MRS Meeting Scene...
Presented by the Materials Research Society
A Publication of the Materials Research Society
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ICMAT 2011—International Conference on Materials for Advanced Technologies

Suntec, Singapore
June 26 - July 1

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## MEETING DAY 1, Monday, June 27

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A professional troupe of Singapore Lion Dancers greeted attendees with a spectacular, acrobatic performance at the Opening Ceremony of the Sixth International Conference on Materials for Advanced Technologies (ICMAT) in Suntec, Singapore today. With drums booming, the lions danced and balanced on elevated poles in the front of the ballroom auditorium before the Guest of Honor, Lim Hng Kiang, Minister for Trade and Industry, Singapore; Tan Chorh Chuan, President of the National University of Singapore; and B.V.R Chowdari, Organizing Chairman of the ICMAT Conference, also from the National University of Singapore. The audience applauded loudly at the stunning spectacle, which launched the conference in great style.

ICMAT, sponsored by the National University of Singapore and Nanyang Technological University, is a week long conference with 40 symposia and nine Plenary talks, including four from Nobel Laureates Albert Fert, Ada Yonath, Andre Geim, and K. von Klitzing. WIth such a distingusihed list of speakers, it promises to be a fantastic conference.


The Lion Dancers

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## Opening Ceremony


B.V.R Chowdari, Organizing Chairman of the ICMAT Conference (left) and Tan Chorh Chuan, President of the National University of Singapore (right), watch as Lim Hng Kiang, Minister for Trade and Industry, Singapore, hits the gong to signal the official start of ICMAT 2011.

"I'm pleased and honored to welcome you to the Sixth ICMAT 2011 on behalf of MRS Singapore," Dr. B.V.R. Chowdari, Organizing Chairman of ICMAT, said by way of introduction. He noted that since 2001, ICMAT has developed a reputation as a respectable forum for the presentation of scientific information, as evidenced by the more than 10,000 attendees and 16 Nobel Laureate speakers the conference has attracted in just six meetings. This year's conference features 40 symposia, nine plenary talks, three theme lectures, and also two public lectures on the University of Singapore campus. Chowdari welcomed the more than 3,200 attendees from all over the world, and the 68

companies that are exhibiting here, before thanking the long list of sponsors who made the conference possible.

The next speaker, Dr. Chorh Chuan Tan, President of the National University of Singapore, said he was "priveleged and honored to be part of this conference, " because "advances in materials science research lie at the heart of development in many fields." He was pleased to note the attendance of the French Ambassador and the Indian High Commisioner at this inaugural ceremony of the conference.

Finally, the Guest of Honor, Lim Hng Kiang, Minister for Trade and Industry, Singapore, spoke about how "Research and development is the cornerstone of Singapore's transformation to a knowledge and technology-based economy." He broke the news of a $16.1 billion (Singapore dollars) Research, Innovation, and Enterprise 2015 (RIE 2015) fund, which will provide funds over the next five years to achieve research and development goals. The initiative's intention is to "support mutidisciplinary and breakthrough science," he said, "while taking ideas from research to commercialization." Materials science is a key research area under RIE 2015. "Conferences such as ICMAT play a significant role," Kiang concluded," by focusing minds on developing solutions for global problems through multidisciplinary research efforts."

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## ■ First Plenary Lecture: Albert Fert on Spintronics

Albert Fert of the Unité Mixte de Physique CNRS/Thales and the Université Paris-Sud (Orsay) followed the Opening Ceremonies with an enlightening talk on the "Challenges and Emerging Directions in Spintronics." Fert received the Nobel Prize in Physics in 2007 for the discovery of the giant magnetoresistance (GMR) effect, which he described as "only a single stage in a much longer process." GMR led to spintronics, Fert said, and spintronics could lead us to such mind bending devices as neuromimetic components to hardwire the brain.

