Thin Films Seek a Solar Future

FEATURE

by Ineke Malsch

Despite setbacks, the technology may yet shine

Energy from the sun—available everywhere, for everybody—has motivated research on solar-energy technologies for about three decades. The U.S. Photovoltaic Industry Roadmap, intended to guide companies in developing solar-energy systems, takes a more prosaic but realistic view of the next three decades. It aims for solar energy to provide 10% of U.S. peak generation capacity and supply a considerable share of foreign markets by 2030.

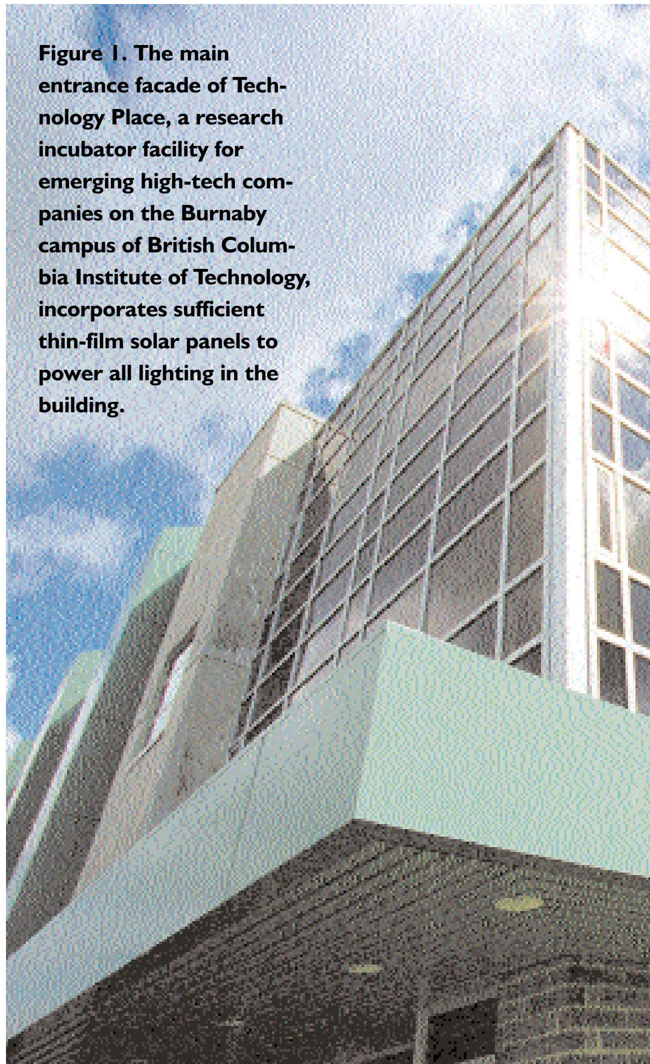
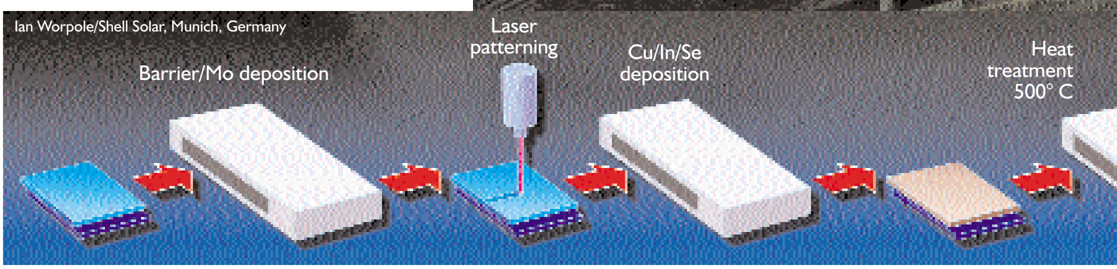


Figure 1. The main entrance facade of Technology Place, a research incubator facility for emerging high-tech companies on the Burnaby campus of British Columbia Institute of Technology, incorporates sufficient thin-film solar panels to power all lighting in the building.

Most photovoltaic (PV) solar technologies rely on semiconductor-grade crystalline-silicon wafers, which are expensive to produce compared with energy from fossil fuel sources. However, potentially less costly thin-film alternatives may make major inroads in the world market in five years, suggests Franz Karg, research manager at the Shell Solar facility in Munich, Germany. Or maybe not. Thin-film solar panels are hard to mass-produce cost-effectively because of the difficulty of coating large areas of glass. “It is my opinion that crystalline-silicon technologies will dominate for at least the next 10 years,” says Jeffrey Mazer of the U.S. Department of Energy (DOE) Office of Solar Energy Technologies (Washington, DC).

