dr. Amalendu Sau**, Gyeong Sang National University, JINJU, South Korea	Role of Streamwise Dynamics in Spreading and Mixing of Flows Through a Rectangular Sudden Expansion Channel	02.01.2013	Invited Lecture
49	**Dr. Santaneel Ghosh,** Associate Professor, Department of Physics and Engineering Physics, Southeast Missouri State University, USA	Role of Engineered Nanocarriers for Axon Regeneration and Guidance: Current Status and Future Trends	07.01.2013	Invited Lecture
50	**Prof. Tapas Chakraborty**, IACS, Kolkata	Role of Flexibility and Weak Molecular Interactions in Bistable Tautomeric Interconversion	24.01.2013	National Seminar on Advanced Functional Materials (NSAFM- 2013)
51	**Prof. S. Ram**, IIT, Kharagpur	Nanostructure and its Role in Shaping Functional Materials for Diversified Applications		
52	**Dr. Pathik Kumbhakar**, NIT, Durgapur	Some Semiconductor Nanostructures for Optoelectronic Applications		
53	**Dr. Mallar Ray**, BESU, Shibpur, Howrah	Unusual Optical and Transport Properties of Semiconductor and Semiconductor-Metal Nanostructure		
54	**Dr. Prasanta Kumar Biswas**, Ex-Chief Scientist, CSIR-CGCRI	Study on Sol-gel Based Multifunctional Indium Tin Oxide (ITO) Semiconductor		
55	**Dr. Kalisadhan Mukherjee**, DST Inspire Fellow, CSIR-CMERI, Durgapur	Hydrogen Sensing Characteristics of Wet Chemically Tailored Spinel Ferrite Nano-structures		
56	**Dr. Tapas Kuila,** DST Inspire Fellow, CSIR-CMERI, Durgapur	Chemical Fictionalization of Graphene and its High Performance Composites with Linear Low Density Polyethylene		
57	**Dr. Mrinal Kaushik**, Assistant Professor, Defence Institute of Advanced Technology, Pune	Passive Control Techniques for Supersonic Jet Mixing	01.02.2013	Invited Lecture
58	**Prof. Raj P. Chhabra**, Professor, IIT, Kanpur	Effect of Shape & Orientation of Heated Objects on Free Convection in Power-Law Fluid	13.02. 2013	Invited Lecture
59	**Prof. Saion Sinha**, Department of Physics, University of New Haven	(1) Nanobiosensors, the Result of Interdisciplinary Applied Research, (2) Biofilms	18.02.2013	Invited Lecture

Sl.	Name	Topic	Date	Programme
60	**Prof. Pradip Dutta**, IISC, Bangalore	Distributed Solar Power for India: A Road to Sustainability	26.02.2013	56th CSIR-CMERI Foundation day Celebration
61	**Prof. R.K. Shevgaonkar**, Director, IIT, Delhi	About Science & Technology	26.02.2013	
62	**Mr. Tejas Canchi**, University of New South Wales, Australia	Micro Air Vehicles - Trying to "Outfly" the "Fly"	25.03.2013	Invited Lecture
63	**Wing T. Lai, Dan Troolin and Jay Singh**, Representing M/s TSI Instruments India Private Limited	Innovation of Fluid Flow Diagnostics on Volumetric 3D3C Measurements	26.04.2013	Invited Lecture
64	**Prof. Siddhartha Mukhopadhyay,** IIT, Kharagpur	Rowards an Oracle for the User… A Cyber Physical Systems Paradigm	11.05.2013	Invited Lecture
65	**Dr. Arabinda Mitra,** Adviser & Head, International Cooperation (Bilateral), DST, Government of India	Opportunities offered through International Programmes of DST	14.05.2013	Invited Lecture
66	**Prof. Aloke Sinha,** Pennsylvania State University, USA	Vibration of a Bladed Rotor with Geometric Mistuning	19.06.2013	Invited Lecture
67	**Toshak Singhal** and **Akshat Harit,** B.Tech students of IIT (BHU), Varanasi	Detection of Biomolecules by Developing a Lab on a Chip Device	20.06.2013	Seminar Lecture
68	**Mr. Stephen Simon and his colleagues,** ACG, Kolkata	US Visa Operations and the Application Process	27.06.2013	Invited Lecture
69	**Prof. D.V. Singh,** Chairman, Research Council of CSIR-CMERI, Durgapur	Foundation Day Lecture	26.09.2013	71st CSIR Foundation day Celebration
70	**Prof. G.K. Ananthasuresh,** Professor, Indian Institute of Science, Bangalore	Micromechanical Signal Processors	09.12.2013	Invited Lecture
71	**Dr. Ambarish Goswami,** Pr. Scientist of Honda Research Institute, USA	Fall Control of Humanoid Robots	16.12.2013	Invited Lecture
72	**Prof. Subir Saha,** IIT, Delhi	Multi-body Dynamics and Robot Kinematics and Dynamics	24.01.2014	Invited Lecture
73	**Prof. Pradip Dutta**, IISc, Bangalore	Status of Semi Solid Casting Process	25.02.2014	Workshop on Rheo-Pressure Die Casting Technology (RPDC-2014)
74	**Mr. Prosenjit Das**, CSIR-CMERI, Durgapur & **Prof. Himadri Chattopadhyay**, Jadavpur University, Kolkata	Physics behind Rheo-Pressure Die Casting		
75	**Dr. A.K. Lohar**, CSIR-CMERI, Durgapur	Development of Rheo-Pressure Die Casting		

Sl.	Name	Topic	Date	Programme
76	**Dr. Aravind Vadiraj**, Manager, Mahindra & Mahindra, Nashik	Issues of Components	25.02.2014	Workshop on Rheo-Pressure Die Casting Technology (RPDC-2014)
77	**Prof. Santanu Das**, Kalyani Government Engineering College	Near Net-Shape Manufacturing and Post Processing using Burr Minimization Techniques		
78	**Prof. Gautam Sutradhar**, Chairman, Indian Institute of Foundrymen, Kolkata Chapter	Status of Foundry Industry		
79	**Dr. Mou Sen**, Directorate of M&SSE	Innovation in MSME		
80	**Prof. H.S. Maity**, Former Director, CSIR-CGCRI	Issues of Technology Development and Commercialization		
81	**Dr. Rajeev Sharma**, Scientist, Department of Science and Technology, New Delhi	Technology System Development Programme of DST		
82	**Prof. Bharat B. Dhar,** Sr. Vice-President, Ritnand Balved Education Foundation (RBEF) and Director, Directorate of Research and Innovation Coordination, Amity University-Uttar Paradesh, NCR, New Delhi.	Foundation Day Lecture	26.02.2014	57^{th} CSIR-CMERI Foundation day Celebration
83	**Dr. Rajat N. Agrawal**, Ophthalmologist & Vitreo-Retinal Surgeon, Founder, Retina Global and RetinaIndia Los Angeles, USA	Bionic Eye Implementation Program	07.03.2014	Invited Lecture

Foreign Deputation of CSIR-CMERI Personnel

SL.	Name	Deputation To	Duration
1	Mrs. Abhilasha Saksena, Scientist	Japan	10/04/2010 to 10/03/2011 to 10/10/2012
2	Dr. Ranajit Ghosh, Scientist	Japan	17/11/2011 to 16/11/2013
3	Mr. Santu Kumar Giri, Scientist	Evanston, USA	01/04/2012 to 06/06/2012
4	Mr. Aman Arora, Scientist	Japan	01/04/2012 to 31/03/2014
5	Dr. Mrinal Pal, Principal Scientist	South Africa	01/04/2012 to 04/04/2012
6	Dr. Debabrata Chatterjee, Senior Principal Scientist	South Korea	29/05/2012 to 31/05/2012
7	Dr. Debabrata Chatterjee, Senior Principal Scientist	University of Erlangen-Nurnberg, Germany	22/07/2012 to 27/07/2012
8	Dr. Aditya Kr. Lohar, Senior Scientist	University of Michigan, USA	01/08/2012 to 30/11/2012
9	Mr. Amit Kumar, Scientist	Beijing, China	19/08/2012 to 24/08/2012
10	Mr. Avik Chatterjee, Senior Principal Scientist	Darmstadt, Germany	02/09/2012 to 16/09/2012
11	Mr. Prosenjit Das, Scientist	Cape Town, South Africa	08/10/2012 to 11/10/2012
12	Dr. Pradip Kumar Chatterjee, Chief Scientist	Belgium	25/10/2012 to 13/11/2012
13	Dr. Malay Karmakar, Scientist	Belgium	25/10/2012 to 13/11/2012
14	Mr. Chanchal Loha, Scientist	Belgium	25/10/2012 to 13/11/2012
15	Dr. Debabrata Chatterjee, Senior Principal Scientist	Dhaka, Bangladesh	07/12/2012 to 09/12/2012
16	Mr. Rajesh Prasad Barnwal, Scientist	China	12/12/2012 to 16/12/2012
17	Dr. Malay Karmakar, Scientist	University of California, USA	19/01/2013 to 04/02/2013
18	Dr. Debabrata Chatterjee, Senior Principal Scientist	Singapore	19/04/2013 to 21/04/2013
19	Dr. P.K. Chatterjee, Chief Scientist	Cranfield University, England	08/05/2013 to 22/05/2013
20	Dr. Malay Kr. Karmakar, Senior Scientist	Cranfield University, England	08/05/2013 to 22/05/2013
21	Mr. Chanchal Loha, Scientist	Cranfield University, England	08/05/2013 to 22/05/2013
22	Mr. Prosenjit Das, Scientist	Sweden & Finland	20/05/2013 to 23/05/2013
23	Mr. Binod Kr. Saha, Scientist	Berlin, Germany	22/05/2013 to 23/05/2013
24	Mrs. Anjali Chatterjee, Senior Principal Scientist	Dearborn, Michigan, USA	22/05/2013 to 23/05/2013

SL.	Name	Deputation To	Duration
25	Dr. P.K. Chatterjee, Chief Scientist	Czech Republic	05/06/2013 to 16/06/2013
26	Dr. Biswajit Ruj, Principal Scientist	Czech Republic	05/06/2013 to 16/06/2013
27	Dr. Debabrata Chatterjee, Senior Principal Scientist	Hungary	11/06/2013 to 15/06/2013
28	Dr. Debabrata Chatterjee, Senior Principal Scientist	Germany	15/07/2013 to 28/07/2013
29	Mr. Saikat Kr. Shome, Scientist	Austria	10/11/2013 to 13/11/2013
30	Dr. Atanu Maity, Principal Scientist	Indonesia	25/11/2013 to 27/11/2013
31	Mr. U.S. Patkar, Senior Scientist	Indonesia	25/11/2013 to 27/11/2013

Outside Training Schedules Attended by CSIR-CMERI Personnel

SL.	Training Programme On	Participants
1	Training Course on “MPT Level-II & LPT Level-II Certification Course”	2
2	Training Programme on “Modelling & Simulation of Renewable Energy System (MSRES-2012)”	1
3	Visiting Fellowship Programme 2011-2012 (JNCASR)	1
4	Intensive Course on “Parallel Programming with MPI/Open MP”	2
5	Training Programme on “LIBSYS Software”	2
6	Training Programme on “Communication and Presentation Skills (CAPS)”	2
7	DST Sponsored General Management Programme	2
8	Short Term Course on “Modern Trends in Power Electronics, Control and Machine Drives (MTPCMD-2013)”	6
9	One week Training Programme on “Hands on Advanced Instruments of Water Quality Testing”	1
10	Short Term Course on “Earthquake Resilient City”	1
11	TEQIP-II Sponsored Short Term Course on “Computer Aided Design and Engineering (CADE 2014)”	2
12	TEQIP-II Sponsored Short Term Course on “Modern Practices in Upstream and Downstream Operations of Petroleum Industries (UDOPI-2014)”	1
13	National Programme for Training of Scientists & Technologists Working in Government Sector on “Soft Computing Techniques for Optimization”	2
14	National Programme on “Entrepreneurship Development & Management for Women Scientist & Technologists with the Government Sector”	1

HRDC Ghaziabad Training Programmes

Sl.	Training Programme On	Duration	Participants
1	Training Programme on “Research Methodology-Part I”	April 23-27, 2012	2
2	Programme on “Work life for Women Scientist and Officers”	April 30- May 02, 2012	1
3	Management Development Programme for Common Cadre Officers	May 07-11, 2012	1
4	Training Programme on “S&T Communication and Presentation Skill”	May 23-25, 2012	4
5	Orientation Training Programme for Technical Group-II Personnel	June 25-29, 2012	1
6	Training Programme on “Competency Development for Group-II Personnel”	August 06-09, 2012	3
7	Orientation Training Programme for PS/PAS’/Sr. Stenographers	February 18-22, 2013	1
8	Orientation Training Programme for Technical Group-III Personnel	March 08-12, 2013	4
9	Programme on “Effective S&T Communication and Presentation Skills”	July 10-12, 2013	2
10	Induction Training Programme for Scientists	July 21-30, 2013	3

In-House Training Programmes Organised for CSIR-CMERI Personnel

Sl.	Training Programme On	Participants
1	An Introduction to Computational Fluid Dynamics with Aerospace Applications	27
2	Course on Communication and Writing Skill in English	50
3	Training on WAM Robot Arm of Barrett Technology Inc.	17
4	Training on “MSC Adams”	14
5	Simulation Capabilities of COMSOL Multiphysics	22
6	Course on “Mechanics and Analog Electronics”	85

Workshops / Seminars / Conferences Attended by CSIR-CMERI Personnel

Sl.	Name of the programme	Participants
1	10th International Symposium on Computer Methods in Biomechanics & Biomedical Engineering	1
2	International Federation for Information Processing in Partnership with the Department of Information Technology, Govt. of India is Organizing the 5th World IT Forum	1
3	Seminar on "Approaching Zero Defect Manufacturing of Castings"	5
4	National Conference on "Condition Monitoring of Engineering Systems & Structures (NCCM-2012)	1
5	International Conference on "Technology Management"	1
6	National Seminar on "Industrial Application of Solar Energy"	5
7	3rd International Conference on "Solid Waste Management"	1
8	4th International Conference on Wireless & Mobile Networks (WiMoN-2012)	1
9	International Conference on Advances in Power Conversion and Energy Technologies 2012	1
10	International Conference on Corrosion (CORCON 2012)	1
11	International Symposium on "Processing and Fabrication of Advanced Materials" (PFAM-21)	2
12	SERC School-cum-Symposium on Molecular Simulation	1
13	4th International & 25th All India Manufacturing Technology Design and Research (AIMTDR-2012)	5
14	5th Chapter Metallurgists' Day Celebration by IIM Durgapur Chapter	4
15	8th International Conference on "Advance in Metrology (AdMet-2013)"	2
16	International Conference on "Industrial Tribology (ICIT-2012)"	3
17	12th International Conference on "Intelligent System Design and Applications (ISDA-2012)"	1
18	International Conference on "Communications, Devices and Intelligent Systems (CODIS)"	1
19	First International Workshop on "Sustainable Monitoring through Cyber-Physical Systems (SuMo-CPS 2013)"	1
20	Conference on "5th Bangalore Nano"	2
21	1st International Workshop on "Nanomaterials (IWoN): Engineering Photon and Phonon Transport"	2
22	International Engineering Post Graduate Research Conference	2
23	1st National Conference on "Micro and Nano Fabrication"	2

Sl.	Name of the programme	Participants
24	International Conference on “Information Communication & Embedded Systems (ICICES-2013)”	1
25	International Conference on “Energy Resources & Technologies for Sustainable Development (ICERTSD-2013)”	5
26	National Meet on “Tractor and Agricultural Machinery Manufacturers (TAMM-2013)”	2
27	International Symposium on “Molecular Organization and Complexity: A Chemical Perspective”	2
28	International Conference on “Signal processing, image processing and Pattern Recognition”	1
29	“National Welding Seminar (NWS 2013)”	1
30	IEEE International Advance Computing Conference	1
31	47th ISAE “Annual Convention and International Symposium on Bio-Energy-Challenges and Opportunities”	1
32	Fourth International Conference on “Recent Advances in Composite Materials”	1
33	“The Coventor Ware Meet 2013”	1
34	“61st Indian Foundry Congress”	1
35	International Conference on “Global Scenario in Energy & Environment (ICGSEE-2013)”	1
36	National Conference on “Mechanical Engineering Retrospect & Prospect (NCMERP-2013)”	3
37	2nd Annual International Conference on “Materials Processing and Characterization (ICMPC-2013)”	1
38	Third National Conference on “Innovations in Indian Science, Engineering & Technology”	1
39	International Conference on “Biosignals, Images and Instrumentation (ICBSII – 2013)”	1
40	Workshop on “Data mining and Industrial Applications”	1
41	IEEE International Multi-Conference on “Automation, Computing, Communication, Control and Compressed Sensing (iMac4s)”	1
42	1st International Conference on “Mechanical, Automotive and Materials Engineering (ICMAME 2013)”	1
43	Fourth National Conference on “Recent Trends in Communication Computation and Signal Processing 2013”	1
44	National Seminar on “Grid Security – Key Issues & Challenges”	1
45	IEEE International Conference on “Communication and Signal Processing (ICCSP’2013)”	1
46	International Conference on “Global Innovations in Technology and Sciences (ICGITS-2013)”	1
47	IEEE International Conference on “Energy Efficient Technologies for Sustainability (ICEETS’2013)”	1
48	National Seminar-cum-Workshop on “Sensor and Sensing System for Taste Characterization of Food and Agro Produces”	2
49	Workshop on “Quartz Crystal Microbalance (QCM) and Surface Acoustic Wave (SAW) Sensors”	1

Sl.	Name of the programme	Participants
50	CEP Workshop on "3D Printing"	2
51	5th International Conference on "Electronics Computer Technology 2013"	1
52	"Advances in Robotics, International Conference of Robotics Society of India – 2013"	3
53	IEEE Workshop on "MEMS & Microsystem with Hands-on training in Device Simulation and Microfabrication Process"	1
54	International Conference on "Design and Manufacturing (IConDM 2013)"	2
55	International Workshop on "Nanotechnology and Advance Functional Materials (NTAFM 2013)"	2
56	"Global R&D Summit 2013"	1
57	Workshop on "Instrumentation and Electrical Engineering for Your Planet People"	1
58	IEEE International Symposium on "Control, Automation, Industrial Informatics and Smart Grid (ICACCI'13)"	1
59	Workshop on "Powder Injection Moulding (MIM+CIM)"	1
60	2nd TAPSUN Conference on "Advances in Futuristic Solar Energy Materials & Technologies"	4
61	National Workshop on "Optimization and its Application (NWOA 2013)"	10
62	Second International Conference on "Computing and System (ICCS-2013)"	1
63	9th International Conference on "Intelligent Unmanned Systems"	2
64	Workshop on "Offshore Structural Engineering: Recent Developments, Challenges & Opportunities"	2
65	IEEE International Conference on "Signal Processing, Computing and Control (ISPCC – 2013)"	1
66	Workshop on "Underwater Technology"	3
67	7th International Symposium on "Feedstock Recycling of Polymeric Materials (ISFR)"	1
68	One Week Workshop on "Advanced Wireless Communication & Networking"	3
69	39th Annual Conference of the "IEEE Industrial Electronics Society (IECON 2013)"	1
70	National Seminar on "Recent Approaches to Water Resource Management (RAWRM–2013)"	1
71	International Conference on "Energy System Modeling and Optimization Conference (ESMOC 2013)"	2
72	IEEE International Conference on "Robotics and Biomimetics (ROBIO 2013)"	1
73	International Conference on "Precision, Meso, Micro and Nano Engineering (COPEN 8 : 2013)"	2
74	IEEE INDICON 2013 "Advancing Technology for Humanity"	1
75	International Conference in Asia – 2013 (IUMRS-ICA-2013)	1
76	1st International & 16th National Conference on "Machines and Mechanisms (iNaCoMM 2013)"	11
77	National Conference on "Computer Vision, Pattern Recognition, Image Processing and Graphics (NCVPRIPG)"	1

Sl.	Name of the programme	Participants
78	58th Congress of the Indian Society of Theoretical and Applied Mechanics	2
79	IETE International Conference on "Computer Electrical and Electronics Engineering (IETE ICCEEE – 2013)"	1
80	22nd National & 11th ISHMT-ASME Heat and Mass Transfer Conference 2013	2
81	International Conference on "Advances in Electrical Engineering 2014 (IEEE-ICAEE)"	1
82	Conference on "Flow Chemistry India 2014"	2
83	National Conference on "Environment: Pollution and Protection (EPP 2014)"	2
84	National Seminar on "Precision Engineering, Metrology, Quality Assurance and NABL Accreditation"	9
85	International Conference on "Functional Materials (ICFM-2014)"	1
86	4th International Conference on "Advance Computing and Communication Technologies"	1
87	National Conference on "ASIATRIB-2014"	3
88	Workshop on "Nonlinearities in Structural Engineering and Mechanics: Concepts, Application and Research-Development (NSEM-2014)"	2
89	IEEE International Advance Computing Conference (IAC-2014)	1
90	Workshop on "Rheo Pressure Die Casting Technology (RPDC-2014)"	18
91	International Conference on Engineering Materials and Processes (ICEMP-2014)	1
92	Workshop on DELNET: Resources, Services and Facilities & Koha: An Open Source Integrated Library System	3
93	2nd IEEE International Students Conference on "Electrical, Electronics and Computer Science (SCEECS-2014)"	1
94	6th International Conference on "Nano Science and Technology (ICONSAT)-2014"	1
95	National Conference on "Emerging Trends in Physics of Fluids & Solids (NCEPFS 2014)"	1
96	2nd International Conference on "Innovations in Automation and Mechatronics Engineering (ICIAME-2014)"	2
97	3rd International Conference on "Materials Processing and Characterization (ICMPC 2014)"	1
98	National Seminar on "Recent Advances in Chemistry 2014"	2
99	National Workshop on "Micro-Manufacturing"	1
100	International Conference on "Advances in Manufacturing and Materials Engineering"	1

