NREL PV

Working With Industry

Winter 1995/96

1995 Successes With Industry

We are hot and heavy into our various research and development activities for 1996. But let's take a quick tour of some of what we—the U.S. PV community of research labs, industry, and universities—accomplished last year. Rich Marczewski, NREL's Business Ventures Center director, starts our tour in this issue by describing the burgeoning growth in 1995 of licensing agreements, cooperative research and development agreements, and patent filings.

Researchers and engineers studying the various technologies making up thin-film photovoltaics made great strides. New world-record efficiencies were achieved. New manufacturing facilities were built. National research teams were expanded.

The PV Manufacturing Technology program also chalked up a successful year. The completion of eight subcontract projects begun 3 years ago marks the end of two PVMaT phases. Efficiencies climbed. Costs fell. Manufacturing capacities expanded. And a new PVMaT phase was kicked off that covers PV system issues.

Not all the successes, though, were in research labs or manufacturing plants. Photovoltaics continued to move into various markets, both domestic and international, and to be used in more and more applications. While PV products were being integrated into houses in the United States, developing countries were turning to PV to supply electricity for basic needs such as lighting and water pumping.

Let's be encouraged by these 1995 successes and press on with the work at hand in 1996!

Features

Departments

Charting a New Course in Technology Partnerships

An editorial by Richard Marczewski

Warren Gretz, NREL PIX 03656

Rich Marczewski, who joined NREL after 26 years at General Motors Corporation, directs the Laboratory's Business Ventures Center.

As we pause for a moment in 1996 to review the achievements of our government/industry PV R&D partnerships in 1995, it is tempting to congratulate ourselves on a job well done and firmly resolve to continue on the same successful course.

For example, we have negotiated more licensing agreements with our industry partners in the past eight months at NREL than we have in the past 17 years. In 1995 we negotiated four new licensing agreements in photovoltaics alone: three in the area of thin films for solar cells based on copper indium gallium diselenide and one in the area of nanocrystalline technology. Last year, our NREL negotiators increased the number of cooperative research and development agreements (CRADAs) signed with industry to 15 or more per year for each negotiator in all technical R&D areas. And we are filing new patent applications at a very brisk pace.

These accomplishments reflect NREL's strong and continuing commitment to pursuing an aggressive course of technology transfer in the 1990s. But they also reflect the PV industry's firm commitment to succeeding in an increasingly competitive global market for advanced energy technologies.

Rather than continuing to conduct "business as usual," however, we're building on this unprecedented activity in licensing agreements, CRADAs, and patents by exploring several promising new mechanisms for rapidly converting collaborative achievements in R&D to commercial successes.

For instance, we recently combined or "bundled" three NREL patents together in one new license to industry, boosting the value to our customers of each innovation. And we are exploring agreements in which other government-funded patents for PV products and processes can be assigned to NREL and bundled into a single portfolio. Each contributor would then share in the revenues accruing from the licensing of that portfolio.

We are also exploring the feasibility of taking equity or risk positions in new energy ventures, to leverage the skills and the finances of all the partners involved.

In this spirit of both technical and commercial innovation, we encourage our industrial partners and the researchers in our sister laboratories to keep in touch with us about ways in which we can continue to fulfill the bright potential of photovoltaics. We pledge to stay in touch with you and continue to pursue the best new ideas in PV.

A Banner Year for Thin Films

If you have time, ask NREL's Ken Zweibel to tell you what's new in the Thin-Film PV Partnership Program. There's plenty; in one eventful year, NREL and our industry partners achieved new efficiency records and R&D breakthroughs, signed new licensing agreements, built or planned new plants, started up new companies, and expanded the national research teams from one to four.

For example, last year NREL's researchers found that a novel "hot-wire" deposition process results in nearly stable amorphous silicon (a-Si) devices. "This deposition process not only increases stability, it also is faster and may be less expensive than conventional glow-discharge processes," Zweibel said. Lab-scale devices are approaching state-of-the-art single-junction efficiencies and near-total stability upon initial exposure to light, in recent tests.

Meanwhile, NREL's researchers once again ramped up the efficiency of a copper indium gallium diselenide (CIGS) device measuring 0.4 cm^2, this time to a record-breaking 17.1%. "The new record demonstrates thin films' potential to achieve the long-term 15% efficiency goal we've set for modules," Zweibel said. NREL also signed new licensing agreements that will enable private firms (such as Architectural Solar Glass, Inc., and Energy Photovoltaics) to manufacture products based on the CIGS technology.

"We're also exploring new licensing opportunities for cadmium telluride systems," Zweibel added, "beginning with our neighbor, Golden Photon." That company recently completed the initial shakedown of its new, 2-megawatt CdTe manufacturing plant in Colorado, the first of its kind anywhere in the world.

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Thin Films, *from page 2*

Elsewhere, a joint venture between United Solar Systems Corp., and Energy Conversion Devices resulted in a new 5-megawatt a-Si plant, sheduled for completion in February 1996, in Troy, MI. As a result of another joint venture—between Amoco and Enron, the largest natural gas company in the United States—the groundbreaking for a new 10-megawatt a-Si plant took place in James City County, VA, last October.

