Research, Development and Commercialisation
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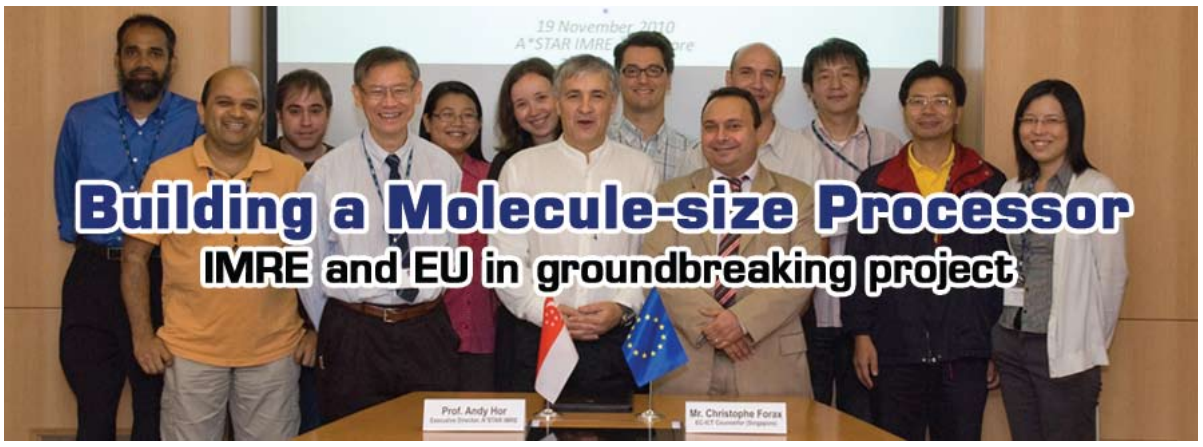
PERSPECTIVES

Institute of Materials Research and Engineering
A*STAR
www.imre.a-star.edu.sg

Creating molecular-sized processor chips

IMRE partners 10 European Union (EU) research organisations to work on the groundbreaking €10 million ATMOL project that lays the foundation for creating and testing a molecular-sized processor chip.



First came the world's first controllable molecular gear. Now, IMRE's scientists will team up with researchers from the EU to build what is essentially a single molecule processor chip. These pioneering steps in atom technology could one day lead to computer processors so small that 1000 such processors could fit into one of today's microchips. Computing power can be increased significantly but take up less than a fraction of the space currently required.

Termed *Atomic Scale and Single Molecule Logic Gate Technologies (ATMOL)*, the project will establish new processes for making a complete molecular chip. The fabrication process involves the use of three unique ultra high vacuum (UHV) atomic scale interconnection machines which build the chip atom-by-atom. These machines physically move atoms into place one at a time at cryogenic temperatures. One of these machines is located in IMRE.

"The UHV interconnection machine at IMRE is one of the three machines in the project that can study the performance of a single molecule logic gate and surface atom circuit logic gate at the moment", added Prof Christian Joachim, who is the Head of Molecular Nanoscience and Picotechnology at the French Centre National de la Recherche Scientifique (CNRS) in Toulouse, and a Visiting Investigator at IMRE. Prof Joachim's team in IMRE was the one that built the first ever controllable molecular gear.

"The work in this project is extremely important in setting the stage for how computer chips and electronics may be made in the future", said Prof Andy Hor, Executive Director of IMRE.

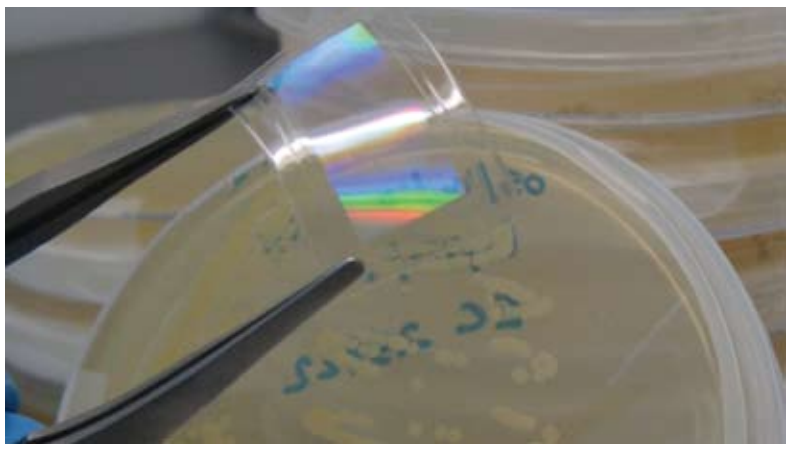
Annual *ATMOL* meetings will gather all the project partners for regular progress updates and synchronisation with the first meeting on atomic scale interconnection machines to be held in Singapore in 2011. The project will officially commence on 1 January 2011.

