The next generation of solar

Venture Capital Investment

Tim Chapman reviews venture capital investment in next generation solar technologies

It's well over a century since Charles Fritts, an enterprising American inventor, found that a carefully prepared cell of selenium and gold could create electricity from sunlight. It's 50 years since silicon-based solar cells were used to power early satellites. But there's never been such a wave of technical innovation and investment as there has been in the past few years, as the climate change and energy security agendas have elevated solar power into the mainstream.

Venture capital (VC) activity can be a useful guide to the commercial potential of a technology. Last year, according to research by the Cleantech Group, VC investment in solar technology topped $1 billion in 71 deals across North America and Europe, as part of a record $5.18 billion invested across the cleantech arena. And the numbers got even bigger in 2008: according to Greentech Media, solar companies raised a total of $1.5 billion in the third quarter of 2008 alone.

Part of that wave of investment is helping increase production of the mainstay of the solar industry, photovoltaic (PV) panels based on crystalline silicon. But the bulk of the money is going to companies which are commercialising a vast array of new solar technologies.

Some companies are working to dramatically improve the efficiency of silicon PV, to get more power out of less silicon, and to slash the cost of producing the cells. A key trend here is the move away from bulky crystalline silicon to thin films which use a fraction of the raw material.

Thin-film cells can also be made with alternative semiconductors, such as cadmium telluride or the copper indium gallium selenide (CIGS) family of compounds, which have also seen intense VC interest.

And then there's a whole new generation of more exotic materials, from organic compounds to nano-engineered quantum wells, emerging from laboratories around the world.

Not all of these technologies will reach their promised potential, of course. Some will run into problems scaling up production from laboratory to factory, some may never become commercially viable because of high material and production costs, and others may just not find their place in a highly competitive market.

The critical factor for many of these solar plays is the price of the high-quality silicon required for the most established PV technologies. Recent years have seen huge price increases as the increasing demands of the solar industry competed with those of the electronics industries. But with new production capacity coming on-stream, material costs are set to fall sharply - analysts at New Energy Finance have predicted a 43% drop in the cost of polysilicon in 2009. While that's good news for the makers and users of silicon PV, it puts a big dent in the business case for some of the new solar technologies.

The following set of three articles introduces some of the most exciting companies developing the next generation of solar PV, concentrating on those that have secured VC funding. The articles originally appeared in Cleantech magazine between December 2007 and May 2008, but have been updated with details of later fundraising and other news.

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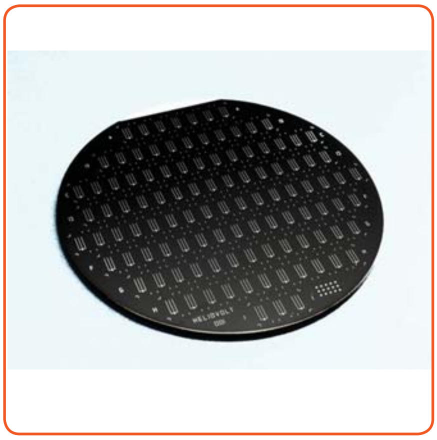
7 flexible super cell in module production. Image courtesy of Odersun

Dye Sensitised Thin Film solar cells. Image courtesy of G24i



Heliovolt circular cell
Image courtesy of Heliovolt

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Improving silicon efficiency

The centre of innovation is California's Silicon Valley

Solar cells are an increasingly familiar sight, helping businesses and households cut their emissions and reduce their energy bills, and powering a host of off-grid installations. But while the conventional photovoltaic (PV) cell technology is well established, it's still relatively inefficient, awkward and expensive to install, often unsightly, and demands a large amount of scarce crystalline silicon.

Making solar power cheaper, more efficient and more flexible is the aim of a host of new companies that are receiving intense interest from venture capital (VC) investors. That's a huge driver for technical and commercial innovation, and promises a strong portfolio of listed solar businesses a few years down the line.

