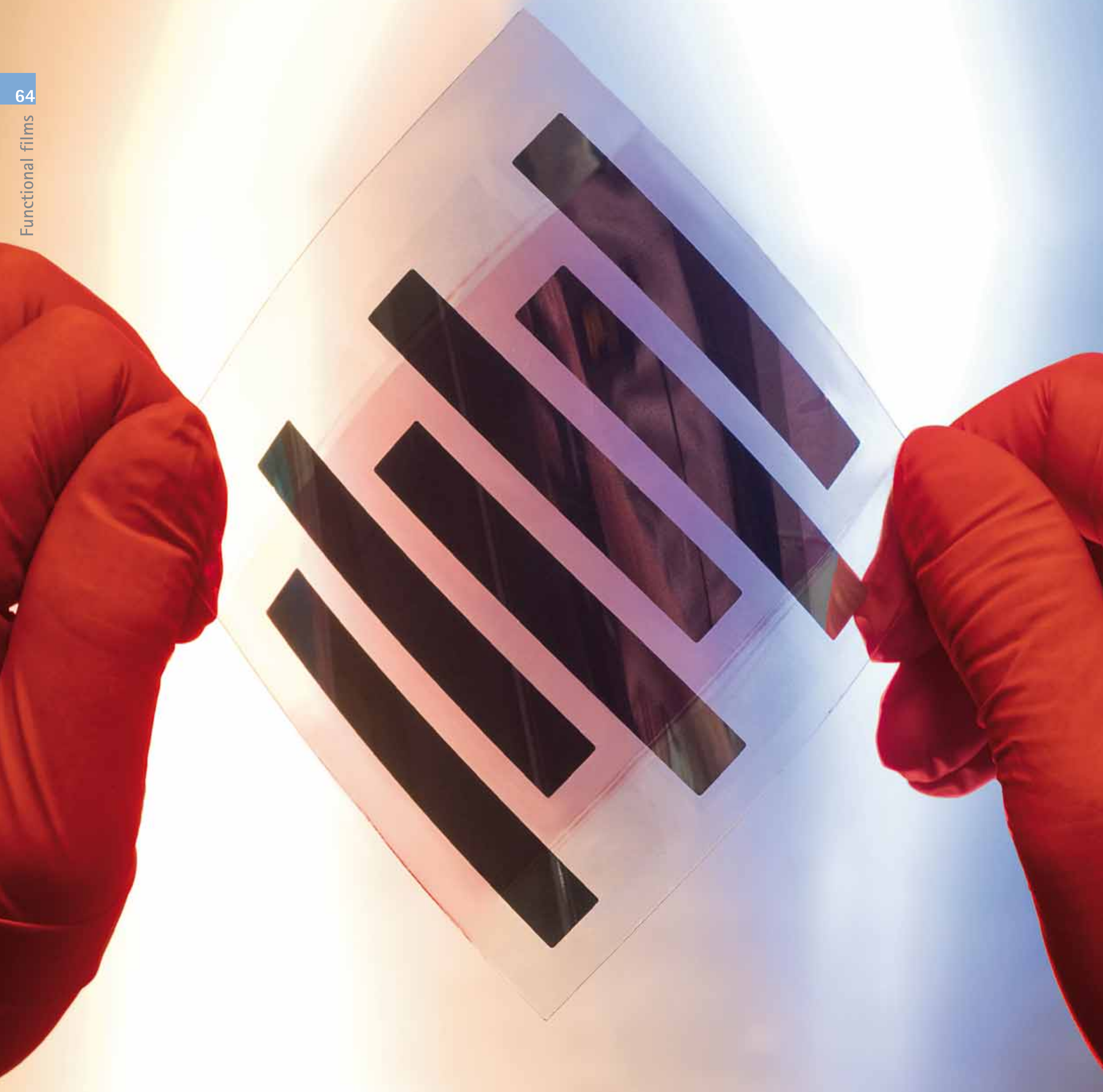
Nanoparticles make solar cells more economical and effective

Electricity from plastics – the stick-on power unit



Solar cells made of flexible plastic film could revolutionize energy technology. Attached to a mobile phone, handbag or house wall, these miniature power plants could convert sunlight into electricity more effectively than is currently possible. At present, their level of efficiency and useful life are still too low. Scientists from Bayer MaterialScience and Bayer Technology Services are therefore looking to nanotechnology to help master the challenges and make a contribution to climate protection.

Solar cells and pocket calculators are made for one another. The postage stamp-sized, shiny blue rectangle made of inexpensive amorphous silicon supplies the easily satisfied calculator with electricity and helps prevent embarrassing homework or examination mistakes. Then, as nobody needs to do mathematical exercises in the dark, the device switches itself off when the protective cover is slid over it.

While pocket calculators with solar cells are manufactured by the million, solar-powered laptops and mobile phones have not yet advanced beyond the prototype stage. The main reason is that most portable electronic devices consume more electricity than a correspondingly sized solar cell can supply. In any case, this would make the device considerably more expensive. Another obstacle is that, because they are made of silicon wafers or produced as ultrathin cells on glass carriers, present-day solar cells are rigid and therefore cannot be shaped to fit the curved contours of modern-day housings.