Higher Qualification Attained

Sl.	Awardees	Qualification
1	**Shri. Rajesh Prasad Barnwal** Scientist	M.Tech. from IIT, Kharagpur **Misbehavior Detection Framework for Vehicular Ad-hoc Networks**
2	**Dr. Dip Narayan Ray** Scientist	Ph.D. from NIT, Durgapur **Autonomous Navigation of Mobile Robots: A fusion of Behavior-based Robotics and Reinforcement Learning**
3	**Dr. Atanu Saha** Principal Scientist	Ph.D. from NIT, Durgapur **Effect of Cyclic Heat Treatment on Microstructure and Mechanical Properties in Various Grades of Plain Carbon Steels**
4	**Dr. Rabi Kant Jain** Senior Scientist	Ph.D. from IIT, Kanpur **Robotic Microassembly using IPMC for Active Compliance in a SCARA Robot and a Flexible 4-Bar Mechanism**
5	**Dr. Suman Saha** Scientist	Ph.D. from Jadavpur University **Some Studies on Application of Fractional Order Controllers in Proportional–Integral-Derivative (PID) Control Loops**
6	**Shri. Ashok Kumar Prasad** Principal Scientist	M.Tech. from B.I.T. Sindri, Dhanbad **Experimental Study of Nd YAG Laser Parameters for Welding of Monel 400 Using Taguchi Method of Optimisation**
7	**Dr. Sankar Nath Shome** Chief Scientist	Ph.D. from NIT, Durgapur **Design and Modelling of a Shallow Water Modular AUV & Performance Evaluation**
8	**Dr. Tapas Gangopadhyay** Principal Scientist	Ph.D. from NIT, Durgapur **Analysis of Multi-stage Forming Process of Mono-block Railway Wheel using Finite Element Method and Soft Computing**
9	**Dr. Swarup Ranjan Debbarma** Principal Scientist	Ph.D. from NIT, Durgapur **Time-dependant Effects in Shape Memory Alloy Reinforced Concrete & Pre-stressed Concrete Flexural Members**
10	**Dr. Chanchal Loha** Scientist	Ph.D. from Jadavpur University **Studies on Fluidizedbed Gasification of Biomass**
11	**Dr. Nilrudra Mandal** Scientist	Ph.D. from Jadavpur University **Development and Evaluation of High Performance Zirconia Toughened Alumina (ZTA) Ceramic Cutting Tool for Improving Machining Characteristics**

Awards and Accomplishments

- **Sri Pranab Mukherjee**, President of India bestowed the **Distinguished Alumnus Award** to **Prof. Gautam Biswas** at the BESUS Convocation, 2013.
- **Prof. Gautam Biswas**, Director, CSIR-CMERI, became a **Fellow** of the **Indian National Science Academy (INSA)**, the most prestigious Science Academy of India.
- **Dr. Naresh Chandra Murmu** won the **National Design Award in Mechanical Engineering – 2012** for outstanding contribution to the field of Mechanical Engineering Design.
- **Shri A.K. Shukla**, Senior Principal Scientist was selected as a **Member** of the **Central Boilers Board** vide **Gazette of India Notification No. G.S.R. 619(E)** dated August 7, 2012.
- **Dr. Biswajit Ruj & Dr. P.K. Chaterjee** was Presented the **Award of Excellence in Presentation of Technical Paper** at the 3rd IconSWM, 2012.
- **Dr. Dipankar Chatterjee** was awarded **Metallurgist for the year 2011-12** by the Indian Institute of Metals, Durgapur Chapter for his contribution in **Computational Fluid Dynamics in Materials Processing Applications.**
- A **'Certificate of Honour'** was presented to **Ms. Henal Shah** by the Indian Institute of Metals, Durgapur Chapter for contribution in **Electrodeposition and Characterization of Metallic and Metal-Ceramic Composite Coatings.**
- **Mr. Prosenjit Das** was awarded a **'Certificate of Honour'** in recognition of valuable services rendered in the field of Metallurgy for the year 2011-12 by the Indian Institute of Metals, Durgapur Chapter for his contribution in **Rheo Pressure Die Casting of Aluminium Alloys and Finite Element Modelling of Cryo Roll Aluminium Alloys.**
- **Dr. Mrinal Pal** became a member of the **International Advisory Board of the South African Nanotechnology Initiative.**
- **Mr. U.S. Ghosh and his team** was granted **US patent** (191NF2006_US Notice of Allowance) for developing a novel low cost **Colposcope to examine an illuminated, magnified view of the cervix and the tissues.**
- **Dr. Krishnendu Kundu** was selected as a **Reviewer** of **the Journal of Current Science** – An extremely prestigious journal.
- **Dr. Krishnendu Kundu** was selected as a **Member** of the **Bureau of Indian Standard (Alternate Fuel).**
- **Mr. Saikat Kumar Shome** was awarded the **"Excellent Oral Presentation Certificate"** in the 5th International Conference on Electronics Computer Technology, 2013 at Kanyakumari, India.
- **Dr. Ranjan Sen**, Chief Scientist, CSIR-CMERI was selected as a "**Distinguished Visiting Professor**" of Indian National Academy of Engineering, New Delhi for a tenure of one year.
- CSIR-CMERI's nomination entitled "Portable magnifying instrument useful for colposcopy" won the **CSIR Technology Award - 2013** for the category "Innovation".
- The Institution of Engineers (India) presented the **"IEI Young Engineers Award"** to **Dr. Sivaprakash S.** in recognition of his contribution in the field of Chemical Engineering on the occasion of the Twenty-ninth National Convention of Chemical Engineers.

- **Dr. Ravi Kant Jain**, Senior Scientist of CSIR-CMERI was awarded **'Best Technical Paper in Motion Track'** at 'MSC Software India User Conference 2013' for the paper entitled "Robotic micro assembly using IPMC for active compliance in a manipulation systems through Adams".
- **Dr. Dipankar Chatterjee** became an **Editorial Board Member** of the newly formed International Journal "American Journal of Heat and Mass Transfer".
- The Institution of Engineers (India) presented the "**Production Engineering Division Prize"** to **Dr. S.N. Shome, Mr. S. Nandy, Mr. D. Pal, Mr. S.K. Das, Mr. S.R.K. Vadali, J. Basu and S. Ghosh** for the paper entitled "Development of Modular Shallow Water AUV: Issues & Trial Results".
- AcSIR-Students **Anand Awarwal, Bijo Sebastian & Miachael Jacob Mathew** bagged **Frist Prize of the Student Mechanism Design Contest** for their design of 'Dish Cleaning Machine' at IIT, Roorkee.
- **Dr. Biswajit Ruj** and **Dr. P.K. Chatterjee** received **'Best Paper (Oral) Award'** for their research paper presented at the National Conference on "Environment: Pollution and Protection" organised by NIT, Durgapur.
- **Miss. Priyanka Das**, Project fellow, was awarded **Third Prize for Poster Presentation** in the national seminar on Recent Advances in Chemistry organised by the Department of Chemistry, Visva-Bharati, Santiniketan.

Journal Publications: 2012

Sl.	Title	Authors	Journal	Details
1	A comparison of hardened properties of fly-ash-based self-compacting concrete and normally compacted concrete under different curing condition	D. Das, A. Chatterjee	Magazine of Concrete Research	2012, 64(2), pp. 129-141
2	A conformal mapping based fractional order approach for sub-optimal tuning of PID controllers with guaranteed dominant pole placement	Suman Saha, Saptarshi Das, Shantanu Das, Amitava Gupta	Communications in Nonlinear Science and Numerical Simulation	2012, 17(9), pp. 3628-3642
3	A lattice Boltzmann model for high energy materials processing application	Dipankar Chatterjee	International Journal for Multiscale Computational Engineering	2012, 10(3), pp. 229-247
4	An approach towards optimization of the extraction of polyphenolic antioxidants from ginger (Zingiber officinale)	Suprabhat Mukherjee, Nilrudra Mandal, Apurba Dey, Biswanath Mondal	Journal of Food Science and Technology	2012, DOI 10.1007/s13197-012-0848-z
5	An experimental evaluation of material properties and fracture simulation of cryorolled 7075 Al alloy	Prosenjit Das, I.V. Singh, R. Jayaganthan	Journal of Materials Engineering and Performance	2012, 21(7), pp. 1167-1181
6	Analysis of flow structure inside a spool type pressure regulating valve	Himadri Chattopadhyay, Arindam Kundu, Binod K. Saha, Tapas Gangopadhyay	Energy Conversion and Management	2012, 53(1), pp. 196-204
7	Assessing concrete quality in structure through statistical interpretation of ultrasonic pulse velocity measurements	Abhijit Chatterjee, Debashis Das	Magazine of Concrete Research	2012, 64(8), pp. 717-725
8	Assessment of drag models in simulating bubbling fluidized bed hydrodynamics	Chanchal Loha, Himadri Chattopadhyay, Pradip K. Chatterjee	Chemical Engineering Science	2012, 75, pp. 400-407
9	Augmentation of heat transfer by creation of streamwise longitudinal vortices using vortex	Gautam Biswas, Himadri Chattopadhyay, Anupam Sinha	Heat Transfer Engineering	2012, 33(4-5), pp. 406-424

Sl.	Title	Authors	Journal	Details
10	Automatic characterization of fracture surfaces of AISI 304LN stainless steel using image texture analysis	S. Dutta, A. Das, K. Barat, H. Roy	Measurement	2012, 45, pp. 1140-1150
11	Biomechanical remedies for degeneration of cervical spine – A review of literature	Partha Sarathi Banerjee, Amit Roychoudhury, Santanu K. Karmakar	Journal of Medical Imaging and health Informatics	2012, 2, pp. 343-351
12	Brown hemp methyl ester: Transesterification process and evaluation of fuel properties	S. Ragit, S.K. Mohapatra, K. Kundu, P. Gill	Journal of Biomass and Bioenergy	2012, 41, pp. 14-20
13	Bubble pinch-off and scaling during liquid drop impact on liquid pool	Bahni Ray, Gautam Biswas, Ashutosh Sharma	Physics of Fluids	2012, 24(8), article no: 082108
14	Control of flow separation around bluff obstacles by transverse magnetic field	Dipankar Chatterjee, Kanchan Chatterjee, Bittagopal Mondal	Journal of Fluids Engineering-Transactions of ASME	2012, 134, article no: 091102
15	Crack growth simulation of bulk and ultrafine grained 7075 Al alloy by XFEM	Prosenjit Das, I.V. Singh, R. Jayaganthan	International Journal of Materials and Product Technology	2012, 44(3/4), pp. 252-276
16	Cyclic fracture behaviour of 304LN stainless steel under load and displacement control modes	H. Roy, S. Sivaprasad, S. Tarafder, K.K. Ray	Fatigue & Fracture of Engineering Materials & Structures	2012, 35(2), pp. 108-113
17	Design and simulation of a thermo transfer type MEMS based micro flow sensor for arterial blood flow measurement	Kalyan Kumar Mistry, Abhijit Mahapatra	Microsyst Technol	2012, 18, pp. 683-692
18	Design of particle-reinforced polyurethane mould materials for soft tooling process using evolutionary multi-objective optimization algorithms	Arup Kumar Nandi, Shubhabrata Datta, Kalyanmoy Deb	Soft Computing	2012, 16, pp. 989-1008
19	Detection of tool condition from the turned surface images using an accurate grey level co-occurrence technique	S. Dutta, A. Datta, N. Das Chakladar, S.K. Pal, S. Mukhopadhyay, R. Sen	Precision Engineering	2012, 36(3), pp. 458-466
20	Development of high strength ductile hypereutectoid steel by cyclic heat treatment process	Atanu Saha, Dipak Kumar Mondal, Koushik Biswas, Joydeep Maity	Materials Science and Engineering: A	2012, 541, pp. 204-215
21	Effect of anisotropy on natural convective flow through a rectangular porous slab	P. Chandra, V. V. Satyamurty	Journal of Porous Media	2012, 15(6), pp. 595-605

Sl.	Title	Authors	Journal	Details
22	Effect of neodymium doping on structure, electrical and optical properties of nanocrystalline ZnO	B. Roy, S. Chakrabarty, O. Mondal, M. Pal, A. Dutta	Materials Characterization	2012, 70, pp. 1-7
23	Effect of pouring temperature on cooling slope casting of semi-solid Al-Si-Mg alloy	Prosenjit Das, S.K. Samanta, Himadri Chattopadhyay, Pradip Dutta	Acta Metallurgica Sinica (English Letters)	2012, 25(5), pp. 329-339
24	Effect of sacrificial electron donors on hydrogen generation over visible light–irradiated nonmetal-doped TiO_2 photocatalysts	Ujjwal Pal, Sarita Ghosh, Debabrata Chatterjee	Transition Metal Chemistry	2012, 37(1), pp. 93-96
25	Effect of thermal buoyancy on the two-dimensional upward flow and heat transfer around a square cylinder	Dipankar Chatterjee, Bittagopal Mondal	Heat Transfer Engineering	2012, 33(12), pp. 1063-1074
26	Effect of Y-doping on the electrical transport properties of nanocrystalline $BiFeO_3$	A. Mukherjee, S. Basu, G. Chakraborty, M. Pal	Journal of Applied Physics	2012, 112, article no: 014321
27	Effective properties of particle reinforced polymeric mould material towards reducing cooling time in soft tooling process	A.K. Nandi, S. Datta, J. Orkus	Journal of Applied Polymer Science	2012, pp. 2567-2581
28	Enhancement of heat transfer using delta-winglet type vortex generators with a common flow-up arrangement	A. Pal, B. Bandopadhyay, G. Biswas, V. Eswaran	Numerical Heat Transfer, Part A	2012, 61, pp. 912-928
29	Enzymatic hydrolysis of water hyacinth substrate by cellulase, xylanase and a glucosidase: Experiments and optimization	A. Ganguly, A. Gupta, S. Das, A. Dey, P.K. Chatterjee	Journal of Biobased Material and Bioenergy	2012, 6(3), pp. 283-291
30	Experimental study on a compressible vortex ring in collision with a wall	T. Murugan, D. Das	Journal of Visualization	2012, 15(4), pp. 321-332
31	Force prediction model of Zirconia Toughened Alumina (ZTA) inserts in hard turning of AISI 4340 steel using response surface methodology	Nilrudra Mandal, B. Doloi, B. Mondal	International Journal of Precision Engineering and Manufacturing	2012, 13(9), pp. 1589-1599
32	Forced convection heat transfer from an equilateral triangular cylinder at low Reynolds numbers	Dipankar Chatterjee, Bittagopal Mondal	Heat and Mass Transfer	2012, 48, pp. 1575-1587
33	Forced convection heat transfer from tandem square cylinders for various spacing ratios	Dipankar Chatterjee, Bittagopal Mondal	Numerical Heat Transfer, Part A	2012, 61, pp. 381-400

Sl.	Title	Authors	Journal	Details
34	Grey relational analysis of micro EDM machining of Ti-6Al-4V alloy	Vijay Kumar Meena, Man Singh Azad	Materials and Manufacturing Processes	2012, 27, pp. 973-977
35	Influence of alloy grain size on high temperature corrosion behavior of 2.25 Cr-1 Mo steel in SO_2+ O_2 atmosphere	D. Ghosh, S.K. Mitra	High Temperature Materials and Processes	2012, 31(6), pp. 727-731
36	Investigating the role of metallic fillers in particulate reinforced flexible mould material composites using evolutionary algorithms	Arup Kumar Nandi, Kalyanmoy Deb, Subhas Ganguly, Shubhabrata Datta	Applied Soft Computing	2012, 12(1), pp. 28-39
37	Kinetics of austenitisation of ductile irons containing two different contents of manganese and copper	R.K. Dasgupta, D.K. Mondal, A.K. Chakrabarti, A.C. Ganguli	International Journal of Cast Metals Research	2012, 25(4), pp. 239-245
38	Mathematical model for predicting the state of health of transformers and service methodology for enhancing their life	Anjali Chatterjee, Partha Bhattacharjee, N.K. Roy	International Journal of Electrical Power and Energy Systems	2012, 43(1), pp. 1487-1494
39	Mathematical modeling of wear characteristics of 6061 Al-Alloy-SiCp composite using response surface methodology	Nilrudra Mandal, H. Roy, B. Mondal, N.C. Murmu, S.K. Mukhopadhyay	Journal of Materials Engineering and Performance	2012, 21(1), pp. 17-24
40	Mechanism of -O-O- bond activation and catalysis by Ru (III)-pac complexes (pac = polyaminocarboxylate)	Debabrata Chatterjee	Journal of Chemical Sciences	2012, 124(6), pp. 1145-1150
41	Mechanism of –O-O- bond activation and substrate oxidation by Ru-edta complexes	Debabrata Chatterjee, Rudi van Eldik	Journal of Molecular Catalysis A: Chemical	2012, 355, pp. 61-69
42	Microassembly by an IPMC based flexible 4-bar mechanism	R.K. Jain, S. Majumder, A. Dutta	Smart Material and Structures	2012, 21(7), article no: 075004
43	Microstructural evolution of A356 Al alloy during flow along a Cooling Slope	Prosenjit Das, S.K. Samanta, B.R.K Venkatapathi, Himadri Chattopadhyay, Pradip Dutta	Transactions of the Indian Institute of Metals	2012, 65(6), pp. 669-672
44	Microstructural modifications and changes in mechanical properties during cyclic heat treatment of 0.16% carbon steel	Atanu Saha, Dipak Kumar Mondal, Koushik Biswas, Joydeep Maity	Materials Science and Engineering: A	2012, 53, pp. 465-475

Sl.	Title	Authors	Journal	Details
45	Microstructure and mechanical properties of As-cast ductile irons alloyed with manganese and copper	R.K. Dasgupta, D.K. Mondal, A.K. Chakrabarti, A.C. Ganguli	Journal of Materials Engineering and Performance	2012, 21(8), pp. 1728-1736
46	Mixed convection heat transfer from an in-line row of square cylinders in cross-flow at low Reynolds number	Dipankar Chatterjee, Gautam Biswas, Sakir Amiroudine	Numerical Heat Transfer, Part A	2012, 61, pp. 891-911
47	Mixed convective heat transfer of nanofluids past a circular cylinder in cross flow in unsteady regime	Sandip Sarkar, Suvankar Ganguly, G. Biswas	International Journal of Heat and Mass Transfer	2012, 55, pp. 4783-4799
48	Modelling and analysis of cutting force and surface roughness in milling operation using TSK-type fuzzy rules	Arup Kumar Nandi	Journal of the Brazilian Society of Mechanical Sciences and Engineering	2012, XXXIV (1), pp. 49-61
49	Multiple path generation by a flexible 4-bar mechanism using ionic polymer metal composite	R.K. Jain, S. Majumder, A. Dutta	Journal of Intelligent Material Systems and Structures	2012, 23(12), pp. 1379-1393
50	Numerical simulation and PIV study of compressible vortex ring evolution	T. Murugan, S. De, C. L. Dora, D. Das	Shock Waves	2012, 22(1), pp. 69-83
51	Numerical visualization of counter rotating vortex ring formation ahead of shock tube generated vortex ring	T. Murugan, Sudipta De	Journal of Visualization	2012, 15(2), pp. 97-100
52	Oblique drop impact on deep and shallow liquid	B. Ray, G. Biswas, A. Sharma	Communication in Computational Physics	2012, 11(4), pp. 1386-1396
53	Peroxydisulfate activation by $[RuII(tpy)(pic)(H_2O)]^+$. Kinetic, mechanistic and anti-microbial activity studies	Debabrata Chatterjee, P. Banerjee, J.C. Bose, S.K. Mukhopadhyay	Dalton Transactions	2012, 41, pp. 2694-2698
54	Polyaminecarboxylateruthenium (III) Complexes on the Mosaic of Bioinorganic Reactions. Kinetic And Mechanistic Impact	Debabrata Chatterjee, Rudi Van Eldik	Advances in Inorganic	2012, 64, pp. 183-217
55	Preparation of high solid loading titania suspension in gelcasting using modified boiling rice extract (MBRE) as binder	S. Mahata, M.M. Nandi, B. Mondal	Ceramic International	2012, 38(2), pp. 909-918
56	Rectifying properties of sol-gel synthesized Al:ZnO/Si (N-N) thin film heterojunctions	S. Sarkar, S. Patra, S.K. Bera, G.K. Paul, R. Ghosh	Physica E-Low-Dimensional Systems & Nanostructures	2012, 46, pp. 1-5

