Makrofol® boosts energy efficiency in OLEDs

More light, please

In the future, organic light-emitting diodes (OLEDs) will illuminate living rooms and even entire facades. These tiny, thin lights are opening the door to entirely new illumination concepts. Researchers at Bayer MaterialScience are using innovative plastics to ensure that these energy-efficient lamps of the future shine especially brightly. Thanks to a wafer-thin polycarbonate-based Makrofol® film, OLEDs have an exceptionally long service life as well.

Light means life – and is just as important for our survival as fresh air and clean water. Fire and light bulbs didn't just make the world a brighter place, they also triggered quantum leaps in technology. Now the next generation of lighting is glowing on the horizon. The pathway to the future is lit by OLEDs, an acronym that stands for "organic light-emitting diode" – components made of ultra-thin, organic layers that produce light when voltage is applied. These surface-emitting lights are opening up completely new design possibilities: in the world of tomorrow, offices and living rooms could be illuminated by lighting panels on the ceiling. The all-new light-emitting diodes will also enable creation of illuminated wallpaper and curtains as well as room-sized television pictures. Furniture designers are already dreaming of using them in bookcases, closets and tables. The wafer-thin lights can even be integrated into window panes and mirrors as transparent light sources or can transform entire facades into gigantic posters.

Replacing eight billion bulbs worldwide

Things are not quite that far along just yet, however. The first step is to replace the faithful old incandescent light bulb with energy-saving lamps. According to the "Initiative Photonik," a German initiative to promote photonics, some eight billion light bulbs worldwide must be exchanged by 2020. Yet the

Light with enhanced energy efficiency: Bayer materials expert Cally Lim (photo, left) checks a third-generation solar cell. These power sources of the future are wafer-thin, flexible and printed directly on film, which Bayer employee Wilfredo Aguilar (right) is shown checking in this photo. Innovative plastic films from Bayer MaterialScience could now also help to obtain an even more efficient light yield from organic light-emitting diodes – OLEDs for short (photo, right).

Materials expert: Dr. Heinz Pudleiner (photo, left) checks the light permeability of a Makrofol® film. These films could for example help the OLEDs from Osram (photo, right) to emit more light and become more energy-efficient in the future.

new light sources are associated with numerous disadvantages, for example their mercury content, which makes disposal more difficult. OLEDs would be a good alternative: they emit a diffuse light that encompasses a wide spectrum of light waves. This combination closely resembles sunlight and is comfortable and natural for the human eye.

OLEDs: colorful light sandwich in nanoformat

The color reproduction and illumination intensity of the new surface-emitting panels bathe our living areas in a pleasant light. After all, our visual comfort is dependent on a wide range of aspects such as the interplay of light and shadow, lighting direction and brightness distribution. Sector experts are already forecasting billions in revenue with the lamps of the future as soon as 2015, but production costs are still very high: "In order to make OLEDs affordable, the technology used to produce them must be optimized. We are also working on improving individual components and materials," explains Dr. Benjamin Krummacher, an engineer and product developer for OLEDs at Osram in Regensburg.

A cross-section of an organic light-emitting diode resembles a sandwich. It consists of several layers embedded between two electrodes: the positively charged anode and the negatively charged cathode. The positive pole is formed by a thin layer of the ceramic material indium tin oxide (ITO). This electroconductive ceramic material is affixed to a glass plate through which the light penetrates outward. The negative pole is formed by a layer of aluminum. At the core of the OLED is a thin film of luminescent material – special organic molecules that emit light. Just a few hundred nanometers thick, it consists of three different color layers: red, green and blue. Known as emitter systems, the layers are combined to enable this new type of light-emitting diode to produce white light. When voltage is applied, the film lights up on its own. The color of the light can be continuously adjusted by mixing the three layers to achieve the desired effect.

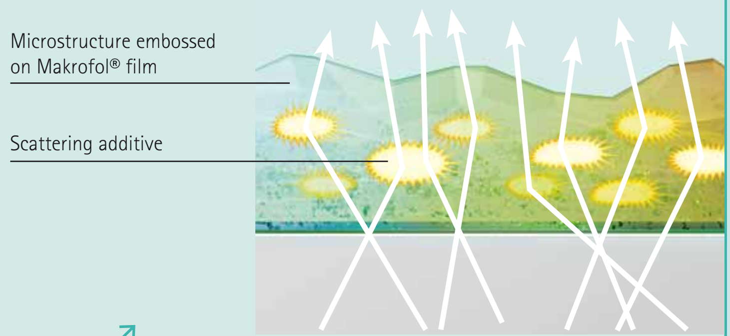
Together with the Osram developers, Dr. Heinz Pudleiner, a chemist and Project Manager in Substrates at Bayer MaterialScience in Krefeld, and his team are trying to help organic light-emitting diodes make their breakthrough. These modern lights could use a little assistance, because they currently have one key disadvantage: they are still far from tapping their full potential. "Until now, OLEDs have only radiated about 25 percent of their light outwards," explains Pudleiner. The reason for this poor output lies in the structure of the OLEDs: at present, glass is still indispensible as a substrate for the active light-emitting layers. In addition, it protects the luminescent organic molecules that are highly sensitive to oxygen and water vapor.

