2010 Materials Research Society Fall Meeting

Symposium Summaries

The 2010 Materials Research Society (MRS) Fall Meeting, chaired by Ana Claudia Arias (Palo Alto Research Center), Robert F. Cook (National Institute of Standards and Technology), Clemens Heske (University of Nevada, Las Vegas), and Shu Yang (University of Pennsylvania), was held in Boston on November 28–December 3.

Through 50 symposia, symposium organizers from around the world offered coverage of developments in the areas of materials for information processing (symposia A–M), materials for infrastructure and mechanical applications (symposia N–V), materials processing and device fabrication (symposia W–EE), materials for energy (symposia FF–MM), biological and environmental applications of materials (symposia NN–RR), and materials exploration (symposia SS–XX).

Following are a few highlights reported in some of the symposia, provided by the symposium organizers; note that some of the summaries were included in full in the main meeting report published in the July 2011 issue of *MRS Bulletin* (www.mrs.org/bulletin), and therefore not repeated here.

Proceedings as well as additional meeting highlights are available at www.mrs.org/fall2010/, and more symposia coverage is available in the Meeting report, "Graphene and other materials highlighted at 2010 Materials Research Society Fall Meeting," published in *MRS Bulletin* **36** (7) (2011) p. 552.

Symposium B
Carbon-based electronic devices—Processing, performance, and reliability

(See MRS Proceedings Volume 1283)

Developing and transitioning graphene and carbon nanotubes (CNTs) into manufacturing environments for nanoelectronics and photovoltaics require technologies for precise control of materials properties and placement, both within the context of materials systems making up real devices. Several talks in symposium B addressed such issues.

C.W. Chen (National Taiwan University) showed that high performance optoelectronic devices could be created through selective reduction of graphene oxide by solution processing methods, resulting in so-called cluster engineering of spectrally tuned photoluminescence centers. The result is the foundation for diodes and lasers potentially spanning the spectrum from near infrared to blue.

K. Banerjee (University of California, Santa Barbara) demonstrated that tremendous energy savings could be realized through the integration of carbon nanomaterials into computer chips. Increases in operating efficiency of up to 30% may be achievable with these materials as used in through-silicon vias and chip-to-package interconnections, through improvements in delay performance, and thermal transport.

P. Avouris (IBM) explained how graphene-based photodetectors could potentially provide strong response up to frequencies in excess of 40 GHz. The key lies in the fact that the metal–graphene interface has a built-in electric field, which can efficiently separate electrons and holes.

E. Pop (University of Illinois at Urbana-Champaign) demonstrated the importance of the quality of the CNT/SiO_2 interface for thermal dissipation and eventual CNT breakdown in electronic interconnect applications. Oxide surface roughness and CNT diameter are the major factors, suggesting that engineering the nanostructured interface could be the key to optimizing device performance with these materials.

Symposium C
Fundamentals of low-dimensional carbon nanomaterials

(See MRS Proceedings Volume 1284)

Symposium C focused on the fundamental issues of low-dimensional carbon nanomaterials; highlighted topical areas included graphene and carbon nanotubes (CNTs), novel properties, and advances in structural characterization. The newly named Nobel laureate, Konstantin S. Novoselov from the University of Manchester, reviewed novel properties of graphene and gave his vision for many potential applications of graphene-based materials.

The invited and submitted talks at the symposium gave a broad and balanced review on the latest advances of low-dimensional carbon nanomaterials, including state-of-the-art graphene growth techniques, novel metal-free CNT growth, atomic-scale structural characterizations, and novel properties of graphene, especially in thermal management areas. For examples, K. Gaskill (Naval Research Laboratory), M. Spencer (Cornell University), and W. Mitchel (Air Force Research Laboratory) described

the growth of high-quality graphene/SiC and its promises in radio frequencies electronics. J. Warner (University of Oxford) and K. Ran (University of Illinois at Urbana-Champaign) demonstrated the atomic resolution characterization of nanocarbon structural transformations using transmission electron microscopy. The metal-free CNT growth and thermal properties of graphene were identified as the emerging issues in the field.

Symposium D
Challenges in roll-to-roll (R2R) manufacturing of electronics and other functionalities

(See MRS Proceedings Volume 1285)

Descendant from well-known technologies such as printing of newspapers and packaging foils, during the last years, roll-to-roll (R2R) processing has been increasingly explored for micro- and nanostructuring tasks to form devices of printed and large-area electronics. However, there are vibrant debates about the advantages and drawbacks of individual processes with respect to process speed and materials performance. Symposium D formed a podium for the various R2R communities including traditional printing, solution processing (coating), vacuum processing, embossing, and laser ablation to discuss recent developments and upcoming challenges.