These three features look at the next generation of VC-backed solar businesses, from companies now in commercial production to the latest spin-outs to emerge from the laboratories. This first feature focuses on companies working to improve the efficiency of silicon in solar cells.

Unsurprisingly, the centre of innovation is California's Silicon Valley. The technical skills learnt in the semiconductor industry are now being applied to the solar sector, with many companies managed and backed by veterans of the IT industry.

Conventional PV cells depend on silicon of a very high quality, although not quite as high as that demanded by the semiconductor industry. While early solar developers depended on scrap silicon from integrated circuit manufacturing plants, there now just isn't enough scrap to go round. Growing demand from both industries has sent the price of polycrystalline silicon skyrocketing in recent years, although new supply capacity should soon bring the price back down. Because silicon makes up the bulk of the cost of cells, its cost has pushed up the price of new solar installations despite manufacturing economies of scale and improvements in conversion efficiency (i.e. the efficiency with which the cell converts photons into useable power).

A relatively well established approach for improving silicon efficiency is to concentrate more light onto the PV cell. One of the leaders in this concentrated photovoltaic (CPV) field is SolFocus. The Silicon Valley firm uses reflective optics to focus sunlight on a small, high-quality silicon cell, achieving double the conversion efficiency of silicon with a fraction of the material. The technology is currently being deployed at a 3MW installation in Spain. SolFocus, which raised $64 million venture capital in late 2007, is also developing a new concentrating system which aims to reduce production costs by integrating all the optical elements into a single piece of glass.

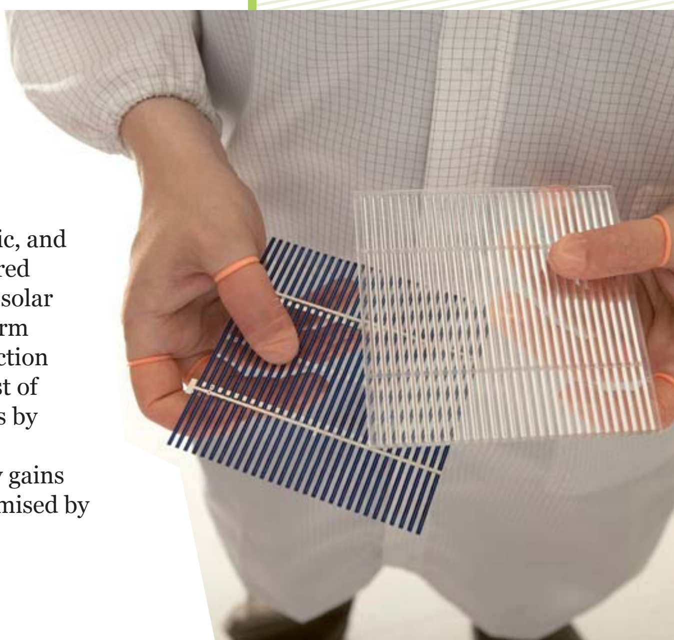
Because they have to closely track the sun as it passes through the sky, CPV installations are unsuitable for many applications. Several firms are instead focusing on producing more efficient cells which can be used just like conventional cells.

Solaria, another Silicon Valley firm, promises to double or treble the efficiency of silicon use by the simple method of taking one conventional cell and making two or three new ones from it. In 2007, the firm raised a $50 million third round of funding led by German solar giant Q-Cells, which is also supplying the firm with 1.35GW worth of cell material over the next decade.

Solaria takes standard crystalline silicon cells and slices them into thinner strips using established techniques from the semiconductor industry. These strips are then alternated with troughs of low-cost plastic, and packaged in a multi-layered cartridge which acts as a solar concentrating cell. The firm estimates that the production technique can cut the cost of conventional PV modules by 15-30%.

Although the efficiency gains are lower than those promised by

Image, courtesy of Solaria



other innovations, Solaria's solution should be much easier to integrate into existing production lines, and the finished cells can be used in the same way as traditional PV cells. The firm is moving towards commercial production at both its California base and a 25MW line in the Philippines.