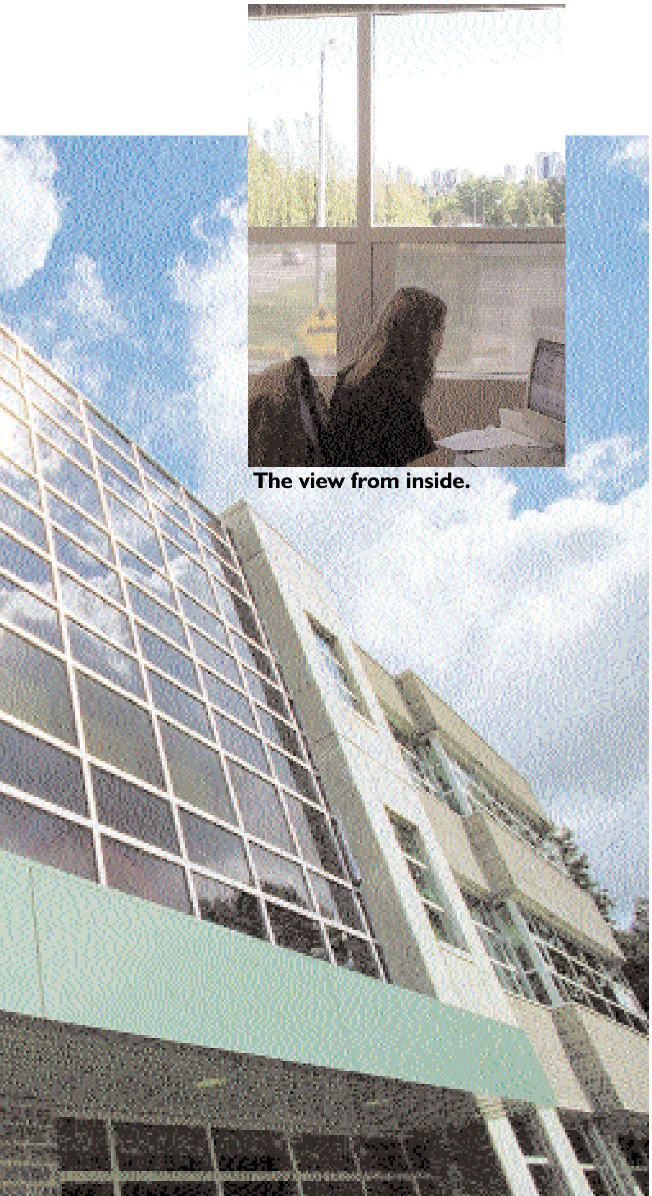
Solar-energy systems pose many challenges for developers, particularly in the current world economy. Last October, Shell Solar (Amsterdam, The Netherlands) announced the closing of two production operations—in Helmond, The Netherlands, and in Munich—in a restructuring meant to make the company more competitive. The next month, BP Solar (Linthicum, MD) decided to close down production of its thin-film amorphous silicon and cadmium telluride (CdTe) solar panels to focus on crystalline-silicon technologies. “While the thin-film technology continues to show promise, lack of present economics does not allow for continued investment,” said Harry Shimp, BP Solar’s president and chief executive officer.



BP’s decision is a setback to the marketing of new thin-film solar technologies. However, First Solar, LLC (Perrysburg, OH), a major maker of CdTe solar cells, remains strongly committed to the technology. Shell Solar continues development of its thin-film technologies. And DOE’s National Renewable Energy Laboratory (NREL) in Golden, Colorado, continues to provide funds for thin-film PV research to its 40 industrial and university partners.

Why solar power?

In 2001, the global market for PV panels and equipment was valued at $2 billion. Worldwide in 2000, solar, geothermal, wind, combustible renewables, and burning garbage and other wastes collectively provided 1.6% of electricity production, according to the International Energy Agency (IEA) in Paris. In its *World Energy Outlook 2002*, IEA described two scenarios for world energy



The view from inside.

British Columbia Institute of Technology

demand and supply until 2030. One scenario assumes only the continuation of current government measures to stimulate sustainable-energy supply and demand. In it, fossil fuels continue to meet more than 90% of energy demand. All renewables except hydropower grow by 3.3% annually, but they will not meet a large share of the total energy demand because of their low-percentage base. Carbon dioxide (CO_2) emissions will grow 70% by 2030 to 38 billion metric tons annually.

In the alternative scenario, governments will implement policies such as promoting energy efficiency, the use of cleaner energy sources, and reducing the environmental impact of producing and burning fossil fuels. Compared with1990, those changes would result in an estimated 16% fewer CO_2 emissions in 2030—a year when the United Nations estimates the world population will be about 8.3 billion—in part because renewable energy sources will grow rapidly.