In addition, three government/industry national research teams now focus on advancing a-Si, CIS, and CdTe technologies; a fourth is tackling related environment, safety, and health issues. Though the teams meet twice a year to discuss common problems and pursue mutual R&D goals, the private firms involved can still maintain a proprietary position in the commercialization of thin-film technologies.

Current team collaborations include the development of hot-wire a-Si (NREL, with United Solar and Solarex); a round-robin examination of CdTe deposition on glass/tin oxide/cadmium sulfide supplied by the University of South Florida; and an in-depth materials and electronic analysis of CIGS cells and materials provided by all the CIS team members.

These and other achievements in 1995 made it another banner year for thin films—and for the Thin-Film PV Partnership Program at NREL.

For further information, contact Ken Zweibel, (303) 384-6441.

Warren Gretz, NREL PIX 03709

Jim Yost Photography PIX 03524

Above: Ken Zweibel is proud of the progress made through the Thin-Film PV Partnership Program.

Left: Researchers in NREL's CIS lab use physical vapor deposition to lay down the basic cell materials.

Some Highlights in Thin Films in 1995

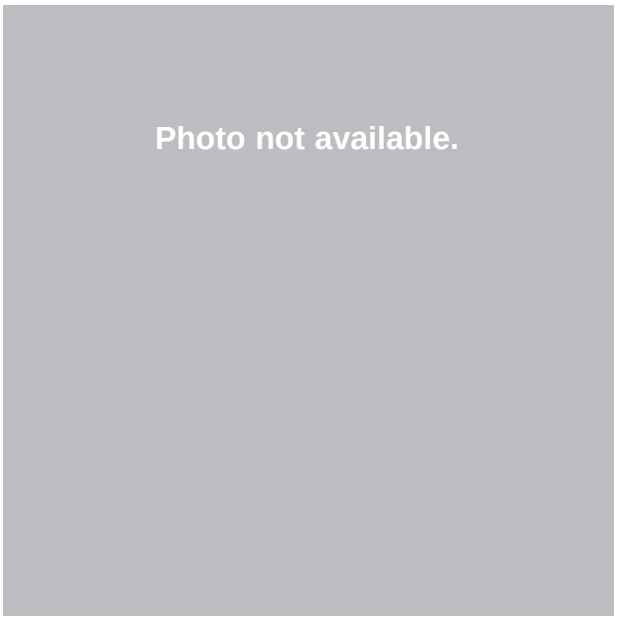
- **NREL's CIS team achieves world-record efficiency (17.1%) for CIGS cell**
- **NREL's a-Si team establishes "hot-wire" deposition as viable alternative to glow discharge**
- **Amoco-Enron breaks ground on new 10-MW a-Si plant to manufacture low-cost a-Si modules**
- **United Solar Systems Corp. begins building 5-MW a-Si plant in Michigan**
- **Solarex-NREL CIS team achieves world-record efficiency (13%) for "minimodule"**
- **Golden Photon completes shakedown tests of new 2-MW CdTe facility**
- **ISET produces high-efficiency CIS cells (>12%) with unique, low-cost process**
- **AstroPower achieves highest efficiency to date (10.5%) for film c-Si device on low-cost substrate**
- **IEC produces high-bandgap, high-Ga-content CIGS cell with efficiency of >13%**
- **Colorado School of Mines achieves 12% efficiency with CdTe cell made with ZnTe contact**
- **Solar Cells Inc. produces world's two largest CdTe arrays (10 kW)**

Advances in Manufacturing Help PV Compete

As NREL's technical monitors for the PV Manufacturing Technology (PVMaT) program, Rick Mitchell and Holly Thomas have kept close tabs on it. As they reviewed the past year's accomplishments recently with project leader Ed Witt, they mentioned some of the program's many successful results.

Mitchell began by focusing in on Phases 2A and 3A of this multiphase program, which are now complete after 3 years of work.

"Phase 2A addressed the process-specific module manufacturing problems of individual manufacturers," he said. "The six 3-year subcontracts we awarded in that phase were just completed.



Phase 3A, using a team approach, addressed problems common to the PV industry as a whole. In that phase, two subcontracts were awarded: one has been completed and the other is almost complete."

Thomas added, "The Phase 2A projects were cost-shared at 47.5% by subcontractors who hoped to accomplish several things. Specifically, they wanted to improve product performance and manufacturing processes, reduce module manufacturing costs, and move toward scaling up PV capacity."

So how have the subcontractors done, with the support of the PVMaT program?

First, conversion efficiencies of various PV materials climbed, as Mitchell noted in these examples: "AstroPower developed a new polycrystalline silicon solar cell product from SiliconFilm™ that demonstrated a 14.6% efficiency for small-area cells. And Energy Conversion Devices demonstrated a 2500-foot production run of dual-junction, amorphous silicon cells. These cells, used in fabricating modules, have an initial subcell efficiency of 10.2%."