The tools and the means to make it 'small'

- **IMRE holds the only patent in the world** for making solid interconnections and packaging of a molecular chip.
- **IMRE's one-of-a-kind ultra high vacuum (UHV) atomic scale interconnection machine** can study the performance of a single molecule logic gate and surface atom circuit logic gate at the moment.

Marine mammal-inspired new chemical-free, anti-bacteria plastic 'skins'

The IMRE-led Industrial Consortium On Nanoimprint (ICON) plans to engineer anti-microbial surfaces for use on ships, lenses and bio-medical devices.



IMRE and its partners are working on new technology for making anti-bacteria surfaces

Marine mammals like dolphins and pilot whales that have anti-fouling skins are showing the way in creating new synthetic surfaces that prevent bacteria from attaching. IMRE scientists and their partners from ICON will use locally-developed nanoimprinting technology to create chemical-free, anti-bacterial surfaces on different materials. The surfaces can reduce infections caused by pathogens such as *S. aureus and E. coli* and can be used on a variety of surfaces such as plastics, ship hulls, lenses and medical devices. Conventional methods for preventing bacterial surface attachment may use potentially harmful metal ions, chemicals or UV-radiation.

The research is the centrepiece of the second project launched by ICON, a coalition of A*STAR research institutes, companies and institutes of higher learning that encourages industry adoption of the versatile nanoimprinting technology. Five companies, namely Nypro Inc (USA), Hoya Corporation (Japan), Advanced Technologies and Regenerative Medicine, LLC (ATRM) (USA), NIL Technology ApS (Denmark) and Akzo Nobel (UK) will be involved in this project. This is also the first time that 3 local polytechnics, namely Singapore Polytechnic, Temasek Polytechnic and Ngee Ann Polytechnic are working with the consortium partners, under a special arrangement.

What is nanoimprint technology?

Nanoimprint technology, a next generation nano-lithography, has been re-developed by IMRE to make complex bio-mimetic nanometer-sized patterns on engineering films and substrates. This gives the engineered material 'natural' properties such as luminescence, adhesiveness, water-proofing and anti-reflectivity.

Want to know more about the Industrial Consortium On Nanoimprint (ICON)?

ICON members enjoy a number of advantages:

- Access to the advanced nanoimprint technology and know-how in A*STAR
- Shared R&D resources and costs to develop new products and applications that reduces R&D risks and investments
- Training of manpower in nanoimprint techniques and tools
- Networking with companies that cover the entire spectrum of nanopatterning service

A new project on roll-to-roll nanoimprint technology is expected to begin in the second quarter (Q2) of 2011.
For more details, please contact Mr Rick Ong (Industry Development Manager) at ongr@imre.a-star.edu.sg

CORPORATE NEWS

Talking shop and shopping - Gathering the brightest young minds in nanotechnology

The Asia Nano Forum's (ANF) 3rd Asia Nanotech Camp brought together 40 hand-picked young researchers from the Asia-Pacific region to discuss, debate, network and collaborate on their favourite pastimes - nanotechnology, eating and shopping!

For one week, top young nanotechnology scientists from some 35 universities in 13 countries across the Asia-Pacific region met in Singapore to discuss nanotechnology and experience the cultures of the host nation. Apart from academic presentations on nanostructured materials, and discussions on the impact of nanoscience and nanotechnology on society, the unique camp had a substantial part of the programme dedicated to activities that allowed participants to discover more about Singapore - research-wise, economically and culturally.

