SPECIAL REPORT

Thin films: ready for their close-up?

New types of solar cell that can be mass-produced cheaply, and integrated into building materials, are popular with venture capitalists and market analysts. But scientists are less gung ho, reports **Declan Butler**.

From the 1950s onwards, big chunks of crystalline silicon have dominated the world of solar cells. But the dominance of these traditional cells — which make up 90% of today's 10-gigawatt-a-year installation market — is now being challenged by 'thin-film' solar cells that are micrometres or mere nanometres thick, and frequently made of materials other than silicon. Some argue that such a change in technology is the only way that solar-cell technology can hope to maintain the 50% annual growth it has enjoyed during the past five years.

Highly-purified silicon is expensive, and the fact that its other users, silicon-chip makers, manufacture high-value products from it has helped to keep it so. That presents a problem for makers of a commodity such as solar cells, a problem exacerbated by manufacturing processes that waste a significant amount of raw material. Thin films, by comparison, can in principle be made cheaply by using reel-to-reel processes similar to those of a printing press and other mass-production techniques. They can also be applied on to flexible sheets of steel and other materials, and so be integrated directly into building materials. These advantages, though, come at a cost. Thin films are normally significantly less efficient than traditional silicon cells, which have conversion efficiencies of 15% or upwards in everyday use.

Nevertheless, Nanomarkets, a consultancy based in Glen Allen, Virginia, issued a report on 21 July that predicted thin films taking as much as half of the world market for photovoltaic cells by 2015. Lux Research, a New-York based analyst firm, reports that investment in the sector climbed from US$481 million in 2006 to $1.36 billion in 2007.

Most thin-film cells sold today still use silicon, but in its amorphous, rather than crystalline, form. This makes the cells thin and cheap but costs them half or more of their efficiency compared with traditional designs. The hope, and to some extent the hype, is focused on new technologies. Of these, cadmium telluride-based systems are the most mature, and hold one third of the thin-film market, according to IDTechEx, a consultancy based in Cambridge, Massachusetts. The technology is dominated by First Solar, a company in Phoenix, Arizona. But the venture capitalists' favourite is a technology known as CIGS (copper indium gallium diselenide).

CIGS's semiconductor cells are the province of established companies such as Würth Solar in Germany as well as Showa Shell Sekiyu and Honda in Japan, and the focus of specialized start-ups Miasolé and Nanosolar, in California's Silicon Valley, and Heliovolt in Austin, Texas. The cells are held to marry the advantages of thin-film manufacture with efficiencies close to those of today's best products. In March, a thin-film solar cell developed at the US National Renewable Energy Laboratory (NREL) in Golden, Colorado, set a CIGS efficiency record of 19.9%, although most commercial thin-film CIGS contenders at the moment offer something much closer to 10%.

Nanosolar of Palo Alto, California, perhaps the most bullish of the thin-film CIGS companies, claims to have developed a production

PHOTOVOLTAIC TECHNOLOGIES

Solar cell	Advantages	Disadvantages	Status	Efficiency*	Type
Crystalline silicon	High efficiencies.	Wafer-based cells use large amounts of expensive silicon, can't be applied as thick film.	Mature technology, long established at industrial scale.	15–22%	Semiconductor. Photons of sunlight are absorbed by a semiconductor, their energy is converted to electrons and positive 'holes' that produce the photocurrent in solar cells, and a photovoltage — both are needed for power.
Multi-junction gallium indium phosphide (GaInP), gallium arsenide (GaAs) and germanium (Ge)	Traditionally used in space, as has highest efficiences.	Expensive crystalline layer production.	At research stage; limited application, but trend towards increased terrestrial applications in combination with light concentrators.	30–40%	Semiconductor.
Thin film	Conventional crystalline silicon cells use solid wafers a couple of hundred micrometres across. Thin-film technologies, which can use inorganic semiconductors, organic dyes or organic polymers, are nanometres to a few micrometres thick, and can be applied in continuous industrial production using, for example, vacuum deposition, sputtering and printing. Thin films also use fewer raw materials compared with silicon wafers, and so cut costs.				
Nano and amorphous silicon	Can be used as thin film unlike crystalline silicon.	Lower efficiency.	Uncertainties over long-term stability.	6–10%	Semiconductor.
Cadmium telluride (CdTe)	Reasonable efficiencies and proven technology. Good at low light levels.	Need careful disposal of toxic cadmium.	Mature, large applications started.	9–11%	Semiconductor.
Copper indium gallium diselenide (CIGS)	Highest efficiency of thin films, can be made transparent. Good optical and electronic properties.	Production processes still relatively untested.	Moving to industrial scale.	10–14%	Semiconductor.
Dye sensitized solar cells (DSSC) — 'Grätzel cell'	Work well at low light levels, and extreme angles. Transparent.	Solvent electrolyte handling.	Moving from development into deployment.	11% (Grätzel cell)	Not a semiconductor. Uses processes mimicking photosynthesis (see text).
Organic	Potentially the cheapest solar cell, allowing incorporation in buildings, clothes and devices. Can be transparent.	Generally poor efficiency. Poor stability.	Research stage.	Typically 2–5%	Uses organic semiconductors, such as polymer fullerenes.