Current applications of PV solar panels include providing power to spacecraft and isolated villages in developing countries, solar-energy systems in homes and buildings in Western countries (Figure 1), and even powering the lamps of remote lighthouses. "Especially where there is no connection to the grid, solar energy is easily cheaper than small-scale electricity production with a diesel generator, to give an example," Karg says. "For electricity production in rural areas in developing countries, solar is the cheaper alternative. To achieve more, we need breakthroughs in large-scale storage of electricity, and solar must be developed in combination with wind, biomass, energy-storage systems, and fossil fuels."

Most people in solar energy consider government subsidies for R&D and sales as necessary for its successful development and increased usage. Indeed, the PV energy business is still largely dependent on government intervention, and most U.S., European, and Japanese projects are subsidized. The Bush administration seeks $79.7 million from Congress for fiscal year (FY) 2004 to support solar-energy research, up 0.1% from its amended FY 2003 request but down from the $87.1 million that Congress appropriated in FY 2002.

Crafting photovoltaics

PV solar panels convert sunlight directly into electricity. A panel consists of several connected 0.6-V dc PV cells, which are made out of a semiconducting material sandwiched between two metallic electrodes. "The photovoltaic effect refers to the separation of minority carriers [electrons and holes] by a built-in electric field," such as a pn-junction or Schottky barrier, says DOE's Mazer. The cells are usually encapsulated behind glass to weatherproof them. In a PV array, several panels are connected to provide sufficient power for common electrical applications such as household electricity. The arrays can be connected to an electricity grid or work as stand-alone systems.

Researchers at what is now Lucent Technologies' Bell

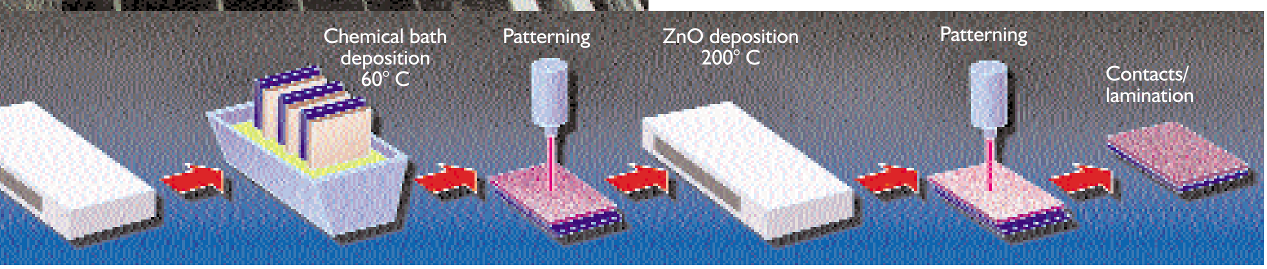


Figure 2. Copper and indium are deposited by magnetron sputtering, followed by selenization to form the high-absorbing p-type semiconductor $CuInSe_2$, which is combined with an n-type electrode of ZnO to create thin-film solar modules.

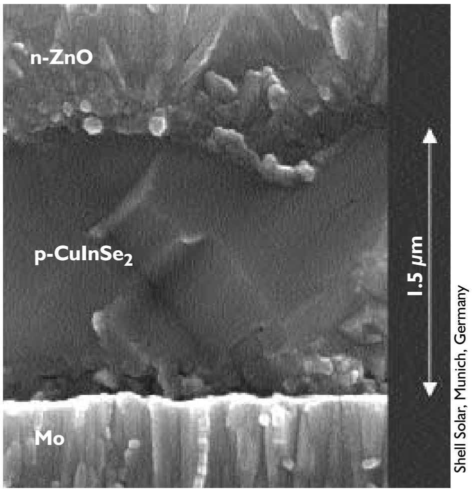


Figure 3. A scanning electron micrograph shows a cross section of the p-type semiconductor $CuInSe_2$ film, about 1.5 μm thick, and the n-type layer of ZnO.

Laboratories first demonstrated silicon solar cells in 1954, and most PV systems today use mono- or multicrystalline silicon as the semiconducting material. "We obtain monocrystalline wafers by sawing them from silicon rods, which we grow by the Czochralski growth process," explains Ronald van Zolingen, professor of sustainable energy at the Technical University in Eindhoven, The Netherlands, and a senior business advisor to Shell Solar. "In this process, we pull a monocrystalline rod from a liquid, starting with a small crystal. The growth speed is relatively low. but we obtain excellent material. Monocrystalline silicon solar cells have the advantage of a high efficiency, about 15%, which is an advantage for specific applications."