Second, manufacturing costs fell. Mitchell highlighted these examples: "Siemens Solar Industries, which uses the Czochralski silicon manufacturing technology, employed several means—better ingot quality, reduced saw waste, and an automated module manufacturing line—to lower the cost of production per solar cell by an impressive 65%. And Utility Power Group's work in amorphous silicon manufacturing lowered by 80% the cost of its advanced encapsulation and termination system developed under PVMaT."

Meanwhile, ENTECH and Solarex each planned large-scale manufacturing lines that will include advances made through PVMaT work. "ENTECH produces linear concentrator modules," Mitchell explained, "and under PVMaT the company increased the automation in its manufacturing line to boost production capacity. Not to be outdone, Solarex began building a 10-megawatt-per-year factory based on large-area deposition of a multijunction, amorphous silicon alloy technology."

"Don't forget the results of the Phase 3A work," Thomas reminded him. "Spire Corporation developed the SPI-Assembler™ 5000, an automated unit that assembles cells into modules. In three shifts a day, the unit can handle 5 megawatts per year using 1.25-watt cells. And early in Springborn Laboratories' work, they determined that the glass commonly used for PV modules contains cerium, which reduces potentially damaging ultraviolet radiation. Springborn is now testing three encapsulant alternatives that show improved performance."

Clearly, because of the stellar results coming out of PVMaT's Phases 2A and 3A, industry partners are helping to approach PVMaT's year 2000 goal: more than 500 megawatts of manufacturing capacity at an average module manufacturing cost of about $1 per peak watt.

For further information, contact Rick Mitchell (303) 384-6479 or Holly Thomas (303) 384-6400. Also see page 11 for a brief description of PVMaT's newest work under Phase 4A.

Keeping the Customer Satisfied:

The PV Performance Characterization Team

Warren Gretz, NREL PIX 03715

In the Outdoor Test Facility's testbed control room, Keith Emery (third from left) is joined by fellow members of the PV Performance Characterization team.

If you ask Keith Emery, who leads NREL's PV Performance Characterization Team, what gives him the greatest satisfaction in his job, he'll tell you it's meeting the customer's needs. "We really like to keep our customers happy," he said.

Judging from the volume of PV cells and modules that move through the team's indoor and outdoor measurement and characterization labs, and all their repeat business, this seven-person team is achieving its goal. Team members perform more than 100 cell measurements and nearly 200 module measurements every month; their customers include NREL's in-house PV researchers, PV companies, university groups, and members of government-industry collaborations such as the Thin-Films PV Partnership Program and the PV Manufacturing Technology project.

"We don't necessarily know what we're going to be looking at next," Emery said. "One of the best things about our work is that every day is different. One day, we'll be verifying the performance of a novel PV device in the lab. The next, we'll be providing technical assistance for a PV demonstration project in another country. In fact, that's what one person on our team, Halden Field, did in India recently."

He tried, however, to describe a "typical" day for his team. "If it's Monday, I'll be meeting with the half of our team that takes module measurements out at the new Outdoor Test Facility," Emery said, "discussing general issues and leaving the details up to them."

Team member Steve Rummel helps Emery coordinate the module tests at the OTF, where there are enough outdoor test beds to measure the performance of more than 40 modules. Indoor test equipment at the facility can handle both small- and large-area modules. "The modules we get are measured multiple times in multiple places," Emery explained, "to provide data for a variety of test conditions."

And nearly every day, Emery gets together with the cell measurements group in the nearby Solar Energy Research Facility (SERF). "Our customers typically need and want performance data immediately," he said, "but the volume makes a priority system necessary. If a test device has to be measured in less than our standard one to three weeks, the requester has to get a priority designation from me."

Team members measure the performance of cells in every PV technology, including experimental devices for thermophotovoltaic systems. They use computers that produce high-accuracy current-voltage curves with respect to standard reporting conditions. Maintaining their equipment and making use of appropriate alternatives are mandatory. "Our equipment has to be running all the time and never damage a customer's sample," Emery said.

Industry members depend on NREL to verify the efficiency of their devices. "Nationally," he said, "we're all on the same page in terms of what the efficiency is."

In addition to state-of-the-art performance measurements, the team provides consultations and support to national and international standards organizations and equipment suppliers. They produce about 10-15 technical papers each year. Emery is often called upon to resolve disputes and solve characterization problems that come up in the PV community. "Our goal is to understand all the various measurement problems and know how to minimize them," he said.

Besides Emery, Field, and Rummel, the team includes Don Dunlavy, Josh Caiyem, Larry Ottoson, and Tom Moriarty. The team is supported in large part by the PV Module and Systems Performance and Engineering Project.

For further information, contact Keith Emery, (303) 384-6632.

A Global Power Surge in PV Applications

Harin Ullal, NREL PIX01993

PV systems are being installed in villages in developing countries to help power vital applications—here, the pumping of potable water in India.

Though "photovoltaics" isn't a household word yet, last year more people than ever before learned more about PV-generated electric power—all over the world.

For example, in South Africa, PV energy systems were picked to help meet a critical need for lighting, water pumping, refrigeration, and communications in rural areas. Helping to dedicate a new, locally owned PV module assembly plant in Johannesburg, U.S. Energy Secretary Hazel O'Leary said the new plant "means jobs for South Africans as well as Americans."