Among the symposium highlights were the talks given by A. Goyal (Oak Ridge National Laboratory) and V. Selvamanickam (University of Houston) presenting R2R epitaxial techniques for low-cost manufacturing of self-assembled nanostructures. Goyal outlined the rolling-assisted biaxially textured substrates (RABiTS) technology to manufacture single-crystal-like heteroepitaxial devices based on superconductors, semiconductors (e.g., Si), diamond-like, ferroelectric ($BaTiO_3$), and multiferroic films ($BiFeO_3$). R2R techniques included electron-beam evaporation, sputtering, metal–organic chemical vapor deposition, and chemical bath deposition. In the same session, Selvamanickam introduced ion-beam-assisted deposition (IBAD) as a complementary technique to achieve, for example, high-temperature superconductors in power transmission cables. Both talks highlighted the importance of process control: R2R compatible x-ray diffraction, reflection high-energy electron diffraction, ellipsometry, and in-line electromagnetic testing. The message was that it should be possible in the near future to fully fabricate such devices in an R2R configuration.

D. Levy (Eastman Kodak, Rochester) introduced R2R-compatible spatial atomic layer deposition at atmospheric pressures. It relies on the spatial isolation of reactive chambers by the use of confined inert buffer gases along a moving web. At deposition rates of 10 nm per minute, metal-oxide thin-film transistors with mobilities above 15 cm^2/Vs could be obtained.

Several presenters outlined the approach of combining standard techniques including printing, vacuum, and photolithography with a flexible manufacturing line. A.C. Arias (Palo Alto Research Center) described the mission to look for sandbox projects that generate particular electronic building blocks (e.g., sensors, displays, memories, and power sources). M. Poliks (State University of New York, Binghamton) reported on an integrated machinery concept to achieve intravascular ultrasound transducers as a low-cost niche application. G. Gustafsson (ACREO AB, Norrköping, Sweden) introduced the concept of shared functional layers, and B. Stadlober (Joanneum Research, Weiz, Austria) demonstrated a working, R2R manufactured pyroelectric proximity sensor.

Symposium F
Low-temperature-processed thin-film transistors

(See MRS Proceedings Volume 1287)

Covering a broad base of materials from organic to inorganic, the symposium on low-temperature-process thin-film transistors explicitly joined science to technological and practical strategies. In addition to the solo sessions, symposium F joined forces with symposium D (Challenges in Roll-to-Roll Fabrication for Electronics and other Functionalities) and symposium G (Novel Fabrication Methods for Electronic Devices) for a session on Novel Manufacturing Strategies for Electronic Devices. Furthermore, symposium F and symposium MM (Transparent Conducting Oxides and Applications) pooled resources for a session in which work was presented by C.J. Kim of Samsung Advanced Institute of Technology, and K. Nomura of Tokyo Institute of Technology, Yokohama, on identifying and remedying the sources of light-bias instability in metal-oxide thin-film transistors.

In further progress toward practical realization, T. Someya of the University of Tokyo demonstrated finely screen-printed 18-μm-wide silver paste lines and spaces for large-area applications, while P. Blom (TNO/Holst Center) described significant advances making possible roll-to-roll processing of organic lighting panels.

No short summary can capture all the excellent talks and fine fundamental science contributing to the advancements in the field. The increasing emphasis, however, toward technologically relevant materials, processes, and devices was undeniable across these sessions, a sign that this field is beginning to mature.

Symposium I
Magnetism and correlated electronic structure of nitrides: Rare-earth and transition metals as constituents and dopants

(See MRS Proceedings Volume 1290)

The search for magnetic semiconductors on which a spintronics technology can be based has been dominated by Mn-doped GaAs. Since the suggestion that wide bandgap semiconductors could yield higher T_Cs in dilute magnetic semiconductors (DMS), there have been numerous reports of magnetic behavior in TM- (Mn, Cr) and RE- (Gd, Eu, Er) doped nitrides but the origins of this magnetism is under discussion because of the unknown role of defects and possible secondary phases.

Furthermore, there are clear advantages in this emerging technology for the freedom to dope for *n*- or *p*-type conduction in intrinsic ferromagnetic semiconductors, and among the simplest of these are the rare-earth mononitrides.

The goal of this symposium was to bring together the communities working on TM and RE nitrides with the DMS community to compare *d*- with *f*-level-induced magnetism in such systems.

Interest in the rare-earth nitrides was highlighted by B.J. Ruck (Victoria University of Wellington) and A. Svane (Aarhus University) who covered, respectively, the experimental and theoretical aspects of their electronic band structure. Both lectures as well as C. Meyer's (Néel Institute) discussed, among other systems, the case of EuN, in which the Eu^{3+} ion has a large magnetic moment but a zero angular momentum that severely complicates its electronic structure and any possible magnetically ordered state.

Presentations concerning Gd-doped GaN had a focus on establishing the character of both the large moment and the room-temperature ferromagnetism, and sought to establish clearly whether these are intrinsic or related to secondary phases. Evidence is assembling that the effects cannot be explained purely by secondary phases, but as yet unidentified defects play a significant role and studies of other hosts (AlGaN) and dopants (Eu) were also reported.

In the field of bulk transition metal nitrides, D. Gall (Rensselaer Polytechnic Institute) shed light on the widely ranging transport properties found by various groups for CrN and B. Alling (Linköping University) provided a theoretical point of view that the magnetic properties are also important for understanding its thermodynamic stability.

Symposium J
Integrated nonreciprocal photonic—Materials, phenomena, and devices

(See MRS Proceedings Volume 1291)

Magnetophotonic and magnonic (microwave) crystals were the primary focus of this symposium. Nanoscaled one- and two-dimensional structures of magnetic materials interspersed with dielectrics and metals can be used to create photonic bandgaps and to confine light. Gold nanoparticles have been used to enhance surface plasmon resonance, but at the expense of strong absorption of the light.

