CdTe Solar Cell of 15.8% Efficiency Developed

University of South Florida (USF) researchers have built a cadmium telluride solar cell that can convert 15.8% of the sunlight falling on it into electricity.

A 15% efficiency rating for CdTe represents a long-sought goal among photovoltaic researchers, a "magic number," according to USF electrical engineer Chris Ferekides. A measurement of 15.8% was "better than we expected," he said. Ferekides and fellow worker Jeff Britt have received official confirmation on the capability of their thin-film cell from the National Renewable Energy Laboratory, which provided test and analysis figures on the unit. Efficiency readings of up to 34% have been recorded for solar cells made of other materials, but their manufacturing costs are higher.

The USF cells could become cost-competitive with traditional methods of power production when mass-produced as large-area devices. The cell is produced by depositing a thin polycrystalline semiconductor film on an inexpensive substrate.

"The goal in solar energy is to bring the cost down," said Lee Stefanakos, chairman of USF's electrical engineering department. The breaking of the 15% barrier "really does bring us a lot closer to developing a cost-effective photovoltaic module that can compete with present utility rates," he said.

Internal Inspection of Hard Materials by MRI Investigated by Argonne, Bio-Imaging

A nine-month, $100,000 project, undertaken jointly by Argonne National Laboratory and Bio-Imaging Research, Inc. (BIR), will seek to develop improved hardware to make magnetic resonance imaging (MRI) more useful to the ceramics, chemical, defense, coal, and oil and gas industries. MRI is a useful noninvasive technique for imaging internal biological materials, such as human organs, "but imaging dry, solid materials is more difficult, and the hardware needs further work to be practical," said Timothy Fox of BIR.

MRI involves surrounding an object with a strong magnetic field—which makes most of the object's atoms point the same way, much like tiny compass needles—then perturbing the alignment with a strong pulse of radio-frequency signals. After the pulse, the atoms relax and realign, giving off radio frequency signals in the process. These signals characterize elements within the sample.

The Argonne-BIR project will focus on improving the coil that generates perturbing radio signals and receives relaxation signals. Argonne will review and evaluate coil designs and use computers to develop and test preliminary models. BIR will develop electronics to tune and control the coil during pulse generation and reception of relaxation signals. "We need to develop coils that put out a more powerful pulse in less time," said Stephen Dieckman of Argonne. "The pulse also has to be more consistent over a greater volume, so we can study larger samples more accurately. The coil also has to recover quickly after it delivers the pulse, so it is ready to receive the relaxation signals. They start coming back immediately after the pulse and may last only a few millionths of a second," he said.

MRI would be useful, for example, in studying voids in ceramics, the makeup of polymers, the internal structure of solid rocket engines, or the geology of deep-earth samples.

Lead Crystals Superheated Up to 120 K Above Bulk Melting Temperature

Using a split-beam laser system, researchers at the University of Rochester have heated [111] lead crystals well above their bulk melting point and quickly recorded images of the crystal structure before it could change to the liquid state. Hani Elsayed-Ali at Rochester's Laboratory for Laser Energetics said of the superheated solid form, "We see the atoms before they 'know' what hit them—the crystal hasn't had time to melt yet." Even at 120 K above the bulk solid-to-liquid transition temperature of 600.7 K, the lead crystals remained solid long enough—a few trillionths of a second—to allow the researchers to observe them.

With an ultrafast laser, Elsayed-Ali and John Herman delivered 180 picoseconds of Nd:YAG laser power to the lead crystal. At this point, a few atoms begin to vibrate out of position, but not enough to shake loose and disorder the lattice, thereby transforming the solid into a liquid. The authors say that the melting is bypassed by the large heating and cooling rates, which are on the order of 10^{11} K/s. Another key to the Rochester experiment is the [111] crystal orientation of the exposed surface of the lead crystal. The tight packing of the atoms in this plane slows the movement of those atoms. Similar experiments on the more open Pb(110) surface did not show this superheating behavior.