Sl.	Title	Authors	Journal	Details
57	Redox reactions of a [RuIII(hedtra)(pz)] complex with biochemically important reductants. Kinetic, mechanistic and anti-microbial studies	Debabrata Chatterjee, Sarita Ghosh, Ujjwal Pal, Sudit Mukhopadhyay	European Journal of Inorganic Chemistry	2012, 12(4), pp. 678-683
58	Simultaneous optimization of multiple performance characteristics in micro-EDM drilling of titanium alloy	M.S. Azad, A.B. Puri	The International Journal of Advanced Manufacturing Technology	2012, 61, pp. 1231-1239
59	Studies on ethanol production from water hyacinth - A review	A. Ganguly, P. K. Chatterjee, A. Dey	Renewable & Sustainable Energy Reviews	2012, 16(1), pp. 966-972
60	Synthesis, characterization and in vitro cytotoxicity assessment of hydroxyapatite from different bioresources for tissue engineering application	Sudip Mondal, Rajashree Bardhan, Biswanath Mondal, Apurba Dey, Sudit Mukhopadhyay, Syamal Roy, Rajan Guha, Koushik Roy	Bulletin of Materials Science	2012, 35(4), pp. 683-691
61	Toxic release of chlorine and offsite emergency scenario - a case study	Biswajit Ruj, P. K. Chatterjee	Journal of Loss Prevention in the Process Industries	2012, 25(3), pp. 650-653
62	Triggering vortex shedding by superimposed thermal buoyancy around bluff obstacles in cross-flow at low Reynolds numbers	Dipankar Chatterjee	Numerical Heat Transfer, Part A	2012, 61, pp. 800-806
63	Use of Fréchet distribution for UPV measurements in concrete	Abhijit Chatterjee, Anindya Chatterjee	NDT&E International	2012, 52, pp. 122-128
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66	An improved method of optimizing the extraction of polyphenol oxidase from potato (Solanum tuberosum L.) peel	Suprabhat Mukherjee, Bidyut Bandopadhyay, Bikram Basak, Nilrudra Mandal, Apurba Dey, Biswanath Mondal	Notulae Scientia Biologicae	2012, 4(1), pp. 98-107
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69	Combustible gases from thermal plasma treatment of plastic waste with special reference to mobile phone waste	Biswajit Ruj, J.S. Chang	International Journal of Plastics Technology	2012, 16(2), pp. 182-193
70	Development of Jal-Kavach - An endeavour to save the victims of boat capsize and floods	Sibnath Maity	BECA 1981	2012
71	Development of modular shallow water AUV: Issues & trial results	S.N. Shome, S. Nandy, D. Pal, S.K. Das, S.R.K. Vadali, Jhankar Basu, Sukamal Ghosh	Journal of The Institution of Engineers (India): Series C	2012, 93(3), pp. 217-228
72	Development of process for disposal of plastic waste using plasma pyrolysis technology and option for energy recovery	M. Punčochář, B. Ruj, P.K. Chatterjee	Procedia Engineering	2012, 42, pp. 420-430
73	Effect of flushing condition on deep hole micro-EDM drilling	Vijay Kumar Meena, Man Singh Azad, Souren Mitra	International Journal of Machining and Machinability of Materials	2012, 12(4), pp. 308-320
74	Effect of pouring temperature on cooling channel semi solid slurry generation process	Prosenjit Das, Sudip K. Samanta, Aditya K. Lohar, Himadri Chattopadhyay, Pradip Dutta	International Journal of Materials and Mechanics Engineering	2012, 1(1), pp. 11-15
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76	Effect of Y-doping on optical properties of multiferroics $BiFeO_3$ nanoparticles	A. Mukherjee, Sk. M. Hossain, M. Pal, S. Basu	Applied Nanoscience	2012, 2, pp. 305-310
77	Evaluation of air drying characteristics of sliced ginger (Zingiber officinale) in a forced convective cabinet dryer and thermal conductivity measurement	Chanchal Loha, Reeta Das, Biplab Choudhury, Pradip K. Chatterjee	Journal of Food Processing & Technology	2012, 3(6), DOI 10.4172/2157-7110.1000160
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80	Growth of time-dependent strain in reinforced cement concrete and prestressed concrete flexural members	Swarup Rn. Debbarma, S. Saha	International Journal of Concrete Structures & Materials	2012, 6(2), pp. 79-85
81	Identity, expression and age information using active appearance model features	N.S. Lakshmiprabha, J. Bhattacharya, S. Majumder	International Journal of Information Processing	2012, 6(2), p. 31
82	Implementation of serpentine locomotion	Atanu Maity, Somjyoti Majumder	International Journal of Intelligent Systems Technologies and Applications	2012, 11(1/2), pp. 81-101
83	Investigating the morphology of the proximal femur of the Indian population towards designing more suitable THR implants	Palash Kumar Maji, Amit Roychowdhury, Debasis Datta	Journal of Long-Term Effects of Medical Implants	2012, 22(1), pg 49-64
84	Kinematic navigation of modular robot	Dilip Kr Biswas, Subhasish Bhaumik, Jyotirmoy Saha	International Journal of Engineering and Innovative Technology	2012, 2(6), pp. 27-37
85	Lattice Boltzmann simulation of heat conduction problems in non-isothermally heated enclosures	Bittagopal Mondal, Dipankar Chatterjee	Heat Transfer–Asian Research	2012, 41(2), pp. 127-144
86	Machining Parameters optimization of developed Yttria stabilized Zirconia Toughened Alumina ceramic inserts while machining AISI 4340 steel	Nilrudra Mandal, B. Doloi, B. Mondal	International Journal of Mechanical and Industrial Engineering	2012, 6, pp. 159-169
87	Mechanical properties and Tensile fracture mechanism of Rheocast A356 Al alloy using Cooling Slope	Prosenjit Das, S.K. Samanta, Tapan Ray, B.R.K Venkatapathi	Advanced Materials Research	2012, 585, pp. 354-358
88	Morphometric analysis of the cervical spine of Indian population by using computerized tomography	Partha Sarathi Banerjee, Amit Roychoudhury, Santanu Kumar Karmakar	Journal of Medical & Allied Sciences	2012, 2(2), pp. 66-76
89	Multi response optimization of Nd: YAG laser welding process using Taguchi method based gray relation analysis	R.K. Padhi, A.J. Banerjee, A.B. Puri	Elixir Mechanical Engineering	2012, 47, pp. 8772-8777

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91	Nano-scale Metal-organic Frameworks (NMOFs)	Nivedita Sikdar, Priyabrata Banerjee, Tapas Kr. Maji	Nano Digest	2012, September, pp. 42-43
92	Nanosuspensions-The next generation Lubricants	R.R. Sahoo	Nano Digest	2012, September, pp. 38-40
93	Obstacle Avoidance and Navigation of Autonomous Mobile Robot	Rekha Raja, S N. Shome, S. Nandy, R. Ray	Advanced Materials Research	2012, 403-408, pp. 4633-4642
94	On the vortex shedding mechanism behind a circular cylinder subjected to cross buoyancy at low Reynolds numbers	Dipankar Chatterjee, Bittagopal Mondal	Computational Thermal Sciences	2012, 4(1), pp. 23-38
95	Optical and electrical properties of codoped nanocrystalline multiferroic $BiFeO_3$	A. Mukherjee, Sk. M. Houssain, S. Basu, M. Pal	Solid State Physics, AIP Conf. Proc. 1447	2012, pp. 315-316
96	Optimization of Growth parameters for Indigenous Algae for Production of Algal biodiesel	R. Karmakar, A. Roychowdhury, K. Kundu, A. Chattopadhyay	International Journal of Genetic Engineering and Biotechnology	2012, 3(1), pp. 1-13
97	Performance analysis of AODV and DSDV protocols using RPGM model for application in co-operative Ad-Hoc mobile robots	Rajesh P. Barnwal, Arnab Thakur	Springer Series on Advances in Intelligent Systems and Computing	2012, 176, pp. 641-649
98	Performance evaluation of Multi-Axis CNC machine tools by interferometry principle using laser calibration system	S. Barman, R. Sen	Journal of The Institution of Engineers (India): Series C	2012, 93(2), pp. 151-155
99	Review of Shape Memory Alloys applications in civil structures, and analysis for its potential as reinforcement in concrete flexural members	Swarup Rn. Debbarma, S. Saha	International Journal of Civil and Structural Engineering	2012, 2(3), pp. 915-933
100	Solar Power Tree – a new concept of harnessing solar power in a smaller space	S.N. Maity	Energy Blitz	2012, 1(V), pp. 6-14
101	Special theory of Relativity - a wrong concept of Einstein?	Sibnath Maity	Science India	2012, 15(8), pp. 25-31
102	Stiffness of concrete flexural members increases on use of shape memory alloy bars as reinforcement	S.R. Debbarma, S. Saha	Recent Trends in Civil Engineering and Technology	2012, 2(3), pp. 24-38

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103	Studies on processing and characterization of Hydroxyapatite Biomaterials from different Bio Wastes	Sudip Mondal, Biswanath Mondal, Apurba Dey, Sudit S. Mukhopadhyay	Journal of Minerals & Materials Characterization & Engineering	2012, 11(1), pp. 55-67
104	Synthesis of TiO_2 nanoparticles by hydrolysis and peptization of titanium isopropoxide solution	S. Mahata, S.S. Mahato, M.M. Nandi, B. Mondal	Functional Materials, AIP Conf. Proc. 1461	2012, pp. 225-228
105	Texture analysis of turned surface images using grey level co-occurrence technique	A. Datta, S. Dutta, S.K. Pal, R. Sen, S. Mukhopadhyay	Advanced Materials Research	2012, 365, pp. 38-43
106	Thermal plasma treatment of mobile phone waste under reduced condition	Biswajit Ruj	International Journal of Environmental Sciences	2012, 2(4), pp. 2400-2407
107	Towards dynamics and control of an Arm-Wheel based Autonomous Stair Climbing Robotic Vehicle	R. Ray, S. Nandy, S.N. Shome, S. Bhaumik	Advanced Materials Research	2012, 403-408, pp. 4743-4752
108	Trajectory based recovery of index finger articulated pose during palmar grasp	Avik Chatterjee, A. Mahapatra, S. Majumdar, I. Basak	International Journal of Computer Applications	2012, 49(14), pp. 6-12
109	Trends in nanotech research for biomedical applications	Nripen Chanda, Ravi Kumar Arun, Nagahanumaiah	Nanodigest	September, 2012, pp. 44-47

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1	A coupled level-set and volume-of-fluid method for the buoyant rise of gas bubbles in liquids	I. Chakraborty, Gautam Biswas, P.S. Ghoshdastidar	International Journal of Heat and Mass Transfer	2013, 58, pp. 240-259
2	A genetic fuzzy based modeling of effective thermal conductivity for polymer composites	Arup Kumar Nandi, Kalyanmoy Deb, Shubhabrata Datta, Juhani Orkas	Journal of Intelligent & Fuzzy Systems	2013, 25(2), pp. 259-270
3	A novel approach of manufacturing Nickel Wicks for loop heat pipes using Metal Injection Moulding (MIM)	S.K. Samanta, Prosenjit Das, A.K. Lohar, H. Roy, S. Kumar, A.K. Chowdhury	Sadhana	2013, 38(2), pp. 281-296
4	A numerical study of vortex shedding from a circular cylinder vibrating in the in-line direction	Satya Prakash Singh, Gautam Biswas, Perumal Nithiarasu	International Journal of Numerical Methods for Heat & Fluid Flow	2013, 23(8), pp. 1449-1462
5	A study of the counter rotating vortex rings interacting with the primary vortex ring in shock tube generated flows	T. Murugan, S. De, C.L. Dora, D. Das, P. Prem Kumar	Fluid Dynamics Research	2013, 45, article no: 25506
6	An approach towards the design and development of a flexible 5-DOF AUV	S.N. Shome, S. Nandy, S.K. Das, D. Pal, V. Kumar, D. Sen, Sukamal Ghosh	Indian Journal of Geo-marine Sciences	2013, 42(5), pp. 565-572
7	An overview of developments in adsorption refrigeration systems towards a sustainable way of cooling	Biplab Choudhury, Bidyut Baran Saha, Pradip K. Chatterjee, Jyoti Prakas Sarkar	Applied Energy	2013, 104, pp. 554-567
8	Assessing flowresponse of self-compacting mortar by Taguchi method and ANOVA interaction	Abhijit Chatterjee, Debashis Das	Materials Research	2013, 16(5), pp. 1084-1091
9	Assessment of micro turning machine stiffness response and material characteristics by fuzzy rule based pattern matching of cutting force plots	Soumen Mandal, Anirudh Kumar, Nagahanumaiah	Journal of Manufacturing Systems	2013, 32(1), pp. 228-237
10	Binding of aquo-ethylenediami netetraacetatoruthenium(III) to apo-transferrin. Fluorescence, antiproliferative and in silico studies	Debabrata Chatterjee, Jagadessh C. Bose, Sudit Mukhopadhyay	Inorganica Chimica Acta	2013, 404, pp. 1-4

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11	Bulk-phase thermodynamic properties and dielectric constant of ethanol: an ab initio quantum mechanical approach combined with a statistical model	Prasenjit Pandey, Tanmoy Chakraborty, Asok K. Mukherjee	Molecular Physics	2013, 111(20), pp. 3098-3130
12	Correlation study of tool flank wear with machined surface texture in end milling	S. Dutta, A. Kanwat, S.K. Pal, R. Sen	Measurement	2013, 46, pp. 4249-4260
13	Current status of electrostatic spraying technology for efficient crop protection	Manjeet Singh, C. Ghanshyam, Pramod Kumar Mishra, Rajesh Chak	AMA-Agricultural Mechanization in Asia Africa and Latin America	2013, 44(2), pp. 46-53
14	Design and control of an IPMC artificial muscle finger for micro gripper using EMG signal	R.K. Jain, S. Datta, S. Majumder	Mechatronics	2013, 23, pp. 381-394
15	Effect of ceria coating on corrosion behaviour of low alloy steel	D. Ghosh, A.K. Shukla, S.K. Mitra	Surface Engineering	2013, 29(8), pp. 584-587
16	Effect of Mn doping on microstructure and optical properties of nanocrystalline ZnO	M. Karmakar, O. Mondal, B. Roy, P.K. Pal, M. Pal	NANO	2013, 8(6), article no: 1350058
17	Effect of Ni-Co codoping on structure and electrical properties of multiferroic $BiFeO_3$ nanoparticles	Sk. M. Hossain, Ayan Mukherjee, Soumen Basu, Mrinal Pal	Micro and Nano Letters	2013, 8(7), pp. 374-377
18	Effects of different orientations of winglet arrays on the performance of plate-fin heat exchangers	Anupam Sinha, K. Ashoke Raman, Himadri Chattopadhyay, Gautam Biswas	International Journal of Heat and Mass Transfer	2013, 57(1), pp. 202-214
19	Effects of hybrid carbon fillers of polymer composite bipolar plates on the performance of direct methanol fuel cells	Joong Hee Lee, Jin-Sun Lee, Tapas Kuila, Nam Hoon Kim, Daeseung Jung	Composites: Part B	2013, 51, pp. 98-105
20	Effects of reduction and polystyrene sulfate functionalization on the capacitive behaviour of thermally exfoliated graphene	Yinan Yan, Tapas Kuila, Nam Hoon Kim, Bon-Cheol Ku, Joong Hee Lee	Journal of Materials Chemistry A	2013, 1(19), pp. 5892-5901
21	Effects of sodium hydroxide on the yield and electrochemical performance of sulfonated poly (ether-ether-ketone) functionalized graphene	Tapas Kuila, Partha Khanra, Nam Hoon Kim, Jae Kyoo Lim, Joong Hee Lee	Journal of Materials Chemistry A	2013, 1(32), pp. 9294-9302

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23	Efficient reduction of graphene oxide using Tin-powder and its electrochemical performances for use as an energy storage electrode material	Nam Hoon Kim, Partha Khanra, Tapas Kuila, Daeseung Jung, Joong Hee Lee	Journal of Materials Chemistry A	2013, 1(37), pp. 11320-11328
24	Electrostatically assembled layer-by-layer composites containing graphene oxide for enhanced hydrogen gas barrier application	Rathanasamy Rajasekar, Nam Hoon Kim, Daeseung Jung, Tapas Kuila, Jae Kyoo Lim, Min Jeong Park, Joong Hee Lee	Composites Science and Technology	2013, 86, pp. 167-174
25	Energy generation from fluidized bed gasification of rice husk	Chanchal Loha, Himadri Chattopadhyay, Pradip K. Chatterjee	Journal of Renewable and Sustainable Energy	2013, 5, article no: 043111
26	Enhanced mechanical properties of silanized silica nanoparticle attached graphene oxide/epoxy composites	Tongwu Jiang, Tapas Kuila, Nam Hoon Kim, Bon-Cheol Ku, Joong Hee Lee	Composites Science and Technology	2013, 79, pp. 115-125
27	Enzymatic hydrolysis of water hyacinth biomass for the production of ethanol: Optimization of driving parameters	A. Ganguly, S. Das, A. Bhattacharya, A. Dey, P.K. Chatterjee	Indian Journal of Experimental Biology	2013, 51(7), pp. 556-566
28	Euler-Euler CFD modeling of fluidized bed: Influence of specularity coefficient on hydrodynamic behavior	Chanchal Loha, Himadri Chattopadhyay, Pradip K. Chatterjee	Particuology	2013, 11, pp. 673-680
29	Eulerian two-phase flow simulation and experimental validation of semisolid slurry generation process using cooling slope	P. Das, S.K. Samanta, H. Chattopadhyay, B.B. Sharma, P. Dutta	Materials Science and Technology	2013, 29(1), pp. 83-92
30	Evaluation of primary phase morphology of cooling slop cast Al-Si-Mg alloy samples using image texture analysis	Prosenjit Das, Samik Dutta, Sudip K. Samanta	Proceeding of Institution of Mechanical Engineers Part B: Journal of Engineering Manufacture	2013, 227(10), pp. 1474-1483
31	Evolution of microstructures during austempering of ductile irons alloyed with manganese and copper	Ranjan Kumar Dasgupta, Dipak Kumar Mondal, Ajit Kumar Chakrabarti	Metallurgical and Materials Transactions A-Physical Metallurgy and Materials Science	2013, 44A(3), pp. 1376-1387

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33	Failure analysis of a head gear pulley used in coal mines	A.K. Shukla, P. Das, S. Dutta, S. Ray, H. Roy	Engineering Failure Analysis	2013, 31, pp. 48-58
34	Fiber Bragg grating sensor for temperature measurement in micro turning of optical surfaces with high surface integrity	Soumen Mandal, Vinod Mishra, Umesh Tiwari, Nagahanumaiah, Rama Gopal Sarepaka	International Journal of Optomechatronics	2013, 7(4), pp. 244-252
35	Gadolinium substitution induced defect restructuring in multiferroic $BiFeO_3$: case study by positron annihilation spectroscopy	A. Mukherjee, M. Banerjee, S. Basu, P.M.G. Nambissan, M. Pal	Journal of Physics D–Applied Physics	2013, 46(49), article no: 495309
36	Genetic algorithm-based design and development of particle-Reinforced silicone rubber for soft tooling process	A.K. Nandi, K. Deb, S. Datta	Materials and Manufacturing Processes	2013, 28(7), pp. 753-760
37	Improved and unusual magnetic properties of ZnO nanorings	Oindrila Mondal, Nguyen T.K. Thanh, Luke A.W. Green, Mrinal Pal	Functional Materials Letters	2013, 6(4), article no: 1350049
38	Influence of CeO_2 superficial coating on the high temperature corrosion behaviour of 2.25 Cr-1 Mo steel in SO_2+O_2 atmospheres	D. Ghosh, A.K. Shukla, S.K. Mitra	Protection of Metals and Physical Chemistry of Surfaces	2013, 49(6), pp. 749-752
39	Investigation of fuel gas generation in a pilot scale fluidized bed autothermal gasifier using rice husk	M.K. Karmakar, J. Mandal, S. Haldar, P.K. Chatterjee	Fuel	2013, 111, pp. 584-591
40	Investigation on bacterial adhesion and colonisation resistance over laser machined micro patterned surfaces	Aneissha Chebolu, Bhakti Laha, Monidipa Ghosh, Nagahanumaiah	Micro and Nano Letters	2013, 8(6), pp. 280-283
41	Investigations on influence of process variables on crater dimensions in micro-EDM of γ-titanium aluminide alloy in dry and oil dielectric media	G. Paul, S. Roy, S. Sarkar, Nagahanumaiah, S. Mitra	The International Journal of Advanced Manufacturing Technology	2013, 65(5-8), pp. 1009-1017
42	Investigations on the kinetics and thermodynamics of dilute acid hydrolysis of Parthenium Hysterophorus L. substrate	Swati Ghosh, S. Haldar, A. Ganguly, P.K. Chatterjee	Chemical Engineering Journal	2013, 229, pp. 111-117

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44	Magnetoconvective transport in a vertical lid-driven cavity including a heat conducting square cylinder with Joule heating	Dipankar Chatterjee, Pabitra Halder, Sinchan Mondal, Supratim Bhattacharjee	Numerical Heat Transfer, Part A	2013, 64, pp. 1050-1071
45	Mechanism of accelerated spheroidization of steel during cyclic heat treatment around the upper critical temperature	Joydeep Maity, Atanu Saha, Dipak Kumar Mondal, Koushik Biswas	Philosophical Magazine Letters	2013, 93(4), pp. 231-237
46	MHD mixed convection in a lid-driven cavity including a heated source	Dipankar Chatterjee	Numerical Heat Transfer, Part A	2013, 64, pp. 235-254
47	Minimizing Stress Shielding Effect of Femoral Stem—A Review	Palash Kumar Maji, Amit Roychowdhury, Debasis Datta	Journal of Medical Imaging and Health Informatics	2013, 3(2), pp. 171-178
48	Mixed convection heat transfer from tandem square cylinders for various gap to size ratios	Dipankar Chatterjee, Bittagopal Mondal	Numerical Heat Transfer, Part A	2013, 63(2), pp. 101-119
49	Mixed convection heat transfer past in-line square cylinders in a vertical duct	Dipankar Chatterjee, Md. Raja	Thermal Science	2013, 17, pp. 567-580
50	Nanomaterial process using self-assembly bottom-up chemical and biological approaches	R. Thiruvengadathan, V. Korampally, Arkasubhra Ghosh, Nripen Chanda, Keshab Gangopadhyay, Shubhra Gangopadhyay	Reports on Progress in Physics	2013, 76, article no: 66501
51	Nonlinear amplification in electrokinetic pumping in nanochannels in the presence of hydrophobic interactions	Suman Chakraborty, Dipankar Chatterjee, Chirodeep Bakli	Physical Review Letters	2013, 110, article no: 184503
52	Numerical simulation of shock–vortex interaction in Schardin's problem	P. Halder, S. De, K.P. Sinhamahapatra, N. Singh	Shock Waves	2013, 23(5), pp. 495-504
53	One-step electrochemical synthesis of 6-amino-4-hydroxy-2-napthalene-sulfonic acid functionalized graphene for green energy storage electrode materials	Tapas Kuila, Partha Khanra, Nam Hoon Kim, Sung Kuk Choi, Hyung Joong Yun, Joong Hee Lee	Nanotechnology	2013, 24(36), article no: 365706
54	Online monitoring of transformers using gas sensor fabricated by nanotechnology	Anjali Chatterjee, Rajat Sarkar, Nirmal K. Roy, P. Kumbhakar	International Transactions on Electrical Energy Systems	2013, 23(6), pp. 867-875

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56	Oxidation of thiocyanate with H_2O_2 catalyzed by [Ru-III(edta)(H_2O)](-)	Debabrata Chatterjee, Barnali Paul, Rupa Mukherjee	Dalton Transactions	2013, 42(27), pp. 10056-10060
57	Potential use of polyphenol oxidases (PPO) in the bioremediation of phenolic contaminants containing industrial wastewater	Suprabhat Mukherjee, Bikram Basak, Biswanath Bhunia, Apurba Dey, Biswanath Mondal	Reviews in Environmental Science and Bio-Technology	2013, 12(1), pp. 61-73
58	Power electronics interface for energy management in battery ultracapacitor hybrid energy storage system	Sumit Kumar, H.P. Ikkurti	Electric Power Components and Systems	2013, 41(11), pp. 1059-1074
59	Predictive modelling of surface roughness in high speed machining of AISI 4340 steel using Yttria stabilized Zirconia Toughened Alumina turning insert	Nilrudra Mandal, B. Doloi, B. Mondal	International Journal of Refractory Metals and Hard Materials	2013, 38, pp. 40-46
60	Preparation of polystyrene-clay nanocomposite by solution intercalation technique	P.K. Paul, S.A. Hussain, D. Bhatterjee, M. Pal	Bulletin of Materials Science	2013, 36(3), pp. 361-366
61	Preparation of sulfonated poly (ether-ether-ketone) functionalized ternary graphene/AuNPs/chitosan nanocomposite for efficient glucose biosensor	Jay Singh, Partha Khanra, Tapas Kuila, Manish Srivastava, Ashok K. Das, Nam Hoon Kim, Bong Joo Jung, Da Yeong Kim, Seung Hee Lee, Dong Won Lee, Dae-Ghon Kim, Joong Hee Lee	Process Biochemistry	2013, 48(11), pp. 1724-1735
62	Progress cutting tool wear detection from machined surface images using Voronoi tessellation method	A. Dutta, S. Dutta, S.K. Pal, R. Sen	Journal of Materials Processing Technology	2013, 213(12), pp. 2339-2349
63	Review on Parthenium Hysterphorus as a potential energy source	Swati Ghosh, S. Haldar, A. Ganguly, P.K. Chatterjee	Renewable & Sustainable Energy Reviews	2013, 20, pp. 420-429
64	SCARA based peg-in-hole assembly using compliant IPMC micro gripper	R.K. Jain, S. Majumder, A. Dutta	Robotics and Autonomous Systems	2013, 61(3), pp. 297-311