GMR has had the most success in the read heads of hard disks, where it has made possible a density of 800 Gbit/ in$^2$. Tunneling magnetoresistance (TMR) is replacing GMR througfh its grid structure of perpendicular bit and word lines. TMR aims to increase data density and reading speed in an non-volatile manner, thus reducing the energy consumed in refreshing volatile memory types.

TMR will be replaced by spin transfer torque (STT) RAM, according to Fert. In this method, the transverse component of the spin current is absorbed and transferred to the total spin of the layer, which allows switching times of 0.1 nanoseconds. STT-RAM offers the advantages of local addressing, smaller current, and decreased energy consumption.

Fert also covered spin transfer induced vortex generation, which involves a vortex induced by out-of-plane spin-polarized current, and spintronics with carbon nanotubes and graphene components. He envisions the possibility of quantum computing with graphene spintronics. Eventually, he says we will have to go to "pure spin" devices. Pure spin is the current -based transport and processing of data, with splitting between the Fermi energies of spin-up and spin-down electrons. This is all leading to "memristors" for brain-inspired computing. At CNRS/Thales, Fert and his colleagues are working on spin memristors--neuromimetic components with synaptic plasticity. It's enough to make one's brain spin at the possiblities.

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## First Theme Lecture: Jonathan Adams

Jonathan Adams of Thomson-Reuters, UK, gave researchers a glimpse into "what happens to the papers you publish," in his talk entitled "Evidence-based Insights into the Global Trend and Hot Spots of Research in Materials Science." The Director of Research Evaluation at Thomson-Reuters, Adams and his colleauges have been studying scientific publishing trends through the "Web of Science" for years, and have developed the report that this talk was based on to determine how global trends affect the publishing environment.

"Materials science is one of the fastest growing areas of science and technology," Adams said. "The number of papers in materials science is growing more rapidly than papers in other areas."

What is changing most is the geographic distribution of the authors of these papers. By examining data from approximately 11,500 leading journals, Thomson-Reuters has quantified what might seem obvious to the scientific community. Specifically, the Asia Pacific area is growing most rapidly, and has "by far the largest bloc of materials research activity," Adams said. From 2005 through 2009, China published approximately 53,000 papers on materials science, compared to 38,000 for the United States, 25,000 forJapan, and 17,000 for Germany. In Asia Pacific, China publishes approximately 14,000 papers per year in this field, compared to Japan's second-place 4,000 per year. But while Asia is the prolific, the United States is still the most cited, although Adams expects that to change in the near future.

Angles and light inside the conference center

## ■ Technical Talks

### Symposium A - Nanostructured Oxides, Interfaces, Heterostructures and Devices

*Mist Deposition Technique as a Green Chemical Route for Oxide Thin Films and Nanostructures*
With the development of mist-deposition thin-film growth, Shizuo Fujita of Kyoto University, Japan, says that many functional materials can be grown in a "green" fashion. He pointed out that oxides are abundant, safe, and cheap, all important qualities for implementation in "green" technologies. Combine oxides with "green chemistry," which doesn't require vacuum systems, produces less waste and requires lower temperatures than conventional growth methods, and there is potential for real environmentally friendly technology.

Fujita described several approaches to the mist deposition technique, in which particles of solvent mist carry source precursors to a substrate surface. An ultrasonic transducer is used to get the heavy precursors, such as Zn, into mist particles. Using these techniques, Fujita and coworkers have successfully grown oxides of numerous elements, including most of the the first-row transition metals, as well as organics such as PEDOT:PSS. As an example of their successes, Fujita showed results for mist-deposited polycrystalline ZnO thin films, from a collaboration with Mitsubishi and Toshima, where some advances in the process resulted in films with good resistivities. Single crystal ZnO films were also achieved by growing on ZnO substrates, with uniformity and resistivities that compare reasonably well with those grown by MOCVD. He points out that these growth techniques are suitable for large areas, not accessible to spin-coating, and for roll-to-roll processing.