The laser was split into two beams—one heated the sample and the other activated an electron gun whose electrons bombarded the sample just a few picoseconds after the sample was heated by the laser. The electrons bounced off the atoms in the sample's surface and formed a reflection high-energy electron diffraction pattern, revealing the lattice of the crystal.

Elsayed-Ali and Herman wrote about their evidence for superheating in the August 24 issue of *Physical Review Letters*.

E.A. Giess Joins UNC Charlotte

Edward A. Giess, formerly with IBM's T.J. Watson Research Center, has taken an assignment as a researcher at the Cameron Applied Research Center, within the College of Engineering (Department of Electrical Engineering) at the University of North Carolina–Charlotte. He received his BS, MS, and PhD degrees in ceramics from the SUNY College of Ceramics at Alfred University prior to his joining IBM, where he received awards for his work on garnet materials and liquid phase epitaxy.

Giess has an international reputation in the field of materials preparation and crystal growth. He pioneered in the application of flux growth to the preparation of magnetic materials and magneto bubble garnets. He has made numerous contributions to the growth of electrooptic materials and more recently to the preparation of high T_c superconductors. His most recent research has been on ceramic-polymer composites for electronic packaging, gaining him an IBM Outstanding Achievement Award.

Giess has published 167 articles and holds nine patents. He is a member of many national and international professional societies, and is a fellow of the American Ceramic Society and the American Institute of Chemists. Giess also reviews for the American Ceramics Society, *Applied Physics Letters*, and the *Journal of Crystal Growth*.

SDI Heat-Resistive Materials Developed for Commercial Application

The Strategic Defense Initiative's Small Business Innovation Research program has selected a company, Ultramet, to further develop a heat-resistant material for the throats of rocket engines. The contract is expected to be valued at about $500,000.

During rocket blastoff, fuel combustion erodes the lining of the throat thermally and chemically. The material developed by Ultramet, a hafnium carbide/tantalum carbide composite, has a higher melting temperature and is more chemically inert than currently marketed materials. The new material allows hotter burning fuel, in turn allowing a higher release of energy.

The composite remains protective at 3900°C, compared to current materials that melt at 3300°C, and erodes at 0.02-0.2 mils per second, a tenth of today's rate of 2-3 mils per second.

Besides jet engines, applications for the material may be found in power generating plants, internal combustion engines, and communications satellites.

Packaging Pursued for Eveready/ORNL Thin-Film Battery

Oak Ridge National Laboratory and the Eveready Battery Company are developing a method for packaging rechargeable thin-film lithium batteries. Eveready is developing a 2.5-volt solid-state battery, while ORNL's is 3.7 volts. The prototype in the ORNL lab is 4-6 μm thick by about 1 cm^2, although thin-film batteries could be designed for a variety of sizes depending on the application. The work is being done under a cooperative research and development agreement (CRADA).

John Bates, leader of the ceramic thin films group at ORNL's Solid State Division, said, "Our goal is to develop a microbattery. The microbattery could be fabricated directly onto a computer memory chip to preserve information in the event of a power failure. But before the thin-film battery is ready for commercialization, we must develop a protective thin-film coating." The coating is necessary to seal the batteries and protect the lithium film from atmospheric corrosion. For now, the batteries are kept in an argon atmosphere. "We will work with Eveready on determining which thin-film material or combination of materials could best seal up the battery without altering the properties of the films," Bates said.

Traditional circuits use nonrechargeable batteries much larger than chips, added as separate components, to prevent data loss during power failures. A thin-film battery could be placed directly into an integrated circuit during manufacture. Besides memory backup, a solid-state microbattery could be used as a power source for miniature sensors and micromotors.

ORNL's thin-film battery is created by depositing one layer of material at a time on a ceramic or glass support. The first layer, noncrystalline vanadium oxide, forms the positively charged electrode, or cathode. The second layer, the electrolyte (lithium phosphorous oxynitride), conducts lithium ions and separates the electrodes between which electrons flow in an external circuit, providing electrical energy. The top layer, lithium, forms the negatively charged electrode, or anode. Eveready's battery uses different materials for the cathode and electrolyte.