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66	Self organised pathways to nanopatterns exploiting the instabilities of ultrathin confined bilayers	Abhiram Hens, Kartick Mondal, Dipankar Bandyopadhyay	Physical Review E	2013, 87(2), article no: 22405
67	Self oscillating potential generated in patterned micro-fluidic fuel cell	Ravi K.Arun, Wasihun Bekele, Animangsu Ghatak	Electrochimica Acta	2013, 87, pp. 489-496
68	Structural variations ahead of crack tip during monotonic and cyclic fracture tests of AISI 304LN stainless steel	H. Roy, A. Ray, K. Barat, C. Hochmuth, S. Sivaprasad, S. Tarafder, U. Glatzel, K.K. Ray	Materials Science & Engineering A	2013, 561, pp. 88-99
69	Study of physical characteristics of nickel wicks developed by metal injection moulding	S.K. Samanta, P. Das, A.K. Lohar	Powder Metallurgy	2013, 56(3), pp. 221-230
70	Study on a solar heat driven dual-mode adsorption chiller	Khairul Habib, Biplab Choudhury, Pradip Kumar Chatterjee, Bidyut Baran Saha	Energy	2013, 63, pp. 133-141
71	Substrate versus oxidant activation in Ru-III(edta) catalyzed dye degradation	Debabrata Chatterjee, Sabine Rothbart, Rudi van Eldik	RSC Advances	2013, 3(11), pp. 3606-3610
72	Synthesis, characterization, structure and dual room-temperature fluorescent and phosphorescent emission in mu-oxalato-bridged rhenium(I) metallacycle	D. Bhattacharya	Inorganic Chemistry Communications	2013, 36, pp. 159-162
73	Ultrafine narrow dispersed copper nanoparticles synthesized by a facile chemical reduction method	O. Mondal, A. Datta, D. Chakravorty, M. Pal	MRS Communication	2013, 3, pp. 91-95
74	Unsteady forced convection heat transfer over a semicircular cylinder at low Reynolds numbers	Dipankar Chatterjee, Bittagopal Mondal, Pabitra Halder	Numerical Heat Transfer, Part A	2013, 63, pp. 411-429
75	Unsteady mixed convection heat transfer from tandem square cylinders in cross flow at low Reynolds numbers	Dipankar Chatterjee, Bittagopal Mondal	Heat and Mass Transfer	2013, 49, pp. 907-920

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76	Unusual and strong emission in visible region from Mn^{2+} and Y^{3+} doped ZnO nanocrystals	Oindrila Mondal, Mrinal Pal	Optical Materials	2013, 35, pp. 1520-1525
77	Usage of nanotechnology based gas sensor for health assessment and maintenance of transformers by DGA method	Anjali Chatterjee, Partha Bhattacharjee, N.K. Roy, P. Kumbhakar	Electrical Power and Energy Systems	2013, 45(1), pp. 137-141
78	Variant of a volume-of-fluid method for surface tension-dominant two-phase flows	G. Biswas	Sadhana–Academy Proceedings in Engineering Sciences	2013, 38(6), pp. 1127-1133
79	Vortex induced vibrations of a square cylinder at subcritical Reynolds numbers	S.P. Singh, G. Biswas	Journal of Fluids and Structures	2013, 41, pp. 146-155
80	Web pillar design approach for highwall mining extraction	John L. Porathur, S. Karekal, P. Pal Roy	International Journal of Rock Mechanics and Mining Sciences	2013, 64, pp. 73-83
81	3D CAD for concept design – a case study	S.K. Mandal, P.K. Maji, S. Karmakar	Scientific Journal of Pure and Applied Sciences	2013, 2(6), pp. 254-259
82	A proposed statistical procedure for assessment of strength of control from low sample size using Monte Carlo Simulation	Debashis Das, Abhijit Chatterjee	International Journal of Engineering Science and Innovative Technology	2013, 2(4), pp. 195-207
83	A review on developments of thermoelectric refrigeration and air conditioning system: A novel potential green refrigeration and air conditioning technology	M.K. Rawat, H. Chattopadhyay, S. Neogi	International Journal of Emerging Technology and Advanced Engineering	2013, 3(3), pp. 362-367
84	Actuation and sensing studies of a miniaturized five fingered robotic hand made with Ion Polymeric Metal Composite (IPMC)	Debabrata Chatterjee, Nagahanumaiah, Yousef Bahramzadeh, Mohsen Shahinpoor	Advanced Materials Research: Materials, Mechatronics and Automation- II	2013, 740, pp. 492-495
85	Agricultural vehicles with automatic navigation	Subrata Kr. Mandal, Atanu Maity, D.N. Ray, S. Majumder	International Journal of Current Engineering Sciences	2013, 3(11), pp. 15-19
86	An experience in testing mechanical properties of self compacting concrete (SCC)	Debasis Das, Abhijit Chatterjee	Civil Engineering & Construction Review	2013, 26(4), pp. 72-75

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87	An investigation of daylight performance and energy saving in foundry shed and staircase building	S.R. Debbarma, S. Kundu, V. Vineet	International Journal of Engineering and Innovative Technology	2013, 3(3), pp. 397-401
88	An investigation on performance characteristics of radial in-flow turbo-expander with backswept curved rotor	Lal Gopal Das, Pranab Samanta, Naresh Chandra Murmu	International Journal of Engineering Research and Applications	2013, 3(5), pp. 229-234
89	Application of digital image processing in tool condition monitoring: A review	S. Dutta, S.K. Pal, S. Mukhopadhyay, R. Sen	CIRP Journal of Manufacturing Science and Technology	2013, 6, pp. 212-232
90	Applications of laser in agriculture: A critical review	Subrata Kr. Mandal, A. Maity	Elixir Mechanical Engineering	2013, 60, pp. 18740-18745
91	Austempered ductile iron material for the design of agricultural machinery	Subrata Kr. Mandal, Atanu Maity	Elixir Mechanical Engineering	2013, 60, pp. 16140-16145
92	Biodiesel plant design for rural application	O.P. Chaturvedi, S. Mande, P. Rajan, K. Kundu	Zenith International Journal of Multidisciplinary Research	2013, 3(9), pp. 46-52
93	Bio-essential anions from solution to nanomaterial	Additi Roychowdhury, N.C. Murmu, Priyabrata Banerjee	Nano Digest	2013, November, pp. 24-26
94	Compensating joint configuration through null space control in composite weighted least norm solution	A. Chatterjee, S. Majumder, I. Basak	International Journal of Robotics and Automation	2013, 4(1), pp. 31-43
95	Construction of low budget road using steel industries waste like blast furnace slag boulders and fly ash	S.R. Debbarma	International Journal of Engineering Research and Industrial Application	2013, 6(1), pp. 141-150
96	Continuous and discrete time domain stability analysis of composite weighted least norm solution in redundancy resolution	A. Chatterjee, S. Majumder, I. Basak	International Journal of Computer Applications	2013, 67(21), pp. 31-38
97	Deep drawing behaviour of CRCA sheet and wrinkling congestion of round flange cup	R. Singh	Journal of Manufacturing Engineering	2013, 8(2), pp. 92-95
98	Deformation fatigue and fracture vis-à-vis deformation induced martensite in AISI 304LN stainless steel	Kalyan Kumar Ray, Himadri Roy, Ayan Ray, Krishna Dutta, Soumitra Tarafder	Advanced Materials Research	2013, 794, pp. 415-428

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99	Design & development of rotavator blade: Interrogation of CAD method	Subrata Kr. Mandal, Basudeb Bhattacharyya, Somenath Mukherjee, P. Chattopadhyay	International Journal of Scientific Research in Knowledge	2013, 1(10), pp. 439-447
100	Design of a typical Autogenous Mill: Part-I	Subrata Kr. Mandal, S.M. Sutar, Atanu Maity	Elixir Mechanical Engineering	2013, 65, pp. 20145-20149
101	Design of a typical Autogenous Mill: Part-II	Subrata Kr. Mandal, S.M. Sutar, Atanu Maity	Elixir Mechanical Engineering	2013, 65, pp. 20150-20153
102	Design of C-Band high speed pulsed power amplifier for pulsed RADAR applications	Santu K. Giri, Saikat K. Shome, Amit K. Ball	International Journal of Electronics and Electrical Engineering	2013, 1(2), pp. 61-65
103	Design optimization of rotary tiller blades: a critical review	S.K. Mandal, B. Bhattacharyya, S. Mukherjee	Scientific Journal of Pure and Applied Sciences	2013, 2(6), pp. 260-269
104	Development of nanofluids as lubricant to study friction and wear behaviour of stainless steels	Rashmi R. Sahoo, Santu Bhattacharjee, Tuhin Das	International Journal of Modern Physics: Conference Series	2013, 22, pp. 664-669
105	Development of a pantograph based micro-machine for nano-scratching, production engineering research and development	S.K. Singh, A. Chebolu, S. Mandal, Nagahanumaiah	Production Engineering Research and Development	2013, 7, pp. 517-525
106	Development of a solar powered adsorption chiller	D. Sarkar, S.N. Tiwari, A. Yadav, B. Choudhury	International Journal of Emerging Technology and Advanced Engineering	2013, 3(3), pp. 382-388
107	Development of animal drawn planting equipment	Subrata Kr. Mandal, S.M. Sutar, S. Sensharma, Shamrao Parate	Journal of Mechanical Engineering: Photon	2013, 123, pp. 146-152
108	Developmental and experimental study of solar powered thermoelectric refrigeration system	Manoj Kumar Rawat, Prasanta Kumar Sen, Himadri Chattopadhyay, Subhasis Neogi	International Journal of Engineering Research and Applications	2013, 3(4), pp. 2543-2547
109	Effect of nozzle velocity, nozzle angle and standoff distance on the dredge output during placer mining	P.K. Sen, L.G. Das, B. Haldar, M. Sundarrajan, P.K. Chatterjee	IOSR Journal of Applied Geology and Geophysics	2013, X(X), pp. 1-5
110	Effect of process parameters for standardization of esterification of cottonseed oil for production of biodiesel	R.K. Pandey, A. Rai, K. Kundu, R. Karmakar, A. Roychowdhury, V.R. Dahake	International Journal of Current Science	2013, 8(E), pp. 74-78

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111	Effect of Yttria on the synthesis, microstructure and mechanical properties of partially stabilized Zirconia in α-Al_2O_3 matrix	N. Mandal, B. Mondal, B. Doloi, D. Sengupta	International Journal of Advanced Materials Manufacturing & Characterization	2013, 3(1), pp. 137-142
112	Enhanced multiferroic properties of nanocrystalline La-doped $BiFeO_3$	Sk. M. Hossain, A. Mukherjee, S. Chakraborty, S.M. Yusuf, S. Basu, M. Pal	Materials Focus	2013, 2(2), pp. 1-7
113	Ethanolysis of Jatropha oil and process optimization	O.P. Chaturvedi, S. Mande, Y.P. Abbi, K. Kundu	International Journal of Recent Scientific Research	2013, 4(6), pp. 1005-1010
114	FPGA Based memory-less phase generation for butterfly operation of CORDIC FFT processor	Saikat Kumar Shome, Santu Kumar Giri, Uma Datta	International Journal of Computer and Electrical Engineering	2013, 5(5), pp. 528-532
115	Fracture toughness measurement of hot pressed ZrB_2-$MoSi_2$ composite	Manab Mallik, Saikat Pan, Himadri Roy	International Journal of Current Engineering and Technology	2013, 3(5), pp. 1647-1652
116	Methanolysis and ethanolysis of raw hemp oil: Biodiesel production and fuel characterization	S.S. Ragit, S.K. Mohapatra, K. Kundu, R. Karmakar	International Journal of Engineering Research & Technology	2013, 2(3) pp. 1-10
117	Modeling and simulation of wave gait of a hexapod walking robot: A CAD/CAE approach	A. Mahapatra, S.S. Roy, D.K. Pratihar	International Journal of Robotics and Automation	2013, 2(3), pp. 104-111
118	Ni-substitution induced inversion in $ZnFe_2O_4$ seen by positron annihilation	P.M.G. Nambissan, O. Mondal, S. Chakrabarty, M. Pal	Material Science Forum	2013, 733, pp. 219-223
119	Optimization of pongamia methyl ester from transesterification process and fuel characterization as diesel substitute	V.P. Sitaram, S.K. Mohapatra, K. Kundu	Zenith International Journal of Multidisciplinary Research	2013, 3(6), pp. 130-140
120	Optimizing the compression ratio of compression ignition engine fuelled with esters of crude rice bran oil	M. Vasudeva, S. Sharma, S.K. Mohapatra, K. Kundu	International Journal on Theoretical and Applied Research in Mechanical Engineering	2013, 2(3), pp. 131-134
121	Performance and emission study of Indian brown hemp oil methyl ester in a 4 stroke, single cylinder water cooled diesel engine	S.S. Ragit, S.K. Mohapatra, K. Kundu, G.J.V. Patil	International Journal of Engineering Research and Technology	2013, 6(5), pp. 15-19
122	Performance evaluation of Innovative Pulse Thresher	Subrata Kr Mandal, Binod Kr Saha, Gopalbhai Suratia	International Journal of Agronomy and Plant Production	2013, 4(S), pp. 3605-3609

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123	Precision farming for small agricultural farm: Indian Scenario	S.K. Mandal, A. Maity	American Journal of Experimental Agriculture	2013, 3(1), pp. 200-217
124	Production of biodiesel from mixed algal culture and its fuel characterization	R.K. Pandey, K. Kundu, V. Prakash, H. Bhaskar, R. Karmakar, V.R. Dahake	International Journal of Recent Scientific Research	2013, 4(6), pp. 794-797
125	Production of bioethanol from mango peel	N.K. Walia, S.S. Bedi, K. Kundu, R. Karmakar	International Journal of Engineering Research & Technology	2013, 2(1), pp. 1-7
126	Production of Ethyl Levulinate (an additive to biodiesel) using paper waste	Shalika Devi, Himanshu Bhaskar, Krishnendu Kundu, V.R. Dahake	International Journal of Current Engineering and Technology	2013, 3(2), pp. 672-676
127	Rapid product development – a case study	Subrata Kr. Mandal, P.K. Maji, A.K. Prasad, S.M. Sutar	Elixir Mechanical Engineering	2013, 62, pp. 17469-17472
128	Resource utilization of multi-hop CDMA wireless sensor networks with Efficient Forwarding Protocols	U. Datta, A. Mukherjee, P.K. Sahu, S. Kundu	Journal of Procedia Engineering	2013, 64, pp. 46-55
129	Rheological characterization of semi-solid A356 Aluminium alloy	P. Das, S.K. Samanta, H. Chattopadhyay, P. Dutta, N. Barman	Solid State Phenomena	2013, 192-193, pp. 329-334
130	Smart Materials – scope and prospects	Subrata Kr. Mandal, Atanu Maity, Dip Narayan Ray	Elixir Mechanical Engineering	2013, 65, pp. 20154-20163
131	Static analysis of simply supported plate	Subrata Kr. Mandal, S.Y. Pujar	Elixir Mechanical Engineering	2013, 61, pp. 16735-16739
132	Studies on rheocasting using cooling slope	P. Das, S.K. Samanta, H. Chattopadhyay, P. Dutta	Solid State Phenomena	2013, 192-193, pp. 341-346
133	Taguchi and ANOVA approach for optimisation of flow characteristics of self compacting concrete	Debashis Das, Abhijit Chatterjee	Emerging Materials Research	2013, 3(1), pp. 37-45
134	The characteristics of a vertical submersible slurry pump in transporting dredged slurry	P.K. Sen, L.G. Das, B. Halder	International Journal of Engineering Research and Applications	2013, 3(1), pp. 516-522

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135	Trajectory following control of AUV: A robust approach	S. Roy, S.N. Shome, S. Nandy, R. Ray, V. Kumar	Journal of The Institution of Engineers (India): Series C	2013, 94(3), pp. 253-265
136	Unconfined flow and heat transfer around a square cylinder at low Reynolds and Hartmann numbers	D. Chatterjee, K. Chatterjee	International Journal of Fluid Mechanics Research	2013, 40, pp. 71-90
137	Wall-bounded flow and heat transfer around a circular cylinder at low Reynolds and Hartmann numbers	D. Chatterjee, K. Chatterjee	Heat Transfer—Asian Research	2013, 42(2), pp. 133-150

Journal Publications: 2014 (Upto March)

Sl.	Title	Authors	Journal	Details
1	7,7,8,8-Tetracyanoquinodimethane-assisted one step electrochemical exfoliation of graphite and its performance as an electrode material	Partha Khanra, Chang-No Lee, Tapas Kuila, Nam Hoon Kim, Min Jun Park, Joong Hee Lee	Nanoscale	2014, 6(9), pp. 4864-4873
2	A paper based self-pumping and self-breathing fuel cell using pencil stroked graphite electrodes	Ravi Kumar Arun, Saurav Halder, Nripen Chanda, Suman Chakraborty	Lab on a Chip	2014, 14, pp. 1661-1664
3	A review on amperometric-type immunosensors based on screen-printed electrodes	Kalyan Kumar Mistry, Keya Layek, Abhijit Mahapatra, Chirasree Roy Chaudhuri, Hiranmay Saha	Analyst	2014, 139, pp. 2289-2311
4	Acetone and ethanol sensing of barium hexaferrite particles: A case study considering the possibilities of non-conventional hexaferrite sensor	M. Karmakar, B. Mondal, M. Pal, K. Mukherjee	Sensors and Actuators B: Chemical	2014, 190, pp. 627-633
5	Assessment of thermally induced shear stress and its effect on pattern waviness in CO_2 laser ablation of birefringent polymers	S. Mandal, Nagahanumaiah	Proceedings of the Institution of Mechanical Engineers Part E–Journal of Process Mechanical Engineering	2014, 228(2), pp. 97-103
6	Behaviour of concrete beams reinforced with SMA and steel bars under cyclic and monotonic load	Swarup R. Debbarma, Showmen Saha	Magazine of Concrete Research	2014, 66(6), pp. 305-314
7	Bio-reduction of graphene oxide using drained water from soaked mung beans (Phaseolus aureus L.) and its application as energy storage electrode material	Milan Jana, Sanjit Saha, Partha Khanra, Naresh Chandra Murmu, Suneel Kumar Srivastava, Tapas Kuila, Joong Hee Lee	Materials Science and Engineering B	2014, 186, pp. 33-40
8	Characterization of micrographs and fractographs of Cu-strengthened HSLA steel using image texture analysis	Samik Dutta, Kaustav Barat, Arpan Das, Swapan Kumar Das, A.K. Shukla, Himadri Roy	Measurement	2014, 47, pp. 130-144

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9	Control of flow separation around bluff obstacles by superimposed thermal buoyancy	Dipankar Chatterjee, Bittagopal Mondal	International Journal of Heat and Mass Transfer	2014, 72, pp. 128-138
10	Covalent surface modification of chemically derived graphene and its application as supercapacitor electrode material	Milan Jana, Partha Khanra, Naresh Chandra Murmu, Pranab Samanta, Joong Hee Lee, Tapas Kuila	Physical Chemistry Chemical Physics	2014, 16, pp. 7618-7626
11	Development of Ce-PSZ-/Y-PSZ-Toughened Alumina inserts for high-speed machining steel	Biswanath Mondal, Nilrudra Mandal, Biswanath Doloi	International Journal of Applied Ceramic Technology	2014, 11(2), pp. 228-239
12	Development of multi micro manipulation system using IPMC micro grippers	R.K. Jain, S. Datta, S. Majumder, A. Dutta	Journal of Intelligent & Robotic Systems	2014, 74(3), pp. 547-569
13	Effect of layered MoS_2 nanoparticles on the frictional behavior and microstructure of lubricating greases	R.R. Sahoo, S.K. Biswas	Tribology Letters	2014, 53, pp. 157-171
14	Effects of acid vapour mediated oxidization on the electrochemical performance of thermally exfoliated graphene	Yinan Yan, Tapas Kuila, Nam Hoon Kim, Joong Hee Lee	Carbon	2014, 74, pp. 195-206
15	Enhanced mechanical properties of a multiwall carbon nanotube attached pre-stitched graphene oxide filled linear low density polyethylene composite	Nam Hoon Kim, Tapas Kuila, Joong Hee Lee	Journal of Materials Chemistry A	2014, 2, pp. 2681-2689
16	Enhanced properties of aryl diazonium salt-functionalized graphene/poly (vinyl alcohol) composites	Dong Sheng Yu, Tapas Kuila, Nam Hoon Kim, Joong Hee Lee	Chemical Engineering Journal	2014, 245, pp. 311-322
17	Enhancement of multiferroic properties of nanocrystalline $BiFeO_3$ powder by Gd-doping	A. Mukherjee, S. Basu, P.K. Manna, S.M. Yusuf, M. Pal	Journal of Alloys and Compounds	2014, 598, pp. 142-150
18	Hydromagnetic mixed convective transport in a vertical lid-driven cavity including a heat conducting rotating circular cylinder	Dipankar Chatterjee, Bittagopal Mondal, Pabitra Halder	Numerical Heat Transfer A	2014, 65(1), pp. 48-65
19	Impact of transverse shear on vortex induced vibrations of a circular cylinder at low Reynolds numbers	Satya Prakash Singh, Dipankar Chatterjee	Computers and Fluids	2014, 93, pp. 61-73

