Building-integrated photovoltaics without a perfect alignment towards the south. This is not a problem for Dye sensitised solar cells, which still generate electricity efficiently.

Photo: Dyesol

On the final straight?

It is hoped that organic photovoltaics will be able to do what the classical silicon-based solar cells so far haven't achieved: generate electricity from solar energy at a competitive price. But the technology is new and still has many hurdles to overcome.

Companies and research groups are not sparing with promises and visions when it comes to the subject of organic photovoltaics. But the organic cell technology itself is not yet fully out of the vision stage either.

There are two main stumbling blocks which are mentioned again and again: the durability and the efficiency. But with the price, it is expected that the promises of really cheap cells can be achieved. The raw materials are cheap and a lack of availability is not on the cards.

One name, two technologies

There is not just one technology behind the expression organic photovoltaics. Taken literally the expression best describes those cells which use semiconducting organic polymers. But there is also a second technology which runs under this label: namely dye-sensitised solar cells (DSSC or DSC).

These DSCs, which are also known as "Grätzel cells" after their inventor Michael Grätzel, imitate photosynthesis as it takes place in plants. The dye is energetically excited by sunlight to a point at which electrochemical exchanges can take place with a semiconductor strip, and electrons are given up to the semiconductor (see diagram on page 94). Nanoparticles of titanium oxide (TiO_2) are usually used as this semiconductor. An electrolyte on the anode side is, in turn, able to give up electrons to the dye, which thus regenerates. This cell type is counted as being organic PV because an organic metal compound is used as the dye. Ruthenium is generally the metal used here, which is a comparatively environmentally friendly metal. Early on, natural dyes such as chlorophyll, or anthocyanin gleaned from blackberries, were also used.

But back to the first type of cells known as organic PV, which are based on so-called heterojunctions. These heterojunction cells (HJC) use mixed organic polymers as a semiconductor. Electron exchange points between a conjugated polymer and an acceptor, such as the fullerene (C_{60}) molecule, for example, are responsible for the carrier transportation. Incident light brings the polymer into an excited electronic state. An electron may then be given up from this energy-rich state to a second molecule, which is generally fullerene, as mentioned above. This carrier-stripping process, which also makes carrier transport possible, is the basis for the main intended function, the generation of electricity.

The development of conducting organic polymers was awarded the Nobel Prize for Chemistry in the year 2000 and back then sparked a boom in research and development in this field. In practise, these polymers have been known about by everyone for ages. Organic light-emitting diodes (OLED) are used in computer screens, televisions and mobile phone displays. Like in the silicon PV and the related semiconductor industry, one can thus fall back on experience from an established technology here.

Comparisons with silicon are problematic

But how far are the manufacturers of organic PV? There are a number of important criteria for being ready to go onto the market. One aim is to be cheaper than silicon on market entry. By how much is unclear, however, and concrete figures are still hard to come by. The German start-up company Heliatek provides a reference figure on its website, that silicon modules lie at 3.50 €/W and that they are aiming to break the 1 €/Watt barrier for organic cells. At first glance this may seem like an ambitious target, but the prices of conventional PV are in free-fall. The module price from established European manufacturers lies at 2.60 €/W. Modules from China are available for nearly 2 €/W. And the inorganic competition is no longer just pinning its hopes on silicon. The US company First Solar is already advertising that it can produce CdTe thin-film modules for less than 1 US$/W. This is already cheaper than the Heliatek target. Further companies are also nearing this mark and will reach it soon. At Dyesol from Australia the material costs in production of their DSCs are claimed to be just 25 %, compared to 50 % for silicon-based solar cells. For organic polymer cells the situation is similar: “The target is to be already cheaper than silicon at very low production capacities”, says Christoph Brabec, CTO of Konarka Technologies in the USA. They can currently achieve production costs of around a third of those for classical PV. One should take into consideration, however, that the costs may only be looked at in relation to the extremely important topic of product lifetimes.