The plant will help to electrify rural schools, hospitals, and residences, and it should employ about 250 local people in module manufacturing, sales, installation, and system maintenance jobs. The solar cells for the modules will be manufactured in the United States. Both nations will gain immediate economic benefits from this new venture.

On another continent, more Brazilian village dwellers than ever before began to benefit from PV-generated electricity. In the Brazil Project, five more Brazilian states joined the original two in this joint endeavor sponsored by DOE, U.S. firms, a Brazilian national energy organization, and Brazilian state utilities. Hybrid PV-wind-diesel systems are also being installed.

Two more trade missions also took U.S. government-industry partners back to the Indian subcontinent, where new agreements were signed between U.S. and Indian organizations for PV-powered systems. In 1994, trade agreements in India promised some $1 billion in new business for U.S. PV companies. And in Russia, DOE and the U.S. Department of State formed a partnership with a Russian enterprise that will manufacture thin-film PV modules in that country. A U.S. PV company will also participate in this new international venture. In 1995, new PV partnerships were also explored or developed in China, Egypt, Indonesia, and Central and South America.

FIRST, Inc. PIX 03612

One PV:BONUS project led by FIRST, Inc. (Hopewell, NJ) focuses on incorporating PV products into modular, manufactured homes.

Meanwhile, back in the U.S.A., the first six modular houses built under the PV:BONUS (Building Opportunities in the United States for PV) program were sold. These houses incorporate such new products as PV systems that double as roofing materials. PV:BONUS participants include PV suppliers, utility groups, building contractors, building materials manufacturers, and architectural and engineering firms. In 1996, the program will demonstrate how well these systems work in attached houses.These are just a few of the many demonstrations of PV applications that were highlights in 1995 as a result of the hard work of industry members and government agencies around the world. It could go on record as the first year of a global PV power surge that lasts well into the next century.

For further information, contact Roger Taylor, (303) 384-6432.

Students Shine in National Solar Car Competition

The DOE- and General Motors-sponsored Sunrayce has been growing in popularity since 1991. A record 65 college and university teams signed up for Sunrayce 95; 38 student-built vehicles eventually qualified for the race. The students raced their sleek, PV-powered cars from Indianapolis, IN, to Golden, CO, over 10 days last June. Along the way, they attracted thousands of spectators and untold representatives of the press and broadcast media, who made it possible for thousands more to follow the Sunrayce.

More than 6,000 people accessed NREL's on-line Sunrayce 95 home page, as well. The top-place finishers were teams from Massachusetts Institute of Technology, the University of Minnesota, and California Polytechnic University at Pomona, but actually, all the students who participated were winners. Sunrayce 95 so captured the public's imagination that several thousand people ignored cool, rainy weather to cheer the teams as they crossed the finish line.

Mike Linenberger, NREL PIX 02514

Many of the students who designed and built solar-powered cars, such as this one at the Sunrayce starting line, will be the PV researchers and engineers of the future.

NREL PV researchers and managers interact with industry on several levels. Although we freely share our research results and the nonproprietary results of our subcontractors, many of our interactions involve the exchange of confidential information, including the results of certain measurements. The following are some notable recent interactions.

During the U.S. DOE/NREL India Initiative-Phase II visit to India in February 1995, **James Brown,** chairman of **Solar Cells, Inc.** (SCI), Toledo, OH, along with **NREL's Harin Ullal,** visited several Indian companies interested in business deals with SCI. As a result, SCI recently signed a Memorandum of Understanding with an Indian business partner in Toledo, OH. The partner will function as a distributor to introduce SCI solar power modules into the market. *(Harin Ullal, 303-384-6486; Jack Stone, 303-384-6470)*

ENTECH, Fort Worth Airport, TX, is optimizing the design of a linear concentrator using GaInP/GaAs cells. Because the two-junction cells are series-connected, deviation from the optimal spectrum will cause the output to be limited by either the bottom- or top-cell photocurrent. If the spectrum is spatially non-uniform the loss can be mitigated by laterally conducting some of the current across the bottom-cell emitter. ENTECH and **NREL** are working together to identify the best ways of predicting and measuring the loss associated with non-uniform spectrum (chromatic aberrations). Using two different algorithms for the calculation, ENTECH and NREL now get quantitative agreement on the predicted loss. Attempts to measure the loss are in progress. This work is being managed by **Able Engineering** of Goleta, CA, as part of the BMDO/NASA SCARLET program. *(Sarah Kurtz, 303-384-6475)*

Work continues on a CRADA with **Energy Photovoltaics** (EPV), Princeton, NJ. Desirable CIS and CIGS deposition sequences have been defined by EPV that can be implemented on EPV's manufacturing equipment. Close approximations to some of these processing schemes were explored under the CRADA. EPV's **Andrew Gabor** spent time at **NREL** using the CIGS lab's deposition facilities to explore and optimize the recipes. The deposition systems at NREL allow greater control and flexibility of film growth than is currently possible at EPV. The best CIGS cell fabricated at NREL by the recipes developed under the CRADA yielded an NREL-confirmed efficiency of 13.9%. *(Rommel Noufi, 303-384-6501)*