D. Haldane (Princeton University) gave a firm theoretical foundation for a series of theoretical and experimental efforts in unidirectional and slow light devices. Other speakers pointed to several theoretical and experimental proofs of novel geometries that provide unidirectional propagation.

Throughout the symposium, different classes of nonreciprocal photonic devices were presented, including Faraday rotating garnet waveguides, nanostructured garnet/air or garnet/metal photonic crystals, and semiconductors overclad with ferromagnets or magnetic garnet. The latter was noted for commercial applicability in Si-on-insulator (SOI) photonics, with the phenomenon of transverse phase delay being utilized. A new technique using dynamic index modulation was also proposed in theory.

Magnetooptic indicator films have found significant applications visualizing phenomena requiring both dynamic and spatial resolution in forensic applications and characterization of high-temperature superconductors. In addition T. Johansen (University of Oslo) showed that the domain walls in the garnet could be used to trap and manipulate everything from magnetic particles to DNA to magnetotactic bacteria and even to form a digital shift register.

Spatial light modulators also use light traveling through the thickness of the garnet structure and one-dimensional magnetophotonic crystals were used to enhance the modulation.

Symposium K
Oxide nanoelectronics

(See MRS Proceedings Volume 1292)

Symposium K provided a broad survey of the rapidly changing field of oxide nanoelectronics. R. Ramesh (University of California, Berkeley) kicked off the meeting with a comprehensive review of the importance of domain walls in multiferroics. Many interesting effects observed in this system were subsequently addressed by other speakers in this session, covering the topics of electrochromism, photoconductivity, and piezoelectricity.

P. Maksymovych (Oak Ridge National Laboratory) presented work in scanning probe microscopy in oxides, performed in an *in situ* variable temperature ultrahigh vacuum-scanning probe microscopy, examining concepts such as piezoelectricity and memristance by spatially resolving features at the nanoscale level.

Resistive switching and memristance were discussed in a session started by T. Yanagida (Osaka University and JST-

PRESTO) covering nonvolatile switching effects in 5 nm NiO/MgO nanowires exhibiting 10^8 cycles. T.W. Noh (Seoul National University) explored resistive switching with the circuit breaker model, which explained switching in TMO. Synchrotron techniques applied to TMO devices were discussed by J.P. Strachan (HP Labs), which were utilized to spatially resolve the structure and chemistry of switching channels. J.J. Yang (HP Labs) presented results on TaOx devices exhibiting 10^{10} switching cycles. The session was concluded with Y.H. Keun (Seoul National University) describing electroforming in unipolar and bipolar devices.

Epitaxially grown oxides on GaN utilizing H_2O as a surfactant were shown by E. Paisley (North Carolina State University), which delayed the onset of three-dimensional growth. D. Schlom (Cornell University) discussed results on Ruddlesden–Popper and Dion–Jacobson series obtained by epitaxial growth, with applications on high permittivity systems and low thermal conductivity systems, respectively.

On the topic of LAO/STO (LaAlO/SrTiO), a comprehensive scanning transmission electron microscopy-electron energy-loss spectroscopy talk given by J. Mundi (Cornell University) investigated the controversial issues of intermixing at the heterostructure interface. Numerous other talks discussing this important system closed the symposium, all characterized by intriguing and excited results by D. Schlom (Cornell), J. Mannhart (Augsburg), C. S. Hellberg (Naval Research Laboratory), S. Chambers (Pacific Northwest National Laboratory), Suzuki (University of California, Berkeley), and C. Cen (University of Pittsburgh), where the focus on the origin of the two-dimensional electron gas formed at the LAO/STO interface was discussed from a rich set of angles. These results underscored the importance of performing a combination of transport and structural/chemical characterization of these systems, which indicate a series of perspectives for this system (Cen), ranging from rewritable electronics, to superconductor-insulator transition.

Symposium L
Liquid crystal materials: Beyond displays

(See MRS Proceedings Volume 1293)

Liquid crystals are a pervasive display technology due to their unique electro-optic properties. However, going forward, the utility of liquid crystals extends beyond displays applications and into a host of other topical areas including biosensing, ultrafast optics and photonics, lasing, and energy harvesting and transport. The combination of liquid crystals with nanomaterials and/or structured metamaterials also shows significant potential. Two of the many highlights are given here.

I.I. Smalyukh (University of Colorado at Boulder) described how confined cholesteric liquid crystals (CLCs) can be realigned with optical phase singularities achieved with laser beams, resulting in the formation of localized twisted structures he coined torons. The utility of torons was demonstrated in the formation of a broad range of stable, two-dimensional, periodic, photonic structures embedded into an untwisted, confined CLC. Smalyukh said that single-beam steering and holographic generation approaches were both used to tailor the periodic crystal lattices of torons, and reorient their crystallographic axes. Dynamic generation and modification of these lattices can be performed in conjunction with the requirements for the particular photonics application. The requirements for such robust control are tightly focused laser beams with powers ranging from 10 mW to 100 mW or low-frequency electric fields with voltages of about 10 V. Smalyukh also demonstrated the optical control of diffraction gratings but lacked the time to show in detail other applications in photonics, diffractive optics, and singular optics.