Product lifetimes are the crux of the matter

The longer a solar cell provides electricity the more it may cost. Konarka assumes a lifetime of between 3 and 5 years for its heterojunction products. This is thus still a long way from conventional PV. You have to consider, however, that the lifetime has increased many-fold in the space of just a few years. A further improvement of polymer cells is therefore likely. The German company

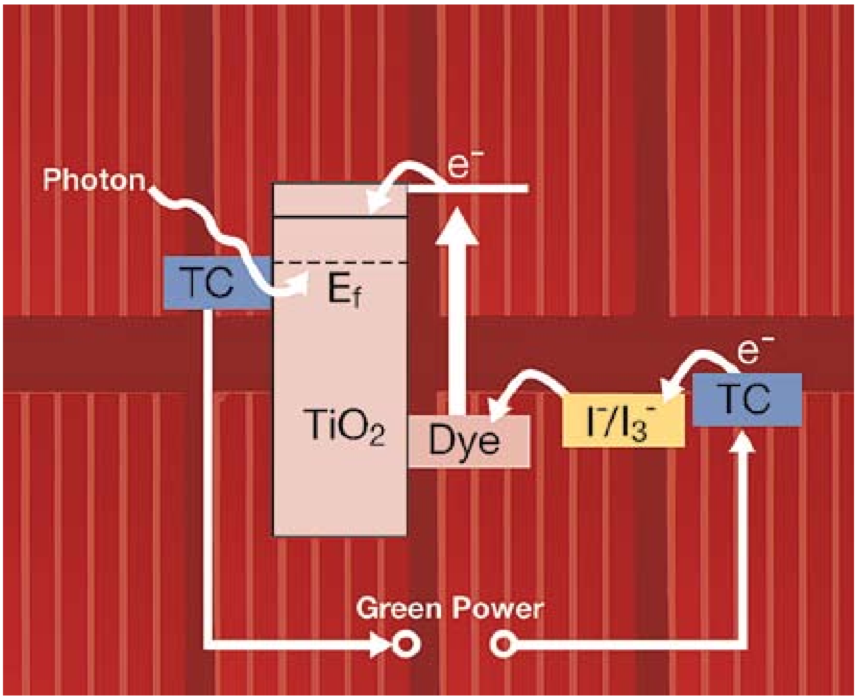
BASF has set firm targets. “A module efficiency of at least 10 % at production costs of under 100 euros per square metre and a lifetime of over 10 years must be achieved”, says Torsten Thomsen, Project Manager for OPV at BASF. But the technology is very new, he admits, and a little more patience will be required. The lifetimes of inorganic cells probably won’t be quickly reached, though. If you assume a lifetime of just 20 years for silicon cells, you don’t have to be a mathematician to see that it won’t be enough to be just a bit cheaper for the same amount of rated power, in order to be able to compete with a lifetime at least four times as long.

Darin Laird, Technology Director at the US company Plextronic notes that “lifetime testing is just starting to really develop and requires well-defined standards and protocols for the entire industry”. This is why they are also working with the National Renewable Energy Laboratory (NREL) to establish these. The reason why one is only now dealing with this is that “efficiency gains are critical to the progress of OPV and have earned a great deal of focus as a result”, says Laird. As market-launch maturity gets ever closer, the subject of product lifetime really has to be dealt with more intensively now.

Things have moved further along in the field of dye-sensitised cells. Hans Desilvestro, Chief Scientist at Dyesol reports: “Accelerated aging tests indicate a service life of at least 40 years in areas experiencing 1,000 kilowatthours per square meter annual solar irradiation (e.g. Central Europe) and 25 years in areas such as Southern Europe.” These forecasts have so far been supported by outdoor testing by Toyota, which has taken place over a five-year period. According to Dyesol the results from these tests were good.