NREL has developed a nondestructive thin-film thickness measurement system for **Golden Photon** of Golden, CO. The catalyst for this work was Golden Photon's need to rapidly monitor their CdS film thickness for statistical process control applications. The technique is an optical transmission measurement to monitor the CdS thickness to within plus-or-minus 4%. A prototype system has been completed and demonstrated to meet Golden Photon's specifications. Golden Photon will be purchasing the necessary equipment to install this diagnostic tool in their facility. NREL will also provide technical assistance in constructing and calibrating the system in their manufacturing environment. *(Pete Sheldon, 303-384-6533)*

The December opening of the Pageant of Peace in Washington, D.C., was highlighted by the lighting ceremony of the National Christmas Tree. Almost 9 kW of PV mounted on the Mall near the Pageant site provided energy during the day to partially replace the energy used by the Pageant of Peace at night. The PV equipment was loaned by four companies (**ASE Americas,** Billerica, MA; **AstroPower, Inc.,** Newark, DE; **Solarex,** Newtown, PA; and **Siemens Solar,** Chatsworth, CA) and was installed by staff of **NREL** and **Ascension Technology, Inc.,** Lincoln Center, MA. Funding for the project was provided by the **National PV Program** and the **Federal Energy Management Program.** Public response to the exhibit was excellent, information packets on PV were distributed, and tours were given for members of the FEMP Renewable Working Group and the public. *(John Thornton, 303-384-6469)*

NREL's Bhushan Sopori organized the Second Working Group Meeting on the Measurement of Minority Carrier Diffusion Length/Lifetime, held in Scottsdale, Arizona, on January 17-19. The major emphasis was to identify techniques suitable for monitoring substrate quality and process control in solar cell manufacturing. The meeting was attended by 34 researchers representing PV and microelectronics industries, universities, and other research organizations. Represented were **Siemens Solar Industries** (Camarillo, CA), **ASE Americas** (Billerica, MA), **AstroPower** (Newark, DE), **EBARA Solar** (Large, PA), **Evergreen Solar** (Waltham, MA), silicon manufacturers for microelectronics industry (**SEH America,** Vancouver, WA; **Siltec,** Salem, OR; **Motorola,** Phoenix, AZ; **MEMC,** St. Louis, MO; **Sematech,** Sunnyvale, CA), equipment manufacturers for lifetime measurement (**GeMeTec**, Germany; **Semilab**, Hungary; **Labsphere,** North Sutton, NH; **SDI,** Tampa, FL), NREL, and **Sandia.** *(Bhushan Sopori, 303-384-6683)*

NREL did a preliminary evaluation of modules produced by a new South African company, **Suncorp Manufacturing.** The results of the initial PV Standardized Module Performance Test (indoor and outdoor), conducted at NREL's Outdoor Test Facility, were compared to the Suncorp test results, and showed a difference of less than 1%, which gave Suncorp confidence in its internal evaluation procedure. The modules will be deployed outdoors at the OTF, where they will continue to undergo periodic evaluation. *(Ernest van Dyk, 303-384-6367)*

In December, 1995, the **IEEE Standards Office** informed **NREL's Dick DeBlasio,** chairman of the

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Subcontracts

Subcontracted research with universities and industry, often cost-shared, constitutes an important and effective means of technology transfer in NREL's PV Program. From October through December 1995, we awarded 61 subcontracts (examples listed below) totaling more than $6.5 million. For further information, contact Tom Surek (303-384-6471).

Washington State University
Alternative Window Schemes for CIS-Based Solar Cells
$158,000 (11/95–11/97)

Solarex
Thin-Film CIS-Based Solar Cells and Submodules
$300,000 (12/95–6/96)

ASE Americas, Inc.
Market-Driven EFG Modules
$500,000 (12/95–6/96)

Georgia Institute of Technology
Post-Growth Quality Enhancement Techniques in c-Si Material
$595,488 (4/92–12/96)

Solar Energy Industries Association
National Electric Code—Article 690 Solar PV Systems Support
$70,956 (6/94–6/96)

Sherring Energy Associates
Bilateral Agreement on Renewable Energy Between U.S. and India
$277,079 (7/94–4/96)

Solar Energy Industries Association
Management and Administration of IEC/TC 82 Secretariat
$119,177 (6/94–8/96)

Ascension Technology, Inc.
Manufacture of an AC PV Module
$755,974 (7/95–7/97)

Siemens Solar Industries, L.P.
PV Cz Silicon Module Improvements
$500,000 (11/95–11/98)

Massachusetts Institute of Technology
Point Defects and Impurities in Processing and Performance of c-Si Solar Cells
$558,822 (7/92–1/96)

Applied Power Corporation
Sustainable Rural Economic Development: Ramakrishna Mission Initiative, India
$201,121

Publications

Dissemination of research results is an important aspect of technology transfer. NREL researchers and subcontractors publish some 300 papers annually in scientific journals and conference proceedings. PV program and subcontractor reports are available from the National Technical Information Service (NTIS), 5285 Port Royal Road, Springfield, VA 22161. For further information, contact Ann Hansen (303-275-3646).