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20	Low temperature tensile deformation and acoustic emission signal characteristics of AISI 304LN stainless steel	K. Barat, H.N. Bar, D. Mandal, H. Roy, S. Sivaprasad, S. Tarafder	Materials Science & Engineering A	2014, 597, pp. 37-45
21	Mechanism of the oxidation of thiosulfate with hydrogen paeroxide catalyzed by aqua-ethylenediaminetetr aacetatoruthenium (III)	Debabrata Chatterjee, S. Shome, N. Jaiswal, S.C. Moi	Journal of Molecular Catalysis A: Chemical	2014, 386, pp. 1-4
22	MHD mixed convective transport in a square enclosure with two rotating circular cylinders	D. Chatterjee, P. Halder	Numerical Heat Transfer, Part A	2014, 65, pp. 802-824
23	Nano-scale study of boiling and evaporation in a liquid Ar film on Pt-heater using molecular dynamics simulation	Abhiram Hens, Rahul Agarwal, Gautam Biswas	International Journal of Heat and Mass Transfer	2014, 71, pp. 303-312
24	Phase field simulation of equiaxed microstructure formation during semi-solid processing of A380 Al alloy	Prosenjit Das, Sudip Kumar Samanta, Pramod Kumar, Pradip Dutta	ISIJ International	2014, 54(7), pp. 1601-1610
25	RuIII(edta) mediated oxidation of azide in presence of hydrogen peroxide. Azide versus peroxide activation	Debabrata Chatterjee, A. Franke, M. Oszajca, Rudi van Eldik	Dalton Transactions	2014, 43, pp. 3087-3094
26	Simultaneous reduction, exfoliation, and nitrogen doping of graphene oxide via a hydrothermal reaction for energy storage electrode materials	Hang Zhang, Tapas Kuila, Nam Hoon Kim, Dong Sheng Yu, Joong Hee Lee	Carbon	2014, 69, pp. 66-78
27	Three dimensional kinetic modeling of fluidized bed biomass gasification	Chanchal Loha, Himadri Chattopadhyay, Pradip K. Chatterjee	Chemical Engineering Science	2014, 109, pp. 53-64
28	Underwater Terrain Mapping with a 5-DOF AUV	Shikha, S.K. Das, D. Pal, S. Nandy, S.N. Shome, Soma Banerjee	Indian Journal of Geo-Marine Sciences	2014, 43(1), pp. 106-110
29	A paradigm shift in nano-composite functional material world	Priyabrata Banerjee, Pritam Ghosh, Sourav Kr. Saha	Nano Digest	2014, January, pp. 26-29
30	Cluster Analysis of Osteological parameters of femur in standardizing its stem size for Indian population	Palash Kumar Maji, Debasis Datta	Indian Journal of Biomechanics	2014, 4(1), pp. 5257

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31	Comparative studies on performance characteristics of CI engine fuelled with Neem methyl ester and Mahua methyl ester and its respective blends with diesel fuel	S.S. Ragit, S.K. Mohapatra, K. Kundu	Journal of Environmental Science and Engineering	2014, 56(1), pp. 73-78
32	Failure investigation of high temperature stud	D. Ghosh, S. Ray, H. Roy	Journal of Failure Analysis and Prevention	2014, 14(1), pp. 17-20
33	Failure of a secondary superheater tube in a 140-MW thermal power plant	Atanu Saha, A.K. Shukla	Journal of Failure Analysis and Prevention	2014, 14(1), pp. 10-12
34	Fatigue life prediction of a hoop-wrapped composite CNG cylinder containing surface flaw	A.K. Agrawal, S. Kumar	International Journal of Emerging Technology and Advanced Engineering	2014, 4(3), pp. 790-796
35	Residual jerk reduction in precision positioning stages using sliding micro step based switching	S. Mandal, S.K. Singh, S. Mandal, A. Kumar, Nagahanumaiah	Journal of Control, Automation and Electrical Systems	2014, 25(3), pp. 311-318
36	Superlens based nano scale imaging	S. Mandal	IEEE Potentials	2014, 33(2), pp. 17-20
37	Wall confined flow and heat transfer around a square cylinder at low Reynolds and Hartmann numbers	D. Chatterjee, K. Chatterjee, B. Mondal, N.B. Hui	Heat Transfer—Asian Research	2014, 43(5), pp. 459-475

Chapter Contribution to Books

1. Soumen Mandal and Dr. Nagahanumaiah, “Dynamic health monitioring in micro turning process: A multi-sensory approach”, Lambert Academic Publishing, GmBH Germany; ISBN: 978-3-659-28770-1, 2012.
2. T. Kuila, P. Banerjee and N.C. Murmu, “Surface Modification of Graphene” in “Advanced Carbon Materials and Technology”; Ed. A. Tiwari and S.K. Shukla, WILEY-Scrivener Publishers, ISBN: 978-1-118-68623-2, January 2014.
3. Samik Dutta, Surjya K. Pal and Ranjan Sen, “Digital Image Processing in Machining” in “Modern Mechanical Engineering, Research, Development and Education”, Series: Materials Forming, Machining and Tribology; Ed. Davim, J. Paulo; Publisher: Springer-Verlag Berlin Heidelberg 2014; ISBN: 978-3-642-45176-8.

Conference Papers: April 2012 – March 2014

Sl .	Title of the paper / poster	Authors	Name of the Conference	Date	Venue
1	A reaching sliding mode scheme for control of brushless DC (BLDC) motors	J.J. Rath, S. Saha, H.P. Ikkurti	IEEE International Conference on Electronics Computer Technology	April 06-08, 2012	Kanyakumari, Tamil Nadu, India
2	Analysis of different maximum power point tracking techniques in MATLAB/SIMULINK environment	A. Bhattacharjee, S. Saha, H.P. Ikkurti			
3	Extraction of phalangeal joint parameters from image sequences during palmer grasp	A. Chatterjee, A. Mahapatra, S. Majumder, I. Basak	10th International Symposium on Computer Methods in Biomechanics and Biomedical Engineering	April 11-14, 2012	Berlin, Germany
4	Flow analysis of a centrifugal slurry pump while handling clear water at design and off-design conditions	L.G. Das, M.K. Rawat, N. Kuri	Conference of Turbomachinery Society of Japan	April 19-20, 2012	Japan
5	Recent development of Dye Sensitized Solar Cells at CSIR-CMERI	B. Mondal	3rd EICOON School on Science and Technology of Renewable & Clean Energy Sources	April 30-May 01, 2012	Kolkata, West Bengal, India
6	Dynamic shear stress evaluation on micro turning tool using photoelasticity	S. Mandal, A. Kumar, Nagahanumaiah	International Conference on Advance Material Design and Mechanics	June 05-07, 2012	Xiamen, China
7	Experimental study of critical speed for rotor-bearing system	R.K. Biswas, T.K. Paul, K.J. Uke, S.K. Laha, B. Swarnakar, S. Kansabanik	National Conference on Condition Monitoring of Engineering Systems & Structures	June 15-16, 2012	Pune, Maharashtra, India
8	A low cost precision pneumatic planter for vegetables - studies and development	P. Rajan, N.P.S. Sirohi	International Conference of Agricultural Engineering	July 08-12, 2012	Valencia, Spain

Sl .	Title of the paper / poster	Authors	Name of the Conference	Date	Venue
9	Grid connected photovoltaic inverters with supportive ancillary features for better grid penetration of solar energy	S. Kumar, S. Saha, H.P. Ikkurti	National Seminar on Industrial Application of Solar Energy	July 27-28, 2012	Durgapur, West Bengal, India
10	Microinverter: promising futuristic solution for building integrated photovoltaics	H.P. Ikkurti, S. Saha, S. Kumar			
11	Nanocrystalline TiO_2 electrodes from modified precursor for dye sensitized solar cell	K. Usha, S. Ghatak, B. Mondal, P. Kumbhakar			
12	Recent development of dye sensitized photovoltaic solar cell	B. Mondal, K. Usha, D. Sengupta			
13	Plasma pyrolysis of plastic waste and option for energy recovery	B. Ruj, P.K. Chattejee, S.P. Goel	3rd International Conference on Solid Waste Management	July 30-August 01, 2012	Mysore, Karnataka, India
14	A new controller for maximum power extraction from photovoltaic system using phase modulated converter	Md. A. Akhtar, H.P. Ikkurti	IEEE International Conference on Advances in Power Conversion and Energy Technologies	August 02-04, 2012	Mylavaram, Andhra Pradesh, India
15	Exact 3D solution of hybrid piezoelectric laminated plates featuring viscoelastic interfaces	A. Kumar, S. Kapuria, N.K. Gupta	23rd International Congress of Theoretical and Applied Mechanics	August 19-24, 2012	Beijing, China
16	Development of process for disposal of plastic waste using plasma pyrolysis technology and option for energy recovery	B. Ruj, P.K. Chatterjee, M. Punčochář	20th International Congress of Chemical and Process Engineering	August 25-29, 2012	Prague, Czech Republic
17	Fabrication study of non linear taper component for 42GHz, 200 kW, CW Gyrotron with improved surface integrity	P. Saha, S. Dutta, A.J. Banerjee, R. Sen	National Conference on Vacuum Electronic Devices and Applications	September 21-24, 2012	Pilani, Rajasthan, India
18	Mechanical properties and tensile fracture mechanism of rheocast A356 Al alloy using cooling slope	P. Das, S. Samanta T. Roy, B.R.K. Venkatpati	International Conference on Advances in Materials and Processing	September 23-26, 2012	Wollongong, Australia

Sl .	Title of the paper / poster	Authors	Name of the Conference	Date	Venue
19	Ceria (CeO_2) and Yttria (Y_2O_3) coating - An effective method of high temperature corrosion protection of industrial grade 2.25 Cr-1 Mo steel plate in SO_2 + O_2 atmosphere	D. Ghosh, A.K. Sukla, S.K. Mitra	International Corrosion Conference	September 26-29, 2012	Goa, India
20	Bubble formation in LBE-Nitrogen system from two orifices	S.P. Singh, G. Biswas	Ninth Asian Computational Fluid Dynamics Conference	October 10-14, 2012	Nanjing, China
21	Inline forced vibrations and various vortex shedding modes of a circular cylinder at Reynolds number = 175	S.P. Singh, G. Biswas			
22	Micro structural evolution of A356 Al alloy during flow along a cooling slope	P. Das, S. Samanta, B.R.K. Venkatpati, H. Chottopadhyay, P. Dutta	Fifth International Conference on Solidification and Processing	November 19-22, 2012	Bhubaneswar, Orissa, India
23	FPGA based model predictive controller for dynamic power management of a battery powered electric car	D. Babu, J. Roychowdhury, A. Kumar	International Conference on Intelligent Systems Design and Application	November 27-29, 2012	Kochi, Kerala, India
24	Intelligent battery management system for runtime optimization of an electric car	A. Kumar, I. Patiyat, S. Jangid, J. Roychowdhury			
25	Geometry optimization of textured micro-thrust bearing	N. Kumar, P. Samanta, N.C. Murmu	8th International Conference on Industrial Tribology	December 07-09, 2012	Pune, Maharashtra, India
26	Numerical investigation on static and dynamic performances of foil air journal bearing	P. Samanta, N.C. Murmu			
27	Wear debris characterization using statistical features of grey level co-occurrence matrix for machine health monitoring	P. Kumar, P. Samanta, A. Sarkar, N.C. Murmu			
28	A series of Cu(II) coordination polymer: Synthesis, structural, several spectroscopic characterization and reactivity	P. Ghosh, A. Roy Chowdhuri, A. Bhowmik, S. Basu N.C. Murmu, P. Banerjee	International Symposium on Processing and Fabrication of Advanced Materials	December 10-13, 2012	Guwahati, Assam, India

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29	Key points based laser scan matching – A robust approach	R. Ray, D. Banerjee, S. Nandy, S.N. Shome	IEEE International Conference on Robotics and Biomimetics	December 11-14, 2012	Guanghou, China
30	Development of nanofluids as lubricant to study friction and wear behaviour of stainless steels	R.R. Sahoo, S. Bhattacharjee, T. Das	International Conference on Ceramics	December 12-13, 2012	Bikaner, Rajasthan, India
31	Heartbeat message based misbehaviour detection scheme for vehicular ad-hoc networks	R.P. Barnwal, S.K. Ghosh	ACM/ IEEE/IFAC/ TRB International Conference on Connected Vehicles and Expo	December 12-16, 2012	Beijing, China
32	Characteristics of compressible vortices near the wall-A numerical study	T. Murugan, S. De, A. Sreevasta	Thirty Ninth National Conference on Fluid Mechanics and Fluid Power	December 13-15, 2012	Surat, Gujarat, India
33	Numerical simulation of bubble formation in a jetting fluidized bed	C. Loha, H. Chattopadhyay, P.K. Chatterjee			
34	Analysis of micro-electric discharge characteristics in a thin plate of Ti-6Al-4V using response surface methodology	K. Mondol, M.S. Azad, A.B. Puri	4th International & 25th All India Manufacturing Technology Design and Research Conference 2012	December 14-16, 2012	Kolkata, West Bengal, India
35	Analysis of micro-electrical discharge drilling characteristics in a thin plate of Ti-6Al-4V	K. Mondol, M.S. Azad, A.B. Puri			
36	Development of advanced composites of Yttria stabilized Zirconia toughened Alumina for high speed machining of AISI 4340 steel	N. Mondol, B. Doloi, B.N. Mondal			
37	Investigation on shape, size and surface quality of high aspect ratio blind micro holes in die sinking micro EDM	S. Barman, Nagahanumaiah, A.B. Puri			
38	Simultaneous position and angular error measurement of a XY-stage using miniature interferometer with step-size variation	S. Dutta, C. Pati, R. Sen			

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39	A novel approach for Freeman Chain Coding with prior modification using cubic interpolation	J. Banerjee, R. Ray, S.N. Shome	IEEE International Conference on Computational Intelligence & Computing Research	December 18-20, 2012	Coimbatore, Tamil Nadu, India
40	A computer vision based solution to identify the biological cells isolated inside the micro-fluidic chip	M. Malik, V. Goel, A. Chebolu, Nagahanumaiah			
41	Lifetime analysis of CDMA wireless sensor networks with efficient channel aware forwarding protocol	U. Dutta, P.K. Sahu, S. Kundu	First International Workshop on Sustainable Monitoring through Cyber-Physical Systems	January 03-06, 2013	Mumbai, Maharashtra, India
42	Performance analysis of piezoelectric energy harvesting device	P.K. Sahu, A. Mukherjee, S. Sen, U. Dutta			
43	Assessment of groundwater suitability for irrigation purpose in North- Eastern part of Bankura district, West Bengal, India	S. Bajpayee, K. Adhikari, B. Ruj, P.K. Chatterjee	100th Indian Science Congress	January 03-07, 2013	Kolkata, West Bengal, India
44	Development of bio-resourced collagen and hydroxyapatite biomaterials for tissue engineering application	Sudip Mondal, B.N. Mondal, A. Dey, Sudit S. Mukhopadhyay			
45	Effect of pouring temperature on cooling channel semi solid slurry generation process	P. Das, S.K. Samanta, A.K. Lohar, H. Chattopadhyay, P. Dutta	International Conference on Mechanical and Materials Research	January 14-15, 2013	Dalian, China
46	Micro-Nano patterning of solid surfaces for enhanced antibacterial properties – challenges and opportunities	A. Chebolu, Nagahanumaiah	The First National Conference on Micro and Nano Fabrication	January 21-23, 2013	Bangalore, Karnataka, India
47	Addressing the photovoltaic and ethanol sensing applications of auto-combustion route derived zinc oxide powder	D. Sengupta, K. Usha, B. Mondal, K. Mukherjee	National Seminar on Advanced Functional Materials	January 24, 2013	Durgapur, West Bengal, India

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48	Multiscale modeling of transport phenomena during high energy materials processing applications	D. Chatterjee, S. Dey	61st Indian Foundry Congress	January 27-29, 2013	Kolkata, West Bengal, India
49	Near net shape manufacturing of austempered ductile iron components for engineering applications	A.K. Chowdhuri, S. Samanta, D.P. Chattopadhyay, S. Kumar, T. Roy, S.S. Roy, A. Maity, J. Bindhani, V.R. Venkatpati			
50	Flow & heat transfer around a square cylinder at low Reynold & Hartmann number	D. Chatterjee, K. Chatterjee, C. Sinha	National Conference on Mechanical Engineering Retrospect & Prospect	February 02-03, 2013	Suri, West Bengal, India
51	Hydromagnetic mixed convection in a vertical lid driven cavity including a heat conducting rotating circular cylinder	B. Mondal, P. Halder, D. Chatterjee			
52	Numerical simulation of flow around a three-wheeled vehicle	A. Kuchlyan, S. Dey, D. Chatterjee, P.K. Maji			
53	Distributed probability density function estimation of environmental function from sensor network data	A. Mukherjee, D. Mukherjee	IEEE International Conference on Signal Processing Image Processing & Pattern Recognition	February 07-08, 2013	Coimbatore, Tamil Nadu, India
54	Filter design for tracking of ballistic target missile using seeker measurements with time lag	A. Mukherjee, D. Mukherjee, A. Sengupta			
55	Facile synthesis of nano composites toughened ceramics for high speed machining application	B. Mondal, N. Mondol, B. Doloi	International Conference on Recent Advances in Composite Material	February 18-21, 2013	Goa, India
56	Intelligent battery management system for runtime optimization of an electric car	A. Kumar, S. Jangid, I. Patiyat, J. Roychowdhury	International Conference on Information Communication & Embedded Systems	February 21-22, 2013	Chennai, Tamil Nadu, India

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57	A holistic design and modeling approach applied to the development of ultra precision CMM for micro and nano metrology	C. Pati, S. Dutta, R. Sen	8th International Conference on Advances in Metrology	February 21-23, 2013	New Delhi, India
58	Form and surface texture characterization of high aspect ratio micro hole in bulk metallic glass machined in micro EDM process	S. Barman, Nagahanumaiah			
59	Weather-predicting atmospheric modulation transfer function	M. Malik, S. Majumder	IEEE International Computing Conference	February 22-24, 2013	Ghaziabad, Uttar Pradesh, India
60	Preparation and characterization of transition metal doped barium hexaferrite nanoparticles	M. Karmakar, M. Pal, S. Basu	Third National Seminar on Recent Trends in Condensed Matter Physics Including Laser Application	March 05-07, 2013	Burdwan, West Bengal, India
61	Wet chemical tailoring of spinel ferrite nano-structures and study on their chemi-resistive type hydrogen sensing characteristics	K. Mukherjee, S.B. Majumder			
62	Enhancement of diabetic retinopathy imagery using histogram equalization techniques	S. Aruchamy, R. Roy, P. Bhattacharjee	International Conference on Biosignals, Images and Instrumentation	March 14-16, 2013	Chennai, Tamil Nadu, India
63	Solar energy for rural India	M.S. Azad, A. Layek, S. Maity, D.K. Biswas, S.K. Das	International Conference on Global Scenario in Environment and Energy	March 14-16, 2013	Bhopal, Madhya Pradesh, India
64	Effect of Yttria on the synthesis, microstructure and mechanical properties of partially stabilized zirconia in alpha-Al_2O_3 matrix	N. Mondol, B. Mondal, B. Doloi, D. Sengupta	International Conference on Materials Processing and Characterization	March 16-17, 2013	Hyderabad, Andhra Pradesh, India
65	A methodology for selection of optimum power rating of propulsion motor of three wheeled electric vehicle on Indian Drive Cycle	P. Mishra, S. Saha, H.P. Ikkurti	International Conference on Mechanical Automotive and Materials Engineering	March 17, 2013	Mangalore, Karnataka, India

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66	Simultaneous quadratic stabilization of a nonholonomic mobile robot	J. Mukherjee, S. Nandy, S.N. Shome, G. Chakraborty, C.S. Kumar	International Multi Conference on Automation, Computing, Control, Communication and Compressed Sensing	March 22-23, 2013	Kottayam, Kerela, India
67	Control of voltage signal for piezoelectric actuator towards micromanipulation	B. Ghosh, R.K. Jain, S. Majumdar	IEEE International Conference on Communication and Signal Processing	April 03-05, 2013	Melmaruvathur, Tamil Nadu, India
68	Detection of retinal microaneurysms using fractal analysis and feature extraction technique	R. Roy, S. Aruchamy, P. Bhattacharjee			
69	Instantaneous and long term defection analysis of shape memory alloy reinforced pre-stressed concrete beams	S.R. Debbarma, S. Saha	International Conference on Global Innovations in Technology and Sciences	April 04-06, 2013	Kottayam, Kerala, India
70	Enhancement of diabetic retinopathy imagery using adaptive histogram equalization techniques	R. Roy, S. Aruchamy, P. Bhattacharjee	National Conference on Recent Trends in Communication, Computation and Signal Processing 2013	April 10, 2013	Coimbotore, Tamil Nadu, India
71	Selection of propulsion motor and suitable gear ratio for driving electric vehicle in Indian city roads	P. Mishra, S. Saha, H.P. Ikkurti	IEEE International Conference on Energy Efficient Technologies for Sustainability	April 10-12, 2013	Nagercoil, Tamil Nadu, India
72	Acetone sensing characteristics of Zinc Oxide particles modified with reduced Graphene oxide	P. Das, D. Sengupta, B. Mandal, K. Mukherjee	National Seminar cum Workshop on Sensor and Sensing System for Taste Characterization of Food and Agro Produces	May 09-10, 2013	Kharagpur, West Bengal, India
73	SiO_2/PVDF coated separator with enhanced thermal stability for Lithium-Ion rechargeable batteries	Sivaprakash S., Prabhavathy S.	223rd ECS Meeting of the Electrochemical Society	May 12-16, 2013	Toronto, ON, Canada

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74	Phase field simulation of equi–microstructure formation during semi-solid processing of A380 Al alloy	P. Das, S. Samanta, P. Dutta	Cutting Edge of Computer Simulation of Solidification and Casting	May 20-23, 2013	Sweden
75	Two phase flow simulation of semi solid slurry generation process of A380 Al alloy	P. Das, S. Samanta, P. Dutta			
76	Numerical simulation of a pressure regulated valve to fix out the characteristics of passive control circuit	B. Saha	International Conference on Fluid Mechanics	May 27-28, 2013	Berlin, Germany
77	A tendon driven biorobotic pectoral fin: mechanism and analysis	S.S. Rathour, S. Sen, P. Saha, S.N. Shome	The 23rd International Offshore (Ocean) and Polar Engineering Conference	June 30– July 05, 2013	Anchorage, Alaska
78	Energy aware battery powered electric vehicles: A predictive model driven approach	D. Babu, A. Kumar, J. Roy Chowdhury	2nd International Conference on Advances in Computer Science and Engineering	July 01-02, 2013	Los Angeles, CA, USA
79	Estimation of mechanical impedance of a flexible nonlinear transmission using partial knowledge of elastic characteristic and its validation	S. Chatterjee, S. Sen, S. Nandi	Advances in Robotics	July 04-06, 2013	Pune, Maharashtra, India
80	Stability analysis of piezoelectric actuator based microgripper for robotic microassembly	R.K. Jain, S. Majumdar, A. Bano, P. Jana, A. Sinha, P. Gupta, M. Das			
81	Flow and heat transfer characterization in ribbed channel using lattice Boltzmann method	P. Sharma, B. Mondal, G. Biswas	ASME 2013 Summer Heat Transfer Conference	July 13-14, 2013	Minneapolis, USA
82	Magnetohydrodynamic flow and heat transfer around a circular cylinder in an unconfined medium	S.K. Gupta, D. Chatterjee, B. Mondal	Future Trends in Structural, Civil, Environmental and Mechanical Engineering	July 13-14, 2013	Bangkok, Thailand
83	MDS-based trust estimation of event reporting node in VANET	T.R.V. Krishna, R.P. Barnwal, S.K. Ghosh	12th IEEE International Conference on Trust, Security and Privacy in Computing and Communications 2013	July 16-18, 2013	Melbourne, Australia