But things could soon change. The solution is called "organic photovoltaics" – electrical energy obtained from sunlight using plastic solar cells. It was known back in the 1980s that certain plastics can convert light into electricity, and because films made of these plastics are flexible they can be stuck to mobile phones, handbags, jackets, cars or even windows and walls, and can generate electricity wherever it is needed. There is no need to search for a mains cable or an electric socket.

Market worth billions: flexible plastic solar cells

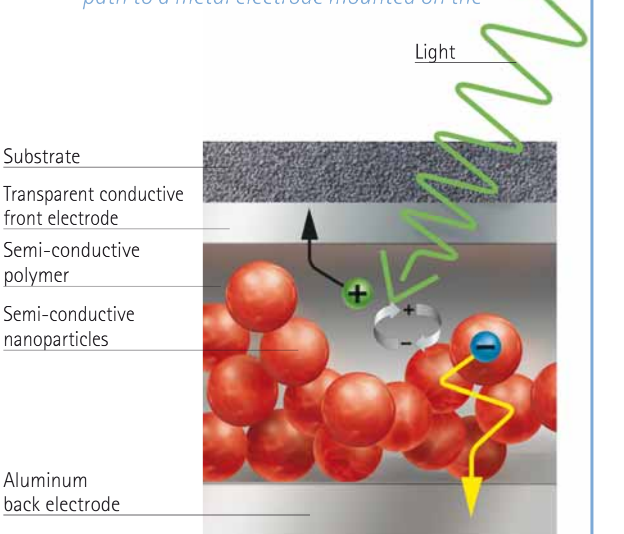
Yet the dream of a mini solar power unit on a phone or briefcase has not yet materialized because the efficiency of the films – the extent to which they can convert light energy into electrical energy – is too low. While cells of monocrystalline silicon can convert over 20 percent of the solar energy into electricity, the best solar films in the lab manage no more than five to six percent. And because the efficacy of these films also begins to decline after just a few months, the boom has not yet happened.

Nevertheless, many companies throughout the world believe the market could amount to billions. Germany's Federal Ministry of Education and Research (BMBF) has also recognized the potential of organic photovoltaics and has decided to invest a total of €60 million in this technology over the next three years. Numerous universities and research institutes as well as companies in the chemical and solar industries are involved – including Bayer as the coordinator of several partners in a project that was officially launched in September 2008. It will run for a period of three years and will be financed by the BMBF to the tune of €3.8 million. "We believe that we can contribute a great deal to this project with our know-how," says Dr. Karsten Dierksen, Head of Polymer Electronics in the Functional Films unit at Bayer MaterialScience. The subgroup has considerable expertise in working with plastics such as polycarbonate, which is one of the hot candidates to play the role of carrier for the organic solar cells. Bayer also has experience in the application of ultra-thin layers – for example by printing processes. Such

Electricity from plastic: Bayer scientists are developing plastic films (photo left) which generate electrical energy from sunlight. The ultrathin solar power plants can create power wherever it is needed, without the inconvenience of searching for a mains cable or electric socket.

Flat solar power plants

Light contains energy. A solar cell converts this into electrical energy. The process takes place at the interface of two semi-conductor materials. With organic photovoltaics, these interfaces are only a few nanometers in size, but they are vital for the efficiency of the cell. Because only the light that is absorbed within this narrow zone can be converted into electricity, the materials must not only be extremely pure, their geometric arrangement also plays a key role. Nanostructures provide a vastly larger interface and thereby improve efficiency by more than one order of magnitude. In the photoactive layer of a hybrid solar cell, the semi-conductor nanoparticles are arranged in such a way that they have direct contact with each other and form an electric path to a metal electrode mounted on the



outside. The cavities are filled with a suitable semi-conducting plastic. When light falls onto this structure, positive and negative charges are momentarily created, still loosely connected to one another. If there is an interface in the direct vicinity of this charge pair, the charges that have formed are separated. The negative charge then flows over the nanoparticles to the metal electrode, while the positive charge moves over the plastic to the transparent conductive front electrode.

Solar power experts: Dr. Karsten Dierksen, Dr. Frank Rauscher and Dr. Werner Hoheisel (photo above, left to right) are contributing their knowledge of plastics such as polycarbonate to the development of cost-effective and long-lasting organic photovoltaic systems.