U.S. Department of Energy. Photovoltaics—The Power of Choice, The National Photovoltaics Program Plan for 1996–2000. Jan 1996; 32 pp. NTIS No. DE95000214.

U.S. Department of Energy. Photovoltaic Energy Program Overview, Fiscal Year 1995. Feb 1996. 32 pp. NTIS No. DE96000533.

Collins, S.R.; Hall, R.B.; Rand, J.A. Silicon-Film™ Photovoltaic Manufacturing Technology: Annual Subcontract Report, 1 Jan 1994-31 Dec 1994. Nov 1995; 38 pp. NREL/TP-411-20143. NTIS No. DE96000477. Work by AstroPower, Newark, DE.

Gordon, R.G. Optimization of Transparent and Reflecting Electrodes for Amorphous Silicon Solar Cells: Annual Subcontract Report, 1 Apr 1994-31 Mar 1995. Oct 1995; 52 pp. NREL/TP-411-20014. NTIS No. DE95013127. Work by Harvard University, Cambridge, MA.

Guha, S. Amorphous Silicon Research, Phase 1: Annual Subcontract Report, 1 Aug 1994-31 July 1995. Oct 1995; 60 pp. NREL/TP-411-20205. NTIS No. DE95013124. Work by United Solar Systems Corp., Troy, MI.

Jester, T. PV Cz Silicon Manufacturing Technology Improvements: Final Subcontract Report, 1 Apr 1992-31 May 1995. Oct 1995; 43 pp. NREL/TP-411-20016. NTIS No. DE95013125. Work by Siemens Solar Industries, Camarillo, CA.

Mrig, L., ed. Photovoltaic Performance and Reliability Workshop: Proceedings of the Workshop, 7-8 Sept 1995, Golden, CO. Nov 1995; 368 pp. NREL/TP-411-20379. NTIS No. DE96000468.

Murphy, R.; Sopori, B L.; Rose, D. Influence of Dislocations on the I-V Characteristics of Silicon Solar Cells. Ashok, S. et al., eds. Defect and Impurity Engineered Semiconductors and Devices: Proceedings of the MRS Symposium, 17-21 Apr 1995, San Francisco, CA. MRS Symposium Proceedings, Vol. 378. Pittsburgh, PA: MRS; 1995; pp. 749-756.

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News at Press Time

GOLDEN, CO ... In January, 165 employees chose to leave the Laboratory under NREL's Voluntary Separation Program (VSP). An additional 29 left NREL in early February under an Involuntary Separation Program (ISP). Many of these 194 people were in administrative positions indirectly impacting NREL's PV Program costs. The direct impact, though, on the PV Program is significant; adding those who resigned near the end of 1995 to the VSP and ISP personnel losses, 16 employees have left NREL's PV Program. And the reductions aren't over yet. Another 32 NREL manager positions will be eliminated on April 1, for a total of 226 VSP and ISP employees leaving the Lab.

NREL's PV Program R&D activities—previously in the Photovoltaics Division and Basic Sciences Division—have been reorganized into four Centers: the Center for Photovoltaics and Electronic Materials; the Center for Basic Science and Advanced Concepts; the Center for Performance Engineering, Qualification, and Reliability; and the Center for Measurement and Characterization.

On February 22, NREL named the following as directors for these Centers: John Benner, director of the Center for Photovoltaics and Electronic Materials; Satyen Deb, director of the Center for Basic Science and Advanced Concepts; Roland Hulstrom, director of the Center for Performance Engineering, Qualification, and Reliability; and Larry Kazmerski, director of the Center for Measurement and Characterization.

Publications, *from page 9*

Myers, D.R. Photovoltaic Radiometric Measurements Workshop Introduction and Overview. PV Radiometric Workshop Proceedings, 24-25 July 1995, Vail, CO. NREL/CP-411-20008. Golden, CO: NREL; Sept 1995; pp. 1-8.

O'Neill, M.J.; McDanal, A.J. PVMaT Improvements for ENTECH's Concentrator Module: Final Subcontract Report, 17 Feb 1992-14 June 1995. Nov 1995; 73 pp. NREL/TP-411-20277. NTIS No. DE96000478. Work by ENTECH, Inc., DFW Airport, TX.

Sandwisch, D.W. High Throughput Manufacturing of Thin-Film CdTe Photovoltaic Modules: Annual Subcontract Report, 16 Nov 1993-15 Nov 1994. Nov 1995; 48 pp. NREL/TP-411-20278. NTIS No. DE96000479. Work by Solar Cells, Inc., Toledo, OH.

Sopori, B.; Cudzinovic, M., comp. First Working Group Meeting on the Minority Carrier Diffusion Length/Lifetime Measurement: Results of the Round Robin Lifetime/Diffusion Length Tests, 18-19 Dec 1993, Scottsdale, AZ. Nov 1995; 70 pp. NREL/TP-413-20470. NTIS No. DE96000480.

Trefny, J.U.; Mao, D.; Kim, D.; Williamson, D.L.; Furtak, T.E. Polycrystalline Thin-Film, Cadmium-Telluride Solar Cells Fabricated by Electrodeposition: Final Subcontract Report, 20 Mar 1992-27 Apr 1995. Oct 1995; 48 pp. NREL/TP-451-8253. NTIS No. DE95013130. Work by the Colorado School of Mines, Golden, CO.