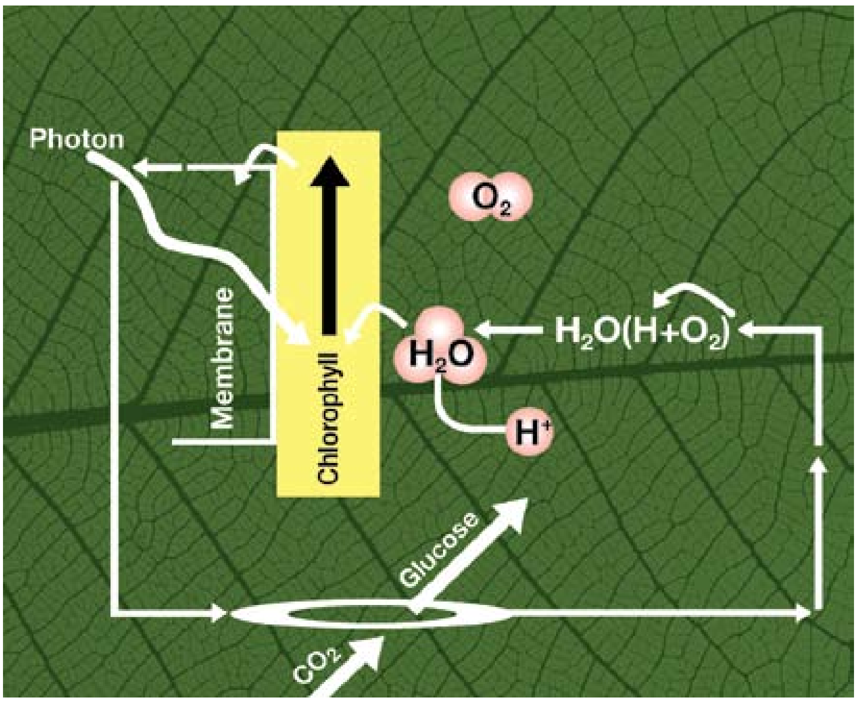
There is also still quite a bit of work to be done on the efficiency of organic PV. Current prototypes of both the dye and polymer cell types have outdoor efficiencies of around 5 to 6 %. In the lab more has sometimes been achieved. DSCs from Grätzel’s group at Lausanne University in Switzerland recently reached 12.2 %. As Dye sensitised cells are partially transparent they can also be layered one on top of another. Such tandem cells currently achieve a maximum efficiency of 12.3 %. Compared to crystalline solar cells they are still a long way behind, however. It is hoped that around 10 % can be achieved outdoors in the next few years, even without using tandem technology. In order to be competitive it is not at all necessary to reach the same efficiency as classical PV, though, explains Sylvia Tulloch, Managing Director of Dyesol. As opposed to silicon, the organic cells should start producing electricity earlier on in the day and continue for longer in the evening. It is claimed that a small amount of electricity generation is even possible in moonlight.

How dye-sensitised cells and natural photosynthesis work



Copying natural photosynthesis: For each step of electricity generation there is a component in the dye-sensitised solar cells. In conventional PV, silicon has to take on all the tasks simultaneously.

Diagrams: Dyesol



Flexible use has its advantages

But even if there is still a lot to do ahead, there are a number of advantages which raise organic solar cells above the classical silicon ones. And they don’t need to shy away from current thin-film technologies either in some areas. Both polymer and dye types are extremely light, thin and bendy. They can thus also be used in places where rigid silicon cells would be unsuitable. The first Konarka modules will be integrated into handbags or sunshades. The Dyesol DSCs are also to be used in this sector. Several suppliers from the thin-film field are additionally opening up this same gap too. The organic cells may gain points in one respect here, which should not be underestimated when it comes to uses with clothing. The technology makes it possible to colour them. If you’ve got a

New markets for photovoltaics: solar power from your handbag/ holdall for your mobile phone or laptop reduces the dependence on sockets and limited battery running times.

