Silicon shortage opens window for CIGS PVs

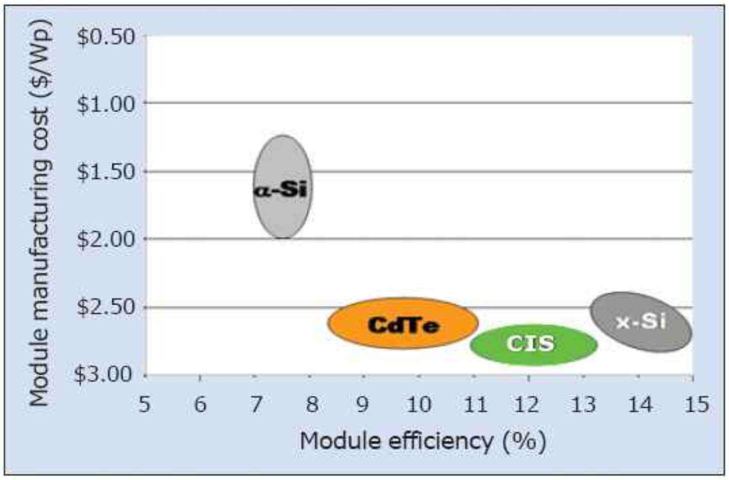
The shortage of polysilicon is constraining uptake of solar power, driving some recent large investments to speed less costly thin-film copper indium gallium diselenide (CIGS) solar cells on flexible substrates into production.

The solar energy industry has grown with a compound annual growth rate averaging 40% over the past eight years. About 90% of solar panels are made of crystalline silicon. However, demand has led to a prolonged shortage of refined polysilicon raw material since 2004 (especially since builders have begun to incorporate solar panels into new homes). This has severely limited sales growth, and may not ease until at least 2008 and possibly beyond.

Given the high cost of oil and instabilities in oil-producing states, President Bush's 'Solar America Initiative' (SAI) calls for an acceleration of US solar cell manufacturing capacity to 5–10GW of generating capacity by 2015 (enough to power 1–2 million households). The US has lagged Japan and Europe in solar production, and is now a distant third, with about 10% of the global market (75% of which is in California). Currently, the world's largest solar factories are run by Sharp and Kyocera in Japan. However, the US has the largest potential for growth, with incentives for photovoltaic (PV) installation in over 20 states.

However, silicon solar panels are made with processes similar to those for ICs, so a solar factory capable of producing 30MW worth of panels a year can cost as much as $70m. A solar-produced kilowatt can cost 35 cents, while a kilowatt straight from the grid can cost 25 cents, says Ron Kenedi, general manager of solar systems at Sharp. Hence, governments are still having to subsidize the cost of solar equipment.

Also, crystalline silicon has an indirect bandgap and is inefficient at photoelectric conversion. In contrast, copper indium gallium diselenide ($Cu(In,Ga)Se_2$ or CIGS) has a direct bandgap and generates far more electricity. A film as thin as 1μm produces a photoelectric effect equal to that of crystalline silicon over 100 times thicker (200-300μm). Hence, CIGS cells use less than 1% of the material required — an inherent cost advantage.



Module efficiencies versus manufacturing costs in practical application (source: HelioVolt).

According to the US Department of Energy's National Renewable Energy Lab (NREL) of Golden, CO, USA, CIGS solar cells have efficiencies for converting solar energy into electricity of up to 19.5% theoretically and 10–15% in high-volume manufacturing. This is higher than other commercially available thin-film technology, but less than silicon, which has a maximum of 30% theoretically but only 10–20% commercially (although CIGS has an R&D roadmap for improvement to 20%).

However, CIGS solar cells have several advantages (eliminating three problems that have slowed adoption of silicon solar cells — cost, fragility, and availability):

- unlike bulky, rigid silicon, CIGS can be either vacuum sputtered or printed as a thin film onto many carrier substrates including thin, flexible foils such as stainless steel only 50μm thick (100 times thinner than a silicon cell) or polymer sheets, cutting material costs;
- CIGS cells weigh correspondingly less than silicon;
- panels cost five to ten times less to manufacture;
- manufacturing equipment and plants cost less;
- flexibility to conform to small-radius curves;
- easier use in PV modules or direct incorporation into roof tiles and materials such as cement in a building's entire exterior;
- higher efficiency in low-angle and low-light conditions;
- stable and reliable in use (unlike some other thin-film technologies in the past), even being self-healing.

