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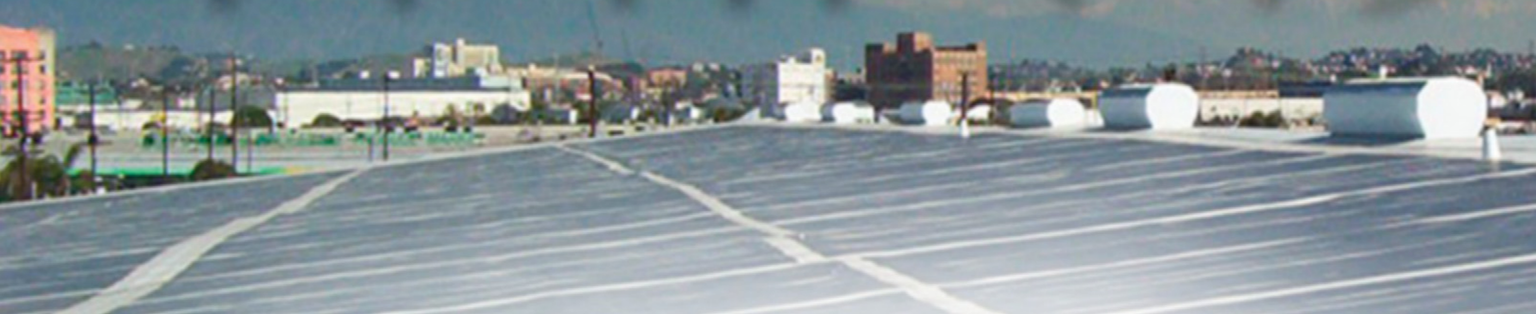

Crystalline silicon, once the undisputed leader of the photovoltaic market, is now facing competition from new thin-film technologies.

By **Kristin Lewotsky**

With record high oil prices putting increased focus on energy, photovoltaics are in the spotlight more than ever. Crystalline silicon is still the workhorse, with efficiencies of 15% to 18% for single-crystal silicon and 12% to 16% for polycrystalline silicon. But crystalline silicon, grown by batch process in a clean room, is not cheap, and materials shortages are increasing the price pressure. Enter the thin-film alternatives, which are poised to move into the mainstream.

Meet the Contenders

Amorphous silicon (a-Si) is the least disruptive of the big-three thin-film technologies. With films less than 1-µm thick, compared to the 200-µm-thick crystalline wafers, amorphous silicon offers a clear benefit in materials costs. Although theoretical efficiencies could be as high as 14%, practical efficiencies for modules are around 6% to 7% so far. And it's not just a laboratory technology.

Using a roll-to-roll process, United Solar Ovonic (Auburn Hills, MI) produces an 18-ft. laminate on adhesive-backed stainless steel that can be applied directly to a roof. According to company president Subhendu Guha, they ship 2.2 MW per month, with an order backlog. The company roadmap calls for annual production of 300 MW by 2010.

United Solar Ovonic produces a triple-junction solar cell—three cells stacked atop each other, tuned to different spectral bands for maximum efficiency. To produce the structure, the company first sputter-coats a layer of aluminum and then zinc oxide on a 14-in.-wide, 1.5-mi.-long stainless steel substrate, then deposits a nine-layer active region consisting of three amorphous silicon layers, each sandwiched by a p- and n-layer to produce a solar cell. The production chamber coats three substrates simultaneously at a speed of 2.2 m/min.

Better Efficiencies, Bigger Area

Another thin-film technology that's generating a lot of interest these days is cadmium telluride (CdTe). CdTe features a bandgap of about 1.5 eV, which is well matched to the solar spectrum. What makes it appealing is that it has an absorption coefficient in excess of 10^5 cm^{-1}, roughly 50 times that of crystalline silicon. Current module efficiencies range around 8% to 9%, but Ken Zweibel, manager at Thin Film PV Partnership at the U.S. National Renewable Energy Laboratory (NREL; Golden, CO) expects that to eventually rise to 12% to 14%. That means currently there are still limitations—producing a set amount of electricity with CdTe rather than crystalline silicon requires significantly greater module area, notes Manfred Bächler of system integrator Phönix SonnenStrom AG (Sulzemoos, Germany).