Photo: Konarka

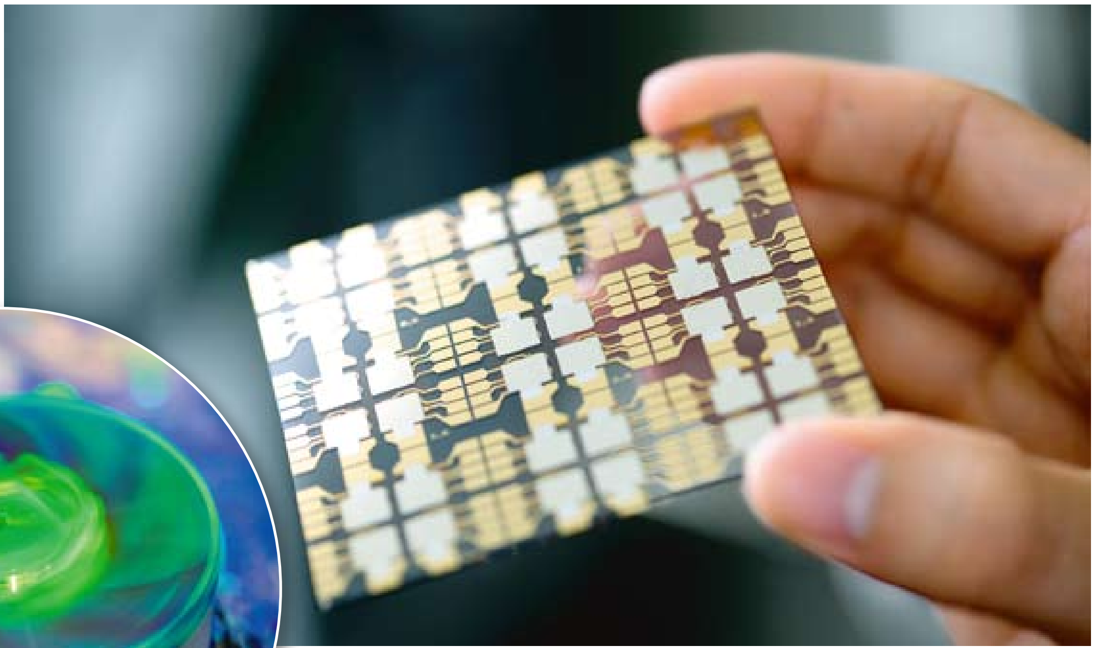
green bag, you could put green cells on it; if you want red you can also get red. The same argument can be used for building-integrated uses. As the cells can be partially transparent they could also be used to cover window areas. Structural problems are not to be expected for applications on buildings. Both polymer and dye-sensitised cell technologies are extremely thin and may be printed onto foils. Their weight may thus be ignored.

Even if their power may still be relatively low, it can be expected that this can be compensated for, in part at least, by low installation costs. The Australian Dyesol is looking at a promising approach in cooperation with the second-largest European steel manufacturer, Corus from Wales. The two partners want to manufacture sheet steel which is printed with Dyesol DSCs ex-works, i.e. during the manufacturing process. This steel is then to be used on steel roofs and façades. As it doesn't require any direct sunlight, these cells may also be installed on the shady side of buildings. Obviously the energetic and financial amortisation would be longer in these cases, but it should still be achievable. With a lifetime of 25 years and upwards, and no requirement for additional mounting systems, this is a very promising application.

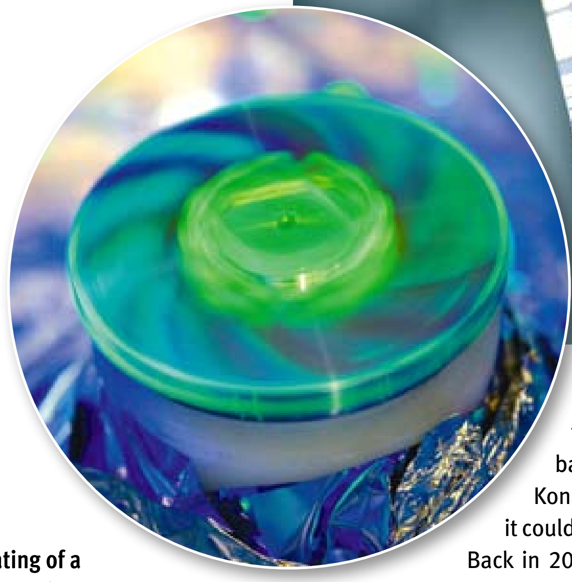
Wales in itself seems to value the potential of OPV particularly highly. G24 Innovation is another big name amongst the paint and dye manufacturers in Wales. The company has already been operating a factory capable of producing DSCs since 2007.