These advantages are further enhanced when incorporated with rugged, flexible encapsulants (rather than glass) into flexible photovoltaic modules.

Table 1: Solar cell technology comparison (source: DayStar Technologies).

Technology	Efficiency	Degradation	Flexibility	Comments
Thin Film				
CIGS	+++	++++	+++	Highest non-silicon efficiency Low material and processing cost Highly flexible Clear roadmap to efficiency improvement
Amorphous silicon	++	++	++	Moderate performance Exhibits instability High cost No clear path to efficiency improvement
Cadmium telluride	++	++++	Rigid	Requires rigid packaging No pathway to efficiency improvement
Crystalline silicon				
Single-crystal silicon	+++++	++++	Rigid	Fully mature technology, Difficult to reduce price or increase performance High material costs & processing cost Fragile, high shipping costs
Polycrystal silicon	++++	++++	Rigid	Similar to single-crystalline silicon

CIGS modules have been tested for over 15 years and produced commercially in modest volumes for experimental installations for nearly a decade. However, high-volume manufacturing technology has been lacking.

But now, given the shortage of polysilicon, CIGS' potential for high module efficiencies and low cost has begun to attract large companies such as Shell and has also led to several recent cases of large investments in specialist CIGS-based companies. The effect is to accelerate development of high-volume manufacturing by years to volume delivery just next year.

Companies ramping up production of CIGS solar cells include Miasolé, DayStar, HelioVolt and Nanosolar.

Miasolé raises $35m for volume production

Miasolé (formerly Raycom Technologies) of Santa Clara, CA, USA has developed a continuous, high-throughput roll-sputtering process to vacuum deposit CIGS over large areas of stainless-steel foil, using proven low-cost thin-film coating process technology used by Miasolé's staff previously in the disk-drive and optical industries. Each production run delivers square miles of product.

"We have the enabling technology to reduce the cost of PV modules from today's $3 per Watt to less than $1 per Watt, making solar-generated electricity competitive with conventional energy sources," claims CEO David Pearce. In 2010, the costs of generating a watt of electricity from a CIGS panel — including installation and other expenses and considering its lifetime — should be about $2.50, roughly equal to grid power, he adds.

After raising $25m over 2004–2005 from investors including Kleiner Perkins Caufield & Byers, VantagePoint Venture Partners, Bessemer Venture Partners, Firelake Strategic Technology Fund, Garage Technology Ventures and Nippon Kouatsu Electric, and Venture Banking Group, in October Miasolé raised another $35m (bringing the total to $58m).

"We are now able to accelerate our ramp to high-volume production," says Pearce. In May, he said Miasolé was building a production facility with annual capacity of 50MW of solar panels (two lines of 25MW each) by Q4/2006. It has since procured material to build two more 25MW lines. It aims to have 200MW of capacity by end-2007. Pearce adds that Miasolé can erect a 100MW/yr factory for $25m (in contrast, silicon solar cell maker Evergreen Solar spent $75m this year to build a 30MW facility in Germany). The goal for 2007 is $100m in revenue and profitability. Pearce is targeting an initial public offering of stock in 12–18 months.

DayStar targeting 100MW capacity

Also using vacuum sputtering deposition on flexible metal foil is DayStar Technologies, co-founded in Grass Valley, CA, USA in 1997 by president and CEO Dr John Tuttle, a former senior scientist at NREL.

In February 2004 an IPO on NASDAQ raised $10.5m. That June, DayStar accepted an $11.1m incentive package from the New York State Department of Economic Development to locate its 'Gen I' R&D and 'Gen II' pilot lines in Halfmoon (Albany Tech Valley), contingent on plans to invest $40m over five years and grow to 250 staff. This came after New York legislation mandated that, by 2013, at least 25% of the electricity sold to consumers is generated from renewable resources. The package includes a series of tax credits and access to grant programs: in January 2005 the New York State Energy Research and Development Authority awarded DayStar a $1m Renewable Energy Technology Manufacturing Incentive Grant — $600,000 based on production capacity milestones (targeting a 1MW/yr production capability), then $400,000 based on product sales coupled with a commitment to expand in 2007 into a new 'Gen III' roll-to-roll factory at the Saratoga Technology + Energy Park in Malta, NY.