Working together, the two groups will deposit protective layers on test cells supplied by Eveready. The procedure will allow the battery to be sealed in place, for example, on a carrier for a computer memory chip.

(continued on page 19)

Government, Academia, Business Join Forces at Advanced Materials Lab

The Advanced Materials Laboratory (AML), a venture of the University of New Mexico (UNM), Sandia National Laboratories, and Los Alamos National Laboratory (LANL), was recently dedicated at the University Center Research Park, a 100-acre business park in Albuquerque, New Mexico. The facility represents a new collaborative approach in research and development that will be applied to transferring resulting technologies to U.S. industries.

Senior Senator from New Mexico, Pete Domenici (right), and MRS First Vice President, Tom Picraux, attend the dedication of the Advanced Materials Laboratory in Albuquerque, New Mexico.

The project is one of the first collaborative laboratories of its type. Sandia scientist and AML co-director Ron Loehman said, "This lab is an excellent example of an entity that brings the GUILD (government-university-industry-laboratory development) concept to fruition. We've done that here. Moreover, we're going to have the staff from the two national labs—Sandia and Los Alamos—working together on a continuing basis in the same building." Also, for the first time, says Sandia president Al Narath, Sandia researchers will be located away from Sandia's main site on Kirkland Air Force Base, on a permanent facility near UNM.

At UNM, the Center for Micro-Engineered Ceramics and the Center for High Technology Materials have long-standing relationships with the national labs and industry, so the new facility evolved from the relationships that already existed between the University of New Mexico and the national laboratories.

AML occupies about 46,000 square feet of a new 64,000-square-foot building. The $5 million facility is being completed in two stages. The south wing is now occupied by Sandia and UNM researchers. The west wing is being completed this fall and will be occupied by LANL.

Initially the AML will house about 65 people, including Sandia staff members, UNM professors, students, postdoctoral researchers, and three companies—Duke Scientific, Superkinetics, and Radiant Technologies. Space is available for collaborations with industrial scientists to facilitate transfer of technology developed at Sandia, Los Alamos, and UNM to U.S. industry.

AML will provide state-of-the-art facilities in materials synthesis, processing, and analysis. For synthesis of some new materials, AML will have class 100 and 1000 clean rooms. Researchers also will be able to synthesize new materials in hydrothermal environments and in supercritical fluids, and to make novel glasses. For processing, AML will have the ability to make fine powders, sol-gel materials, electroceramic films, ceramics, chemical sensors, and advanced battery materials. For characterization and analysis, AML will contain equipment for ion microprobe analysis, nuclear magnetic resonance, imaging ellipsometry, dynamic light scattering, electron microscopy, and spectroscopies including electron spin, Raman, x-ray photoelectron, Auger electron, and thermal. Initially, about two thirds of the research will focus on ceramics and one third on metals and polymers.

R.M. Christensen Named Honorary Member of ASME

Richard M. Christensen, a senior scientist in the Chemistry and Materials Science Department at Lawrence Livermore National Laboratory, has been named an honorary member of the American Society of Mechanical Engineers (ASME). Honorary membership is awarded for lifetime service to engineering. Christensen received the honor "for distinguished contributions to mechanical engineering through original research, conceptual design of materials, and service to the profession and governmental laboratories."

Christensen earned his BS degree from the University of Utah in 1955 and his M.Eng. and D.Eng. from Yale University in 1956 and 1961 respectively.

Polycrystalline Cubic Boron Nitride to be Commercially Produced

The Research Development Corporation of Japan (JRDC) has commissioned Denki Kagaku Kogyo K.K. to commercialize the production technology of high-purity, polycrystalline cubic boron nitride, originally a result of research by the National Institute for Research in Inorganic Metals of the Science and Technology Agency. The company recently developed a better production method than was earlier available for its mass production.

Polycrystalline boron nitride particles. (Photo courtesy of Hideo Ohara.)