"We obtain multicrystalline wafers from ingots grown by casting liquid silicon in a large container followed by controlled cooling," van Zolingen adds. "This technique is less complicated than the pulling of single-crystalline rods. Multicrystalline-silicon solar cells have a slightly lower efficiency than monocrystalline, about 13.5%." Worldwide, the production of multicrystalline-silicon solar cells outpaces that of monocrystalline-silicon solar cells.

Among the major bottlenecks to the output of crystalline-silicon PVs is the high loss of materials during production of the wafers. "In addition, we need to saw the silicon. We typically lose 0.2 mm at the kerf," says van Zolingen. Despite these problems, crystalline silicon remains the dominant solar-cell material. One reason for this is the support provided by the federal government's PV program since the 1970s for R&D projects focused on crystalline-silicon technologies.

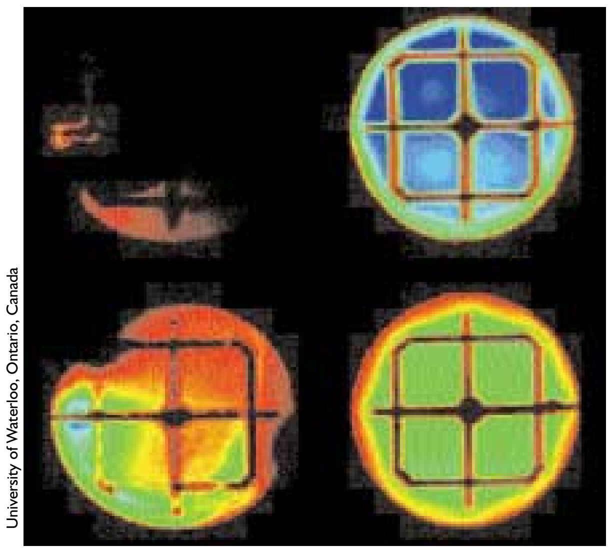


Figure 4. Optical-beam-induced current imaging (in false color) of these four $CdS/CuInSe_2$ thin-film solar cells connected in parallel gives a high-resolution photocurrent map, in which defects appear dark.

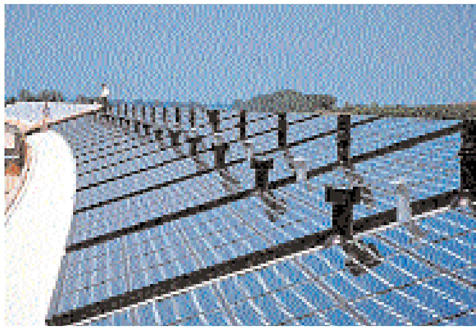
Thin-film alternatives to standard PV solar cells are already available or in development. Amorphous silicon, the most advanced of the thin-film technologies, has been on the market for about 15 years. It is widely used in pocket calculators, but it also powers some private homes, buildings, and remote facilities. An amorphous-silicon solar cell contains only about 1/300th the amount of active material in a crystalline-silicon cell. Amorphous silicon is deposited on an inexpensive substrate such as glass, metal, or plastic, and the challenge is to raise the stable efficiency. The best-stabilized efficiencies achieved for amorphous-silicon solar panels in the U.S. PV program are about 8%. The goal is to produce a stable device with 10% efficiency. United Solar Systems Corp. (Troy, MI) pioneered amorphous-silicon solar cells and remains a major maker today.

Thin-film crystalline-silicon solar cells consist of layers about 10 μm thick compared with 200- to 300-μm layers for crystalline-silicon cells. Researchers at NREL use porous polycrystalline silicon on low-cost substrates and trap light in the silicon to enable total absorption. They have fabricated working solar cells with this material.

New thin films

Copper indium diselenide (CIS) is a more recent thin-film PV material. Siemens Solar developed a process for depositing layers of the three elements on a substrate in a vacuum, and Shell Solar later acquired the technology when it bought Siemens Solar (Figures 2 and 3). CIS modules currently on the market reach stable efficiencies of more than 11%. In the laboratory, NREL scientists have achieved cell efficiencies of 19.2% with the semiconductor. Research now focuses on increasing efficiency (Figure 4), reducing costs, and raising the production yield of CIS panels. Karg predicts that thin-film technology will eventually halve the present production cost per unit kilowatt peak (kWp), which is the peak power that a solar panel can produce at optimum intensity and sun angle (90°). This implies a cost reduction for a complete system of 35% or more.