*Efficiencies given are industry estimates. Table compiled from personal communications and from reports by IDTechEx.com, luxresearchinc.com and nanomarkets.net.

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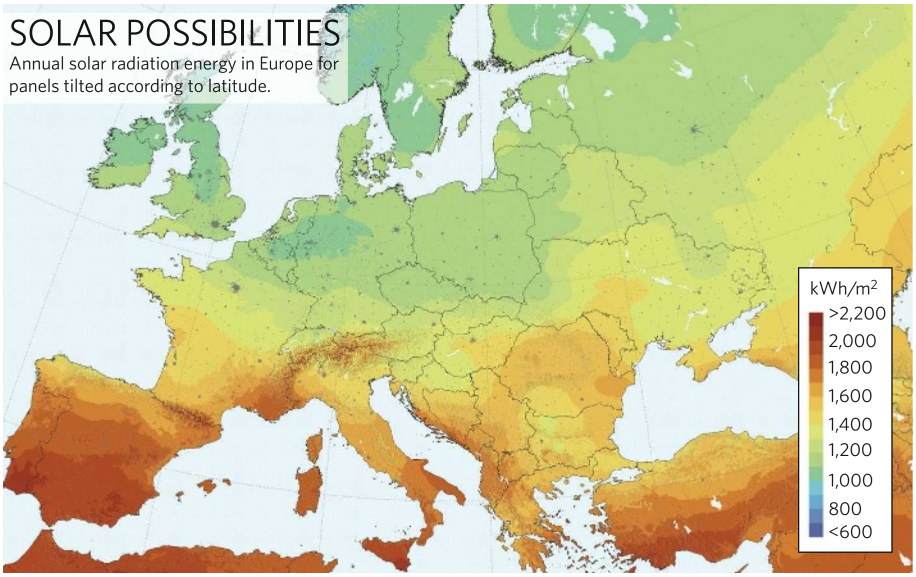
HYDROGENASE REVEALED
Enzyme structure reveals key ingredients for making hydrogen.
www.nature.com/news



SOLAR POSSIBILITIES
Annual solar radiation energy in Europe for panels tilted according to latitude.

PVGIS/ŠÚRI, M. *ET AL. SOL. ENERGY* **81,** 1295–1305; 2007.

system that, for a capital cost of $1.65 million, could churn out 600 metres of solar panels per minute, for an annual yield of one gigawatt of capacity. This is orders of magnitude cheaper and faster than conventional thin-film vacuum deposition techniques: *Forbes* magazine has reported that Showa Shell Sekiyu, part of Shell's Japanese arm, is looking at spending 100 billion yen ($930 million) on a one-gigawatt-a-year solar-cell facility using more traditional thin-film manufacturing.

In development

Some scientists are sceptical as to whether CIGS will, in practice, live up to its extravagant promise. Mass-producing CIGS films with consistent microstructure and composition is a challenge that in effect may trade off the benefits of increased manufacturability and increased efficiency. "CIGS is a very difficult technology to manufacture, having larger moisture sensitivity compared with other technologies," says Martin Green, a solar-cell researcher at the University of New South Wales, Australia. Printing of solar cells, *à la* Nanosolar, "is still at the R&D stage", says Tonio Buonassissi, a photovoltaics researcher at the Massachusetts Institute of Technology in Cambridge. "In industrial production today, expensive vacuum equipment is used, for example for plasma-enhanced chemical vapour deposition or sputtering," he says. Buonassissi is also sceptical about the cited high efficiencies for CIGS, arguing that in mass production they so far come in at around just 9%.