Asia Nanotech Camp 2010 at IMRE, Singapore

Participants of Asia Nanotech Camp during one of the presentation sessions

The participants visited local universities, research organisations and companies that made use of nanotechnology research such as Hyflux. Cultural immersion programmes also introduced them to the sights, sounds, diversity, and tastes of Singapore.

"Just as important as the exchange of ideas on research are, the camp allowed the participants to learn more about the culture and lifestyle of people living in Singapore and how R&D impacts that lifestyle", explained Prof Andy Hor, Executive Director of IMRE, whose own nanotechnology R&D includes nanostructured materials, nanocomposites, nanopatterning and nanoimprinting.

Echoing his sentiments, Dr Lim Khiang Wee, Vice-President of ANF said, "The camp is a networking opportunity for these young researchers. This 'peer support group' will be essential to them in the future when they begin to take on their roles as principal drivers of research and innovation in their respective countries".

The camp, organised in Singapore by IMRE from 4-9 October, was just the first leg in a two country journey, with the second leg hosted by *Akademi Sains Malaysia*.

Scanning Probe Microscope (SPM) - From moving atoms to super high resolution surface images of living cells

SPM studies can also help engineer novel techniques to reduce friction between surfaces at the molecular level and further miniaturise electronics.


The word 'IMRE' written with individual gold atoms on Au(111)

Once found only in the domain of physics, now a tool used even by biologists, the unique scanning probe microscope (SPM) can move single atoms in a controlled manner or map the terrain of living cells and allows biologists to obtain high-resolution images of a cell's surface.

The SPM creates extremely accurate atomic-scale resolution images of a specimen's surface by moving an extremely fine metal probe - which is a thousand times less than a hair's breadth - across the surface, one parallel line at a time. SPM is special as it allows biologists to study the surfaces of living cells in their original liquid-filled environments. The SPM was the tool that allowed IMRE scientists to create the world's first controllable molecular gear and secure a place in the €10million European Union (EU) project to build a molecule-sized processor chip.

The versatility of the tool is underscored in a new book edited by IMRE researchers, Dr Johnson Goh and Dr Nikodem Tomczak, and entitled "*Scanning Probe Microscopy*", published by World Scientific Publishing. It showcases Singapore's concerted effort in translating science into technology as well as highlighting the latest SPM research in Singapore, with many of the works looking beyond fundamental science to applications in nanoelectronics, biology and scalable nanolithography. The book was launched at the Singapore SPM Symposium 2010 organised by IMRE on 15 Dec 10.

IMRE's SPM capabilities

- ***Versatility*** - IMRE has more than 10 SPM systems which are used across multiple disciplines, such as physics, chemistry, and biology.
- ***Benefits to Industry*** - Data gained from SPM can be used to benefit the semiconductor industry, advance molecular electronics, control friction between two surfaces at the molecular level and help in further scaling down the size of electronics.

RESEARCH

Publication highlights

Listed below are some highlighted IMRE research publications.

Supramolecular quantum dot (QD) patterns for sensing

Visualizing Resonance Energy Transfer in Supramolecular Surface Patterns of CD-Functionalized Quantum Dot Hosts and Organic Dye Guests by Fluorescence Lifetime Imaging; Small 2010, 6 (24), 2870-2876; A. H. Velders, G. J. Vancso, et al.

Abstract: Colloidal quantum dots (QDs) are bright, long-lasting, light emitting nanoparticles that have revolutionised the field of biological imaging and sensing. In particular, the low photobleaching rates of QDs make them suitable for applications in devices designed for sustained monitoring. However, integrating QDs with sensing devices requires chemical engineering of their surface to provide specific functional groups. In a publication co-authored by IMRE researchers a strategy that combines supramolecular attachment to "molecular printboards" and supramolecular host-guest sensing via a Fluorescence Resonance Energy Transfer (FRET) transduction mechanism using QDs was demonstrated. The QDs had been coated with cyclodextrin, a member of the cyclic sugars family of molecules that can act as hosts in the complexation of small organic molecule guest in the cyclodextrine cavity. To overcome the reversible nature of the supramolecular host-guest binding, multiple host-guest interactions that effectively anchor the QDs to guest-functionalised substrates were needed. Fluorescence Resonance Energy Transfer (FRET) occurs when a suitable energy donor-acceptor pair is brought to each other's proximity to within a few nanometers. FRET systems are therefore ideal for use as nanoscopic optical rulers and proximity sensors because they use the correlation between the energy transfer efficiency and distance between the donor and acceptor. QDs, which have broad absorption spectrum are well-suited for FRET. Using QDs, one can therefore avoid interference between the FRET emission and directly excited acceptor signal.