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84	Motion and force analysis in pantograph mechanism for micro-nano patterning	S.K. Singh, S. Mandal, Nagahanumaiah	International Conference on Design and Manufacturing	July 18-20, 2013	Kancheepuram, Tamil Nadu, India
85	Resource utilization of multi-hop CDMA wireless sensor networks with efficient forwarding protocols	U. Dutta, A. Mukherjee, P.K. Sahu, S. Kundu			
86	Optimization of micro-EDM drilling operation with multiple performance characteristics using Taguchi's quality loss function	M.S. Azad	International Conference on Manufacturing Science and Technology	August 03-04, 2013	Dubai, UAE
87	Biological swimming mechanism analysis and design of robotic frog	J. Pandey, N.S. Reddy, R. Ray, S.N. Shome	IEEE International Conference on Mechatronics and Automation	August 04-07, 2013	Takamatsu, Kagawa, Japan
88	Robust localization of an Autonomous Underwater Vehicle: A comparative study	S. Roy, S. Nandy, S.N. Shome, R. Ray	IEEE International Conference on Automation Science and Engineering	August 17-21, 2013	Madison, WI, USA
89	Active 4 DOF based RCC wrist using segmented IPMCs for robotic peg-in-hole assembly	R.K. Jain, S. Majumdar, A. Dutta	The Society of Instrument and Control Engineering (SICE) Annual Conference	September 14-17, 2013	Nogoya
90	Hand gesture recognition algorithm using image processing technique for security applications	J. Roy Chowdhury, A. Ghosh, S. Mandal, A. Biswas	Second International Conference on Computing and System	September 21-22, 2013	Burdwan, West Bengal, India
91	Controller for attitude stabilization with disturbance rejection for steady hover of rotary-wing flying robot	S. Dutta, U. Patker, S. Majumder, M.C. Majumder	9th International Conference on Intelligent Unmanned System	September 25-27, 2013	Jaipur, Rajasthan, India
92	FPGA based battery management system for battery powered electric car	D. Babu, A. Kumar, J. Roy Chowdhury			
93	Dither control for DAHL model based hysteresis compensation	S.K. Shome, M. Prakash, A. Mukherjee, U. Dutta	2013 IEEE International Conference on Signal Processing, Computing & Control	September 26-28, 2013	Shimla, Himachal Pradesh, India

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94	E-waste (cell phone) treatment by thermal plasma technique	B. Ruj, J.S. Chang	7th International Symposium on Feedstock Recycling of Polymeric Materials	October 23-26, 2013	New Delhi, India
95	Plasma pyrolysis of scrap tyres – an option for energy recovery	B. Ruj, M. Punčochář, M. Syc, P.K. Chatterjee, V. Pandey, B. Bhattacharya			
96	Plasma pyrolysis for recovery of energy from plastic waste	B. Ruj, P.K. Chatterjee, A.K. Goel			
97	Design and impedance estimation of a biologically inspired flexible mechanical transmission with exponential elastic characteristics	S. Sen, S. Chatterjee, C. Har	IEEE/RSJ International Conference on Intelligent Robots and System	November 03-07, 2013	Tokyo, Japan
98	Design and Implementation of speed controller with anti wind up scheme for three phase induction motor used in electric vehicle	P. Mishra, S. Saha	International Conference on Recent Trends in Power, Control and Instrumentation Engineering	November 08-09, 2013	Hyderabad, Andhra Pradesh, India
99	Dither based precise position control of piezo actuated micro-nano manipulator	S.K. Shome, S. Pradhan, A. Mukherjee, U. Dutta	39th Annual Conference of IEEE Industrial Electronics Society	November 10-13, 2013	Vienna, Austria
100	Optimization of Nd:YAG laser parameters for cutting of thick steel sheet using Taguchi's design of experiments	A.J. Banerjee, A. Msipha, M.K. Biswal, A.K. Prasad, S. Karmakar, P.K. Maji	ASME 2013 International Mechanical Engineering Congress & Exposition	November 15-21, 2013	San Diego, CA, USA
101	Amphibian subterranean robot for mine exploration	A. Maity, S. Majumder, D.N. Roy	International Conference on Robotics, Biomimetics, Intelligent Computational Systems	November 25-27, 2013	Yogyakarta, Indonesia
102	Studies on effect of basic maneuvering operation on quadcopters thrust generated	U.S. Patker, S. Dutta, S. Majumder, M.C. Majumder, D.N. Ray, S.K. Char			

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103	Studies on ground water quality for drinking purpose applying water quality index in Bardhaman District, West Bengal, India	A.K. Batabyal, S. Chakraborty, B. Ruj	National Seminar on 'Recent Approaches to Water Resource Management'	December 09-10, 2013	Dhanbad, Jharkhand, India
104	A patterned membrane less microfluidic fuel cell	R.K. Arun, M. Chatterjee, Vijay, A. Ghatak	Energy System Modelling & Optimization Conference	December 09-11, 2013	Durgapur, West Bengal, India
105	Low-dimensional chaos for flow past staggered rows of square cylinders	D. Chatterjee, B. Mondal, G. Biswas			
106	Magnetoconvective transport in a vertical lid-driven cavity in presence of a heat conducting rotating circular cylinder	K. Chatterjee, D. Chatterjee, N.B. Hui, B. Mondal			
107	Development of piezoelectric actuator based compliant micro gripper for robotic peg-in hole assembly	R.K. Jain, S. Saha, S. Majumder	IEEE International Conference on Robotics and Biomimetics	December 12-14, 2013	Shenzhen, China
108	Multibody dynamics of a swimming frog - A co-simulation approach	J. Pandey, N.S. Reddy, R. Ray, S.N. Shome			
109	An wavelet-based characterization of fractographs	S. Dutta, H. Roy, R. Sen	International Conference on Precision, Meso, Micro and Nano Engineering	December 13-15, 2013	Calicut, Kerala, India
110	Analysis of overcut and taper in micro-electrical discharge drilling on Ti-6Al-4V	K. Mondol, M.S. Azad, A.B. Puri			
111	Investigative study on shape size, surface quality MMR, EWR and material characterization of high aspect ratio microholes drilled in bulk metallic glass (BMG) by micro EDM	S. Barman, Vijay, Nagahanumaiah			
112	Lifetime of a CDMA wireless sensor network with route diversity	U. Dutta, P.K. Sahu, S. Kundu	IEEE INDICON 2013	December 13-15, 2013	Mumbai, Maharashtra, India

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113	Zinc oxide particulate film based photo-anodes for dye sensitized solar cell	K. Mukherjee, P. Das, D. Sengupta, B. Mondal	International Conference in Asia-2013, International Union of Materials Research Society	December, 16-20, 2013	Bangalore, Karnataka, India
114	A strategy for finding a 2D stable grasp and learning	A. Das, U. Patker, S. Dutta, S. Majumder, S. Jain	1st International & 16th National Conference on Mechanics & Mechanism	December 18-20, 2013	Roorkee, Uttarakhand, India
115	An experiment driven approach of Braille embossed print head design using analytical and computational techniques	S. Jain, S. Majumder, K.J. Uke			
116	An innovative mechanism for plate washing for parties / hotels	A.K. Agrawal, B. Sebastian, M.J. Mathew			
117	An integrated computer vision based approach for driving assistance to enhance visibility in all weather conditions	M. Malik, S. Majumder			
118	Design and development of a spherical robot	D. Pokhrel, N.R. Luitel, D.N. Ray			
119	Optimization of design parameters for rotary tiller's blade	S.K. Mondal, B. Bhattacharyya, S. Mukherjee			
120	Performance analysis of different controllers for a 2 DOF electro hydraulic motion simulator	B.B. Ghosh, B.K. Sarkar, R. Saha			
121	Variable impedance actuator with exponential elasticity for robots with joint flexibility and estimation of the joint impedance	S. Sen, C. Har, S. Chatterjee			
122	Computer aided design of swirl hole nozzle	S.K. Mondal, H. Chatterjee	ISTAM 2013	December 18-21, 2013	Howrah, West Bengal, India
123	Design and development of rotary tiller's blade	S.K. Mondal, B. Bhattacharyya, S. Mukherjee			
124	Static analysis of a cantilever plate	S.K. Mondal, A. Prasad			

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125	Shape recognition based on shape-signature identification and condensability: Application to underwater imagery	Jeet Banerjee, R. Ray, S.R.K. Vadali, Ritwik Layek, S.N. Shome	National Conference on Computer Vision, Pattern Recognition, Image Processing and Graphics	December 18-21, 2013	Jodhpur, Rajasthan, India
126	Effect of Ceria (CeO_2) and Yttria (Y_2O_3) coating on high temperature corrosion resistance of 2.25 Cr-1Mo steel in SO_2+O_2 atmosphere	D. Ghosh, S.K. Mitra	International Conference on Materials Engineering and Technology	December 24-25, 2013	Bangkok, Thailand
127	Image texture analysis using GLCM technique for evaluation fractographs	H. Roy, S. Dutta, K. Bharat, H.N. Bar			
128	Diabetic Retinopathy image enhancement using CLAHE by programming TMS320C6416	Srinivasan A., M. Bhat, R. Roy, P. Bhattacharjee	IETE International Conference on Computer, Electrical and Electronics Engineering	December 26-27, 2013	Lonere, Raigad, India
129	Effect of hot wire aremometry systems over heat ratio on turbulence statistics	S. Dutta, T. Murugan, P.K. Chatterjee	22nd National and 11th International ISHMT-ASME Heat and Mass Transfer Conference	December 28-31, 2013	Kharagpur, West Bengal, India
130	Forced convection heat transfer around a rotating square cylinder in an infinite medium	S.K. Gupta, D. Chatterjee, B. Mondal			
131	Modified evaporation in a flat evaporator loop heat pipe with modified VOF approach	B.B. Sharma, S. Samanta, G. Biswas, Balewgize, A. Zeru, H. Chattopadhyay			
132	Multiphase flow model of semi-solid slurry generation of A380 Al alloy	P. Das, S.K. Samanta, P. Dutta, H. Chattopadhyay			
133	Studies on Euler-Euler CFD modeling of fluidized bed hydrodynamics	C. Loha, M.K. Karmakar, H. Chattopadhyay, P.K. Chatterjee			
134	Thermo-magneto-convective transport in a vertical lid-driven cavity including a heat conducting square cylinder	D. Chatterjee, K. Chatterjee, P. Halder			

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135	A low cost wavelength sensor using dual layer photodiode	S. Mandal, Nagahanumaiah	IEEE-International Conference on Advances in Electrical Engineering-2014	January 09-11, 2014	Vellore, Tamil Nadu, India
136	Measurement of turbulence statistics using hot wire anemometry	T. Murugan, A. Kumar, M. Singh, Subhendra, V. Kumar, P.K. Chatterjee	International Conference on Recent trends in Engineering and Technology	January 18, 2014	Cochin, Kerala, India
137	Paper-pencil based self pumping membraneless microfluidic fuel cell	R.K. Arun, S. Halder, N. Chandra	Flow Chemistry India 2014	January 23-24, 2014	Hyderabad, Andhra Pradesh, India
138	Gold iron oxide based smart magnetic nanosensor for toxic metal ions detection & extraction	P. Nath, R.K. Arun, N. Chandra, Nagahanumaiah			
139	Plasma pyrolysis of plastic waste for safe disposal and energy recovery	B. Ruj, P.K. Chatterjee, A. Bakre, V.K. Srivastava	National Conference on Environmental: Pollution & Protection	January 30-February 01, 2014	Durgapur, West Bengal, India
140	Disposal of plastic waste by different thermal process - An overview	P. Jash, Biswajit Ruj, P.K. Chatterjee, A.K. Sadhukhan, P.P. Gupta			
141	Performance analysis of synthesised $LiFePO_4$ cathode material for Lithium-Ion batteries	Sivaprakash S., Prabhavathy S.	International Conference on Functional Materials	February 05-07, 2014	Kharagpur, West Bengal, India
142	Introduction of passivating layer in TiO_2 based photo-anode for dye sensitized solar cell application	P. Das, B. Mondal, K. Mukherjee			
143	A solution to inverse kinematics problem using the concept of sampling importance resampling	R. Sapra, M. Mathew, S. Majumder	Fourth International Conference on Advanced Computing and Communication Technologies	February 08-09, 2014	Rohtak, Haryana, India

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144	Understanding the role of emulsifiers defined by chemistry and structure to the performance of metal working nanoemulsions	R.R. Sahoo, N.C. Murmu	ASIATRIB 2014	February 17-20, 2014	Agra, Uttar Pradesh, India
145	Numerical Investigation on delamination in different coatings of cutting tools used in micro-machining applications	P. Samanta, P. Shetty, P. Banerjee, T. Kuila, N.C. Murmu			
146	Tire pyrolysis oil as a lubricant	N.C. Murmu, R. Bubai, A.P. Harsha, P. Samanta, P. Das			
147	Measurement of form and areal surface texture of high aspect ratio blind micro hole die sinked in micro EDM by destructive method	S. Barman, A.B. Puri	3rd National Conference on Advances in Metrology	February 19-21, 2014	Patiala, Punjab, India
148	Tactile sensing based softness classification using machine learning	I. Bandyopadhyaya, D. Babu, A. Kumar, J. Roychowdhury	4th IEEE International Advance Computing Conference	February 21-22, 2014	Gurgaon, Haryana, India
149	Finite element analysis of effects of CNT waviness on effective mechanical properties of nanocomposite	S. Paunikar, S. Kumar	International Conference on Emerging Materials & Processes	February 26-28, 2014	Bhubaneswar, Orissa, India
150	Optimization of process parameters for development of Al-SiCp composites through RP integrated investment casting using response surface methodology	H. Goyal, S.K. Mitra, N. Mandal, B.N. Mondal			
151	Zinc oxide photo-anode based chlorophyll sensitized solar cell	D. Sengupta, P. Das, K. Usha, B. Mondal, K. Mukherjee			
152	Elimination of marine snow effect from underwater image - An adaptive probabilistic approach	S. Banerjee, G. Sanyal, S. Ghosh, R. Ray, S.N. Shome	2nd IEEE International Students' Conference for Electrical, Electronics and Computer Science	March 01-02, 2014	Bhopal, Madhya Pradesh, India

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153	Analysis of effects of Carbon nanotube waviness and aspect ratio of effective mechanical properties of nanocomposite using finite element method	S. Paunikar, S. Kumar	International Conference on Nano Science & Technology	March 03-05, 2014	Mohali, Punjab, India
154	Paper based membrane less microfluidic fuel cell	R.K. Arun, Vijay, K. Chatterjee, N. Chandra			
155	Investigation of the jetting regimes of PEDOT:PSS ink in electrohydrodynamic (EHD) printing using PET substrates	P.K. Raje, N.C. Murmu, S. De, Tapas Kuila			
156	Modelling turbulent transport in high energy materials processing application: Large eddy simulation and parallelization	D. Chatterjee	National Conference on Emerging Trends in Physics of Fluids & Solids	March 06-07, 2014	Kolkata, West Bengal, India
157	Constant current control of stepper motor in microstepping mode using PIC16F877A	A .Mukherjee, S. Sen, P. Karmakar, Somesh B.S.	IEEE-II International Conference on Devices, Circuit & System	March 06-08, 2014	Coimbatore, Tamil Nadu, India
158	Online tuning of diether for micro-nano positioning platform: a PID based approach	S.K. Shome, S. Pradhan, M. Prakash, A. Mukherjee, U. Dutta	IEEE International Conference on Recent Advances in Engineering & Computational Science	March 06-08, 2014	Chandigarh, Punjab, India
159	Design optimization of serial link redundant manipulator: An approach using global performance metric	V. Kumar, S. Sen, S.S. Roy, C. Har, S.N. Shome	2^{nd} International Conference on Innovations in Automation and Mechatronics Engineering	March 07-08, 2014	Gujarat, India
160	Noise induced feature enhancement and object segmentation of forward looking SONAR Image	S. Banerjee, R. Ray, S.N. Shome, G. Sanyal			
161	Synthesis of Al7075/Al_2O_3 composite and corrosion study	Sivaprakash S., V. Anandakrishnan, R. Devi, C. Raja	The International Conference on 'Recent Advances in Mechanical Engineering and Interdisciplinary Developments'	March 07-08, 2014	Nagercoil, Tamil Nadu, India

Sl .	Title of the paper / poster	Authors	Name of the Conference	Date	Venue
162	Surface texture and elemental characterization of high aspect ratio blind micro holes on different materials in micro EDM	S. Barman, Vijay, Nagahanumaiah, A.B. Puri	3rd International Conference on Materials and Characterization	March 08-09, 2014	Hyderabad, Andhra Pradesh, India
163	Ethanol and formaldehyde sensing characteristics of peanut like hematite iron oxide nano-particles	P. Das, D. Sengupta, B. Mondal, K. Mukherjee	National Seminar on "Recent advances in Chemistry"	March 09, 2014	Santiniketan, West Bengal, India
164	Designed synthesis of CO_2 promoted copper (II) coordination polymers: synthesis, structural, spectroscopic characterization and versatile functional property studies	P. Ghosh, S.K. Saha, N.C. Murmu, P. Banerjee			
165	Modeling of cutting force and deflection of medical needles with different tip geometrics	A. Chebolu, A. Mallimoggala, Nagahanumaiah	International Conference on Advances in Manufacturing and Materials Engineering	March 27-28, 2014	Mangalore, Karnataka, India

Dateline

Date	Events
May 11, 2012	National Technology Day Celebration
May 21, 2012	Observance of Anti-Terrorism Day
August 15, 2012	Independence Day Celebration
August 17, 2012	Observance of "Sadbhavana Diwas"
September 11-18, 2012	Hindi week
September 21, 2012	27th Management Council Meeting
September 24, 2012	70th CSIR Foundation Day Celebration
October 08, 2012	47th Research Council meeting of CSIR-CMERI
October 18, 2012	Hindi Unicode Workshop
October 29 – November 3, 2012	Observation of Vigilance Awareness Week
November 19-25, 2012	Observation of Quami Ekta Week
December 11-17, 2012	11th Indo-German Winter Academy
December 23-24, 2012	Indo-US Workshop on Fabrionics for Healthcare
January 18-20, 2013	XXXXIV SSBM (Indoor Zonal) Tournament
January 24, 2013	National Seminar of Advanced functional Materials (NSAFM 2013), inauguration of "CAMP Annexe building" and inauguration of "Gopal P. Sinha Reading Room"
January 26, 2013	Observation of Republic Day
February 23-24, 2013	CSIR-CMERI Annual Sports
February 21–March 03, 2013	CSIR-CMERI Cricket Tournament
February 26, 2013	56th CSIR-CMERI Foundation Day Celebration
March 8-9, 2013	48th Research Council Meeting
March 8, 2013	Inauguration of Condition Monitoring Laboratory & Inauguration of S.K. Basu Grove
March 19, 2013	One Day Workshop on ERP Applications
March 22, 2013	Interactive Session with United States-India Educational Foundation
April 1-4, 2013	Annual 'VOLLEYBALL' Tournament -2013
May 11, 2013	National Technology Day Celebration
May 21, 2013	Observance of Anti-Terrorism Day
July 30, 2013	28th Management Council Meeting
August 15, 2013	Independence Day Celebration
August 20, 2013	Observance of "Sadbhavana Diwas"
September 10-19, 2013	Hindi Divas Samaroh Saptah
September 26, 2013	71st CSIR Foundation Day Celebration
October 28 - November 02, 2013	Observance of Vigilance Awareness Week

Date	Events
November 19-25, 2013	Fund Raising Week for Communal Harmony Campaign
December 06-07, 2013	49th Research Council Meeting of CSIR-CMERI
December 18-19, 2013	International Workshop on 'Advanced Biomass Thermal Conversion Processes'
January 26, 2014	Observation of Republic Day
February 08-09, 2014	CSIR-CMERI Annual Sports
February 14, 2014	ERP Training Programme
February 25, 2014	Workshop on "Rheo-Pressure Die Casting Technology (RPDC-2014)"
February 26, 2014	57th CSIR-CMERI Foundation Day Celebration

Scientific Manpower as on 31.03.2014

Sl.	Name	Group Affiliation
Junior Scientists		
1	Priyabrata Chattopadhyay	Advanced Design & Optimisation
2	Srinivasan Aruchamy	Cybernetics
3	Pradyumna Kumar Sahu	Electronics & Instrumentation
4	Abhijit Das	Surface Robotics
Scientists		
1	Dr. Ranajit Ghosh	Centre for Advanced Materials Processing
2	Dr. Nilrudra Mondal	Centre for Advanced Materials Processing; Planning & Performance Division
3	Ajay Yadav	CMERI-CoEFM, Ludhiana
4	Jagdish M.	CMERI-CoEFM, Ludhiana
5	Dr. Swarup Kumar Laha	Condition Monitoring
6	Amon Arora	Cybernetics
7	Hanumath Prasad Ikkurti	Drives & Control System Technology
8	Dr. Suman Saha	Drives & Control System Technology
9	Sumit Kumar	Drives & Control System Technology
10	Md. Afroz Akhtar	Drives & Control System Technology
11	Rudra Prasad Chatterjee	Electronics & Instrumentation
12	Santu Kumar Giri	Electronics & Instrumentation
13	Saikat Kumar Shome	Electronics & Instrumentation
14	Anirudh Kumar	Embedded System Lab
15	Rajesh Prasad Barnwal	Information Technology
16	Dr. Pradipta Basu Mandal	Mechanics & Stress Analysis
17	Abhiram Hens	Microsystem Technology Laboratory
18	Soumen Mandal	Microsystem Technology Laboratory
19	Ravi Kumar Arun	Microsystem Technology Laboratory
20	Dr. Himadri Roy	NDT & Metallurgy
21	Prosenjit Das	Near Net Shape Manufacturing Technology
22	Samik Dutta	Precision Engineering & Metrology
23	Dr. Siva Prakash S	Process Plant Engineering; Thermal Engineering
24	Binod Kumar Saha	Product Design & Simulation Division
25	Dibyendu Pal	Robotics & Automation
26	Subhra Kanti Das	Robotics & Automation
27	Shikha	Robotics & Automation