Because diamond wears easily when cutting iron, cubic boron nitride—which is almost as strong as diamond and wears more slowly when cutting iron—is used for grinding and cutting materials containing iron. Traditional methods for producing cubic boron nitride use, as a starting material, hexagonal boron nitride powder processed under ultrahigh pressure and high temperature. The product has been a single crystal with low toughness.

In the new technology, high-purity, polycrystalline thermolytic boron nitride is formed, the material is synthesized by a chemical gas-phase growth method, and then laminated plurally and by means of a direct conversion method and a reaction crystallization method. Polycrystalline boron nitride consisting of crystal particles as large as 10 times that of traditional ones (50 μm compared to 5-6 μm) can be produced. The product is expected to be used for cutting cast iron and cemented carbide and, due to its high thermal conductivity, for heat sinks of electronic devices.

F.S. Myers

Bumps Improve Efficiency of Solar Cells

Taiyo Yuden Co. and the Agency of Industrial Science and Technology's Electrotechnical Laboratory have developed a new way to make amorphous silicon solar cells thinner without sacrificing the conversion efficiency. Their technique involves growing a bumpy layer of tin oxide on a glass substrate. Light passing through the amorphous silicon layer on top of the tin oxide is reflected back into the solar cell, thereby increasing the path of the light and giving the amorphous silicon more time to convert light into electricity. The bumps consist of micron-sized crystals made during the fabrication of the tin oxide conductive layer over the glass substrate. But unlike the transparent tin oxide layer, the bumps are opaque.

According to the researchers, the bumps boost to 10.7% the conversion efficiency of a solar cell made with an amorphous silicon layer 0.6 μm thick, which is nearly double the rate of conventional solar cells of similar thickness without bumps. The bumpy structure helps resolve one problem with solar cells: when the amorphous silicon layer is too thin, the absorption of sunlight may not be enough; a thicker layer, however, can impede the carrier flow.

F.S. Myers

Electron-Beam-Excited Plasma Etching System Developed

The Institute of Physical and Chemical Research (RIKEN) and Kawasaki Heavy Industries Ltd. have jointly developed new etching equipment that applies the method of electron-beam-excited plasma (EBEP). A plasma, produced using electron beams, is used to etch large-scale integrated circuits onto a silicon substrate.

Plasmas are conventionally generated using electron cyclotron resonance. While this method can produce high-density plasma under low pressure, it is not as effective at producing uniform large-diameter plasmas in the presence of a magnetic field. The EBEP method can produce a uniform, high-density plasma all over the substrate and without causing any damage to the substrate. The system introduces a high-current low-energy electron beam into the etching gas chamber. This new equipment is expected to play an important role in the production of future semiconductor devices such as 64M DRAM chips, the next generation of semiconductor memory devices.

F.S. Myers

Chemat Awarded SBIR Grant for Sol-Gel Thin Film

Chemat Technology, Inc. has been awarded a $50,000 Phase I Small Business Innovation Research Grant for development of low-cost, weather-resistant photochromic thin films. Under the Defense Advanced Research Projects Agency grant, the large photochromic coatings will be placed on field equipment using the sol-gel technique. If successful, the development could provide a low-cost approach for making photochromic articles.

Anticipated application areas include optical storage, optical switches, photochromic window glasses, glass lenses, and automatic glasses. Photochromic window glasses could be beneficial for energy conservation, for example.

Nanoprecision Manufacturing Laboratory Established at UCONN

The Advanced Technology Center for Precision Manufacturing at the University of Connecticut (UCONN) at Storrs has recently established a Nanoprecision Manufacturing Laboratory. The objective of the laboratory is to conduct basic research to precisely assemble large numbers of atoms and molecules into bulk nanostructured materials, and at low cost.