The research opens the way for devices integrating proximity sensing, e.g. via FRET, that have higher detection selectivity. Such sensors can be used in devices for early detection of diseases and for the monitoring of contaminants in water.

For more information about the publication, please contact:

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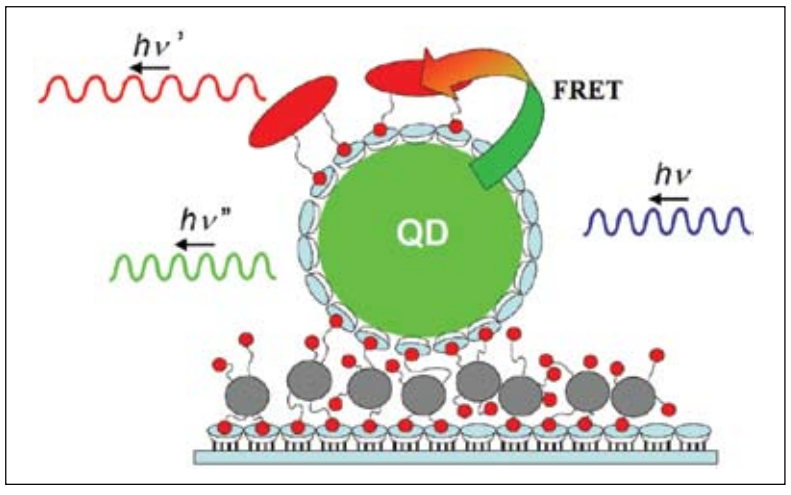

Cyclodextrin-coated QDs are attached to a molecular printboard by using a multivalent supramolecular "glue". Binding of model analytes to the cyclodextrin on the QD surface results in FRET

RESEARCH

A simple 'cap' enables multi-coloured LEDs to be grown on a single chip

The effects of cap layers on electrical properties of indium nitride films; Appl. Phys. Lett. 97, 042110 (2010); doi:10.1063/1.3475400; Wei Liu, Rayson Jen Ngee Tan, Chew Beng Soh, and Soo Jin Chua

The coloured LEDs based on indium gallium nitride (InGaN) quantum wells (QWs) / quantum dots (QDs). The colour changes with the amount of indium in the materials. The improvement of InN material quality by capping will lead to high quantum efficiency for long-wavelength LEDs and make it possible to fabricate monolithic multi-coloured and white LEDs.

Abstract: IMRE has developed a new fabrication method that significantly improves the material properties of indium nitride (InN), which enhances the performance of InN-based light emitting diodes (LEDs). By simply placing an additional thin layer of semiconductor material, or a 'cap', on the surface of InN thin films during the growing process, surplus electrical charge can be effectively displaced. This results in improvements in material performance such as the electron density, which decreased from 3.5×10^{19} to 5×10^{18} cm^{-3} and electron mobility, which increased from 4 to 457 $cm^2V^{-1}s^{-1}$. This can be explained by assuming the film consists of a surface accumulation layer and a bulk layer. It was found that the accumulation layer could be eliminated by capping the surface with silicon nitride, gallium nitride or zinc nitride of 2 nm each, respectively; while an aluminum nitride (AlN) cap layer caused the formation of two-dimensional electron gas at the AlN/InN interface.

The innovative capping allows the creation of more efficient nitride-based LEDs across the whole visible spectrum. More importantly the research will make it possible to grow LEDs of different colours on one semiconductor chip and in a single growth process.

