MRS collaborates with E-MRS on energy symposia within the 2011 E-MRS Spring Meeting/ IUMRS-ICAM Meeting

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The Materials Research Society teamed up with the European Materials Research Society to offer a set of symposia on energy, organized in parallel with the 2011 E-MRS Spring Meeting/International Union of Materials Research Societies-International Conference on Advanced Materials. The Meeting was held on May 9–13 in Nice, France. The energy portion—chaired by David S. Ginley (National Renewable Energy Laboratory, USA), Sossina M. Haile (California Institute of Technology, USA), Juan R. Morante (Catalonia Institute for Energy Research, Spain), and Abdelilah Slaoui (Laboratoire InESS, France)—comprised 11 of the 27 symposia of the larger meeting, which was chaired by Hanns-Ulrich Habermeier (Max Planck Institute, Germany), Joerg K.N. Lindner (Universität Paderborn, Germany), Giovanni Marletta (Università di Catania, Italy), and Hailing Tu (General Research Institute for Nonferrous Metals, China).

The set of energy symposia featured three keynote lectures. The first one was by Anke Weidenkaff of EMPA and the University of Bern who received the inaugural Kavli Foundation Lecture Award given at an E-MRS Meeting. Weidenkaff is enthusiastic about the prospects of thermoelectric power to convert the heat of the sun directly into electricity, but the technology faces many challenges, including energy density, energy storage, and potential scarcity of the elements used in the technology.

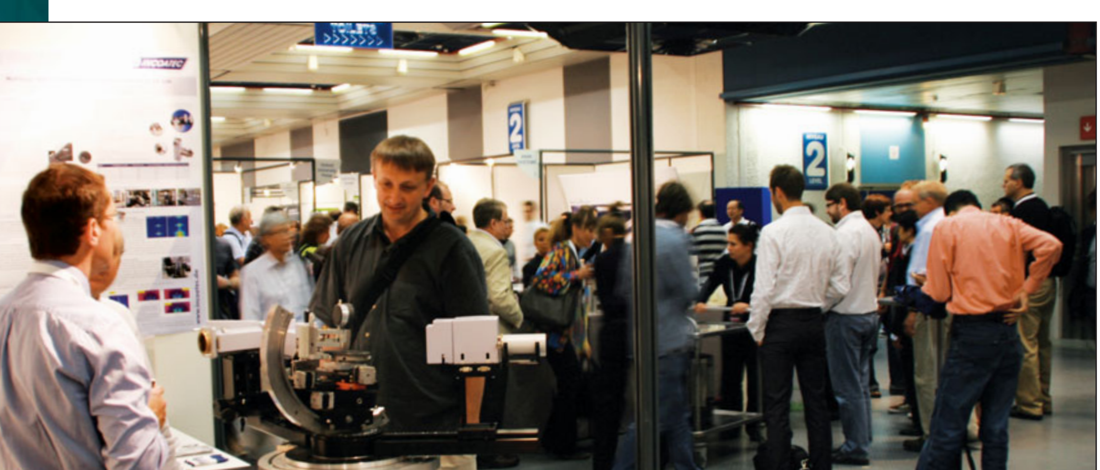
Her research team is approaching the challenges by investigating the chemical stability of materials at the high temperatures needed to achieve high efficiencies; exploring the means to achieve large thermopower conversion through a better understanding of correlated electronic systems; and achieving low thermal conductivity by hindering phonon transport.

The materials used in Weidenkaff's solar concentrator must be stable in open air at high temperatures, and be able to withstand large temperature gradients. Weidenkaff is investigating very stable perovskite-type oxides with their strongly correlated electrons for this application. Her team is synthesizing a wide variety of perovskite oxides in powder and thin film forms by "soft chemistry" (e.g., micelles, sol-gel) methods. Strontium titanate with the formula $SrTi_{1-x}Nb_xO_{3+\delta}$ proved to be too electrically resistive, but the research team discovered that exchanging oxygen with nitrogen increased the conductivity; the same method was used for europium titanate. To reduce the thermal conductivity of perovskite oxides, the researchers increased the phonon scattering at grain boundaries by reducing the particle size.

Besides materials for thermoelectric power devices, Weidenkaff is interested in solar production of hydrogen by photoelectrochemistry, using perovskite oxides as photocatalysts. Her research team found that by nitriding $LaTiO_{3.5}$ to $LaTiO_2N$, this catalyst captured more sunlight by shifting the absorption edge into the visible light range.