Another frequently voiced concern is that there may be material constraints on the technology. Highly refined silicon may be pricey, but in its unprocessed form it is the second most abundant element in Earth's crust. Large-scale deployment of CIGS could lead to shortages and price hikes in its scarcer raw materials, says Buonassissi. Martin Roscheisen, chief executive of Nanosolar, sees such fears as overblown: "The cost of indium is less than 1% of revenue [for Nanosolar]."

Nor are these thin film designs the only alternatives to crystalline silicon. Grätzel cells, named for their inventor Michael Grätzel at the Swiss Federal Institute of Technology in Lausanne, use dyes painted onto the surface of nanometer-size particles of titanium dioxide. These are immersed in an electrolyte to produce current in a way more like that used in photosynthesis than the semiconductor technology of normal photovoltaics. As yet, the technology has proved hard to commercialize, but companies such as Konarka in Lowell, Massachusetts, and G24i, in Cardiff, UK, continue to work on it. And Grätzel now thinks he has overcome some of the problems using a modified cell that uses a salt melt as the electrolyte (Y. Bai *et al. Nature Mat.* **7,** 626–630; 2008).

Still, Buonassissi is one of several scientists who argue that both economics and new research are on the incumbent technology's side. Vast new silicon refineries in China and elsewhere, expected to be online by the end of the decade, promise a glut of silicon. That will reduce the cost of conventional silicon solar cells. And new research is also opening up possibilities of combining the best of both worlds: making thin films with crystalline silicon and thus benefiting from its attendant higher efficiencies without all the cost. Stefan Glunz and colleagues at the Fraunhöfer Institute for Solar Energy Systems in Freiburg, Germany, Europe's largest solar research institute, are working on a process that melts a fine layer of high-quality silicon on to a substrate of lower grade silicon or ceramic. Prototypes of these cells, which can be mass produced in the same way as some CIGS thin films, have this year yielded solar cells 40 micrometres thick with an efficiency of 20%. Innovalight, a startup in Sunnyvale, California, is developing silicon cells that make use of nanoparticle dyes that could also result in high-performance silicon thin-films produced in high-throughput processes.

"The thin film era will also be about silicon," says Daniel Lincot, a solar researcher at the National Higher School of Chemistry in Paris. "We are set to enter the post-bulk-silicon era, rather than the post-silicon era."

Reducing costs

More broadly, academic researchers consider the current thin films as a second generation of photovoltaics, but not the end-point of all development. "They lower the cost per unit area but do not reduce the cost per kilowatt hour that much because the efficiencies are generally lower or not increased over silicon," says Arthur Nozik, a photovoltaics expert at NREL. Solar electricity currently costs around 30 cents per kilowatt hour, and thin films will reduce this to 15–20 cents per kilowatt hour, but that's still higher than the 5 cents per kilowatt hour of electricity produced from coal.

Happily for the industry, though, solar cells installed at home or for a specific business do not compete with the cost of producing electricity, but with the price at which utilities subsequently sell it. In sunny climes, 'grid parity' — electricity generated by photovoltaics as cheaply as it is sold by utilities — is expected within four years or so. And subsidies for solar energy have proved politically acceptable in some places, at least so far. In Germany, generous feed-in tariffs that guarantee a high price for solar energy sold back to the grid have encouraged the technology's uptake and have stimulated an indigenous industry in cell and panel making and installation. But the subsidies involved are expensive, and were trimmed earlier this year. A future in which such feed-in tariffs taper off as solar cells get cheaper to install could wean the sector from subsidies without causing a collapse.

"There is a place and market niches for every one of these technologies. There won't necessarily be only one winner," says Harry Zervos, a photovoltaics technology analyst with IDTechEx. That does not mean there will not be losers. Analysts expect a shake-out in the field — through failures and mergers — to start soon. But those who come through should be well placed: "If solar energy doesn't lift off at this point in time," says Zervos, "it never will." ■

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