*Manipulating Strongly Interacting Electrons by the Interface in Heterostructures of Complex Oxides*
Why do we need interface-controlled materials? Jak Chakhalian, of the University of Arkansas, answered his question by demonstrating some of the numerous "handles" that interfaces provide for manipulating thin film properties. He gave a whirlwind tour of several examples of interface-controlled systems, highlighting the work from his group in film growth and spectroscopy. For example, in $YBa_2Cu_3O_{7-d}$ and $La_{2/3}Ca_{1/3}MnO_3$ superlattices, they found that orbital reconstruction and chemical shifts at the interface led to the highly unusual ferromagnetic configuration of Cu. For a system of and $CaMnO_3$, Chakhalian presented spectroscopic data indicating that spin-canting magnetism arises from a competition between antiferromagnetism and super-exchange. (In his own words, this one slide represented two years of someone's life.) In that system and several others, Chakhalian showed that they were able to grow and study some of the intriguing systems proposed by theorists in the realm of strongly correlated materials. In concluding, Chakhalian stated that correlated interfaces can provide control over cohesive energies and covalency, access to new magnetic ground states, manipulation of orbital symmetry and spin interactions, charge doping without chemical disorder and the engineering of new quantum states. "With further advances in growth and characterization," he said, "the only limit is our imagination."

Rubber arms reach out in greeting from a glove box
at the Charleston Technologies booth at the Exhibition

**Symposium B: Synthesis and Architecture of Nanomaterials**

*Colloidal Chemical Approaches toward Inorganic Nanomaterials with Controlled Architectures*
Traditionally, gold has been used as a model system for colloidal crystals due to its resistivity to corrosion, ease of nanoparticle synthetic routes, and wide variety of potential applications. The main methods of shape control are through surfactant and ligand choice, as well as carefully controlled reduction reactions. Limin Qi of Peking University presented several methods of obtaining different nanostructures of gold, including belts and combs by mixing of ligands, leaf-like

dendritic structures with ionic liquids, as well as porous nanobelts and thorned plates by carefully adjusting surfactants during synthesis. These colloidal crystals can be used by themselves for applications or as templates for other functional nanomaterial growth.

Qi explained how they are fabricating highly crystalline and porous $TiO_2$ nanoparticles with acetic acid and arranging them into patterns. Then they use the primary particles with metal-ionic liquids to create templates. For example, a hexagonal array of particles would leave behind a honeycomb structure, or "nanonet," after being reacted with a metal ionic liquid. Essentially the researchers are using the space around a nanoparticle or colloidal crystal as a reaction vessel; this leaves the desired nanostructure's shape to be determined by the starting particle assembly. His research team calls this "nanosphere lithography," as they are using the particles to synthetically etch out a pattern. They were able to make nanonets, honeycomb structures, and nanostar or nanorod arrays, as well as others. According to Qi, some of these $TiO_2$ nanoparticles and secondary template structures are already being used to improve Li-ion battery performance.

Members of the lion dance troupe out of costume--almost

## Symposium J: Nanoscale Patterning, Assembly, and Surface Modification

*Self-assembly of Nanoscale Particles*

Although there are countless technology applications for self-assembled structures comprised of individual nanoparticle building blocks, the mechanism behind self-assembly is not so clear. Self-assembly typically occurs when a stable system is pushed from equilibrium by an external factor, such as the crystallization of ionic salts during liquid evaporation. In an eloquent manner, Nicholas Kotov of the University of Michigan put self-assembly of colloidal particles into perspective. Classic colloidal systems are stabilized by a balance of electrostatic repulsion and van der Waals attraction (dipole attraction). Kotov explained that typically in metallic nanostructures, a dipole moment causes self-assembly; for example, tetrahedra do not possess a dipole moment due to their innate symmetry, however a slightly truncated tetrahedron has a dipole and many can thus crystallize into rod-like shapes.