Sl.	Name	Group Affiliation
28	S. Reddy	Robotics & Automation
29	Dr. Bittagopal Mondal	Simulation & Modelling Laboratory
30	Dr. Priyabrata Banerjee	Surface Engineering & Tribology
31	Dr. Pranab Samanta	Surface Engineering & Tribology
32	P.K. Mallisetty	Surface Engineering & Tribology
33	Dr. Dip Narayan Ray	Surface Robotics
34	Man Singh Azad	Technology Innovation Centre
35	Dr. Chanchal Loha	Thermal Engineering
36	Dr. T. Murugan	Thermal Engineering
37	Amit Kumar	Virtual Reality & Virtual Prototyping
Senior Scientists		
1	Subrata Kumar Mondal	Advanced Design & Optimization
2	Bibhuti Bhusan Ghosh	Advanced Design & Optimization; Product Design & Simulation Division
3	Dr. Ujjwal Pal	Chemistry & Biomimetics
4	Dr. Dibyendu Bhattacharya	Chemistry & Biomimetics
5	Dr. Krishnendu Kundu	CMERI-CoEFM, Ludhiana
6	Dr. Pradeep Rajan	CMERI-CoEFM, Ludhiana
7	U.S. Patkar	Design of Mechanical Systems
8	Dr. Ravi Kant Jain	Design of Mechanical Systems
9	Dr. Arpita Mukherjee	Electronics & Instrumentation
10	Rajpal Singh	Manufacturing Technology Group
11	Palash Kumar Maji	Manufacturing Technology Group; Product Design & Simulation Division
12	Dr. Debashis Das	Material & Structure Evaluation Group
13	Dr. Nripen Chanda	Microsystem Technology Laboratory
14	Dr. Lal Gopal Das	Process Plant Engineering
15	Anupam Sinha	Product Design & Simulation Division
16	Dr. Ranjit Ray	Robotics & Automation
17	Siva Ram Krishna Vadali	Robotics & Automation
18	Virendra Kumar	Robotics & Automation
19	Dr. Dipankar Chatterjee	Simulation & Modelling Laboratory
20	Dr. Sudipta De	Simulation & Modelling Laboratory
21	Dr. Satya Prakash Singh	Simulation & Modelling Laboratory
22	Dr. Rashmi Ranjan Sahoo	Surface Engineering & Tribology
23	Kalyan Kumar Mistry	Surface Robotics
24	Dr. Sarita Ghosh	Technology, Publication & Patent
25	Dr. Malay Kumar Karmakar	Thermal Engineering
26	Abhijit Mahapatra	Virtual Reality & Virtual Prototyping

Sl.	Name	Group Affiliation
Principal Scientists		
1	Dr. Atanu Maity	Advanced Design & Optimization
2	Dr. Arup Kumar Nandi	Advanced Design & Optimization
3	Dr. Mrinal Pal	Centre for Advanced Materials Processing
4	Aswani Kumar Kushwaha	CMERI-CoEFM, Ludhiana
5	B.D. Bansal	CMERI-CoEFM, Ludhiana
6	Rajesh Kumar Chak	CMERI-CoEFM, Ludhiana
7	Kamalkishor J Uke	Condition Monitoring
8	Amit Ganguly	Horticulture & Institute House Keeping
9	Sankar Karmakar	Manufacturing Technology Group
10	Ashok Kumar Prasad	Manufacturing Technology Group
11	G.S. Reddy	Material & Structure Evaluation Group
12	Dr. Surendra Kumar	Mechanics & Stress analysis
13	Manju Singh	Near Net Shape Manufacturing Technology
14	Dr. Sudip Kumar Samanta	Near Net Shape Manufacturing Technology; Central Research Facility
15	Dr. Aditya Kumar Lohar	Near Net Shape Manufacturing Technology
16	Dr. Debasish Ghosh	NDT & Metallurgy
17	Dr. Atanu Saha	NDT & Metallurgy
18	Swapan Barman	Precision Engineering & Metrology
19	Dr. Tapas Gangopadhyay	Product Design & Simulation Division; KRC
20	Dr. Asit Kumar Batabyal	QMRE; Technology, Publication & Patent
21	Dr. S.R. Debbarma	Resource Planning & Business Development Group
22	Sambhunath Nandi	Robotics & Automation
23	Dr. Soumen Sen	Robotics & Automation
24	Dr. Naresh Chandra Murmu	Surface Engineering & Tribology
25	Dilip Kumar Biswas	Technology Innovation Centre
26	Dr. Biswajit Ruj	Thermal Engineering
27	Biplab Choudhury	Thermal Engineering
Senior Principal Scientists		
1	Dr. Debabrata Chatterjee	Chemistry & Biomimetics
2	Syd. Salman Mojiz	CMERI-CoEFM, Ludhiana
3	Rabin Kumar Biswas	Condition Monitoring
4	Tapan Kumar Paul	Condition Monitoring
5	Dr. Partha Bhattacharjee	Cybernetics
6	Anjali Chatterjee	Cybernetics
7	Joydeb Ray Chaudhury	Embedded System Lab
8	Partha Sarathi Banerjee	HRD; Product Design & Simulation Division
9	Dr. Somnath Mukherjee	Mechanics & Stress Analysis

Sl.	Name	Group Affiliation
10	Dr. Nagahanumaiah	Microsystem Technology Laboratory
11	B.N. Singh	NDT & Metallurgy
12	Pankaj Kumar Roy	NDT & Metallurgy
13	Prasanta Kumar Sen	Process Plant Engineering
14	Maw Nandi Sarkar	Process Plant Engineering; QMRE
15	Debojyoti Banerji	Robotics & Automation
16	Sarbari Datta	Surface Robotics
17	Soumya Sen Sharma	Technology, Publication & Patent; Drives & Control System Technology
18	Avik Chatterjee	Virtual Reality & Virtual Prototyping
Chief Scientists		
1	Dr. Biswanath Mondal	Centre for Advanced Materials Processing; Planning & Performance Division
2	Cdr. V.R. Dahake	CMERI-CoEFM, Ludhiana
3	Dr. Somajyoti Majumder	Design of Mechanical Systems; Information Technology; Surface Robotics
4	Uma Dutta	Electronics & Instrumentation
5	Amit Jyoti Banerjee	Manufacturing Technology Group
6	Abhijit Chatterjee	Material & Structural Evaluation Group
7	Ashish Kumar Chowdhury	Near Net Shape Manufacturing Technology
8	Awadhesh Kumar Shukla	NDT & Metallurgy; Engineering Service Group
9	Dr. Ranjan Sen	Precision Engineering & Metrology
10	Tapas Sarkar	Resource Planning & Business Development Group; QMRE
11	Dr. Sankar Nath Shome	Robotics & Automation; School of Mechatronics
12	Dr. Sibnath Maity	Technology Innovation Centre
13	Dr. Pradip Kumar Chatterjee	Thermal Engineering
DST INSPIRE Fellows		
1	Dr. Kalisadhan Mukherjee	Centre for Advanced Materials Processing
2	Dr. Tapas Kuila	Surface Engineering & Tribology
DST Women Scientist		
1.	Dr. Prabhavathy Sivaprakash	Process Plant Engineering

Indo-German Winter Academy 2012

The Indo-German Winter Academy was basically conceived for establishing a model for promoting international cooperation and building early research partnerships.

Three different research areas were identified for the purpose. These include

- ✓ Modeling and algorithms for fluid dynamics and heat transfer
- ✓ High performance computing for engineering problems
- ✓ Semiconductor processes, devices and systems

The Academy has a core group of faculty members drawn from various research areas under consideration. This core group selects and advises students as they prepare for the Academy. A total of about forty eight students and sixteen faculty members participate in the Academy. Lead speakers are also identified from various institutions to deliver keynote presentations on the issues most germane to each of the research areas. The participating professors of Winter Academy 2012 were Prof. Ulrich Ruede and Prof. Heiner Ryssel (University of Erlangen-Nuremberg, Germany); Prof. Katarina Gustavsson (KTH, Sweden); Prof. Sanjay Mittal (IIT Kanpur); Prof. S.C. Mishra (IIT Guwahati); Prof. Parag Bhargava (IIT Bombay); Prof. Gautam Biswas, Dr. Bitta Gopal Mondal, Dr. P. Halder and Mr. U.S. Ghosh (CSIR-CMERI); Prof. A Dasgupta and Prof. N. Dasgupta (IIT Madras); Prof. Amit Dhiman (IIT Roorkee); Prof. Suman Chakraborty and Prof. C. Jacob (IIT Kharagpur); Prof. Vivek Buwa and Prof. Prabal Talukdar (IIT Delhi).

On each day, three parallel workshops were run, one in each of the broad subject areas. Selected keynote speakers presented a broad overview on chosen specific aspects of the research area followed by presentations from students of each institution who did independent work aligned most closely to that topic. A summation period at the end of the day was devoted for identifying the multidisciplinary facets of the problems under consideration. A day was also devoted for a trip to a nearby place and one evening for a vibrant cultural programme. The Academy believes that such an exercise would entail growth of technological leadership in the new global milieu. During the Winter Academy 2012, a visit to Santiniketan was arranged on December 14 and in the evening a dance-drama of Poet Rabindranath Tagore, named “Chandalika” was staged at CSIR-CMERI Auditorium by a select group of performers from Kala Bhavan, Viswa Bharati, Santiniketan.

As mentioned earlier, this is the eleventh academy in a series of several such meetings that were planned. Further plans include assessment of the learning outcomes from the academy and constitute a factor in the "lessons learnt" in the future plans that include expanding the academy to Swedish students and students from other European countries. In order to summarize, the outcomes that have been already observed over the years are as follows:

- ✓ Research experience develops in students a desire to pursue advanced degrees, and seek careers in professions related to research and development.
- ✓ Students develop an appreciation and understanding of research and discovery from an international perspective.
- ✓ Students gain an understanding of another culture, and learn to feel comfortable in working in a diverse environment.

Indo-German Winter Academy 2012 Showcase

Dignitaries on the dais from the left: Prof. Gautam Biswas, Director, CSIR-CMERI, Prof. Katarina Gustavsson, KTH, Sweden & Prof. Heiner Ryssel, University of Erlangen-Nuremberg, Germany

Prof. Ulrich Rüde, University of Erlangen-Nuremberg, Germany lighting the inaugural lamp on the occasion of the **Indo-German Winter Academy 2012**

Prof. Katarina Gustavsson, KTH, Sweden lighting the inaugural lamp on the occasion of the **Indo-German Winter Academy 2012**

Prof. Gautam Biswas, Director, CSIR-CMERI lighting the inaugural lamp on the occasion of the **Indo-German Winter Academy 2012**

Prof. Suman Chakraborty, IIT, Kharagpur addressing the participants of the **Indo-German Winter Academy 2012**

Participants of the **Indo-German Winter Academy 2012** from Germany

Prof. Ulrich Rüde, University of Erlangen-Nuremberg, Germany addressing the participants of the **Indo-German Winter Academy 2012**

Prof. Sanjay Mittal, IIT, Kanpur & Prof. Katarina Gustavsson, KTH, Sweden in discussion with Dr. Nagahanumaiah, Senior Principal Scientist, CSIR-CMERI

Cultural Programme organized on the occasion of the **Indo-German Winter Academy 2012**

Cultural Programme organized on the occasion of the **Indo-German Winter Academy 2012**

Indo-US workshop on "Fabrionics for Healthcare"

An Indo-US Workshop on **Fabrinoics for Healthcare** was organized by CSIR-CMERI during December 23-24, 2012 under the ongoing collaborative programme of the Indo-US Center for Research Excellence in Science and Engineering on Fabionics, which is a center to facilitate and promote US-India collaborations in science, technology, engineering and biomedical research. The participating Institutes in this Indo-US Virtual Center are IIT Kanpur, IIT Kharagpur, CSIR-CMERI and BESU, Shibpur from India and the University of California - Irvine, the University of Illinois - Urbana-Champaign and the Northwestern University - Evanston from the USA.

Background

The ability to manufacture micro and nanosized devices like lab-on-a-chip (LOC) constitutes a major scientific and technological challenge. A lab-on-a-chip (LOC) is a device that integrates one or several laboratory functions on a single chip of only millimeters to a few square centimeters in size. In its most basic form, a lab-on-a-chip makes use of a stream of fluids or minute droplets as carriers of biochemical samples to carry out sample manipulation procedures. A lab-on-a-chip miniaturizes analytical and/or bio-analytical techniques and integrates them in a micro-fabricated format, thus promising significant advantages in analytical speed, separation efficiency, reduced sample/ reagent consumption, cost reduction and reduced contamination. Credit card sized plastic or glass lab-on-a-chip devices with multiple fluidic functionalities can therefore eliminate the macroscopic to microscopic interconnects, thereby facilitating biochemical hazard monitoring, point-of-care diagnostics and drug screening processes. Scientifically, there is an interesting interplay of centrifugal, Corriolis (important only at high rotational speeds), surface tension, and viscous (fluid friction) forces, which decides the manner in which a fluid sample like blood gets transported along different tiny channels. Recently, CD-based microfluidics has demonstrated a promising role in the field of clinical diagnosis, with the use of cheaply available polymeric devices. These devices are easy to handle and are biocompatible. A biological fluid such as blood under diseased conditions may react with suitable reagents to bring in a change in colour while flowing through conduits located on the CD, thereby providing a visibly detectable signal for identifying potentially life threatening diseases.

CD-based microfluidics has two major components for analysis: a polymeric CD and a driving motor. In addition, there are several other components which are used for testing and analysis. The polymeric CD is fabricated using a lamination technique, which looks very similar to the commercially available data storage disks but contains engraved in it a network of microchannels. Different fluidic samples are loaded through the vents into the reservoirs present inside the CD. They are transported to other reservoirs containing reagents for analysis through the microchannels connecting different reservoirs. Different fluidic operations like mixing are also performed in these microchannels. These are made of polycarbonate materials which are found to be biocompatible, rendering it apt for clinical diagnosis. The second major component is the driving motor. The CD is driven by a rotating AC servo motor whose rotor may be programmed at several rotating speeds and tuned to obtain the desired flow. After the reactions are complete, the readout is taken using a camera to analyse the results of the diagnosis. This uses the forces in the rotating platform to drive and manipulate fluid flow.

Two forces become essential because of the system rotation, viz. the centrifugal force acting in a radially outward direction, and the Coriolis force acting in a transverse direction. Use of varying rotation speed, however, results in another force pertinent to the rotational system. In addition, the fluid also experiences viscous force which acts to resist its motion. At low rotation speeds, Coriolis force contributes less in comparison to the centrifugal force and the flow behaviour is similar to a pressure driven flow. As the Coriolis force dominates, a transverse component is introduced into the flow. In multiphase flow, surface tension force also plays a key role in tailoring the fluid flow. All these forces are tuned to achieve desired flow patterns in the microchannels present in a CD-based microdevice. Importantly, forces in the rotating platform are functions of the rotational speed and the geometry of the channel, which may be altered dynamically with real time monitoring of the system. Though in the limit of constant low rotation speed the flow behaviour is analogous to pressure driven flows, it can be used efficiently to multiplex several operations on a single platform.

A number of research groups worldwide are using CD-based microfluidics to automate several fundamental biological operations like blood separation, cell lysis, protein purification, nucleic acid amplification, DNA hybridization, immunoassays and colorimetric analyse detection, etc. The density differences in the components of blood have been exploited to separate plasma from the whole blood. Mechanical cell lysis is an improvement over chemical lysis for rupturing the cell membrane and extracting DNA for subsequent analysis, especially for cells with thick walls like Gram-positive microbes. Such an operation can be performed in a CD by imparting mechanical force of beads over cells in a lysis chamber. A standard CD may be integrated with specialized modules for analyzing protein microarrays. Thermocycling operation, used for amplification of DNA, can be integrated with a CD with a Peltier thermoelectric device and a thermistor for temperature measurement and control. Evaporation loss of samples at enhanced temperatures is compensated intelligently by condensation in an upstream chamber and spinning back to the original chamber. Immunoassays are used to evaluate drug targets for detection of specific antigens or antibody using biomarkers. The binding reactions of antigen / antibody with enzymes are associated with a detectable signal, most commonly in the form of a colour change. ELISA, a commonly used immunoassay, has been successfully implemented in a CD by functionalizing the disk surface, spotting directly on it and subjecting it to subsequent reactions to obtain detectable signals from the antigen-antibody complex. A CD is also utilized to create a hyper gravity environment and its effects on biological cells are useful for space applications.

The progress in the Indo-US collaborative research – exclusively involving research groups from UC Irvine, USA and IIT Kharagpur, India – and pertaining to CD based microfluidics began from initial theoretical developments in rotating microdevices, which was later translated to experimental investigation. Experimental facilities originally available at the UC Irvine have also been established at IIT Kharagpur for seamless coordination of activities involving the two Institutes.

The CD-based platform serves as a substitute for standard consumables like glass slides, centrifuge tubes and microwell plates. The platform and requisite liquid consumables contribute significantly towards an increase in the cost required to test a single sample through traditional medical diagnostics. In contrast, a CD-based platform is efficient in integrating different steps in a non-intrusive manner, and such advantages do not come with an increase in cost. Such devices also help in eliminating a centrifuge as centrifugal force required to drive the flow is inherently used. Different standard fluidic operations like mixing and valving separation have been successfully integrated into this platform. As this platform does not require much human intervention, it can easily be used to cater to the needs in places where skilled personnel and sophisticated instruments are not available. The CD-based diagnostic platform may also be utilized for detection of several diseases like malaria, typhoid, dengue, etc.

The Programme

The Programme started with the welcome address of Prof. Gautam Biswas, Director, CSIR-CMERI, Durgapur. This was followed by speeches of Prof. Amitabha Ghosh, Coordinator, Center for Research Excellence in Fabrionics and Dr. V. Rao Aiyagari, the Chief Guest for the programme.

The workshop also accommodated lectures by eminent experts like Prof. Ajoy Kumar Roy, Vice Chancellor, BESU; Dr. Tapan Mukherji of the Biomedical Devices of Kansas, USA; Prof. Debojyoti Banerjee, Texas A&M University; Prof. G.K. Ananthasuresh, IISc, Bangalore; Prof. Sree Sivakumar, IIT Kanpur; Prof. Suman Chakraborty and Prof. Rabibrata Mukjerjee from IIT Kharagpur; Prof. Santanu Karmakar, Prof. Chirosree Roy Chowdhury and Prof. Subhasish Bhaumik from BESU and Prof. Manidipa Ghosh from NIT, Durgapur. Dr. N.C. Murmu, Dr. Nripen Chanda and Dr. Tapas Kuila, Scientists from CSIR-CMERI, Durgapur also spoke about their research work. There were a number of interesting Flash Presentations by students. The evenings were dedicated to cultural programmes that brought together of different tastes. ‘Dance of India’ performed by students of Uday Shankar School of Dance and Belly Unit, Durgapur and ‘Chow Dance’ by performers from Purulia District, West Bengal.

Proceedings

Technical Session I / Day 1 started with very exciting speeches delivered by Prof. Ajoy Kumar Roy on **Molecular imaging as diagnostic tool** and thereafter by Dr. Tapan Mukherji on **Changes in medical devices industry & corporate outlook - A paradigm shift**.

In the next Technical Session of the day, Prof. Suman Chakraborty deliberated on the future of **Lab-on-A-Chip** application and the recent advent of paper based microfluidic devices, which are cost-effective, miniaturized and circumvent the need for operational expertise. The technical background of **Bio-microfluidics and scanning probe lithography platforms for nano-manufacturing** was nicely elaborated by Prof. Debojyoti Banerjee.

A presentation by Dr. Nripen Chanda on **smart integrated Nano-diagnostic system for healthcare applications** followed.

In the last technical session of the first day, Prof. Santanu Karmakar described the **Relevance of biotribology in health care,** which constitutes an emerging field of study embracing basic concepts in physics, chemistry, biology, materials science and engineering. The Session also included a poster presentation by young researchers from different institutes.

The first Technical Session of the second day saw detailed deliberation on the concepts of stiffness and inertia maps and non-dimensional intrinsic kinematics map by Prof. G.K. Ananthasuresh in his lecture entitled **Soft tuning the stiffness of compliant grippers for characterizing soft cells and hard rocks**. Prof. Sree Sivakumar enthralled the audience with a guided tour of **Nanoengineered smart materials for bio and photonic applications.** A novel class of multifunctional nanoparticle loaded polymer nano / microcapsules for a variety applications were also discussed. Prof. Chirosree Roy Chowdhury discussed the prospect and challenges of **Silicon micro/nano pore impedance biosensors**.

During the Second Technical Session of the second day, Prof. Subhasish Bhaumik enlightened the audience with the footsteps of gripping techniques in bio-medical applications while Prof. Rabibrata Mukjerjee explained in detail the potential application of soft lithographically patterned surfaces in biological applications. Speaking on enzymatic detection of glucose using water soluble poly-ether-ether ketone functionalized graphene, he explained the excellent performance of the constructed biosensor which has been fabricated by immobilizing glucose oxidase on the surface of gold nanoparticles decorated modified water dispersible graphene and chitosan on the surface of an indium tin-oxide glass electrode by the casting method.

The final technical Session for the Workshop comprised a presentation on preliminary studies on **Dip-pen nanolithography** by Dr. N.C. Murmu and **Dendritic cell - A double–edged sword for immunotechnology** by Prof. Monidipa Ghosh.