A pilot-scale facility for synthesizing large quantities of nanostructured powders has been completed and includes an industrial-scale spray-drying unit, and a fluidized-bed reactor system. Chemistry and materials processing methodology for synthesizing some composites have also been developed. Materials characterization will be emphasized. Facilities exist for atom imaging using STM and AFM. SIMS, XPS, AES, and HRTEM are available to researchers as well. These new facilities augment existing materials synthesis laboratories at the university's Institute of Materials Science, such as the laser laboratory, the ion beam surface modification laboratory, controlled atmosphere hot-wall reactors with ultrasonic spray atomizers, and instruments for high-temperature thermal analysis.

The composites being developed have been specifically selected for high-temperature, high-heat conductivity, and ultrahigh hardness applications. Also, chemically synthesized nanostructured powders are being investigated as special property thin films and industrial coatings. A thermal spray laboratory and robotics will be used to achieve precision and reproducibility.

The chemical synthesis program is headed by Kenneth E. Gonsalves, Department of Chemistry and Polymer Science, and Peter R. Strutt of the Metallurgy Department.

GE, NREL Sign Agreement on Superconductivity Research

The Department of Energy's National Renewable Energy Laboratory (NREL) and General Electric Corporation have signed a cooperative research and development agreement (CRADA) to advance research in superconductivity. The CRADA builds on scientific collaboration during the past year by researchers at the General Electric Research and Development Center in Schenectady, New York, and NREL.

A novel coating technique led the two groups into the formal agreement. Harley Lake, project development manager at GE's materials research center, said, "We're delighted to have the opportunity to work collaboratively with NREL on this new technology for a high-temperature superconducting material."

The agreement aims to develop new techniques for processing thallium-based oxide material in order to find cheaper methods of manufacturing high-temperature superconducting wires and tapes. Thallium-based oxides are more flexible than other high-temperature superconducting materials, and the GE/NREL CRADA seeks a cheaper way to manufacture wires and tapes from it. The CRADA is for one year and specifies lowering the cost of generating and supplying electricity to utilities.

Researchers Link Metal Oxide Structures with Catalytic Properties

Researchers at the Georgia Institute of Technology have found a way to choose or create metal oxide catalysts for reactions more reliably by studying the links between the structure of catalysts and their effects on chemical reactions. Mark G. White, director of Georgia Tech's Focused Research Program in Surface Science and Catalysis, said, "We are showing unambiguous relationships between structure and catalytic properties." The research was presented at the American Chemical Society's annual meeting in Washington, DC.

The key to the work is the creation of single layers of special metal-containing catalytic molecules on a ceramic oxide surface. The researchers synthesize metal complexes using nucleophilic groups present as ligands—particles that form a molecular "glue" that binds to metals, such as those in the catalytic molecules. The ligands also show an affinity for the surface of ceramic substrates, promoting the deposition of the molecules in a thin layer on the substrate.

Depositing a single layer of molecules is harder than making multilayers, but it is more efficient since only the top layer is effective. Also, "by forming a single layer," White said, "you can effect a great deal of control on the structure that these special molecules will form on the ceramic oxide surface. You must know the structure to relate to properties."

The researchers developed a family of copper-bearing catalysts, each of which contains the same amount of copper—between one and two percent by weight—but have different configurations of the copper atoms. Researchers verified the structures of the substances using selective chemisorption, electron paramagnetic resonance, and TEM. The researchers then incorporated the catalysts into several important industrial reactions and studied the results. The addition of hydrogen to acetaldehyde proceeded with all four catalysts present, but the distribution of the products that resulted from each catalyst were different. Only the catalysts having two or more copper atoms per ensemble were active in the decomposition of methanol; the catalysts having six atoms per ensemble were active in the synthesis of methanol and ethanol from methyl acetate and hydrogen.

White said the work helps explain catalytic action and offers the ability to produce good catalysts without much trial and error. These processes could be applied to making fine chemicals, substances that are expensive to create and are used in small amounts in products such as detergents, and could provide high quality control and selectivity. Other uses of the technology would be as a chemical enhancer in protective clothing, a pollution removal agent for power plant flues, and as the basis for reducing methyl acetylene into propylene.