This might seem trivial; however Kotov expanded this idea to the processes by which many biological systems self-assemble. Proteins, viruses, and amyloid peptides (which are responsible for neurodegenerative diseases such as Alzheimer's) can self-assemble due to dipole interaction. Surprisingly, these biological entities are governed by the same mathematical equations as their metal and semiconducting nanoparticle counterparts. However, as was pointed out, this can be used to improve on nature's design; it was shown that lower nanoparticle concentrations than human protein concentration was needed to inhibit amyloid fibril formation and polymerization. By understanding the effects of charge (dipole interaction), one can improve on nature's design.

*Functional Nanostructured Materials by Self-assembly*

An interesting report on a novel self-assembled nanoparticle was presented by Yadong Ying of UC Riverside. In most nanoparticle synthesis methods, nanoparticle stability is conferred by a layer of protecting material. However, simply adding a stabilizing molecule will not give a desired chemical effect. In order to sidestep this inconvenience, Ying and coworkers synthesized host oxide particles coated with a layer of silicon dioxide, and then assembled particles onto this scaffold. Titanium, nickel, and copper oxide were all confirmed to behave in this manner. When particles are absorbed to the host particle surface like this, the overall structure becomes highly porous, which drastically alters many of their properties, such as water solubility.

This method is quite different than more traditional solution-based nanomaterials syntheses because the synthesis of the particles occurs on other host particles. Yin then elaborated on the use of these porous nanoparticles for biomolecular transport and catalysis. The functionalization of the host-particle provided the flexibility needed to synthesize various coated nanoparticles.


Bird's eye view of milling attendees

**Symposium K: Nanotechnology with Soft Matter**

*Design of Non-disruptive, Free-standing Monomolecular Membranes for Biological Applications*
Self-assembled monolayers (SAMs) are frequently used in surface chemistry because functionalized SAMs are highly versatile. Hydrophobic, hydrophilic, and specific moieties can be introduced to a SAM, which when assembled on the surface, bestow their tailorable properties to the substrate. Here, Michael Zharnikov of Universität Heidelberg describes the fabrication of an ultra-thin free-standing film which is protein repellent.

Naturally, a large hurdle to overcome in protein and cellular characterization is the high affinity for many proteins and cells towards a hydrophilic substrate. The membranes themselves usually bind the biological particles, making obtaining an accurate measurement difficult. By coating 30-300 nm thick gold films with oligo(ethylene glycol)-based molecules, polymethymethacrylate, and then dissolving the gold film, a semi-robust thin film, which is highly protein repellent, was fabricated. Due to the chemical surface reactivity and its small thickness (< 5 nm), these membranes are ideal for transmission electron microscopy of proteins and cells. The membranes are not only protein-repellent, but they are also electron transparent. For example, these methods will help improve protein characterization by permitting the use of TEM and electron beam templates.

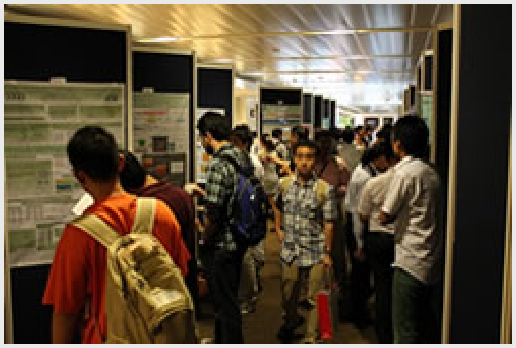
*Small Molecules Control the Surface Structure of Metal Nanocrystals*
The catalysis community is intensely interested in the role that nanoparticle surfaces play in the adsorption and reaction of small molecules. Due to the naturally high surface area of a small nanoparticle, nanocatalysts have seen an explosion in research and development. However, catalysis is complicated at the nanoscale, as it is both size-dependent and material dependent. For example, the pioneering work of Masatake Haruta has broken the long-standing wisdom that platinum is a better catalyst than gold. In fact, on the nanoscale gold outperforms platinum by orders of magnitude in some cases. Professor Nan-Feng Zheng of Xiamen University proposed an interesting hypothesis: since nanoparticle size and structure determines the likelihood for a molecule to be adsorbed, is it possible that adsorbed small molecules have an effect on the surface structure of the catalytic particle?