In 2000, CdTe solar panels were field-tested on a large scale in the United States. NREL researchers consider CdTe a promising material because of its lower cost of production, which uses techniques that include electrodeposition and high-rate evaporation. Prototype CdTe panels have reached 11% efficiency, and research now focuses on improving efficiency and reducing panel degradation at the electrode contacts. "Studies at Brookhaven National Laboratory strongly suggest that CdTe modules can be safely made in a large-scale manufacturing environment, and that CdTe can be safely disposed of when the modules are eventually retired," Mazer says.



Progress in solar PV research and the development of new applications are guided by national and international collaborations between industry and government, such as those described in the U.S. PV roadmap and carried out by national research teams organized by NREL. Japan and Germany have similar ongoing programs, and leading manufacturers are collaborating with other companies to install solar panels on commercial buildings. For example, a recent agreement between Volkswagen and BP Solar calls for installing solar-energy systems on the roofs of the automaker's dealerships throughout Germany. Each company is investing in several different technologies.

Solar's big four

Which PV technologies will dominate future solar-energy markets may depend on the companies developing, manufacturing, and selling them. The four industry leaders are Sharp (Osaka, Japan), BP Solar, Kyocera (Kyoto, Japan), and Shell Solar.

Sharp produces mono- and multicrystalline and amorphous silicon solar cells. The monocrystalline modules have an efficiency of 17.5%, and the multicrystalline cells have 16% efficiency. In 2001, the company shipped 19.2% (75 MWp) of the world's total solar cells. Last July, Sharp opened a new multicrystalline-silicon solar-cell production plant in Nara Prefecture, Japan, and the company's total production capacity now totals 200 MWp.

BP Solar also manufactures nearly 20% of the world's solar-electric panels and systems, using technologies that include polycrystalline solar cells. "We also have our own Saturn technology, which is a highly efficient monocrystalline technology," said a spokesman at BP Solar's U.K. office in Sunbury on Thames, England. The company also sells amorphous silicon thin-film modules. BP developed its proprietary PowerView thin-film silicon laminate partly with funds from NREL. The PV coating converts part of the incoming light into electricity while remaining transparent to the rest of the light. The coating can be used to integrate a solar-energy-generating capacity into building skylights and windowpanes to produce electricity and reduce reliance on utility companies.

Kyocera focuses on off-grid solar systems for private homes in developing countries, communication systems, water pumping, and industry (Figure 5). It sells its own multicrystalline-silicon systems, and amorphous silicon systems produced by United Solar Systems.

Shell Solar makes mono- and multicrystalline silicon as well as thin-film CIS solar systems. It produced solar panels with a total capacity of about 50 MWp in 2002, and it expects to double its crystalline production capacity by 2004. The company now employs about 900 people in the United States, Canada, Portugal, and Germany after cutting 170 jobs last October.

Although the market growth rate for PV solar panels has declined sharply after four years of annual growth of more than 30%, the growth rate is predicted to be 15 to 20% this year and next. Worldwide production capacity almost doubled last year to 760 MWp, up from 400 MWp in 2001. The main producers of these panels have different business strategies. Shell Solar strongly believes in thin-film alternatives, including its CIS technology. Other companies see crystalline silicon as the dominant technology during the next decade.

Few people doubt solar energy's potential, but many wonder when it will be reached. "In the long term, solar may well play an important role," Karg says. "I personally expect a contribution of 10 to 20% of the global electricity production, mainly in the form of grid-connected systems." However, he does not foresee that happening within the next 20 years.

Figure 5. Examples of local photovoltaic installations include, left to right: Tibetan home with 20-W panel and 500-W wind machine (Simon Tsuo); water-pumping station in West Bengal, India (Harin Ullal); and the world's largest residential project, in Amersfoort, The Netherlands (BP Solarex).

Further reading

Fairley, P. BP Solar Ditches Thin-Film Photovoltaics. IEEE Spectrum Web only edition, Jan. 8, 2003; www.spectrum.ieee.org, click on Newsletter Archive.

Photovoltaics: Energy for the New Millennium, the National Photovoltaics Program Plan 2000–2004; NREL Office of Solar Energy Technologies: Golden, CO, 2000; available at http://www.nrel.gov/ncpv/pvmenu.cgi?site+ncpv&idx=3&body=pvplans.html.

Solar Electric Power: The U.S. Photovoltaic Industry Roadmap; NICH Report No. BR-520-30150, 2001; 36 pp.; http://www.nrel.gov/docs/fy01osti/30150.pdf.

Franz Karg's views on solar cells appeared in *Shell Venster*, September/October 2002, pp. 4–9, Shell Nederland, Den Haag, The Netherlands, and are quoted with permission.Key world energy statistics are available at www.iea.org.

BIOGRAPHY

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