A younger rival, Silicon Valley Solar, also aims to double silicon efficiency through its proprietary internal concentrator design. Its modules are outwardly similar to conventional modules, so can easily be installed or integrated into existing systems. The firm raised a $10 million first round in 2007, and is developing a 2MW production line at its California headquarters.

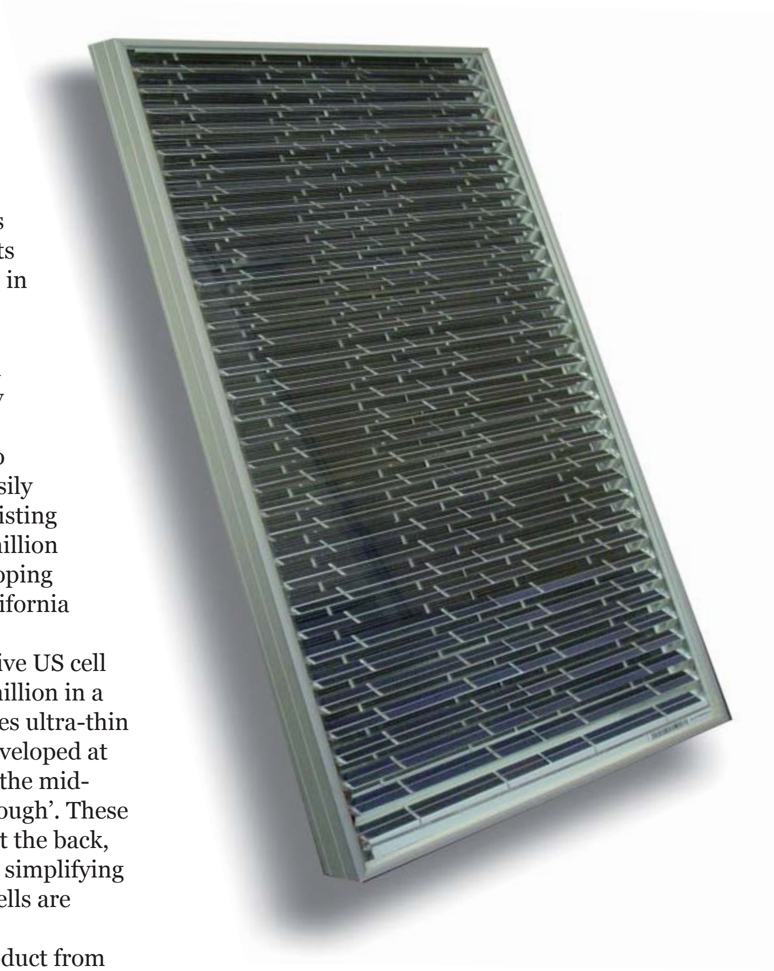
Advent Solar, another innovative US cell manufacturer, raised over $70 million in a fourth round in 2007. Advent uses ultra-thin silicon wafers in a cell design, developed at Sandia National Laboratories in the mid-90s, known as 'emitter wrap-through'. These cells have all the infrastructure at the back, improving efficiency by area and simplifying assembly. Advent also says the cells are aesthetically superior.

Advent is already shipping product from its 25MW production line in its native New Mexico, and signed a 250MW supply deal with European partners in September 2008. Opened in early 2007, the factory also aims to cut waste through lean manufacturing principles.

Other firms are taking silicon beyond the crystalline cell and into the emerging thin-film arena. Thin-film PV promises substantially lower material costs and increased flexibility, replacing conventional solar panels and opening up new markets and applications. Although many thin-film companies are working with other materials, others are exploring new forms of silicon.

One of the most commercially advanced is another Silicon Valley firm, Innovalight. Based on research from the US Department of Energy, Innovalight has developed a proprietary ink containing silicon nano-crystals, or 'quantum dots', which have a substantially higher efficiency than silicon wafers. The ink can be printed directly onto a substrate, to produce ultra-thin solar modules for residential and commercial use, potentially at a tenth of the cost of conventional cells.