Another notable presentation was given by H. Coles (Cambridge University), who discussed a number of topics generally related to the use of liquid crystals in optics, photonics, and lasing. Coles illustrated the profound impact that liquid crystal materials could have in each of these areas including demonstration of a beautiful photonic crystal pattern on the ceiling by illuminating a miniature liquid-crystal–based optic with a green laser pointer. Coles and colleagues at Cambridge University touched on recent results that reveal greatly enhanced slope efficiencies in mirrorless lasers based on cholesteric liquid crystals, which is important for potential realization of these materials optical sources in photonics.

Other highlights from this symposium can be found in the July 2011 issue of *MRS Bulletin*.

Symposium Q
Structural materials and fuels for future fusion and fission technologies

(See MRS Proceedings Volume 1298)

The aim of this symposium is to provide a bi-annual forum for the discussion of materials issues and problems in the field of nuclear energy on an experimental and modeling platform. Since nuclear energy is re-emerging as a viable alternative to the greenhouse gas emitting fossil energy and many governments have started to increase research funding for nuclear energy, the presentations and discussion made during the symposium were robust and covered a large variety of topics. These include issues on diverse structure materials, such as ferritic-martensitic steels and their nanostructured ferritic or oxide-dispersed strengthened (ODS) variants; microalloyed steels; stainless steels, zirconium alloys; refractory metals; and silicon carbide, as well as on both ceramic and metallic fuels. A great deal of research results (~30%) presented was from computational studies ranging from atomic-scale to macroscale simulations.

The sessions discussed the key radiation-induced phenomena such as gas bubble formation and its impact, defect behaviors at grain boundaries, and the role of nanoparticles in radiation effects. Interestingly, two whole sessions and more related talks were for the nanostructured ferritic or related alloys. This reflects the increasing interest in understanding their in-reactor performance as the alloys are considered the only viable materials for some extreme conditions in the next generation reactors. Silicon carbide and nuclear fuels became one of the mainstream topics in the symposium.

Symposium T Nanostructured materials in harsh environment

(See MRS Proceedings Volume 1298)

Symposium T on "nanostructured materials in harsh environments" highlights interfaces, stability, design, and the need for coupling modeling and experiments.

Due to excess free energy associated with interfaces, grain boundaries, or free surfaces, nanostructured materials are intrinsically far from thermodynamic equilibrium. On the other hand, interfaces, grain boundaries, and free surfaces are often the source of desirable functionalities that make these materials attractive for applications in harsh environments. One of the main themes of symposium T was therefore to understand the influence of interfaces and grain boundaries on radiation tolerance, thermal stability, and mechanical behavior under high strains and stresses. These issues were discussed in the context of metals, ceramics, composites, and nanotubes.

A spectrum of modeling methods including density functional theory, off-lattice kinetic Monte Carlo, dislocation dynamics, and phase field revealed the potential for understanding the behavior of interfaces and grain boundaries from electronic to continuum length scales. Several modeling studies aimed to facilitate the design of interfaces with unique functionality. In many cases, a combination of modeling and experiments proved to be an effective approach to revealing the fundament physics of nanostructured materials in harsh environments. These studies also highlighted the urgent need for improved methods of synthesizing nanostructured solids with controlled atomic- and microstructure-level architectures.

Symposium Y Nanomaterials integration for electronics, energy, and sensing

(See MRS Proceedings Volume 1303)

A major theme of symposium Y was enabling improved performance in electronics, photovoltaics, energy harvesting, and sensing by the incorporation of nanoscale materials. Specific areas described in the symposium included photovoltaics, water splitting, nanoelectronics, and nanopower generation.

One of the main drivers of nanotechnology is the realization that nanoscale materials can have superior properties that are often tunable. As the field matures, increasing emphasis is being placed on the challenges of integrating nanomaterials into devices in a scalable, cost-effective way.

Advances in the areas of novel device architectures and scalable methods for synthesis and integration were particularly noteworthy. For example, H.A. Atwater (California Institute of Technology) and A. Polman (FOM-AMOLF, Amsterdam) showed that solar cells with periodic, nanopatterned interfaces can trap more light than cells with planar interfaces. Clever nanopatterning can also be used to create unusual metamaterials with engineered optical properties (e.g., with a negative index of refraction).

Several speakers said that nanomaterials can offer improved performance with potentially lower overall cost, as nanofabrication methods become more widely available. For example, advances in the large-scale assembly of semiconductor nanomaterials were discussed by A. Javey (University of California, Berkeley) and T. Mayer (the Pennsylvania State University).

J. Rogers (University of Illinois at Urbana-Champaign) presented efficient transfer methods to incorporate nanoscale devices onto flexible substrates for applications in electronics and photovoltaics. T. Barwicz (IBM) described an oxidation process that can be used to produce "top down" silicon nanowires suitable for high-performance logic applications.