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New 'coat' for water-soluble quantum dots (QDs) helps enhance stem cell labelling

IMRE researchers have patented a new coating and bio-conjugation method for QDs for use in stem cell labelling.

Organic dyes are currently used to label stem cells but QDs may prove to be a better alternative because of its longer fluorescence stability. QDs are basically semiconducting nanocrystals exhibiting size-dependent optical properties that have a wide range of applications, from solar cells to bioimaging. The synthesised QDs are soluble only in organic solvents. The QDs have to be coated with hydrophilic ligands to make them water-soluble so that they can be used in biological applications. This has been shown to be the biggest challenge as conventional coating (surface functionalisation) of the QDs resulted in some loss of fluorescence, making the labelling less effective.

IMRE scientists have developed a peptide coating method which prevents loss of fluorescence and produces QDs with a high quantum yield. This method also enabled the researchers to label the nucleus of stem cells.

The nucleus labelling is important in targeted drug delivery applications as it allows researchers to anticipate the passage of drugs to the nucleus via actin filaments during the drug delivery process. The labelling of stem cells is an important area in regenerative medicine.

For more information about this patent, please email

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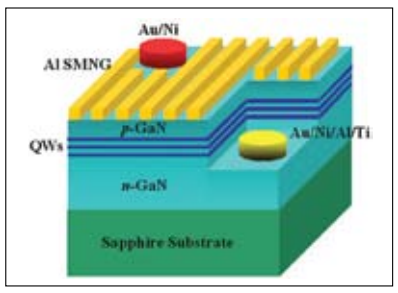
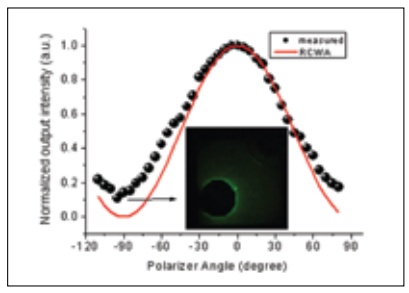
Unique light emitting diodes (LEDs) that produce polarized light

New invention produces polarized light from a conventional InGaN/GaN LED structure by using a sub-wavelength metal grating (SWMG) and does away with the need for additional polarizer in LED display and imaging devices.





Schematic diagram of a polarized LED with SWMG (far left) and EL intensity versus polarizer angle with inset image of polarizer at extinction position (left).

LEDs are quickly becoming the primary light source in LCD back lighting panels and other displays and imaging applications. An additional polarizer is currently needed to convert LED light as conventional LEDs produce non-polarized light. Direct polarized light emission from LEDs helps reduce costs and the profile of display devices by removing the need for the extra polarizer. Several methods have been reported before, such as using photonic crystals or non-polar or semi-polar substrates, but these are poorly suited for the mass LED products market due to complicated designs, low tolerance to change, low polarization ratio and high cost.

IMRE has developed a simple method for creating a polarized LED made from a conventional InGaN/GaN LED structure by using a sub-wavelength metal grating (SWMG). The SWMGs have proven to be easier to fabricate and integrate with LED structures. The new devices are also much less sensitive to wavelength and device parameters than LEDs created using the photonic crystal method. The extinction ratio that can be achieved is also potentially much higher. The process itself is compatible with conventional LED fabrication methods such as the flip-chip LED for high power devices and for membrane LEDs formed by lifting them off the sapphire or silicon substrate.

Apart from the thriving LED backlighted LCD TV market, the new, easy-to-make polarized-light LED has the potential to make an impact on pico-projectors and imaging devices. The technology is also compatible with current industry manufacturing processes.

For more information about this patent, please contact:

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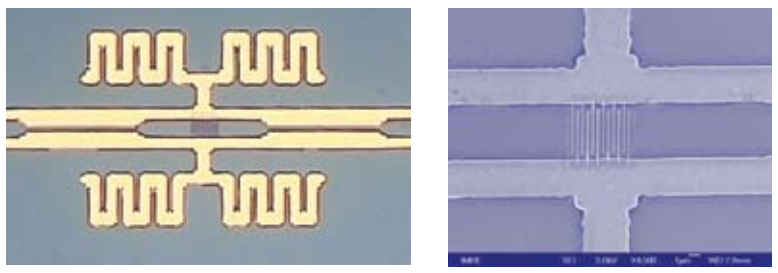
Giving a boost to terahertz (THz) emissions

New patented method enhances the efficiency of photoconductive antenna (PCA) terahertz (THz) photomixers and increases the output power of such devices.