Innovalight raised a £28m third round in late 2007, and secured further government funding in September 2008. The firm is developing a major new manufacturing facility, with commercial production scheduled to begin in late 2009.



Image, courtesy of SV-Solar

Another promising Silicon Valley firm is Solexant, which raised a $4.3 million first round in September 2007. The firm is developing nano-structured materials which can harvest infra-red light that conventional silicon doesn't respond to. Combining that with thin-film silicon can dramatically increase efficiency by capturing more energy from the same light.

Xunlight (formerly MWOE Solar) is a spin-out from the University of Toledo. It is commercialising thin-film technology which adds a little germanium to the silicon to achieve record-breaking conversion efficiency. The firm raised a $22 million second round in May 2008 and is working on a 100KW pilot production line.

Thin-film silicon faces tough competition from films based on other materials, including cadmium telluride and the compound semiconductor known as CIGS. In the next article, we'll look at the most exciting businesses taking solar power beyond silicon. CT

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Thin-film PV - CIGS and CdTe

Thin-film cells can be more flexible in their applications and, depending on the substrate, physically more flexible.

While many solar cell manufacturers are struggling with the rising cost of silicon, others are reaping the benefits. For the new generation of companies developing photovoltaic (PV) cells based on alternative materials, high silicon costs can only increase demand for their own products.

The most advanced alternatives are in thin-film technology. Thin-film PV has a lower material cost than traditional crystalline silicon cells as it typically uses just one per cent as much semiconductor material for the same output.

There's other benefits too. Thin-film cells can be more flexible in their applications and, depending on the substrate, physically more flexible. Solar panels can be wrapped around different structures and, because the PV film can be applied to range of base materials, can be integrated into buildings, vehicles or even clothing.

Several different semiconductors can be used in thin-film PV. In the last issue, we introduced some silicon-based thin film developers. But two other materials are drawing most attention - the copper indium gallium selenide (CIGS) family; and cadmium telluride.

Thin-film developer HelioVolt calls CIGS "nature's best solar-absorbing material". Actually, it's not as effective as crystalline solar in capturing energy from sunlight. PV modules based on silicon have a net efficiency of around 18 per cent, while current CIGS modules have a net efficiency of only up to around 12 per cent. That's forecast to approach 14 per cent as full-scale production allows improved deposition and encapsulation technology, but it still lags silicon.

CIGS does perform better in low-light or low-angle conditions, however. It also has an advantage over other semiconductors in that its performance isn't as sensitive to the exact concentration of its constituent elements, giving more tolerance and flexibility in manufacturing.

But its big advantage is in cost. The production cost of CIGS modules is forecast to fall to $1 per Watt peak (Wp, a measure of optimum output) by 2010, half that of monocrystalline silicon and less than all other silicon-based tech. More power per dollar means than thin-film is forecast to make up 20% of the total PV market by 2010, up from around 8% today, and potentially dominate the industry by 2020.

That's made thin-film very attractive for venture capital investors. Investment rounds have tended to be large, as they have to fund purpose-built manufacturing facilities. Firms which have secured funding are nearly all in the US, with many around Silicon Valley - even though they're not using silicon, their manufacturing methods are often based on techniques from the ICT industry.

Texas-based HelioVolt closed a massive $101m second round in October 2007. The money goes towards opening Heliovolt's first plant, with the initial capacity to produce 20MW worth of cells a year. The firm's production technology prints the CIGS-based thin film directly onto a range of materials, although initial production is concentrated on glass. HelioVolt's core market is the construction industry, where its flexible production process allows cells to be integrated into the building itself.

Thin-film production lends itself to a range of manufacturing methods, including direct printing, sputtering, vapour and plasma deposition on a variety of rigid or flexible substrates. Many companies are experiencing problems and delays in moving to full-scale commercial production, however.

One of the first CIGS developers to begin large-scale production is California-based Nanosolar, which started production in late 2007. The firm's San Jose facility, previously owned by IT giant Cisco, is thought to be the world's largest solar cell factory. It's also developing the world's largest panel-assembly facility near Berlin, Germany.