Shell Solar CIGS PV installation in Wales, UK (left) and roll-printing at Nanosolar (right). Credit: NREL.

In May 2005 DayStar started pilot manufacturing of TerraFoil cells, and in the June signed its first client, European PV system integrator Blitzstrom GmbH of Mainbernheim, Germany, for monthly delivery to end-2008 of 30m 1W TerraFoil solar cells (30MW), worth at least $60m, for Blitzstrom's contract module manufacturer Titan Energy in India. At September 2006's 21st European Photovoltaic Solar Energy Conference in Dresden, the agreement was expanded to 130MW through to end-2010. July 2005 also saw the first sale of TerraFoil-SP small-power cells when Micro Energy Group Inc of China agreed to buy up to 500kW for flat-plate PV modules and specialty consumer electronic products. This October, DayStar received a $1m US Air Force award to develop its LightFoil cells (CIGS on titanium foil) for lighter-than-air vehicles.

After transitioning from pilot- to commercial-scale production of Terrafoil on the Gen II line in Q2/2006 and in response to evolving market conditions, in May DayStar raised $15m from selling 12% of its stock to Castlerigg Master Investments Ltd. This will enable it to start up its Gen III line earlier than planned, installing equipment in early 2007 for a capacity 10MW per year, increasing to at least 20MW per year by end-2007. The first target is to fill the facility with 100MW of capacity, then expand through duplication at other plants worldwide, while developing an expanded platform for greater economies of scale.

GSE selling CIGS to silicon PV panel makers

Global Solar Energy Inc (GSE) of Tucson, AZ, USA (established in 1996) uses roll-to-roll manufacturing of CIGS cells on flexible materials to make 6.5–55W foldable, portable solar panels.

This March, module manufacturer Solon AG of Berlin, Germany acquired a 19% stake in GSE (the balance being privately owned by a German investor). At October's Solar Power 2006 conference, Solon launched 130–220W modules based on GSE's cells, for delivery in North America in Q2/2007. GSE also said it had begun selling CIGS cells in power strings to established silicon module manufacturers, as a replacement for traditional silicon cells.

"We are going up to 4.2MW by January 2007 and 40MW by January 2008 to keep up with the demand for our current flexible, foldable, portable solar panel line as well as this new demand for our cell strings", said president Michael S. Gering.

HelioVolt seeking funding

HelioVolt Corp of Austin, TX, USA was founded in 2001 by president and CEO Dr Billy J. Stanbery. He argues that the vacuum deposition in conventional thin-film production can be capital intensive, and is difficult for CIGS films over large areas with the precision necessary to achieve both high performance and low cost, compared to his patented non-vacuum deposition 'FASST' process. A two-year Cooperative Research and Development Agreement (CRADA) with NREL indicated that FASST enables simpler, faster manufacturing and improved flexibility. Greater controllability allows it to be adapted; FASST can also print CIGS directly onto construction materials, including architectural glass, steel, roofing and polymers.

In June 2005, HelioVolt raised $8m in a Series A round from New Enterprise Associates, and is using the funding to build prototypes of commercial-scale manufacturing equipment. This September, the CRADA was extended to optimize FASST for commercialization. HelioVolt is now aiming to raise $50m.

Nanosolar raises $100m for 430MW/yr fab

Nanosolar Inc of Palo Alto, CA, USA was founded in 2002 by president Brian Sager and CEO Dr Martin Roscheisen (a Stanford University engineering graduate who sold Internet firm eGroups to Yahoo for $432m in 2000). Seed funding came from Google co-founders Sergey Brin and Larry Page.

After Nanosolar re-focused in 2003 from organic technology to CIGS, in 2004 it was awarded a $10.3m R&D contract by DARPA, and has also received funding from the California Energy Commission as well as the US National Science Foundation.

In 2004 it recruited director of process engineering Craig Leidholm (who, at International Solar Electric Technology Inc, developed CIGS thin-film processes). By using its all-solution-based coating process to embed nanostructured CIGS into thin polymer films, Nanosolar was first to roll-print a CIGS-based solar cell. It claims that its technology allows roll-to-roll printing with more than an order of magnitude faster throughput over the best in conventional silicon or vacuum technology, as well as being very inexpensive and quick to scale to production volume.