Prof. Amitabha Ghosh inaugurating the
Indo US Workshop on Fabrinoics for Healthcare

Prof. Gautam Biswas, Director, CSIR-CMERI, Durgapur
lighting the Inaugural Lamp

Prof. Gautam Biswas, Director, CSIR-CMERI, Durgapur delivering the Welcome Address

Prof. Ajoy Kumar Roy, Vice Chancellor, BESU Speaking on **Molecular imaging as Diagnostic Tool**

Prof. Amitabha Ghosh, Coordinator, Center for Research Excellence in Fabrionics detailing on the objectives of the Workshop

Dr. V. Rao Aiyagari, Advisor and Head, SERC, Department of Science and Technology, Government of India, speaking on the occcasion

Dr. Tapan Mukherji, Biomedical Devices of Kansas, USA delivering lecture on **Changes in Medical Devices Industry & Corporate Outlook - A Paradigm Shift**

Prof. Suman Chakraborty, IIT Kharagpur deliberating on the future of lab-on-a-chip applications

Prof. Debajyoti Banerjee, Texas A&M University speaking on **Bio-microfluidics and Scanning Probe Lithography Platforms for Nano-Manufacturing**

Dr. Nripen Chanda, CSIR-CMERI detailing on **Smart Integrated Nano-diagnostic System for Healthcare Applications**

Prof. Santanu Karmakar, BESU explining the **Relevance of Biotribology in Health Care**

Prof. G.K. Ananthasuresh, IISc, Bangalore delivering a seminal lecture on **Soft Tuning the Stiffness of Compliant Grippers for characterizing Soft Cells and Hard Rocks**

Prof. Sree Sivakumar, IIT Kanpur taking the audience on a guided tour of **Nanoengineered Smart Materials for Bio and Photonic Applications**

Prof. Chirosree Roy Chowdhury, BESU discussing the **Prospect and challenges of Silicon Micro/Nano Pore Impedance Biosensors**

Prof. Subhasish Bhaumik, BESU speaking on gripping techniques in bio-medical applications

Prof. Rabibrata Mukherjee, IIT Kharagpur exaplining in detail the potential application of soft lithographically patterned surfaces in biological applications

Dr. Tapas Kuila, CSIR-CMERI speaking on the occasion

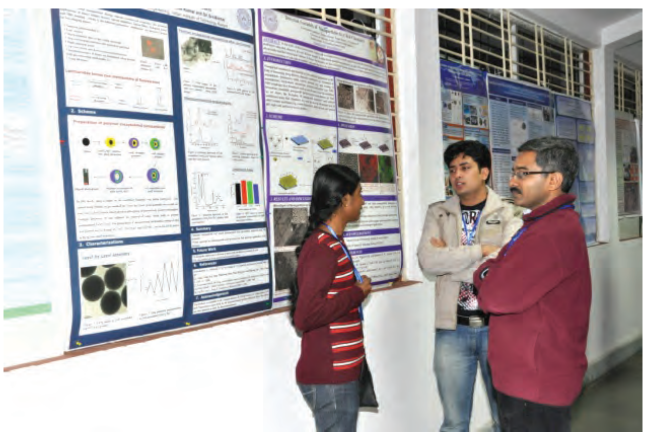
Dr. N.C. Murmu, CSIR-CMERI speaking on **Dip-pen Nanolithography**

Prof. Manidipa Ghosh, NIT, Durgapur speaking on **Dendritic Cell - A Double–edged Sword for Immunotechnology**

Dr. Nagahanumaiah, CSIR-CMERI speaking on the occasion

Prof. Sourav Pal, Director, CSIR-NCL, Pune speaking on the occasion

All the participants



Poster presentation

'Dance of India'

'Chow Dance' presented during the Cultural Evening

'Chow Dance' presented during the Cultural Evening

National Seminar on Advanced Functional Materials (NSAFM-2013)

A **National Seminar** on **Advanced Functional Materials (NSAFM-2013)** was organized by the Center for Advanced Materials Processing, CSIR-CMERI on 24th January, 2013. The Seminar provided a platform for interaction amongst eminent professionals and researchers from both academic and R&D Institutes to discuss exciting advancements in the field of multifunctional materials with improved and novel properties that are of prime importance in the fields of energy, environment, health care, transportation, communication, etc.

Background

The Center for Advanced Materials Processing, CSIR-CMERI was created in the year 2005 to address the challenges in the area of advanced materials. The CAMP embraces Scientists and researchers from different disciplines like Physics, Chemistry, Biochemistry, Biotechnology, Mechanical Engineering, Materials Science and Engineering. The CAMP focuses on research and development in functional and nanomaterials processing for different applications. Development of Dye Sensitized Solar Cell (DSSC), nano hybrid materials for tissue engineering, structural nano composite materials for strategic applications, opto-electronic, advanced magnetic and multiferroic materials for sensor development are other areas of attention.

The Programme

The Programme started with the inauguration of new CAMP Annexe building by the Chief Guest Prof. T. Kumar, Director, National Institute of Technology, Durgapur and the inauguration of Gopal P. Sinha Reading Hall by the Guest of Honor Dr. Gopal P. Sinha, former Director, CSIR-CMERI, Durgapur.

In his welcome address, Prof. Gautam Biswas, Chairman, NSAFM-2013 and Director, CSIR-CMERI enlightened the audience about the significance of materials sciences which is now merging with other areas of technology. In their respective speeches, Dr. G.P. Sinha, Guest of Honour and Prof. T. Kumar, Chief Guest emphasized on the importance of material science in the emerging technological scenario. The Inaugural Session concluded with a vote of thanks offered by Dr. B.N. Mondal, Head, Center for Advanced Materials Processing, CSIR-CMERI.

The Technical Session started with an exciting lecture delivered by Prof. Tapas Chakraborty, IACS, Kolkata on the **Role of Flexibility**

and weak molecular interactions in bistable tautomeric interconversion. Prof. Chakraborty presented studies of low-frequency molecular vibrations and weak molecular interaction on tautomeric conversions in the ground and excited electronic states.

Thereafter, Prof. S. Ram, IIT Kharagpur discussed issues realted to **Nanostructure and its role in shaping functional materials for diversified applications**. He spoke about a new class of nanomaterials and a material of self-confined finite dimension that have unique thermodynamic activities highly determined by the surface, localized surface states and surface boundaries.

Dr. Pathik Kumbhakar, NIT Durgapur explained **Some semiconductor nanostructures for optoelectronic applications**. He discussed about room temperature synthesis of undoped and different metal doped nanostructures of ZnS and ZnO by using the simple chemical precipitation method.

In his lecture entitled **Unusual optical and transport properties of semiconductor and semiconductor-metal nanostructure**, Dr. Mallar Ray, BESU described the potential application of semiconductor based small systems in electronic, opto-electronic, photovoltaic, sensing and energy harvesting devices. Light emitting nanostructured silicon promises to revolutionize present day electronics. He vividly described the fabrication of stable nanodots and nanorods of Si/SiO_2 core/shell structure and Si-Ag hybrid nanocomposites by mechano-chemical technique.

The wide band gap Indium Tin Oxide (ITO) materials possess multifunctional properties according to its cluster size. Prasanta Kumar Biswas, Ex-Chief Scientist, CSIR-CGCRI succintly elaborated a **Study on sol-gel based multifunctional Indium Tin Oxide (ITO) semiconductor** with some typical examples highlighting prospective optical and photonic applications.

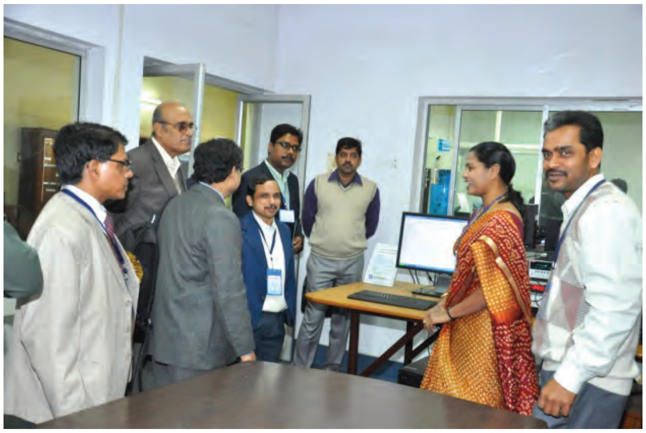
Dr. Kalisadhan Mukherjee, DST Inspire Fellow, CSIR-CMERI explained the **Hydrogen sensing characteristics of wet chemically tailored spinel ferrite nano-structures.** Spinel Ferrites are considered to be attractive for making sensitive, selective and stable hydrogen sensors through a cost effective wet chemical synthesis route. The effective detection of flammable and explosive hydrogen gas has major application in aeronautic, space, automotive and chemical industries.

Dr. Tapas Kuila, DST Inspire Fellow discussed the prospect and challenges of **Chemical fictionalization of graphene and its high performance composites with linear low density polyethylene**.

The seminar also comprised an interesting poster presentation by researchers from different academic institutes and R&D organizations. A. Maity, A. Ghosh and S.B. Majumder, Materials Science Centre, IIT Kharagpur received the First Prize for their presentation of **Portable microprocessor based tungsten oxide thin film gas sensor as a breath analyzer: early diabetic detection as a case study**. **Optimization of Mechanical properties and cytocompability of biomimetic hydroxyapatite for tissue engineering application** by Sudip Mondal, Nilrudra Mandal, Biswanath Mondal, Apurba Dey, CAMP, CSIR-CMERI, Durgapur received the Second Prize while the presentation on **Enhanced Non linear Optical Effects and Tunable Photoluminescence Emission in Cu^{2+} doped ZnS Quantum Dots** by A.K. Kole, P. Kumbhakar, Nanoscience Laboratory, Department of Physics, NIT, Durgapur received the Third Prize.

Prof. T. Kumar inaugurating the CAMP Annexe building

Prof. T. Kumar inaugurating the CAMP Annexe building



Guests visiting the CAMP

Guests visiting the CAMP

Dr. Gopal P. Sinha inaugurating the Gopal P. Sinha Reading Hall

Prof. Gautam Biswas, Director, CSIR-CMERI, Durgapur lighting the Inaugural Lamp

Prof. Gautam Biswas, Director, CSIR-CMERI, Durgapur delivering the Welcome Address

Audience of NSAFM-2013

Dr. Gopal P. Sinha, Former Director, CSIR-CMERI, Durgapur speaking on the occasion

Prof. T. Kumar, Director, National Institute of Technology, Durgapur speaking on the occasion

Prof. Tapas Chakraborty, IACS, Kolkata speaking on the **Role of Flexibility and weak molecular interactions in bistable tautomeric interconversion.**

Prof. S. Ram, IIT Kharagpur speaking on **Nanostructure and its role in shaping functional materials for diversified applications**

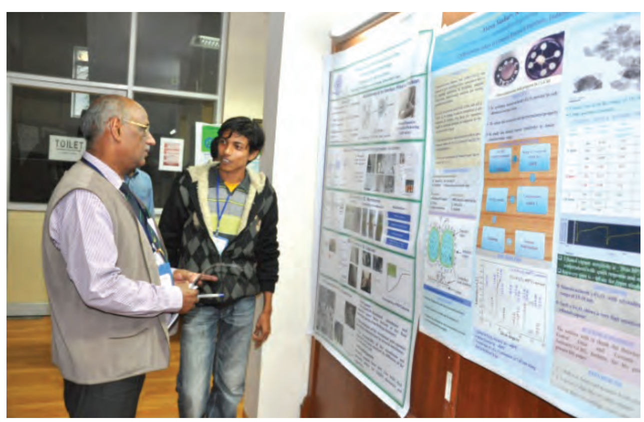
Dr. Pathik Kumbhakar, NIT Durgapur explaining **Some semiconductor nanostructures for optoelectronic applications**

Dr. Mallar Ray, BESU speaking on **Unusual optical and transport properties of semiconductor and Semiconductor-Metal Nanostructure**

Prasanta Kumar Biswas, Ex-Chief Scientist, CSIR-CGCRI elaborating a **Study on Sol-gel Based Multifunctional Indium Tin Oxide (ITO) Semiconductor**

Dr. Kalisadhan Mukherjee speaking on **Hydrogen sensing characteristics of wet chemically tailored spinel ferrite nano-structures**

Dr. Tapas Kuila discussing **Chemical fictionalization of graphene and its high performance composites with linear low density polyethylene**.



Poster presentation

Poster presentation

Prof. S. Ram awarding the 1st prize for Poster Presentation

Dr. Mallar Ray awarding the 2nd Prize for Poster Presentation

Prof. Tapas Chakraborty awarding the 3rd prize for Poster Presentation

CoEFM developed Indigenous MBIU Technology Demonstrated to the Director General, CSIR

It was a historic moment when the technology for **Mobile Bridge Inspection Unit (MBIU)** developed indigenously by CSIR-CMERI Centre of Excellence for Farm Machinery (formerly MERADO, Ludhiana) was demonstrated to Prof. Samir Kumar Brahmachari, Director General, CSIR & Secretary, DSIR on April 6, 2013. The project was sponsored jointly by the Department of Science & Technology, New Delhi and CSIR-CRRI, New Delhi. The MBIU is expected to provide quick, easy and convenient access to the intricate and often inaccessible parts of concrete road bridges and facilitate scientific inspection. The MBIU also accommodates modern gadgets for bridge inspection of the including Non-Destructive Testing kits.

MBIU mounted on Truck chassis in action mode

Currently no such device is available indigenously. A few companies in the world like ‘MOOG’ of Germany and ‘HYDRA’ of U.S.A. are manufacturing MBIUs which are hydraulically operated folding machines and costs in excess of Rs. 7 Crore. Annual maintenance cost of such machines range between Rs. 20-30 Lakh and requires highly skilled manpower. In contrast, the MBIU designed & developed indigenously by CSIR-CMERI, CoEFM, Ludhiana costs only about Rs. 1 Crore. The unit is mounted on a 25 Ton truck chassis. The articulated structure having three rotary and three linear joints are activated individually through PLC controlled electric drives. Adequate safety features have been built in the system keeping in view the operating nature and environment. The MBIU employs an elegant and robust construction. In addition, the maintenance cost is very low and can be easily operated by semi-skilled manpower.

Prof. Gautam Biswas, Director, CSIR-CMERI, welcomed D.G., CSIR and briefed about the MBIU. The Director, CSIR-CMERI, Durgapur also briefed about the current ongoing projects and elucidated his vision for CSIR-CMERI Centre of Excellence for Farm Machinery, Ludhiana. The occasion was graced by the presence of dignitaries like Prof. B.S. Dhillon, Vice Chancellor, Punjab Agriculture University, Ludhiana; Prof. D.V. Singh, Expert, DST; Dr. Sudeep Kumar, Head, PPD, CSIR; Mr. S.S. Kohli, Scientist 'F'/ Director, SERC, DST; Prof. Vedachalam, Former Director, LPSC, ISRO; Prof. S.R. Verma, Ex-Dean, Faculty of Agricultural Engineering, P.A.U., Ludhiana and Prof. V.P. Agarwal from Thapar University, Patiala.

Speaking on the occasion, Prof. D.V. Singh, Expert, DST, expressed his satisfaction in the successful conclusion of the DST sponsored MBIU project and acknowledged the great efforts made by the CoEFM in spite of the limited resources. He also stated that the project, despite different challenges faced on the way, due to the determination of the development team was completed.

Prof. Brahmachari, D.G., CSIR appreciated the efforts of the CSIR-CMERI CoEFM Scientists for developing the MBIU technology. He expressed that the region has vast potential in the manufacturing field because of a spirit of entrepreneurship typical of the region. He desired that the Centre also emerges as a part of the Network of laboratories for Manufacturing Technology. Prof. Brahmachari also inaugurated the renovated building for the **Centre for Precision & Conservation Farming Machinery**. This Centre shall be equipped with state-of-the-art tools like CAD & CAM, advanced manufacturing processes, automation using sensors, PLC and computers in farm equipment. The Centre has developed prototype units such as Precision Planter, Irrigation Scheduler, Inter- row Rotary Cultivator, Cotton Picker Head and Offset Rotavator being developed for orchards are under progress. CoEFM is also working with Agricultural Universities such as PAU. Ludhiana, IARI, New Delhi, G.B. Pant University, Pant Nagar, CICR, Nagpur, CSIR labs, CMERI, CSIO and other institutes like C-DAC, Mohali in the network mode.

While mechanization and Automation in Agriculture has been the thrust area, usage of sensors, computers and automatic systems are likely to enhance productivity and quality. Modern manufacturing tools like CAD, CAM, concurrent engineering, modern and precision manufacturing methods need to be utilized for development and production of Farm equipment.

D.G., CSIR, inaugurating the CPCFM building

Workshop on "Rheo Pressure Die Casting Technology"

Modern industries make abundant use of aluminium alloys, particularly in manufacturing related to automobiles, defence, aerospace, packaging, infrastructure, housing etc. because of its light weight, high strength-to-weight ratio and resistance to corrosion. Conventional processing for aluminium in most cases is carried out either in fully liquid (e.g., sand casting, die-casting) or fully solid (e.g., forging, extrusion) conditions. Semi solid manufacturing (SSM) is a relatively new metal processing technique introduced during the early part of 1970 in which metallic alloys are cast at a temperature lying between the solidus and the liquidus. One of the popular ways to achieve this is by introducing forced convection in the melt during solidification. The strong fluid flow arrests the growth of dendrites by detachment from the solid-liquid interface, thereafter conducting the semi solid matrix into the mould to form slurry. This slurry has fragmented solid particles immersed in liquid, which offers less resistance to flow even at a high solid fraction (~0.5). Subsequently, the semisolid slurry is either cast into parts in a die (the "rheocasting" process) or produced in the form of solidified billets for further processing. Upon solidification of the slurry, the microstructure obtained is characterized by globular, non-dendritic primary phase particles, separated and enclosed by a near-eutectic lower-melting second phase.

Recently, a rheo pressure die casting system has been developed using cooling slope semi solid slurry generation technique at CSIR-CMERI in collaboration with IISc-Bangalore and JU-Kolkata along with Mahindra & Mahindra as Industrial partner under the project entitled **Facility for Rheo Pressure Die Casting**. In this system, semi solid slurry of aluminium alloys can be generated continuously as well as on demand. Moreover, the system can be adapted easily in the existing setup of the pressure die casting industry with little modification.

A workshop was organized on **Rheo Pressure Die Casting Technology** at CSIR-CMERI in association with IISc, Bangalore and Jadavpur University-Kolkata on 25th February, 2014. Around 50 delegates from industries such as Sona Koyo Steering Ltd., Gurgaon and academia attended the workshop. Technical lectures were delivered by the project team and the invited speakers on rheocasting technology including its implementation in Indian industries. The developed rheo pressure die casting system and process was demonstrated live in front of the members by casting a steering knuckle; this was followed by interaction with delegates in the valedictory session. The delegates manifested great enthusiasm about the rheo pressure die casting technology and suggested organizing more training / interactive schedules for participants from industries and academia for knowledge dissemination and awareness generation. The photographs of the workshop are shown below:

Dr. Pijush Pal Roy, Prof. Pradip Dutta, Prof. H.S. Maity and Dr. Rajeev Sharma on the dais

Dr. Pijush Pal Roy, Acting Director, CSIR-CMERI delivering the Inaugural Address

Prof. H.S. Maity, Former Director, CSIR-CGCRI addressing the Workshop

Prof. Pradip Dutta, IISc-Bangalore delivering his lecture

Dr. A.K. Lohar, CSIR-CMERI delivering his lecture

Dr. Rajeev Sharma, DST delivering his lecture

Mr. S. Natarajan, Sona Koyo Steering addressing the Workshop participants

Prof.. Himadri Chattopadhyay, JU-Kolkata delivering his seminal lecture

The Workshop in progress

Live technology demonstration in progress

Live technology demonstration in progress

Prof. H.S. Maity inspecting the developed steering knuckle

Mr. S. Natarajan inspecting the developed steering knuckle

Dr. Rajeev Sharma of the DST, Government of India with the project team members

Activities of the TePP Outreach cum Cluster Innovation Centre (TOCIC)

India is a developing country with an enormous potential of emerging as a knowledge leader in the global scenario. The role of innovation in this context therefore can not be overemphasized, and the Department of Scientific & Industrial Research, Government of India (DSIR) is perfectly justified in reaching out to tap the resource pool of innovation in the country through flagship programmes like the PRISM (Promoting Innovations in Individuals, Start-ups and MSMEs'. Though a major component is devoted to the small and medium enterprises constituting a major plank in the Indian economy, the programme also realizes that development should lead not only to new products and technologies, but also to new approaches to improving the livelihoods of rural poor.

In the development realm there is no such thing as a purely technological innovation, as each innovation entails enabling changes at social, institutional and policy levels. Innovation is needed both to develop new practices and technologies, in order to address rural poverty, and to facilitate an empowering institutional and policy environment for innovation.

The cooperation in innovation between firms in the manufacturing and service sectors, research institutions and government sponsored promotional agencies continues to grow in importance in this emerging paradigm of innovation-catalysed business success and economic growth. Innovation management is also considered to be a major instrument to increase the innovation capacity of small and medium-sized companies (SME).

The goal of the strategy to popularize PRISM is to ensure that innovation is systematically and effectively mainstreamed in processes and in its practice in region and cluster specific programmes. And as an outreach component of the overall programme, the purpose of this strategy is to enhance TOCIC-CMERI'S capacity to work with partners to find and promote new and better products, novel and innovative services and unique ways to enable the rural poor to overcome poverty.

TOCIC-CMERI relies on a promotion strategy intrinsically incremental in nature, that builds on current efforts, and focuses on elements of people, processes, environment and outcomes - which require specific attention. To strengthen its innovative capabilities and become a better catalyst of high technology and society-induced innovation, TOCIC-CMERI proposes to focus on four clusters of activities as under:

- ✓ Building capabilities and understanding of challenges requiring innovation

- ✓ Nurturing partnerships and facilitating an innovation network
- ✓ Embedding rigorous innovation processes and the related risk management into the core practices
- ✓ Facilitating a more supportive organizational environment for innovation

Projected output/outcome/deliverables

- ✓ A strengthened learning in region-specific, sector-specific and country-specific programmes and in regional and thematic networks
- ✓ Development of a better knowledge management infrastructure
- ✓ Fostering partnerships and promoting a supportive organizational culture
- ✓ Effective knowledge management and innovation at the individual, industrial and cluster levels facilitating replication and scaling up of innovation
- ✓ Popularization of PRISM through disseminating knowledge of innovations
- ✓ Evolution of thematic and regional networks and knowledge-sharing partnerships
- ✓ Continued participation in MSME Cluster Level technology promotion initiatives

TOCIC-CMERI has successfully concluded the following Projects:

1. Alternate Growth Medium for Rice Straw Mushroom for increasing production per unit space
2. Electricity from Tidal Waves
3. Portable Microscope Slide Projector (Teaching Aid)
4. Self Propelled Three Row Potato Seeding Device
5. Solar Powered DC / BLDC Motor Operated Kerosene Dispensing Unit with Biometric / Bar-Code Based Access Control for PDS
6. Low Specific Cost Solar Parabolic Dish Concentrator System
7. An Innovative Technology for Recharging Alluvial Aquifers

Four variants of the prototype **Portable Microscopic Slide Projector (Teaching Aid)** innovated by Chandra Narayan Bairagya under the TePP Programme of the Department of Scientific & Industrial Research, Government of India.

Different views of the full scale demonstration unit of the **Low Specific Cost Solar Parabolic Dish Concentrator** – a modular solar dish with a novel receiver for maximum energy harvest innovated by Madan Mohan Reddy under the TePP Programme of the Department of Scientific & Industrial Research, Government of India. The innovation has been shortlisted in all the three categories of the DST-Lockheed Martin India Innovation Growth Programme 2014.

Fully functional prototype of the **Solar Powered DC/BLDC Motor Operated Kerosene Dispensing Unit with Biometric/Bar Code Based Access Control for PDS** innovated by Samir Kumar Neogi under the TePP Programme of the Department of Scientific & Industrial Research, Government of India.

Working prototype of the **Self Propelled Three Row Potato Seeding Device** innovated by Sk. Abdul Aziz under the TePP Programme of the Department of Scientific & Industrial Research, Government of India.

An Innovative Technology for Recharging Alluvial Aquifers: A novel solution for utilizing surface run-off water for recharging alluvial aquifers innovated by Md. Mohasin. Process developed and demonstrated successfully.

Performance Indices