Silicon eats its own energy up again

There is hardly any criterion better at comparing various renewable energy technologies than the energy payback time. Current estimates put this at between 1.5 and 3.5 years for silicon-based cells. OPV scores



The substrate of an organic solar cell: there are 144 test cells on this with a diameter of 1 mm each. The substrate has been coated with thin films of organic material using sputtering technology. Photos(2): BASF



Coating of a glass substrate using spincoating: the previously sprayed substrate is placed on an aluminium plate and a dye solution is allowed to drop onto it. Through a quick spinning movement the dye solution spreads out to form a thin layer.

points here. At Dyesol they reckon with a payback time of under a year, Konarka even estimates that it could require just a few weeks. Back in 2006 Michael Grätzel commented in the Technology Review that the organic cells have an especially big advantage over silicon cells in terms of embedded energy. The solar industry is growing rapidly, but so too is its energy demand. A large amount of the energy generated has thus been used up again by the solar industry itself, and the ecological use in thus strongly reduced. This is especially true in regions without much sunshine. Crystalline cells work best in direct sunlight and diffuse lighting conditions are poorly utilised. This disadvantage has brought with it a whole industrial sector: solar tracking. This is exactly where polymer and dye-sensitised cells score, as they are relatively insensitive to the angle of the incident light. Thus, along with roofs, building façades also become potential areas of use. Although façades are sometimes also fitted with silicon modules, such installations do not really have any economic potential.

Several paths lead to higher efficiency

In order to increase the efficiency of polymer cells the manufacturers are following various paths at the same time. An important area being worked on is the polymer. The most commonly used one is P3HT – a polythiophene. This class of materials has been known for ages and has been studied thoroughly. Synthesis at the kilogram scale, something not to be taken for granted in chemistry, makes polythiophenes pretty cheap, and this is thus a big group which is available for research.

This material is particularly attractive as it forms a very good donor/acceptor pair with PCBM, a C60 fullerene derivative. Attempts are being made to increase the efficiency by widening the absorption band. A band of approx. 500 nm is the norm. By increasing this, more light should be absorbed by the solar cell, which should thus generate electricity more efficiently. A second approach being tried is with tandem cells, which contain various polymers with overlapping absorption band ranges, thus increasing the power. "At this time, single layer OPV

As the modules are very light and may be transported without taking up much space, even military circles are showing an interest in this technology.

Photo: Dyesol

cells still outperform the tandem examples to date", says Darin Laird from the American polymer manufacturer Plextronics. But he expects that the tandem approach will remain an important area of work and still has a fair amount of potential to offer. Apart from the absorption band width there is also potential for improvement in the absorption efficiency. By specially designing the polymer, researchers are trying to increase the absorption cross-section – i.e. the number of photons which can react with the cell. Bandwidth alone is not enough to be able to make a good solar cell.

It is a similar story with the Grätzel cells. Here too the approach of combining several dyes is being taken, or the creation of multi-layered cells. With DSC tandem cells, things are the other way round compared to polymer cells. Here, it is tandem cells which currently have a higher efficiency than single-layer applications. It is interesting that one would even accept shorter lifetimes; more than 20 years doesn't have to be reached everywhere. If you want to equip mobile phones with solar cells, for example, then these should be primarily cheap. Such devices aren't going to be used for decades.

Even though organic photovoltaics are new and still have many hurdles to overcome, the prospects are good. They are cheaper than conventional silicon technology even today. Although this is somewhat countered in heterojunction cells by the problems they are facing with durability, it can be assumed that things will continue to improve here. Colleagues from the dye-sensitised front have shown that it can be done. The biggest strength of OPV must be seen as the opening up of new markets, however. With potential uses in small mobile products, sunshades, clothing, windows, plus additional building applications, or even their use as sensors, markets can be opened up and supplied that classical silicon PV just can't reach, or simply wouldn't be able to keep up in when compared directly.