Symposium Z Hierarchical materials and composites—Combining length scales from nano to macro

(See MRS Proceedings Volume 1304)

Hierarchical materials are composed of characteristic structures on multiple length-scale levels, ranging from nanometers to millimeters. The presence of material hierarchy can provide materials with many unique qualities of scientific importance. This symposium sought to report on the development of hierarchical materials for a wide range of applications, including structural composites, liquid repellency, photonics, biomimetics, water sterilization, and shape-memory effects.

One of the most promising roles for hierarchical materials is for photonic-based applications. The structural hierarchy of these materials can result in unique physical properties, such as negative-index of refraction materials, photovoltaic materials, photoemitters, photocatalytic reactions, and photo sensors.

Although many approaches can be taken to fabricate material hierarchy, many researchers are focused on assembly through colloidal solutions. Nanoparticles can be used as a fundamental building block to assemble larger scale crystals, polymer networks, microparticles, and thin films that contain material hierarchy.

Perhaps the most widely reported material structural unit of the symposium was carbon nanotubes. Unique bulk materials properties can be achieved by tailoring constituent nanotube structures. For example, electrical conductivity can be controlled by altering the molecular structure of nanotubes. Mechanical properties can be improved by reinforcing polymers with chemically bonded nanotubes or nanotubes woven into larger scale fibers. Nanotubes can be used as the fundamental building block to assemble antennae, solar concentrators, and structural health-monitoring sensors in composite materials.

Symposium AA Group-IV semiconductor nanostructures and applications

(See MRS Proceedings Volume 1305)

Group-IV elemental semiconductors and their alloys feature many advantages as opposed to compound semiconductors. This is best illustrated by the most advanced silicon technology where high-end microfabrication techniques such as e-beam lithography and ultrafine dry etching are the main vehicles. As a result, silicon-based electronic devices currently occupy most, if not all, of the market. As opposed to electronics, a very limited number of group-IV photonic devices have been developed so far.

In the opening talk of this symposium, H. Atwater (California Institute of Technology) discussed the advantages of reducing the absorption layer thickness of solar cells from a general photovoltaic viewpoint. He demonstrated the production technology of plasmonic silicon wire array solar cells with enhanced absorption characteristics. Charge generation and separation in group-IV wires were discussed by B. Grandidier (IEMN-the National Center of Scientific Research) and M. Palummo (University of Rome). The type-II offset between Si and Ge will be instrumental for efficient carrier separation.

The most critical requirement for silicon photonic devices is the compatibility with the mainstream complementary metal oxide semiconductor. Light sources of such kinds using Si nanocrystals were demonstrated by Professor Kik (University of Central Florida) and B. Garrido (University of Barcelona). D. Negro's group at Boston University also presented a CMOS-compatible, Er-doped light-emitting device operating at 1.55 μm with low turn on voltage. Efficient electrical pumping was demonstrated by L. Pavesi (University of Trento), with an overview of recent progress in Si-based light emitters.

Compared to absorption, light emission involves energy relaxation and hence is susceptible to nonradiative pathways. This is why the quantum efficiency is always an issue. A. Irrera (IMM, The National Research Council) suggested nanowires as a viable alternative of a room-temperature emitter. Much improved light-emitting properties were demonstrated for potential-engineered SiGe nanostructures by L. Tsybeskov (New Jersey Institute of Technology). The unique properties of single Si quantum dot were presented by J. Linnros (Royal Institute of Technology, Stockholm). He stressed that highly efficient dots are prerequisite for characterization.

Group-IV interband lasers hold great promise in silicon photonics for such use as optical interconnects. L.C. Kimerling (Massachusetts Institute of Technology) demonstrated room-temperature lasing of an I-doped, strain-engineered direct bandgap Ge grown on Si.

Photonic bandgap engineering of group-IV semiconductors most likely boosts such light-manipulating capabilities as waveguiding, confinement, and even control of spontaneous emission that may eventually lead to a low-threshold group-IV laser. Microcavity-based light emitters were demonstrated by J. Vuckovic (Stanford University) and E. Hadji (INAC/SP2M, Energies and Atomic Energy Commission). Photonic crystals made of wide bandgap SiC were presented by B.-S. Song (Kyoto University).

Engineering spin more than adds another degree of freedom to the design of optoelectronic devices; weak spin-orbit scattering warrants long spin coherence, which makes Si best placed. Successful tunnel injection of spin-polarized electrons into Si from ferromagnetic metals was demonstrated by B.T. Jonker (Naval Research Laboratory). Expitaxial Si-based ferromagnets were presented by K. Hamaya (Kyushu University).

Free-standing silicon thin films like an exfoliated silicon-on-insulator have inspired many potential applications not limited to electronics. Fabrication and application of magnetron-sputtered Si nanocrystal membranes was presented by P. Fauchet (University of Rochester).

Symposium DD Artificially induced crystalline alignment in thin films and nanostructures

(See MRS Proceedings Volume 1308)

A crystallographic alignment in thin films or nanostructures on top of polycrystalline or amorphous substrates is beneficial for improved properties of functional materials used in various applications. Numerous techniques are being applied to achieve such a long-range order texturing as, for example, ion-beam-assisted deposition (IBAD), oblique angle deposition, ion beam treatment, or surface templating.