If area were not a factor, however, it all comes down to cost per kilowatt hour. "And there, thin film is in most cases the best choice for a customer," says Bächler.

"Within thin film I think for the next two to

three years, CdTe and CIS will provide the lowest total system costs, whereas amorphous silicon may face problems if the efficiency does not improve significantly."

Crystalline silicon is a mature technology, so it has less room for improvement. A significant portion of the cost of a CdTe system comes from inverters, substructure, and installation, says Bächler. Module improvements could permit the use of more economical inverters. Better yet, increased efficiency reduces module square footage, which reduces the system-level costs already mentioned.

CdTe photovoltaics are already being shipped commercially by First Solar (Perrysberg, OH). The company was in an SEC-mandated quiet period at the time of writing, but their IPO prospectus shows net sales of $48.1 million in 2005 with a backlog of 745 MW. Although there has been discussion of toxicity with CdTe thin films, NREL studies show the concern is unwarranted (see www.nrel.gov/cdte/cadmium_facts.html).

Promising Underdog

A competing technology with a longer time to market is copper-indium-sulfur-selenium-gallium, also known as CIS or CIGS. With a bandgap of 1.1 eV and an absorption coefficient over 10^5 cm^{-1}, it has the potential to reach cell efficiencies of 20% to 22% and modules of 13% to 15%. Currently, though, it's still in the development stage. "It's a technology with great promise but nobody's turned the corner on first-time manufacturing," says Zweibel.

One issue is material growth. CIS is a mixture of five elements that have to be deposited at precise stoichiometric ratios and evenly across a large area. It's not simple, particularly when the materials have a tendency to form undesirable alloys. Encapsulation is another issue; CIS oxidizes much faster than amorphous silicon, which is quite robust, or even CdTe.

Ultimately, though, it comes down to engineering. "Somebody will make it work, there's no question in my mind," says Zweibel. "It's just a lot harder and a lot slower [than cadmium telluride]. Cadmium telluride is much further along. It's in full production and it's got kind of an open-ended future."

As with most things in engineering, there will not be a wholesale replacement of crystalline silicon with thin-film photovoltaics, but a case of the solution fitting the problem. "We believe that thin-film [photovoltaics] will gain significant market share within the next two to three years, but we know that crystalline modules will still dominate in the next couple of years," says Bächler. "Beyond 2010, crystalline modules will still have more than 50% of the world market." One thing is certain, the thin-film technologies will begin giving crystalline silicon, and eventually fossil fuels, a run for their money.

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The Business of Solar Cells

In the case of alluring technologies like thin-film photovoltaics, following the money represents the best way to get an understanding of where the technology really stands.

"Our bank has been active in the clean energy space for over 20 years," says Mark Waller, president of BridgeWorks Capital (Lake Oswego, OR), one of the reference banks for the NREL. "We have never seen anything remotely approaching the market-place we're in now." He credits the confluence of rising oil prices and crystalline silicon short-ages with technology maturity for the surge in solar energy investment.

According to market research firm NanoMarkets (Glen Allen, VA), the market for thin-film photovoltaics should rise from its current level of $220 million to reach $2.3 billion by 2011. "Much of the surge of interest in thin-film photovoltaics has come about as the result of the shortage of crystalline silicon," says principal analyst Lawrence Gasman. "Unless it turns out that this was the sole reason thin-film photovoltaics are ascendant, which seems unlikely, [the end of the shortage] should not stop the forward march."

Gasman does caution that if the market pressure imposed by skyrocketing oil prices disappears, the situation may change. "A similar growth in expecta-tions for alternative energy sources occurred in the 1970s after a similar rise in oil prices, but the interest all but evaporated after oil prices declined."