Ramamoorthy Ramesh of the U.S. Department of Energy (DOE) gave a less technical, more policy oriented keynote address on the government's SunShot Program, whose goal is to produce solar energy at $1 per watt by the end of this decade. The program's name comes from a comparison with the "MoonShot" program declared by President John F. Kennedy in 1960 to put a man on the moon before the end of that decade. Ramesh said that President Barack Obama's SunShot initiative was designed to make solar energy cost-competitive with fossil fuels "without subsidies."

One way of making solar energy cost-competitive is to make the components lighter, as noted by keynote speaker



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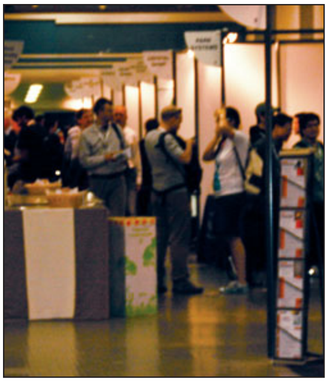
Harry Atwater of the California Institute of Technology. Atwater argued for the development of lightweight, flexible solar energy conversion devices with at least 18% module efficiency as essential to meeting the goal of a $1 per watt solar energy cost. Only fifty cents of that dollar per watt can go to the actual solar conversion module, he said; the rest must go to the balance of systems costs, such as manufacturing, transportation, and installation costs. All of the heavy materials that go into making rigid solar devices quickly exhaust the fifty cent budget for the modules, leading to his call for lightweight and flexible devices.

Atwater proposed two possible materials systems that could meet these criteria: (1) III–V semiconducting-compound films, and (2) a semiconducting Si nanowire array. In the first category, Alta-Devices already makes thin film GaAs solar cells with 27.6% efficiency, but Atwater thinks the future lies in the second category. He waved in the air a sample of a flexible, peel-off, wafer-scale (150-mm diameter) polymer made of embedded Si nanowire arrays and called it "the most promising polymer solar cell." The absorption (~96% in the mid-visible range with dielectric scattering and a back-reflector) and quantum efficiency (greater than 0.90 internal quantum efficiency throughout most above-bandgap wavelengths) of this large-scale Si nanowire array is comparable to high-quality Si wafers.

While the keynote speakers gave the attendees a high-level overview of the field, there were many technical sessions that delved deeper into the technologies involved. Following are a few highlights of the research on materials for energy that were reported in the technical sessions.

Technical highlights

Reducing the cost of photovoltaics is a major global initiative, and the many ways of accomplishing this goal was a theme of the technical talks. For instance, surface plasmons may be used to further increase the efficiency in solar cells and help to drive down the cost. Supriya Pillai of the University of New



South Wales, Australia, has been working on doing this with metal nanoparticles on silicon solar cells. To benefit from using metal nanoparticles in solar cells, there are a number of design considerations, including size, shape, and location of the nanoparticles, and thickness of a dielectric layer. Her talk covered many recommendations for these design elements based on experimental results. Silver nanoparticles were found to be optimal, with larger nanoparticles having higher polarizability and being more effective at scattering light into the solar cell. It was also noted that locating the nanoparticles on the back side of the cell, with light passing through the transparent substrate, resulted in no loss of light intensity from the presence of nanoparticles, and was more beneficial in increasing overall efficiency. Using an oxide dielectric layer before depositing the nanoparticles helped reduce losses when placed on the front side of the cell, but had little effect for the back side configuration.

Another solar technology option is to use visible light to split water into hydrogen and oxygen; this would provide a clean and sustainable method of energy conversion from solar energy to hydrogen fuel for use in fuel cells. Laurent Le Gendre addressed the challenge of creating a photocatalytic material sensitive to visible light by discussing his research on oxynitride thin films performed at the Université de Rennes, France, and other locations. The requirements for a photocatalytic material, he said, include the ability to absorb visible light, chemical stability in water, and a suitable bandgap position for the oxidation and reduction of H_2O. Starting with $LaTiO_3$ as the base

oxide with a bandgap larger than 3 eV, Le Gendre and his colleagues were able to reduce the bandgap below 2.5 eV by adding nitrogen. This was done by sputtering films of $LaTiO_2N$ on Nb-doped $SrTiO_3$ using both a $LaTiO_2N$ target and thermal nitridation from flowing ammonia. Higher nitrogen plasma content further lowered the film bandgap down to ~2 eV, but this had a detrimental effect on crystallinity. The optimal photocatalytic behavior this research group demonstrated was for epitaxial $LaTiO_2N$ films further modified with a colloidal IrO_2 catalyst, which helped to enhance the photocurrent.