Nano solar energy panel.
Photographer:MARK THIESSEN/National Geographic Image Collection

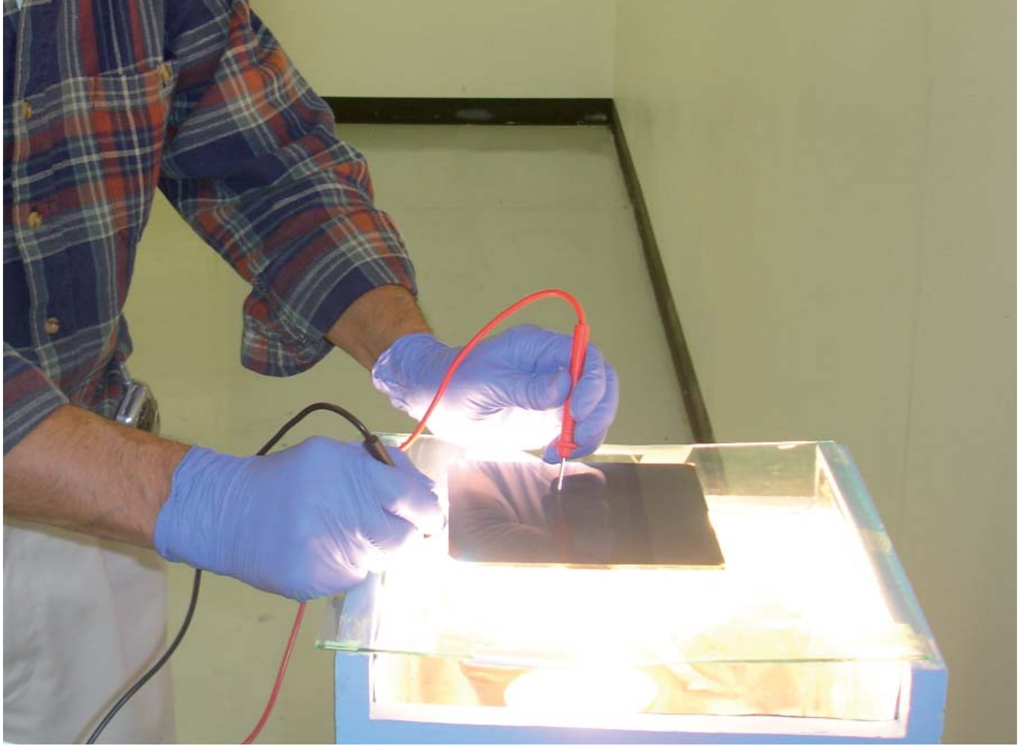


Image: Mehran Sadeghi, a senior scientist at Prime Star Solar, measures a solar cell's efficiency

Nanosolar is one of the best-financed companies in the solar arena, most recently raising a $300 million strategic equity round in August 2008. The firm uses a continuous roll-to-roll process, printing a CIGS nanoparticle ink onto low-cost aluminium foil. The metal substrate removes the need to deposit a separate electrode layer, as is needed on glass, while the roll-to-roll printing allows high throughput.

Another San Jose firm, SoloPower, is also developing a roll-to-roll manufacturing process. The firm says its electroplating production technique, borrowed from the semiconductor industry, is significantly more cost-effective than other methods. SoloPower raised a $30m second round in July 2007, and is also supported by the US Department of Energy.

Still in California, Miasolé is also gearing up for commercial production. Miasolé raised $50m in a fourth round in September 2007 and is currently raising a further round of some $200 million. Headed by a seasoned management team from the hard disc industry, Miasolé uses a proven high-throughput sputtering technique to deposit CIGS onto a stainless steel foil. The finished modules can weigh less than a fifth as much as glass plate modules, and can be integrated into building materials.

The other thin-film material winning serious attention is crystalline cadmium telluride (CdTe). CdTe offers a similar module efficiency to CIGS but potentially an even lower cost, forecast to reach around $0.80/Wp by 2010. Like CIGS, it's effective in low light situations, and also copes well in high-temperature environments.