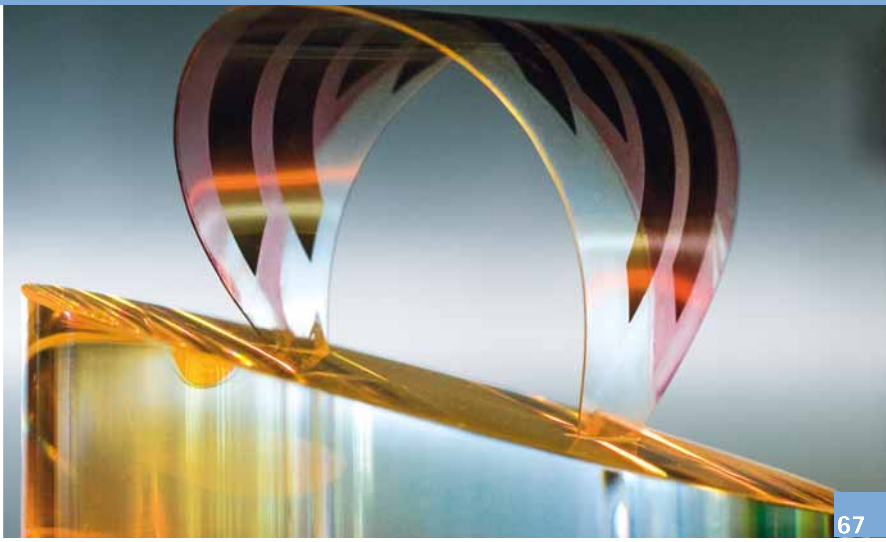
experience is urgently needed because the structure of an organic solar cell is like a sandwich, consisting of several ultra-thin layers, sometimes only tens of nanometers thick. In most cases they have only a passive function as their job is to protect the actual light-sensitive layer from attack by atmospheric oxygen and make the solar cell sandwich more flexible.

Deliberately creating a structure from nanoparticles

The success of organic photovoltaics, however, stands and falls with the light-sensitive layer. It must convert sunlight as effectively as possible into positive and negative charge carriers and conduct them without loss via a network of very fine nanostructures. What the optimum structure for a cell that is as efficient as possible will look like is currently the subject of much intensive research.

Bayer favors a novel kind of solar cell technology with inorganic nanoparticles known as quantum dots, and is therefore taking a different approach than most other companies. This is not because they distrust Bayer's line of attack but because there are only very few companies with a command of this process. "We can even specifically control the structure of the nanoparticles," says Dr. Frank Rauscher. He and his colleagues at Bayer Technology Services are currently developing suitable nanomaterials and researching the physical principles of electricity generation in the plastic/nanoparticle sandwich, which consists of a network of semi-conductive plastics, in which the nanoparticles, finely dispersed, are embedded. "The decisive factor is that the nanoparticles do not stick but interconnect as a network. In this way, both components can serve as drainage for the positive and negative charge carriers," says physicist Dr. Werner Hoheisel, explaining the principle. He works at Bayer Technology Services and his responsibilities include the development of the new type of solar cell. It is also important that the contact area between inorganic quantum dots and the organic carrier is as large as possible, because it is here at this interface that the conversion of light into electrical charge takes place.

The U.S. start-up company Konarka is already advertising a "world without wires," but the solar cells developed by the American company are likewise unable to achieve more than six percent efficiency in the laboratory.



Flexible mini power plants: organic photovoltaics contain several layers of ultrathin materials that are only tens of nanometers thick. Melanie Treichel prepares the printing procedure for this in clean-room conditions (photo left). The flexible film sandwich (photo right) can be easily formed into different shapes.

Hoheisel regards the targeted design of materials and production processes as a huge challenge. "Despite good concepts and ideas, we are still right at the beginning, so there is always a residual risk." To keep the risk to a minimum, the Bayer research team relies on the support of cooperation partners.

2011: less than one euro per Watt of peak power

Q-Cells and the start-up company Soluxx are working primarily on industrial realization of the technology. Other partners in the BMBF program are the universities of Cologne and Wuppertal, the Karlsruhe Institute of Technology and the Fraunhofer Institute for Solar Energy Systems. The German Federal Research Ministry is also playing safe by adopting a multi-tracked approach, and has not put all the €60 million of its "Organic Photovoltaics" research program in one basket. "At the end of the day, however, there may be more than one winner," says Dierksen. For example, companies may develop solar films with different strengths and weakness for different applications. Whether Bayer will be among the winners will be decided primarily by the market. "Seven to eight percent efficiency, three years of service life and a price of less than €1 per Watt of peak power are ambitious milestones that we want to reach in the next three years," says Dierksen. Only then would organic solar cells have a chance of penetrating the lucrative consumer goods market. 2013 could be the earliest for the first applications, and Dierksen does not expect any impact on the mass market before 2015. It is a case of making preparations now, for example with partnerships with large companies. Dierksen is confident: "We are right up there with the leaders."

Nobel pioneers

It was the discovery of conductive plastics by Alan Heeger and Alan MacDiarmid from the United States and Hideki Shirakawa from Japan that made applications such as LEDs and mobile phone displays possible. In 2000, they were awarded the Nobel Prize for Chemistry for their work. Heeger, MacDiarmid and Shirakawa first succeeded in producing a conductive plastic with polyacetylene. The researchers doped the plastic with iodine, which increased the electrical conductivity several million times.

www.podcast.bayer.com/en/homepage.aspx
Bayer's Podcast Center offers a video with background information on this topic.

www.bmbf.de/en/10413.php
This website contains further information on the "Organic Photovoltaics – Plastics for Energy from Light" research program.