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Further information:
www.dyesol.com
www.konarka.com
www.plextronics.com
www.basf.com
www.g24i.com
www.heliatek.de

OPV will open up new market segments

At the 3rd Intertech Organic Photovoltaics 2009 Conference in Philadelphia, scientists from industry and universities discussed the challenges of this new promising technology. Main topics were lifetime and efficiency of current products.

Organic Photovoltaics had barely made its appearance when Konarka Technologies introduced its first customer applications. "We are the first and only company who actually sells products made of organic photovoltaics", says Stuart Spitzer, Vice President, Materials & Engineering, in an interview following the third Intertech Pira's Organic Photovoltaics 2009 Conference in Philadelphia in April. Due to its pioneer features – that it is printed as second generation thin-film using third generation material, carbon based polymers – Konarka's power plastics target a niche market, which conventional solar systems cannot serve. OPV is not at all competing with conventional photovoltaics, says Stuart Spitzer, because of its unique characteristics: it is flexible, even wearable on clothes, and 16 times lighter than silicon based applications.

The third OPV conference, with its exclusive target of the organic approach to photovoltaics, gathered about 20 experts and 80 participants. The event was a success, according to Jessica Johnson, Conference Producer for Intertech Pira. Co-chaired by Russell Gaudiana, Vice President Research, at Konarka Technologies Inc. and Dana Olson, Research Scientist at the National Renewable Energy Laboratory, the conference brought in experts, researchers, but also potential partners and investors.

Organic solar modules are very light and bendy, and can thus also be used on sunshades.

Photo: Konarka

"With OPV we are approaching completely different market segments", said Spitzer. For example, in the agricultural industry, the lightweight panels can be installed on less solid structures such as greenhouses or temporary cattle sheds, without jeopardizing their stability. And being organic also means they are easily recyclable and not made of hazardous materials, like other thin-film products.

Consumer products with the Konarka logo, developed in partnership with Skyshapes, are the "Powerbrellas," where an outlet in the umbrella's stand allows one to charge his laptop, while enjoying the shade with an ice tea in a street café. There are also charging stations, which can be pulled out and collapsed into a case, like an old time home movie screen, usable anywhere in the field to charge a cell phone, PDA or other small devices. And why not charge your cell phone while carrying it in a brief case or handbag, fitted with OPV on the bag's surface?

Despite these successful developments, the experts at the conference agreed that OPV has potential for improvement when it comes to durability (currently they have only a 3 to 5-year lifetime) and efficiency (limited at about 5 %). Solarmer Energy Inc., one of the two other main players in the US market, along with Plexotronics, announced a panel efficiency of 6.31 % measured in the lab. Solarmer is developing translucent plastic solar cells usable in solar windows with an up to 45 % transparency replacing standard windows, opening up a large field of applications in the construction and architectural sector. But it yet has to come to market.

According to Spitzer, OPV will have reached silicon based photovoltaics by 2012, and he is convinced that carbon based systems are the real third generation photovoltaic: affordable, long lasting and efficient.

Spitzer also emphasized in his presentation the fast paradigm shift of the OPV technology: It has only been nine years since the Nobel Prize for Chemistry was awarded „for the discovery and development of conductive polymers".

It started out with the discovery of conductive polymer film, replacing silicon as a conductor with much cheaper plastic, and is now followed by the conversion of polymers into fluids, which allows a production process as simple as an inkjet printer.

That is what Konarka did in 2008 when it took over the closed down Polaroid production facility in New Bedford, Massachusetts. Konarka not only retrofitted the Polaroid inkjet printers; it also hired the former Site Manager of Polaroid and 13 of its employees, helping the region whose economy suffered following the closure of such a large facility. Konarka has also remained steadfast it its production goals, hoping to reach a production capacity of 1 GW in the near future.

Anja Limperis

Further information:
http://www.organicphotovoltaics2009.com