There are very few sources capable of producing continuous wave (CW) THz radiation at room temperature, with PCA THz photomixers being one of the best choices to date. By 'mixing' two separate laser beam sources with frequency differences in THz range, continuously tunable THz frequency waves can be transmitted or received using the PCA.



Optical image of the dipole antenna (left) and the SEM image of nano-electrode in the active region of the PCA (right).

IMRE researchers have enhanced THz emissions by changing the configuration of the active region electrodes. The new configuration aligns the nano-antenna and the dipole antenna in the same direction which greatly enhances the electric field intensity in the active region. This results in higher photocarrier density and higher THz wave emission efficiency.

Current PCA THz photomixing emitters suffer from low efficiency and generate low power emissions due to the way the electrodes on the devices are configured. Interdigitated electrodes in its active region, which are the current sources for the planar THz antenna, have the nano-antenna oscillation direction perpendicular to the dipole antenna direction, thus reducing the overall device efficiency. The capacitance of the circuit is also large because of the large space between finger electrodes making the device unsuitable for high frequency operations.

Unlike high energy, penetrating X-rays, THz waves have just the right frequency and energy that oscillates with many molecules and penetrates material like paper, plastic or fabrics making them useful in non-invasive or non-harmful imaging and sensing technologies. Continuous wave (CW) THz waves are becoming increasingly important in security, sensing and imaging applications as they can produce high spectral resolution images, have fast response, have frequency tuning capability and are low cost.

For more information about this patent, please contact:

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AWARDS

2010 AsiaNANO Young Researcher Award

Dr Tan Yen Nee was one of the winners of the AsiaNANO 2010 Young Researcher Award.

IMRE's Dr Tan Yen Nee, a Research Engineer with the Materials Characterisation and Analysis group, was one of the winners of the 2010 AsiaNANO Young Researcher Award at the AsiaNANO meeting held in Japan from 1-3 November 10. The award, which is in recognition of outstanding papers authored by young researchers and presented at the conference, was given out for her presentation on *"Gold Nanoparticles-based Biosensor"*.

From aerospace, food packaging to armour: New age composite materials developed for a variety of industries

IMRE showcases polymer and nanocomposites R&D for new transparent high-barrier film packaging, low dental shrinkage materials, anti-scratch coatings, aerospace carbon-fibre reinforced polymers and soft, high-impact resistant protective padding.

Made from two or more physically and chemically distinct materials, engineered composites are versatile materials that have been used to produce anything from lightweight, high-strength plastics for aircraft to barrier films for food packaging. IMRE showcased its composites R&D at the JEC Composites Show Asia 2010 at Suntec Convention Centre, Singapore from 12-14 October 2010.

IMRE's booth at the JEC Composites Show Asia 2010

The composite technologies included:

- **New transparent polymer films** - Keeping food fresher for longer
- **Soft, lightweight, flexible composite** materials that harden on impact for use as protective armour
- **Strong, light and low-cost carbon-fibre reinforced polymers (CFRP)** - A fraction of the weight, many times the load
- **Anti-scratch coating** to protect optical, camera and spectacle lenses
- **High performance, low shrinkage dental nanocomposites** for prevention of tooth decay

Reaching out to secondary school students

6 & 9 Sep 10

Two groups of secondary schools students were given a tour of IMRE's laboratories and a briefing on some of the R&D done here. Some 30 Secondary 3 students visited IMRE on 6 Sep 10 in an event organised by the Science Centre Singapore. Separately, the Institute of Engineers Singapore (IES) and A*STAR arranged for nine secondary school students to visit IMRE on 9 Sep 10 in conjunction with the National Engineering Carnival. The students were introduced to research life and R&D in IMRE and visited the biosensors, nanoimprint, chemical synthesis and Scanning Tunnelling Microscopy laboratories.