Novel battery components for improved energy storage was another popular theme of the technical sessions. Nanostructured materials have been extensively considered as electrode materials for lithium batteries owing to the high demand of increasingly efficient electric battery storage capabilities. Palani Balaya from the National University of Singapore gave an overview of nanostructured materials based on $LiFePO_4$, TiO_2, and $LiFePO_4/C$. Balaya and his team compared the morphology, rate of storage capability, and storage

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performance with mesostructures based on these materials. The observations showed that mesostructured $LiFePO_4$ exhibits superior storage performance with significantly less polarization. Such an enhanced storage performance in meso-$LiFePO_4$ is attributed to the two-dimensional diffusion of both lithium ions and electrons, consistent with reports on single-crystal $LiFePO_4$ and *ab initio* simulations, according to Balaya. Mesoporous-TiO_2 with high surface area exhibits superior reversible storage capacity. $LiFePO_4$ nanoplates exhibit high polarization at high rates, dissipating the energy in the form of heat. However, the tap density (the bulk density of the powder after a specified compaction process, usually involving vibration or "tapping" of the container) of meso-TiO_2 is found to be about 6.6 times higher than that of commercial TiO_2 nanopowders. Mesopores favor facile lithium ion insertion/extraction, while the intimate contacts across the nanograins (15–20 nm) within micron-sized meso-TiO_2 provides continuous wiring for electronic transport. Lithium storage at low rates is observed even in the absence of additive carbon.

Continuing the discussion of battery components, Joseph Dennes, a researcher with Dupont in Wilmington, Delaware, described the company's new Energain Battery separator, which is based on a nanofiber/nanowoven polyimide material. This material is made by combining spinning and electroblowing processes to create continuous polymer filaments with diameters between 200 nm and 1000 nm. This polyimide material was subject to heat curing to produce a battery separator with desirable properties. Characterization of the separator demonstrated that increased crystallinity has a significant effect on the mechanical properties and solvent susceptibility of the separator.

Robert Nemanich of Arizona State University turned the discussion to thermionic energy conversion, which uses ions released by a heated material to create a circuit. He described his investigations of chemical vapor deposition-grown doped diamond thin films in a configuration that allows for high thermionic emission. The diamond thin films were doped with nitrogen, resulting in a significant reduction of the film's work function. This allowed electrons to be easily emitted from the diamond film surface. Using hydrogen or methane gas also improved the thermionic emission up to a critical pressure where the gas still aided in the charge transfer but did not significantly reduce the mean free path. The films exhibited high efficiency in the 500°C range. The application of visible light greatly enhanced the electron emission, suggesting possible applications in photoassisted thermionic emission energy conversion configurations.

In the broader E-MRS/IUMRS-ICAM program, Nobel laureate Yuan T. Lee of the University of California–Berkeley, reviewed the world's energy history and concluded that "it is time for us to wake up and accede to the fact that our world is overdeveloped." But instead of recommending that we retreat, in his plenary address Lee proposed alternative ways of development that would be sustainable.

He advocated for the reestablishment of the sun's central role in powering the earth, and restoration of the planet's ability to absorb carbon dioxide. Materials science can play a major role here, but only if society succeeds in appropriately educating the next generation of materials scientists, Lee said. Another priority, according to Lee, is to reorient the development of science and technology to better benefit the community. This means designing cities along rational lines, so that most things people need are within walking distance of their homes. We must also tap into the diverse cultures and traditions of the people of this planet to learn more sustainable ways of living, he said.

Lee called for a movement from international to global science. "The nation state is still the major source of science funding," he said, "and there is much international competition. But nature does not know these boundaries."

To remedy this, Lee proposed the establishment of a global science organization that brings together the best minds in the sciences and humanities to produce an independent, global science agenda. He suggested that this organization should be funded by 1% of global research and development funds. Lee pointed to the International Council for Science, saying that with 121 national member organizations representing 142 countries, it might just be the seed for this global science organization.

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