After completing its initial R&D phase and moving into commercial production with a pilot manufacturing facility, in May 2005, Nanosolar appointed the following staff:

- VP of engineering Dr Chris Eberspacher, former head of R&D at ARCO Solar (now Shell Solar), where he developed the first commercial CIGS cells, before co-founding Unisun Corp and pioneering printed CIGS cells;
- Executive VP of operations Werner Dumanski, former manufacturing executive for Hitachi/IBM's $4.5bn storage components business;
- independent director Dr Siva Sivaram, COO of Matrix Semiconductor, a former general manager of Intel's IC Procurement and Enabling Division.

After receiving $750,000 in SBIR Phase-II funding in February 2005, that June Nanosolar raised $20m in Series B funding (bringing the total to $37m). The round was led by MDV-Mohr Davidow Ventures and included Mitsui (Japan's largest distribution company) and Onpoint Technologies (the US Army's venture fund), as well as previous investors including Benchmark Capital and Stanford University.

"Thin-film printing overcomes the complexity, high cost, and yield and scalability limitations associated with vacuum-based processes," claims Eberspacher. "This allows us to produce cells very inexpensively and assemble them into panels that are comparable in efficiency to that of high-volume silicon-based PV panels." Dumanski adds that, "Given the square meter economics of solar, high-throughput high-yield processes have to be used to succeed in this industry. With Nanosolar's printing process, the fully loaded cell cost — including materials, consumables, energy, labor, facility, and capital — is less than the depreciation expense alone that vacuum thin-film companies have to pay for the equipment that produces their cells."

This June, Nanosolar raised Series C equity funding of more than $75m (bringing the total to over $100m). New investors included SAC Capital and GLG Partners; Swiss Re; Grazia Equity (the original backer of Conergy AG, the largest PV system integrator); Christian Reitberger (the original backer of Q-Cells, the largest independent silicon PV maker); Capricorn Management (the investment arm of Jeff Skoll, a supporter of clean energy causes); the investment arms of SAP founders Klaus Tschira (via FirstVentury) and Dietmar Hopp; and PV power plant system integrator Beck.

The funds are going towards building "the world's largest thin-film solar factory", sited in the San Francisco Bay area and due to open in 2007. The targeted annual capacity is 200m cells, or 430MW (compared to 500MW for a large coal-burning power plant), almost triple the USA's current total 153MW PV-making capacity. Nanosolar is also to build a 1m panel/yr assembly plant in Berlin, Germany (one of the world's biggest solar markets), making it also one of the world's largest solar-panel manufacturers.

(Left) Flexible CIGS solar panels. (Right) A foldable portable power pack. Credit: Global Solar Energy.

Nanosolar's new plant alone would move the US to second, ahead of Europe and behind Japan. "This is a very important step for us to address the energy crisis we face in this country," says Rhone Resch, president of the Solar Energy Industries Association in Washington DC. "We cannot drill our way out or mine our way out, but we can manufacture our way out."

"A factory of this capacity would cost more than $1bn to build if one used conventional solar technology...we can achieve this scale with a tenth of the capital and as a start-up company," says Dumanski. "There are three miles of solar cells on a single roll of polymer film," said Roscheisen. "We're going to have the economies of scale of the print business."

Initially, Nanosolar will embed its cells into relatively standard solar panels and sell them to utilities for solar farms, followed by plastic sheets for the rooftops of 'big box' retailers. In August, Nanosolar signed a long-term supply agreement with Conergy Group of Hamburg, Germany (the largest solar company in Europe, which intends to expand its North American market share). The aim is to develop large-scale PV systems with "tightly interconnected panel and equipment design innovations". Conergy's expertise in the integration of components will provide "custom-tailored and cost-efficient solar solutions", it claims. "Delivering the next level of innovation in solar electricity requires product design work that takes a systems-wide perspective," adds Roscheisen.

Future prospects

Regardless of whether vacuum sputtering or roll printing manufacturing methods prevail, both technologies have attracted large amounts of venture capital investment. Hopefully, unlike previous, more expensive and perhaps more speculative technologies like InP-based optoelectronic integrated circuits for example, start-ups won't burn through their investors' cash interests before achieving high-volume revenues. But even if they do, it seems established solar cell makers like Shell are committing to a long-term interest in CIGS. ■