Some of the secondary school students being briefed on IMRE's R&D

IMRE Workshop on Characterisation of Photovoltaic Materials and Devices

Prof Andy Hor, IMRE's Executive Director, opening the joint IMRE-AIST-JST-NMC workshop

13 Oct 10

The workshop by IMRE, National Institute of Advanced Industrial Science and Technology (AIST), Japan Science and Technology Agency (JST) and A*STAR's National Metrology Centre (NMC) introduced and expanded upon the key techniques involved in PV characterisation. Some 160 participants attended the workshop that looked at ways to better understand the fundamentals of power conversion from solar light and to improve solar cell efficiencies.

Top company executives from Japanese companies tour IMRE

IMRE hosts top Japanese company executives at an event for the Japanese Chamber of Commerce and Industry

13 Oct 10

IMRE hosted 20 senior management executives of Japanese companies for a tour organised by the Japanese Chamber of Commerce and Industry. An in-depth briefing of IMRE's R&D capabilities, opportunities for collaboration, tour of the facilities and networking session was arranged for the attendees who included Managing Directors and General Managers from chemicals and materials-related companies such as Mitsui Chemicals, Toray International, Sumitomo Seika, Sekisui Plastics, Nagase and Teijin Polycarbonate.

IMRE Workshop on Biosensors for Medical Diagnosis, Environmental Monitoring and Fundamental Research

28 Oct 10

The workshop aimed to demonstrate how new materials, advanced microfabrication technology and nanotechnology have led to highly integrated and miniaturised biosensors / sensor systems with excelled performance. Some 100 participants attended the workshop that served as a platform for the biosensor R&D community to interact, identify technical challenges and gaps between research and product development, and to develop commercialisation strategies.

IMRE Workshop on Atomic Layer Deposition (ALD) and Its Applications

Participants networking at the ALD workshop

23 Nov 10

IMRE, in association with Beneq and Azimuth Technologies, organised the workshop to introduce recent ALD developments, particularly its novel applications as well as its equipment and precursor design for such applications. Some 80 attendees were treated to presentations by invited speakers from Beneq, Picosun, NUS, NTU, and IMRE.

IMRE Symposium on Organic and Polymer Electronics

9 - 10 Dec 10

More than 100 participants attended the symposium where some of the world's top organic electronics scientists and industry players converged to discuss new materials, research and techniques that will advance the manufacturing of affordable and versatile plastic electronics. A range of topics were covered including new materials, theoretical studies, and device fabrication and characterisation of organic light emitting diodes, organic photovoltaics and organic field effect transistors.

Participants at the Symposium on Organic and Polymer Electronics

IMRE Workshop on Magnetic Materials and Characterisation

13 Dec 10

The workshop showcased the capabilities for magnetic characterisation and modelling in IMRE, A*STAR Institute of High Performance Computing (IHPC) and NUS and provided a platform for researchers to share their experiences in characterisation techniques for measurement of magnetic properties of a variety of magnetic materials.

3rd Singapore Scanning Probe Microscopy Symposium (SingSPM 2010)

15 Dec 10

Organised by IMRE, SingSPM 2010 aimed to promote Singapore's SPM research and foster international interactions by featuring internationally renowned keynote speakers in the field of SPM. More than 70 participants attended talks by SPM practitioners who presented their research, which ranged from novel instrumentation to applications in biology, and featuring special talks highlighting technology areas where SPM can create impact. In addition, this year's SingSPM 2010 saw the launch of a new book on *"Scanning Probe Microscopy"* co-edited by IMRE's Dr Johnson Goh and Dr Nikodem Tomczak.

UPCOMING EVENTS

Diary of upcoming events @ IMRE

10 – 11 January 2011
Molecular Materials Meeting (M3) @ Singapore
Biopolis, Singapore

12 January 2011
IMRE – Hong Kong Baptist University Workshop
IMRE, Singapore

21 January 2011
Singapore - Kyoto Forum on Nanotechnologies and Engineering for the Green Future
IMRE, Singapore

To find out more about IMRE's seminars and events, please visit www.imre.a-star.edu.sg/eventsall.php

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