Tsuo, Y.S.; Xiao, Y.; Moore, C.A. Device Applications of Porous and Nanostructured Silicon. Feng, Z.C.; Tsu, R. eds. Porous Silicon. Singapore: World Scientific; 1994; pp. 347-362.

Weisiger, D.; Albright, S.P.; Brines, J.; Thompson, R. Cadmium Telluride Photovoltaic Manufacturing Technology: Annual Subcontract Report, 7 Jan 1994-6 Jan 1995. Nov 1995; 41 pp. NREL/TP-411-8259. NTIS No. DE96000476. Work by Golden Photon, Inc., Golden, CO.

Zhang, S.B.; Wei, S.H.; Zunger, A. d-Band Excitations in II-VI Semiconductors: A Broken-Symmetry Approach to the Core Hole. Physical Review. B, Condensed Matter. 15 Nov 1995 - I; 52(19); pp. 13975-13982.

Industry Update, *from page 8*

IEEE PV SCC21 (Standards Coordinating Committee on PV Systems) that the IEEE Standards Board approved IEEE 1262 (IEEE Recommended Practice for Qualification of PV Modules). The standard represents 5 years of effort by the 50 members of SCC21, as well as their sponsors' support. The document was developed for flat-plate PV modules with testing directed toward evaluating crystalline silicon and thin-film module technologies. *(Dick DeBlasio, 303-384-6760)*

From October through December, the **Measurements and Characterization Branch** evaluated 4480 components, devices, and PV materials for more than 25 research and industry groups for properties ranging from composition and microstructure to cell and module performance. *(Larry Kazmerski, 303-384-6600)*

From October through December, the **NREL PV Performance Lab** performed 263 one-sun I-V, 264 QE, and 78 dark I-V measurements on PV cells for a variety of groups including **ASE Americas, Arizona State University, Colorado School of Mines, Florida Solar Energy Systems, University of Delaware—Institute of Energy Conversion, Solarex, Solar Cells Inc., RES PV** (India), and the **Russian Academy of Sciences.** *(Keith Emery, 303-384-6632)*

In December, 155 module measurements were performed outdoors under prevailing clear-sky conditions and on the SPIRE 240 solar simulator to support in-house contract deliverables, PVMaT, the technology validation program, the amorphous silicon light-soaking program to determine stabilized efficiency, the stability/reliability program, and the PV industry. Samples were evaluated from **APS/Chronar, ARCO, AstroPower, Energy Conversion Devices, Fuji, Golden Photon, Photocomm, RES PV, Siemens Solar Industries, Solar Cells Inc., Solarex, Solems, Texas Instruments, United Solar Cells Corp.,** and **Utility Power Group.** *(Keith Emery, 303-384-6632)*

Colorado School of Mines (CSM), Golden, CO, recently delivered and **NREL** verified a 12.9%-efficient CdS/CdTe solar cell with the following parameters: V_{OC} = 0.778 V, J_{SC} = 22.4 mA/cm^2, FF = 74.0%, and area = 0.103 cm^2. CSM deposits CdTe by electrodeposition. The new cell uses a SnO_2 substrate obtained from the **University of South Florida** (Tampa, FL) and a ZnTe/metal rear contact. The result shows that solar cell parameters are critically dependent on the non-semiconductor layers used for the cells. The NREL-implemented **CdTe research teams** helped in the exchange of SnO_2-coated substrates that led to CSM's achievement. *(Bolko von Roedern, 303-384-6480)*

NREL confirmed that a co-evaporated CdS/Cu(In,Ga)Se_2 (CIGS) solar cell prepared at the **University of Delaware's Institute of Energy Conversion** (IEC) reached 15.4% efficiency (V_{OC} = 0.653 V, J_{SC} = 32.0 mA/cm^2, FF = 73.5%, cell area 0.412 cm^2). The estimated Ga/In ratio of the absorber layer is ~35%. Compared to an earlier, 15.1%-efficient cell, the present cell has a lower voltage and larger current density. According to IEC, no specific new processing features were used in fabricating the latest cell. This work is part of IEC's general focus on producing high-voltage CIGS cells with Ga contents that are higher than commonly used. NREL confirmed 10.2% efficiency for a cell with the following parameters: V_{OC} = 0.781 V, J_{SC} = 21.0 mA/cm^2, FF = 62.0%. The Ga/In ratio in this device is estimated to be ~75%. A recent study by **A. Delahoy** of **Energy Photovoltaics,** Princeton, NJ, suggests that the power production under prevailing outdoor operating conditions will favor modules with solar cells with larger V_{OC}, even if the higher voltage cells possess a somewhat lower efficiency. *(Bolko von Roedern, 303-384-6480)*