The answer is yes. Zheng and students used iodine as an example to show this. By making nanorods with and without iodine ions, they were able to control the surface roughness, and also decompose rods into individual nanoparticles. Also, carbon monoxide, a common chemical oxidized by nanoparticle catalysts, was shown to stabilize the [100] crystal plane, thus enabling the synthesis of six-sided nanocubes. Other "small molecules" were used to generate very thin nanowires, ultrathin nanohseets, or hollow nanocubes. One particularly interesting product was the synthesis of "Pd blue" which has large light absorbance in the infrared wavelength, despite its small size. When injected into cancerous tumors in rats and illuminated with ~800 nm laser light, the cancer cells were killed.


Smiling, friendly exhibitors

**Symposium L: Spintronics-I**

*Optical Vortex Beam for Perpendicular Magnetic Recording*
Guillaume Vienne of the Data Storage Institute, Singapore, and his colleagues are using simulations to study opto-magnetic effects for all-optical magnetic recording (AOMR). They are trying to take advantage of the inverse Faraday effect, in which a permanent *H* field is induced by an oscillating *E* field. Basic requirements include a large *H* field that is concentrated in space and is mostly perpendicular to the recording surface ($Hz >>> Hx$, $Hy$). Initial studies showed that a circular polarization at 4.4 Tesla can produce a beam that is mainly perpendicalar to the surface. However, they later discovered that a vortex beam with azimuthal polarization can give rise to a magnetic field that is perpendicular, eliminating the need for circular polarization. The need to keep the beam focused to a diameter no larger than 10 nm means that this technique would require optical nano-antennas to function.

A full house for a popular lecture, and students getting ready for a poster session

**Symposium N - Advanced Materials for Energy Storage Systems - From Fundamentals to Applications**

*The Materials Genome: A Large -scale Computational Assessment of Phosphates as Cathode Materials for Li Batteries*
Kicking off the symposium on materials for energy storage, Gebrand Ceder showed some fresh results on the battery material $LiFePO_4$. He introduced the topic by pointing out that, even after all these years of progress in first principles calculations, kinetics still pose a special challenge. That said, he proceeded to demonstrate that computational materials science can shed light on

complex, kinetic systems.

The new work Ceder shared calls into question the conventional model for lithium intercalation in $LiFePO_4$ cathodes. The process is typically thought to involve nucleation and growth of nanoparticles, but Ceder pointed out that such processes are not compatible with the high transformation rates achieved in this material. His group at MIT studied the system with a combination of first-principles calculations, cluster expansions, and molecular dynamics simulations. They calculated the mixing energy as a function of Li concentration and found that a mere 30 meV of overpotential is required to access the solid solution, and furthermore that neighboring nanoparticles go through the solid solution sequentially, one giving up all its Li before its neighbor begins to de-lithify. The absence of nucleation in this model is much more compatible with the high transformation rates observed. Ceder concluded with the intriguing question of whether this model can be extended to other fast two-phase systems.

In addition, Ceder showed a sampling of data from the Materials Genome Project. The project has thus far generated and compiled data for over 25,000 compounds, focusing on potential electrode materials. To demonstrate the power of the approach, Ceder discussed some of the results comparing the stability of a range of oxides and phosphates. Though conventional wisdom holds that phosphates are much safer than oxides, his data mining found that oxides are only moderately less stable than their phosphate counterparts at a given voltage. It is worth noting that in the future the project will go by a new title, as the group ceded the name to a new US government program called the Materials Genome Initiative.