Cadmium is an extremely toxic heavy metal in its raw state, but solar developers take pains to ensure production and use of their products remain thoroughly environmentally friendly. Using cadmium as an input can reduce waste from other industries - leading developer First Solar, for instance, sources its cadmium from zinc smelting waste.

Arizona-based First Solar is one of the elders of the thin-film world, forming in 1999.

The firm floated on Nasdaq in early 2007, and is now on track to hit its target of 1GW annual production from its plants in the US, Germany and Malaysia. Its production process uses high-speed vapour transport deposition onto glass.

German solar giant Q-Cells is also investing in CdTe technology, acquiring Ohio-based Solar Fields in November 2007 and merging it with its own Calyxo subsidiary. Solar Fields also uses vapour deposition technology, which it had previously licensed to Q-Cells. Calyxo is now working on a 60MW production line.

Colorado-based AVA Solar meanwhile raised a $104m second round of venture investment in September 2008, to fund its new 200MW factory. The firm has developed a continuous high-throughput process for manufacturing CdTe-based cells with a conversion efficiency of around 12 per cent.

Early-stage CdTe developers are also winning investor interest. Georgia-based PrimeStar Solar raised an undisclosed round from GE Energy in June 2008, with the engineering giant taking a majority stake in the company. The firm is commercialising CdTe technology developed at the US National Renewable Energy Laboratory which has achieved a record 16.5 per cent cell efficiency, and is currently developing a pilot manufacturing plant for its deposition technology.

Meanwhile, other firms are developing thin-film PV based on other semiconductors, including novel copper-based compounds, titanium dioxide, and organic polymers. In the next article, we'll look at these and other businesses leading the third generation of solar power. CT

The next generation of solar 3

Third generation materials

Companies are developing new kinds of solar cell based on a variety of more exotic materials.

It's a happy fact of chemistry that solar cells can be built from a wider variety of materials than many people might realise. The vast majority of photovoltaic (PV) panels now on the market are based on silicon - and, as we've seen, there's a plethora of companies working to get more power out of that semiconductor by developing new cell configurations or by using silicon in thin films. Other firms are developing thin film cells based on copper indium gallium selenide (CIGS) semiconductors or cadmium telluride.

There's also a third set of companies which are developing new kinds of solar cell based on a variety of more exotic materials. Each of these technologies presents its own benefits and challenges in terms of cost and conversion efficiency, but all promise to take solar power into new arenas.

Not all of these materials are radically different. Odersun, a German solar developer which was recently picked as Europe's hottest private cleantech company, is developing thin films based on copper indium disulphide, a compound that is chemically similar to the CIGS family.

Odersun prints its semiconductor onto centimetre-wide copper tape, a technology it calls CISCut, in what it claims is the industry's fastest reel-to-reel production process. Applications range from utility-scale installations and building-integrated systems, to personal items such as the solar bags it is developing with Berlin-based Bagjack.

The firm is currently building its first commercial-scale (30MW) factory in eastern Germany, with the aid of a Euro21 million public grant. Odersun has also been successful in attracting venture capital, with a Euro40 million second round in February 2008 from investors including Doughty Hanson and Virgin Green Fund.

Other solar firms are working with very different materials. Technologies which have secured investor interest fall into two broad categories - organic materials, and III-V compounds.

The most advanced company in the organic space is Konarka, originally a spin-out from the University of Massachusetts. Konarka is developing what it calls 'Power Plastic' - a lightweight, cheap and versatile solar cell manufactured by direct printing.