Syracuse University, Syracuse, NY, measured the built-in potential (V_{bi}) of n-i-p amorphous silicon solar cells obtained from **United Solar Systems Corporation,** Troy, MI. These cells were prepared with a microcrystalline boron-doped p-layer. V_{bi} values are 0.3 to 0.4 V lower than those determined from fundamental materials measurements and are similar to values found in p-i-n solar cells having a-SiC:H p-layers. From a photocarrier grating study, Syracuse University concluded that the ambipolar diffusion lengths can be inferred from the hole mobility and the recombination response time by using the Einstein relation. The work suggests that holes are not captured by deep levels prior to recombination, but are instead annihilated while still undergoing their early-time, multiple-trapping, transport phase. *(Bolko von Roedern, 303-384-6480)*

The four Amorphous Silicon Team Leaders (**E. Schiff, H. Branz, S. Wagner,** and **S. Hegedus**) described recent NREL a-Si:H research progress to industry, NREL, and DOE managers at the 6th Amorphous Silicon Guidance Team review meeting, January 12, in Denver, CO. For example, **Howard Branz (NREL)**, the Metastability and Midgap Alloy Team leader, focused on team effort to improve and evaluate amorphous silicon devices and materials deposited by hot-wire and electron cyclotron resonance CVD. After the meeting, NREL's **Harv Mahan, Brent Nelson,** and **Richard Crandall** discussed how to further improve a-Si:H hot-wire devices with **Subhendu Guha** and **Jeff Yang** of **United Solar Systems Corp.** Industry representatives on the various teams expressed their satisfaction with the overall team performance and progress. The collaboration among university members and between university and industry members is at a high level. *(Richard Crandall, 303-384-6676)*

Going Through Another Phase: PVMaT 4A Kicks Off

Like all the previous phases, the PV Manufacturing Technology program's latest one, Phase 4A, presents a challenge to the U.S. PV industry. Phase 4A covers manufacturing research that is product-driven. These PV products include elements such as balance-of-system components, system integration, and module manufacturing.

In earlier phases, the emphasis has been on improving modules and module manufacturing processes. During this new phase, the push is to perfect and package entire, integrated PV systems, including components such as inverters. Phase 4A1 focuses on this integrated approach to PV products and improvements of subsystems, while Phase 4A2 primarily focuses on module manufacturing.

In late 1995, NREL awarded the eight 2-year Phase 4A1 and five 3-year Phase 4A2 subcontracts listed to the right.

Phase 4A1 subcontractors

- Solar Design Associates, and Solarex Corporation (subtier)
- Solar Electric Specialties, Inc.
- Trace Engineering
- Omnion Power Engineering Corporation
- Utility Power Group, and Siemens Solar Industries (subtier)
- Ascension Technology, Inc., and ASE Americas, Inc. (subtier)
- Evergreen Solar, Inc.
- Advanced Energy Systems, Inc.

Phase 4A2 subcontractors

- AstroPower, Inc.
- Iowa Thin Film Technologies
- Solar Engineering Applications
- Siemens Solar Industries
- ASE Americas, Inc.

PV Calendar

March 12-15, 1996, **SOLTECH '96** and **UPVG Annual Meeting.** Sponsors: SEIA, UPVG. Location: Palm Springs, CA. Contact: SEIA, Michelle Birkenstock. Phone: 202-383-2620.

March 13-15, 1996, **11th Symposium on Photovoltaic Solar Energy**. Sponsor: Ostbayerisches Technologie-Transfer Institut e.V. Location: Staffelstein, Germany. Contact: OTTI-Technologie Kolleg, Herr Dipl.-Kfm. E. Guenther, Wernerwerkstr. 4, D-93049, Rengensburg, Germany. Telefax: 0941/29688-19.

April 13-18, 1996, **SOLAR 96, National Solar Energy Conference.** Sponsors: Energy Division, North Carolina Department of Commerce, Tennessee Valley Authority, U.S. DOE. Location: Asheville, NC. Contact: American Solar Energy Society. Phone: 303-443-3130.

May 12-17, 1996, **25th IEEE Photovoltaic Specialists Conference.** Sponsors: IEEE, NREL/Washington, D.C. Office. Location: Washington, D.C. Contact: Fran Hodson. Phone: 202-651-7518.

June 15-21, 1996, **World Renewable Energy Congress IV.** Sponsor: World Renewable Energy Network. Location: Denver, CO. Contact: NREL, Jessica White. Phone: 303-275-4358.

September 16-19, 1996, **10th DGS International Solar Forum.** Sponsor: Deutsche Gesellschaft für Sonnenenergie e.V., International Solar Energy Society e.V., Fraunhofer-Institut für Solare Energiesysteme. Location: Freiburg im Breisgau, Germany. Contact: Deutsche Gesellschaft für Sonnenenergie e.V., Augustenstr. 79, D-80333, Muenchen, Germany. Telefax: +49(0)89-521668.

November 17, 1996, **Photovoltaics in Buildings: Design Guidance for Practicing Architects and Design Professionals.** Sponsor: American Institute for Architectural Research. Location: Los Angeles, CA. Contact: AIA, Stephanie Vierra. Phone: 202-879-7752.

The purpose of this quarterly report is to encourage cooperative research and development by providing the U.S. PV industry with information on the activities and capabilities of the laboratories and researchers at NREL.

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