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Laser-Excited CVD Produces Diamond Coating Without Using Hydrogen Gas

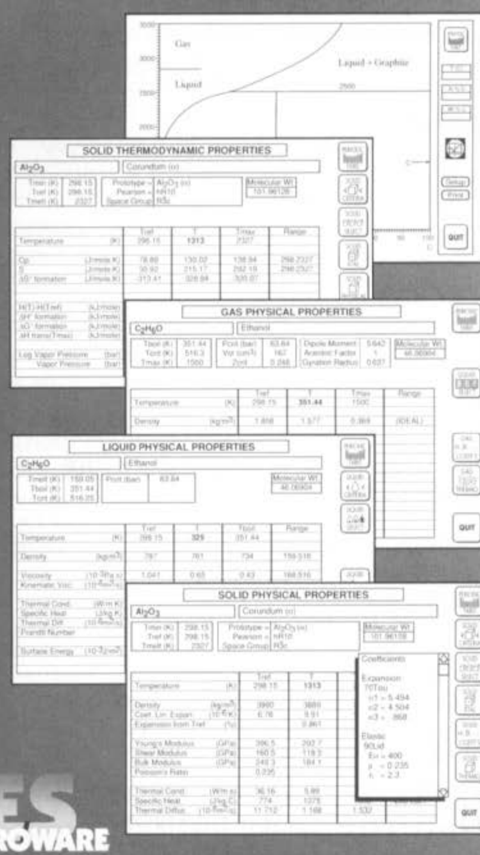
A new way to produce diamond coatings by chemical vapor deposition (CVD) without hyperdilution with hydrogen or a halogen has been developed and patented by engineers at Ohio State University. The process, called laser-excited chemical vapor deposition (LECVD), can form diamond at 600-700°C. A paper on the process, which received a U.S. patent in March, was published in the August 1 issue of the *Journal of Applied Physics*.

Diamond is important to industry for several reasons. For example, its hardness protects drill bits and saw blades used for cutting metals and, because it can absorb five times as much heat as copper or gold, it may soon be used in heat sinks for integrated circuits. But while diamond has been synthesized in low-pressure chambers for more than 20 years, the CVD process used is not well-understood and is inefficient. CVD techniques are hard to study because they use intense heat and produce extremely bright sources of light, which precludes monitoring with spectroscopy. CVD diamond techniques use large amounts of expensive hydrogen gas or corrosive halogens and often produce impure films. It was thought that hydrogen or halogens were essential to making diamond films but the new technique, LECVD, produced by Vish Subramaniam, an assistant professor of mechanical engineering at Ohio State, does not use hydrogen gas and produces diamond without any other forms of carbon. "In other processes, lots of nondiamond material, or soot, is deposited with the diamond. That makes the film less pure and changes its electrical and optical properties." The soot makes the diamond less transparent and more electrically conductive.

Subramaniam and colleagues were able to grow diamond particles on a silicon sample in a chamber filled with 5% methane and 95% carbon monoxide. An infrared laser sets the carbon monoxide molecules vibrating rapidly, and then the carbon monoxide ultimately transfers its energy to the methane. Although Subramaniam does not yet understand exactly how the diamond is formed, he attributes it to either the excited methane or to the fragments that are dissociated from the methane.

J. F. Young Receives Copeland Award

J. Francis Young, professor of civil engineering and materials science and engineering at the University of Illinois at Urbana–Champaign, has received the Copeland Award from the Cements Division of the American Ceramic Society. The award, given on an irregular basis, recognizes "his outstanding contributions to the development of advanced cement-based materials and to the sciences on which they are based." Young, also associate director of the National Science Foundation Center for Advanced Cement-Based Materials, has been a symposium organizer and committee chair for the Materials Research Society, and in 1988 was a meeting chair.



Ni Captures Helium Ash in Fusion Reactor

A new device that removes "ash" from a fusion "burn" could save $100 million in the cost of a commercial fusion reactor. Invented by scientists from Argonne National Laboratory and Sandia National Laboratories, the "helium self-pumping module" could eliminate the need for large, expensive vacuum systems to remove fusion ash.