The photovoltaic capability depends on nanoparticles of titanium dioxide coated with an organic dye similar to those used in some LED displays. These particles are printed in a continuous reel-to-reel process, onto a thin plastic film along with electrode layers made of semi-conductive polymers. Light is absorbed by the dye, which excites electrons out of the titanium dioxide and

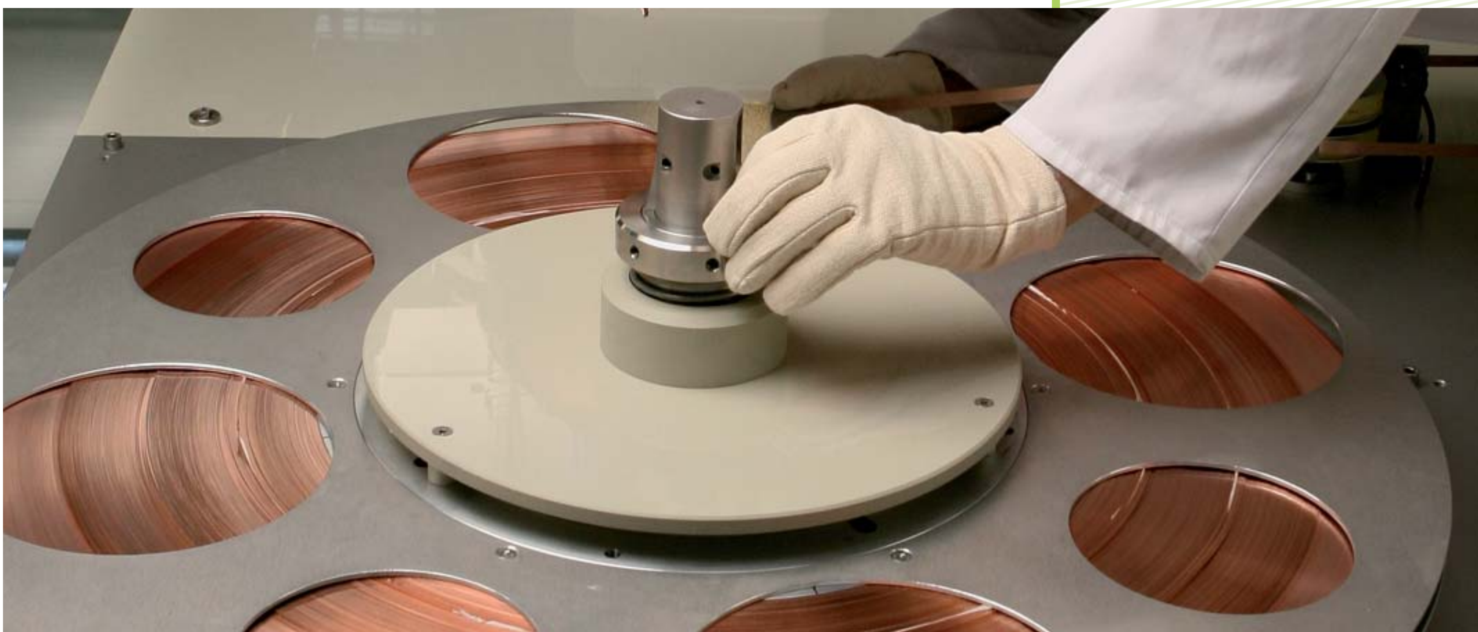


Image: Four cell production at Odersun AG into the electrodes, producing an electric current.

The conversion efficiency is low, at around five per cent compared with around 10 per cent for CIGS and up to 18 per cent for silicon. The production costs are low enough to compensate, however - the cost per watt output is around a fifth that of traditional silicon PV.

Konarka is supported by some major VCs, including 3i and cleantech stalwarts Good Energies and Draper Fisher Jurvetson. The firm has also secured government support, including funding from the US Department of Defense. The US military is a major customer for Konarka, which is already supplying portable battery chargers to the Army to keep the modern soldier's multiple devices fully charged, and materials for portable military buildings to the Air Force.

Cleantech and the military might be an uneasy mix for some, but the technology has far wider applications. Power Plastic could bring great benefits to developing countries and areas with limited power infrastructure, while domestic applications range from construction materials to consumer items.

Konarka is itself a shareholder in Cardiff-based G24 Innovations, which holds the European manufacturing rights for the same TiO_2 nanoparticle technology. G24i is developing a range of products for consumer and business applications, and secured £50 million in summer 2008 to expand its manufacturing facilities.