Self-assembly is another important concept for the artificially induced alignment, which can lead to highly oriented nanostructures on imperfect macroscopic templates. T. Xu (University of California, Berkeley) demonstrated the application of block-copolymers to fabricate nanocomposites of organic and inorganic nanomaterials including metal nanoparticles. Three-dimensional artificial structures can be fabricated with this approach.

The *in situ* characterization of texturing processes and film growth is critically important to understand the artificially induced alignment. Several speakers presented state-of-the-art techniques to study these processes. As an example, R. Spolenak (ETH Zurich, Switzerland) used *in situ* ion irradiation inside a transmission electron microscope, whereas G. Sazaki and co-workers from Hokkaido University developed an optical microscope, which is able to observe a single molecular step motion of melting ice.

Symposium GG Next-generation fuel cells—New materials and concepts

(See MRS Proceedings Volume 1311)

The direct conversion of chemical energy to electricity through fuel cells has attracted significant attention for many decades. However, the mass marketing of fuel cells is often limited by high component costs and inadequate durability in service. Breakthroughs in materials and concepts are necessary for the development of viable fuel cells for stationary, transportation, and portable applications. J. Maier (Max-Plank-Institute for Solid State Research) gave an overview of this topic and presented his group's activities in low-, intermediate-, and high-temperature fuel cells. V. Stamenkovic (Argonne National Laboratory) reported electrocatalysts for polymer electrolyte fuel cells.

Addressing new fuel cell concepts, R. Chen (Indiana University-Purdue University Indianapolis) presented work on alkaline exchange membrane fuel cells, P.A. Kohl's group (Georgia Institute of Technology) reported on a hybrid acid/alkaline electrolyte fuel cell, and S.M. Haile (California Institute of Technology) reviewed the state of the art in solid acid fuel cells.

Symposium JJ Nanostructured polymeric materials—Synthesis and assembly

(See MRS Proceedings Volume 1312)

Block copolymers have emerged as a new type of resist material for creating small features over large areas. Shrinking the size of these domains and achieving defect-free assembly has driven the discovery of new block copolymer materials for nanopatterning. T. Iyoda's group in Tokyo Institute of Technology has developed a series of poly(ethylene oxide) (PEO) liquid crystalline (LC) block copolymers which consist of PEO and polymethacrylate bearing azobenzene mesogen in the side chain and has fabricated hexagonally arranged and normally aligned PEO nanocylinder domain structures in the thin films. The researchers further demonstrated that the resulting nanostructures can be translated on a roll-poly(ethylene terephthalate) film substrate by continuous coating.

Nanostructured templates are being increasingly explored to improve the device performance of a dye-sensitized solar cell. Two factors limiting the performance of organic and nanoparticle-hybrid solar cells are limited spectral response and restricted charge transport. M. Durstock's research team at Wright-Patterson Air Force Base presented means to control the assembly of dye molecules on the surface of the mesoporous titania film. By utilizing an interfacial modification technique based on layer-by-layer assembly, nanoparticle surfaces can be functionalized with electronically active species and integrated into device structures. This technique is amenable to developing "energy cascade" device architectures commonly utilized in photosynthetic organisms.

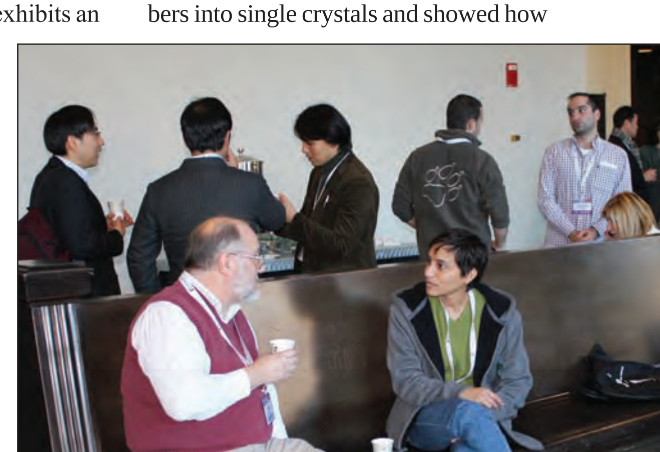
In organic electronics, research has been focused on new electroactive material, device design, and transparent gas barriers to protect the electroactive polymer from oxygen. J. Grunlan's research team at Texas A&M University presented the use of polymer-clay nanobrickwall thin films as flexible and transparent gas barriers. The transparent film exhibits an oxygen transmission rate (OTR) of 0.03 cm^3/m^2/day. Unlike inorganic oxides, this film is highly flexible and deposited under ambient conditions. These nanobrickwall thin-film assemblies are good candidates for flexible electronics, food, and pharmaceutical packaging due to their transparency, super gas barrier (that rivals SiOx), and lack of metal (for microwaveability).

Symposium NN Biomineralization and bioinspired inorganic and inorganic/organic materials

(See MRS Proceedings Volume 1301)

The symposium presented a combination of experimental, numerical, and theoretical approaches to advance the understanding of biomineralization and the use of ideas from biological systems to design new materials.