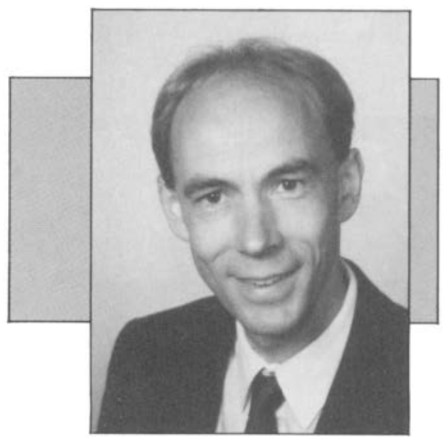
Fusion combines two hydrogen atoms to make a single helium atom and releases energy. The fusion burn takes place in a plasma, a thin, hot gas of charged particles. The plasma is so delicate that the buildup of too much helium—the "ash"—can shut it down.

The new device takes advantage of the ability of nickel to trap helium when kept at temperatures around 500°C. Energetic helium ions from the plasma are trapped in the surface of a nickel-coated plate. As the nickel becomes saturated with helium, more nickel is vaporized from a coil heated to about 1400°C. The vapor settles onto the plate to form a fresh nickel layer.

The module was invented by Jeffrey N. Brooks and Alan R. Krauss of Argonne and Richard E. Nygren, formerly of Argonne, now with Sandia, and has already passed tests at an experimental fusion facility in Jülich, Germany.

W.C. Sinke Receives Kistemaker Prize

The 1992 Jacob Kistemaker prize, established by the Foundation for Fundamental Research on Matter (FOM) in The Netherlands, has been awarded to W.C. Sinke, head of the R&D solar energy group within the Renewable Energies Unit of the Netherlands Energy Research Foundation. The prize honors Dutch physicists who have performed outstanding research beneficial to other sciences, technology, industry, or society in general. Recipients are awarded Dfl. 25,000, or about $15,000.



Sinke and his group performed extensive research on pulsed-laser induced explosive crystallization of amorphous silicon, which can form microcrystalline silicon or single-crystal silicon, depending on sample preparation. Sinke was also the first to prove that structural relaxation of amorphous silicon is accompanied by a substantial heat release, and characterized this process in terms of its kinetics and the role of network defects. One aspect of his work, in the field of polycrystalline silicon solar cells, concerned gettering of impurities and passivation of crystal defects. Implementation of results yielded a considerable improvement of the efficiency of Dutch manufactured cells.

Sinke's work constitutes an essential contribution to technology and industry, and to society through the application of solar cells as a source of clean energy.

Penn State MRL Celebrates 30th Anniversary

The Materials Research Laboratory (MRL) at Pennsylvania State University recently celebrated its 30th anniversary with a symposium and a reunion of alumni. The symposium focused on successful MRL examples of "Materials Synthesis and Processing," including cement, characterization, composites, ferroics, new materials synthesis, and thin films.

A second focus was realistic planning for the future. Several speakers emphasized the radically altered research climate from 30, or even 10, years ago and the need for greater responsiveness to societal needs. For example, William Harris, assistant director for mathematical and physical sciences at the National Science Foundation (NSF), reported on a proposal at NSF to reorient some of its missions toward civilian industry support. The point was also made that universities would have to be more aggressive in serving society and industry if they wished to maintain public support.

Russell Messier, MRL director, and Rustum Roy and L.E. Cross, former directors, presented a historical perspective on the scientific and administrative achievements of the lab. MRL was the first materials lab established in the United States with no external block grant, and is now the largest MRL in the United States. In addition to leading other MRLs in its emphasis on ceramics and synthesis and characterization, it was also the founding place for the Materials Research Society. □

Correction

Bernd Stritzker's affiliation in the October MRS Bulletin, p. 15, "E-MRS Holds Elections," should have been listed as the Institute of Physics, University of Augsburg, Germany.

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