Other companies are working on improving the conversion efficiency of organic materials. Heliatek, a new company spun out from the Technical University of Dresden and University of Ulm in 2006, is developing new organic materials and production techniques which it says can significantly improve efficiency and cut costs.

In its first, pre-production, phase of development, Heliatek is aiming to achieve conversion efficiencies of 8-10 per cent and to prove its reel-to-reel production process. The firm's organic semiconductor is very thinly deposited in this vacuum process, with one gram covering a square metre of solar cell.

Heliatek is aiming to reduce costs to below Euro1 per peak Watt, on par with the aims of CIGS developers. The firm has secured funding and research support from BASF and Bosch, as well as VC investment.

University spin-out companies are also pioneering a relatively untested area for solar tech - the III-V semiconductors, named for the positions in the periodic table of the compounds' constituent elements. Common III-V compounds include gallium arsenide (GaAs) and indium phosphide (InP), substances which are also used in the optoelectronics industry.

These materials can potentially make highly efficient solar cells. The problem is that the semiconductor crystals need to be extremely pure, so cells have very high costs of production. The materials are also heavier and mechanically weaker than silicon.

The key to tapping their potential may lie in quantum wells. Despite sounding like something from science fiction, quantum wells are a well-established technology used in lasers and low-noise electronics such as infra-red imagers. When constructed with III-V crystals, quantum wells can effectively be tuned to reap the maximum energy from incident light, while using a tiny amount of the semiconductor.

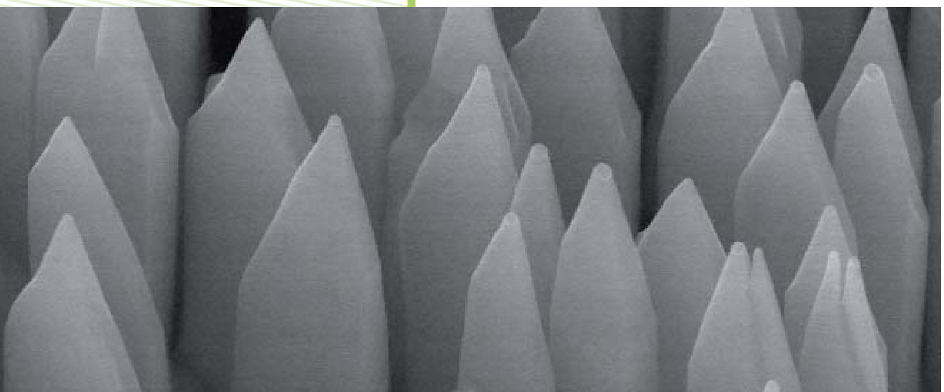
QuantaSol, a spin-off from Imperial College London, is developing what it calls a stress-balanced quantum well. This uses a mix of GaAs and other III-V compounds to absorb the maximum light energy while being more stable than single-compound crystals.

Following a £1.35 million seed round in 2007, QuantaSol secured £500,000 follow-on funding in April 2008 after demonstrating conversion efficiencies of 27 per cent with a single-junction cell. This was achieved with light equivalent to 500 suns, which means the cells should be ideal for use in solar concentrating installations which use optics to focus a large amount of sunlight onto a relatively small PV cell. The firm aims for 35 per cent efficiency in a multi-junction cell before the end of the year.

SunFlake, spun out from Copenhagen University last year, is also aiming for conversion efficiencies of 30 per cent and above. The firm is developing solar cells based on a III-V semiconductor nanostructure called 'NanoFlakes' which lead researcher Martin Aagesen has called 'a perfect crystalline structure'.

These crystals act as a quantum well when printed onto a low-cost silicon substrate. Initial work has involved indium arsenide, but the same technique can potentially be used with range of III-V compounds.

These quantum well technologies are still years away from commercialisation, and the complex nanostructures mean that they're unlikely to ever match the production speed of the thin-film technologies, but they might still play an important role in the future of solar power. CT



NanoFlakes - a perfect crystalline structure
Picture courtesy of SunFlake