New work on nucleation of calcium phosphate (G. Nancollas, University of Buffalo and J. de Yoreo, Lawrence Berkeley National Laboratory) demonstrates the problems using classical nucleation theory for biomineralizing systems. Amorphous precursors, possibly based on Posner clusters, play an important role. Nancollas showed that two distinct amorphous types were present in his work. However, when different levels of supersaturation are considered, it is far from clear that amorphous precursors are always present (de Yoreo). L. Estroff (Cornell University) presented data showing the incorporation of gel fibers into single crystals and showed how



the gel strength can determine whether the fiber is pushed aside by the growing crystal or incorporated. The talk of R. Kroger (University of York) on coral mineralization and organic matrices built upon Estroff's polymer work and demonstrated how organic matrices adapt to biominerals. J. Vasquez (University of California, San Diego) introduced a new analyzing system using polymer nanopost arrays for studying macrostructures of crystals.

A. George (University of Illinois) and C. Tameler (University of Washington) discussed the roles of peptides, peptide domains, and proteins in controlling crystal growth. R. Latour (Clemson University) presented data (obtained using surface plasmon residence spectroscopy) on the free energies of adsorption of amino acid residues on surfaces which will be of considerable use in obtaining and validating force-fields. L. Hamm (Virginia Tech) discussed the role of such molecules in removing the hydration sphere from ions in solution and so promoting mineralization. D. Laurencin (University of Montpellier) presented a comprehensive study of the incorporation of Mg into apatite.

E. Spoerke (Sandia National Laboratories) showed how microtubules could be used as templates for mineral growth, producing spatially resolved selective mineralization on the nanoscale. Similarly, various biomolecules were proposed to use as templates for biomineralization to develop functional nanomaterials (S. Behrens, Karlsruhe Institute for Technology; Y. Lee, KAIST; R. Chhabra, University of Alberta; and Y. Maeda, University of New York—Hunter College). I. Yamashita (Nara Institute of Science and Technology) demonstrated the translational research of these organic/inorganic nanohybrids in the development of electro-devices.

A number of presentations, including ones by G. Munir (University College London), A. Mieszawska (Tufts University), and Q. Fu (Lawrence Berkeley National Laboratory), explored the possibilities of biomaterials for bone tissue regeneration.

Symposium RR
Interdisciplinary approaches to safe nanotechnologies
(See MRS Proceedings Volume 1317)

With the aim of contributing to the sustainable development of nanomaterials and nanotechnology, the diverse scientific communities (materials scientists, chemists, toxicologists, ecotoxicologists, environmental engineers and scientists, metrologists, regulators, and other stakeholders of nanotechnology) are mobilized to establish the environmental, health, and safety (EHS) risks of the use of such materials and to define novel nanomaterials that will have as little impact on human health and the natural environment as possible. One of the challenges of this research is to propose biological models to obtain reliable answers for the understanding of involved mechanisms. R.L. Tanguay (Oregon State University) presented an approach that utilizes a dynamic *in vivo* zebrafish embryonic assay. Results show the great potential of Tanguay's strategy to deliver rapid, relevant, and efficient responses on nanoparticle impact on biological systems.

Besides the deployment of the EHS risk analysis tools, an important part of the work in this area is to identify the relevant systems of nanoparticles to be studied in accordance with the recommendation of national and internal governances and OCDE. Silver nanoparticles largely used for their anti-microbial properties are particularly attractive since that lethal median concentration is closed to those of ionic silver according to a presentation given by A. Kennedy (U.S. Army Engineering Research and Development Center).

Symposium TT
In situ x-ray synchrotron radiation spectroscopies in energy-related materials science and heterogeneous catalysis
(See MRS Proceedings Volume 1318)

The search for new efficient energy conversion and storage materials and devices and heterogeneous catalysis is rapidly becoming one of the most pressing technological challenges. Such effort requires new materials developed through the control of atomic, chemical, and electronic structure. Enabling such control of properties requires an intimate collaboration between materials synthesis and electronic structure characterization of complex materials. L. Vayssieres (National Institute for Materials Science, Tsukuba) presented quantum rods and dots-based structures and devices from low-cost aqueous synthesis and bandgap engineering for solar hydrogen and solar cells. Electronic structures of non-Pt carbon alloy catalysts for polymer electrolyte fuel cells were revealed (M. Oshima of University of Tokyo) and structural and electronic characterization of high-performance hematite (α-Fe_2O_3) for solar water splitting was given by K. Sivula (École Polytechnique Fédérale de Lausanne). T. Gustafsson and K. Edstrom (Uppsala University) reviewed lithium ion batteries—a challenge for *in situ* characterization.

Several fields in materials science have significantly benefited from advancements in synchrotron instrumentation. Electrochemical technologies offer efficient routes to convert and store energy while no carbon-containing species are introduced into the atmosphere. Batteries, supercapacitors, fuel cells, and electrolytes are the most important electrochemical devices used to interconvert electrical and chemical energy. New diagnostics based on ambient pressure (10 Torr) x-ray photoemission spectroscopy has been developed by Advanced Light

Source, Lawrence Berkeley National Laboratory (H. Bluhm and Z. Liu), Sandia National Laboratories (F. El Gabaly), and Brookhaven National Laboratory (D. Starr) for *in situ* characterization of solid-oxide fuel cells and Ni-based batteries and for learning about how charge-transfer occurs. At higher pressure of 1 bar and liquids, for example, *in situ* soft x-ray spectroscopy of materials for electrochemical water splitting has been demonstrated by L. Weinhardt (University of Wurzburg) and J. Guo (Lawrence Berkeley National Laboratory). Furthermore, F.M. de Groot (Utrecht University) presented *in situ* scanning transmission x-ray microscopy of catalytic solids and nanomaterials with a potential under 5 bars reaction condition.