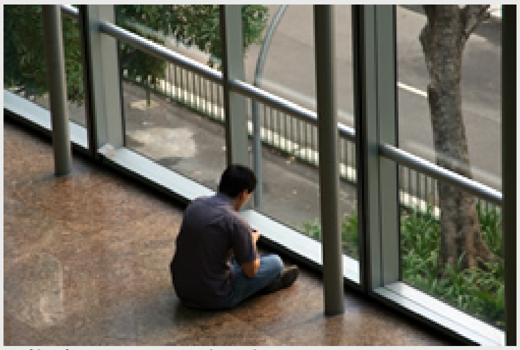

Around the balcony

## Symposium S: Trends in Metamaterials

*A Roadmap for Metamaterials*
Nikolay Zheludev of the Optoelectronics Research Center, University of Southampton, United Kingdom, decided to take a detour from his "roadmap of metamterials" and talk about his own work, which is comprehensive enough in itself to be a good survey of the field. His first goal is the development of non-linear, switchable metamaterials for all-optical data processing, storage, and telecom switrching. He defined the ultimate non-linear medium as one in which "all atoms within the light absorption length absorb a photon." Zheludev counts four possible paths toward his goal: (1) hybrid metamaterials consisting of a non-linear medium plus a plasmonic metamaterial; (2) a phase change material plus a plasmonic metamaterial; (3) a reconfigurable metamaterial that can change size mechanically; and (4) a flux quantization metamaterial. Various materials he has considered and investigated are carbon nanotubes with plasmonic metamaterials, which could provide good positional control of plasmonic resonance; graphene coupled with a metameterial; gold non-linear metamaterials, which could be ultrafast and tunable; and superconducting metamaterials. For the reconfigurable devices in point (3) above, Zheludev is considering the reconfiguration of photonic metamaterials in syuch a way that whole rows in an array change position through electrical stimulation. YBCO and niobium supercomputing metamaterials are also possibilites because of their extraordinary transmisson capabilities and Fano resonances.

*Using Light to Attract*
Che Ting Chan of the Hong Kong University of Science and Technology took the audience on an exploration of whether light can attract particles, like the "tractor beam" in *Star Trek*, or whether

the momentum of photons cause them to always push particles away. Optical tweezers control a particle by trapping it, but this is not thjhe same as pulling it, he said. Plane waves of light cannot attract because incident photons have a greater momentum than a scattered photon, resulting in a positive, "pushing" force. In this theoretical investigation, Chan and his colleagues determined that using light to pull is difficult but not impossible. For example, light can attract some metamaterial particles with simultaneous electric and magnetic responses. Also, propagation invariant beams can exert a pulling force under certain conditions. For instance, when a dielectric particle is trapped in the center of a propagation invariant beam, the force is negative (attractive) in some cases. Theoretically a particle could be miles away, but more practically, scientists might want to start by looking at the near field using optical forces between parallel plates to try to attract a particle using light.



A little peace and quiet

**Symposium II - Computational Science of Transport Phenomena in Materials**

*First Principles Studies of Single -molecule Junctions: Conductance, Thermopower, and Mechanically-controlled Switching*

In the afternoon, Su Ying Quek of the Institute of High Performance Computing, Singapore, showed that first-principles calculations can deliver quantitative trends for electronic transport in molecules. In understanding molecular-level electronics, she pointed out that two of the key challenges are developing a physical understanding of transport and of the structure-conductivity relationship. Quek and coworkers calculated the electronic structure of organic molecules on metallic surfaces, compensating for the shortcomings of density functional theory with a DFT +sigma method, resulting in remarkably good agreement between theory and experiment.

The method has proved successful for studies of amine- and bypyridine-Au junctions. Quek highlighted the case of bypryidine-Au junctions, in which they found that the bonding angle of the molecule on the surface heavily influenced the transport due to the different symmetry of the molecule and surface bonding states. From the calculations, they rationalized the observation of two distinct conductive states seen in the molecular break junction experiments performed by their collaborators.

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## Scanning the Meeting


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## ABOUT THE MEETING SCENE

The Meeting Scene e-newsletter of the Materials Research Society (MRS) presents news from MRS and other conferences directly from the conference venue.

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