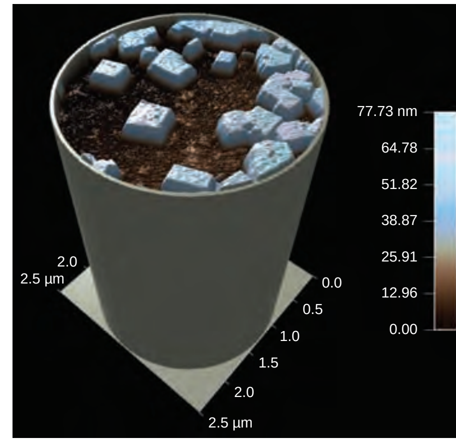
Symposium UU
Real-time studies of evolving thin films and interfaces

(See MRS Proceedings Volume 1318)

The study of transient and intermediate structures and morphologies is at the forefront of materials research. Probing these processes requires sub-angstrom spatial resolution on time scales that are comparable to the vibrational period of the atoms.

J.D. Brock (Cornell University), B. Stephenson (Argonne National Laboratory), and E. Vlieg (Radboud University) presented examples of using high brilliance synchrotron x-rays for real-time studies of film growth, and transformations at solid and liquid interfaces on a wide range of time scales. The talks on x-ray diffraction culminated in the conclusion that with the coming online of the Linac Coherent Light Source (LCLS) at SLAC National Accelerator Laboratory in California, and x-ray lasers elsewhere in the world, the study of atomic motion in real time is now within reach. Impressive achievements have been reported with using electron diffraction for probing ultrafast processes. Using a pump-probe scheme with a delayed probe electron beam with respect to the excitation laser, N. Gedik (Massachusetts Institute of Technology) showed that it is possible to study nonequlibrium phase transitions in cuprate superconductors on a picosecond timescale.

Direct imaging of dynamic processes is the second area where significant achievements have been reported. Direct imaging of oxide film growth by pulsed laser deposition using scanning probe microscopy in real time was discussed by G. Rijnders (University of Twente). N.D. Browning (University of California, Davis and Lawrence Livermore National Laboratory) discussed the development of dynamic transmission electronic microscope (DTEM) imaging with nanoscale spatial resolution using electron beam pulses of variable time duration triggered by pulsed laser irradiation of a photocathode. Several members of the Lawrence Livermore National Laboratory group reported on various experiments illustrating the limitations and the potential of DTEM. R.M. Tromp from IBM showed the vast possibilities using low-energy electron microscopy, which allows a variety of spectroscopic probing of surfaces besides its surface imaging capability.



Symposium VV. A 2.5 µm × 2.5 µm atomic force microscope topography image of 50-nm tall FeTe islands grown on MgO. Although cropped here to look like a cup of hot chocolate, similar images of, for example, height, conductivity, surface potential, mechanical compliance, and thermal properties are feasible with scanning probe microscopy as showcased throughout symposium VV. Image courtesy V. Palumbo, D. Telesca, B.D. Huey, University of Connecticut.

Symposium VV
Advances in scanning probe microscopy

(See MRS Proceedings Volume 1318)

In this symposium, atomic resolution measurements drew tremendous interest, especially for chemical identification (F. Mohn, IBM Research, J. Pethica, Trinity College Dublin, and U. Schwarz, Yale). Nano-mechanical scanning probe microscopy (SPM) capabilities continued to be popular, particularly for studies of local friction (R. Carpick, University of Pennsylvania) and stiffness mapping (D. Hurley, NIST Boulder, and O. Kolosov, Lancaster University). Increasingly important topics include thermal measurements (A. Narayanaswamy, Columbia, and W. King, University of Illinois), nanomanufacturing (J. Weaver, University of Glasgow and X. Li, University of South Carolina), and new probe functionalities (H. Ko, Samsung, R. Westervelt, Harvard, P. Ashby, LBNL, S. Hong, ANL). Also, significant developments were featured by numerous presenters for novel electrical measurements (D. Bonnell, University of Pennsylvania, S. Kim, Penn State, S. Kalinin, ORNL, H. Shin, Kookmin University), combinations of SPM and optics for materials identification (G. Haugstad, University of Minnesota, K. Wickramasingh, UC Irvine), and even three-dimensional nanoscale probing (M. Miles, Bristol). Significant advances in high-speed imaging and property mapping revealed the dynamics of systems such as catalysis and data storage (B. Huey, University of Connecticut, J. Frenken, Leiden, J. Hobbs, Sheffield, F. Besenbacher, Arhus iNANO). Visually beautiful and data-rich images, datasets, and movies were the norm throughout the symposium, along with spirited discussion best exemplified by an expert panel session which is summarized separately as part of in the main meeting report.

Other highlights from this symposium can be found in the July 2011 issue of *MRS Bulletin*. □