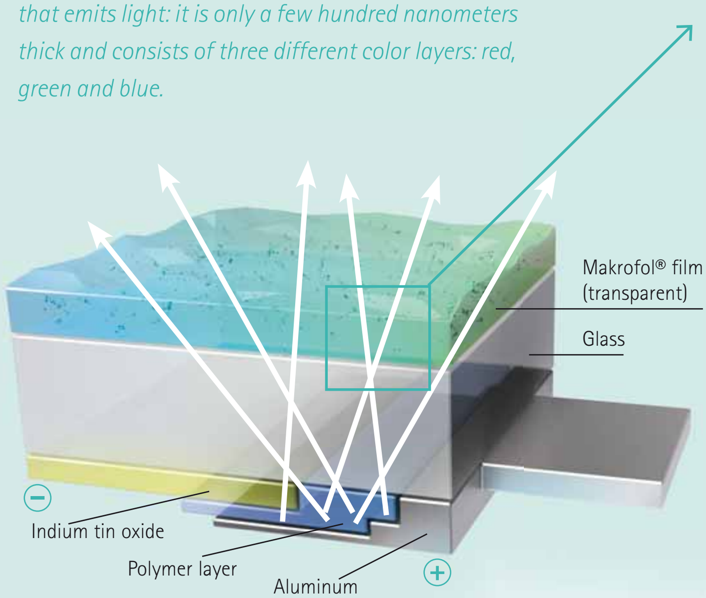
Makrofol® puts OLEDs in the right light

However, using glass as a working material creates an optical problem for diode manufacturers: refraction. When light passes from one optical medium to another – for example from the OLED glass into the air – it changes direction. The beam of light is broken and diverted in another direction. This change of course is caused by the different speeds at which light travels in the different media. "Glass and air have different refractive indexes," explains Klaus Meyer, a product developer in Functional Films at Bayer MaterialScience in Dormagen. "The effect is similar between water and air. If you dip a stick into a pond, it will appear to bend at the interface between the two materials because of their different refraction," says the mechanical engineer. Thus, when the organic molecules light up inside the OLEDs, the beams at the interface between the glass layer and the air are reflected back into the interior. A large portion of the light cannot escape.

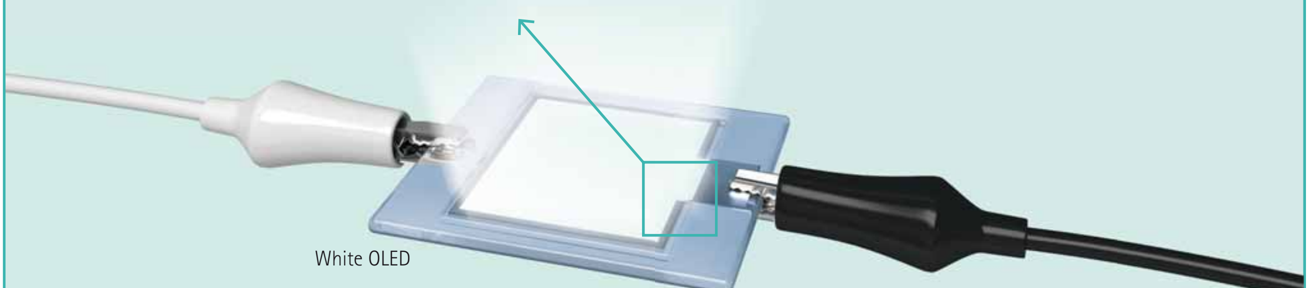
The light scatterers

An OLED is made up of several layers embedded between two electrodes: a thin layer of the ceramic material indium tin oxide, or ITO for short, forms the positive pole. The negative pole is formed by an aluminum layer. At the heart of the OLED is a thin film consisting of special organic molecules (polymer layer) that emits light: it is only a few hundred nanometers thick and consists of three different color layers: red, green and blue.





Glass and air have different refraction indexes. Some of the emitted light is reflected back into the OLED – the light then cannot escape.
Thanks to the Makrofol® film, more light can be released. This is due firstly to the microstructure on its surface and secondly to the scattering additives integrated into the film. More light is emitted, and the OLED shines more brightly.



In order to tap the OLEDs' full potential, the beams of light must be freed from their glass cage. "But the excellent traits of glass as a barrier are hard to replace," explains Pudleiner. The first OLED lighting tile on the market, Orbeos® from Osram, relies on the transparent substrate as well. With a thickness of 500 nanometers, the active layer in this OLED is just a hundredth the thickness of a human hair. "You might say the rest is packaging. If the glass layer could be eliminated, it would be possible to produce significantly thinner organic light-emitting diodes," says Krummacher.

To this end, the OLED experts from Osram entered into a development contract with the Bayer material researchers in May 2008. Using a wafer-thin film made of Makrofol®, Pudleiner and his team are now guiding the light from organic diodes in the right direction. Based on the Bayer polycarbonate Makrolon®, they developed a special film that can be affixed to glass to extend the light's pathway. This all-new plastic layer prevents the beams from being absorbed by the OLED. "At just 300 micrometers thick, the film helps ensure that more light reaches the outside. Light yield is increased up to 60 percent as a result," says Pudleiner. Instead of producing a luminance of 1,000 candelas per square meter as was previously the case, these OLEDs deliver 1,600 candelas per square meter. The luminance (candela) per unit of area is a measure of what humans perceive as brightness.

Two traits built into the film by the Bayer researchers are responsible

High-tech light on a roll: Erkan Bozkurt monitors the manufacture of the wafer-thin Makrofol® films for the OLEDs on an extrusion machine (photo, left). The effects that elevated temperatures and humidity have on the ageing process of the illuminating films are investigated by Alexander Pogorzalek in a special test chamber at Bayer MaterialScience in Leverkusen (photo, right).

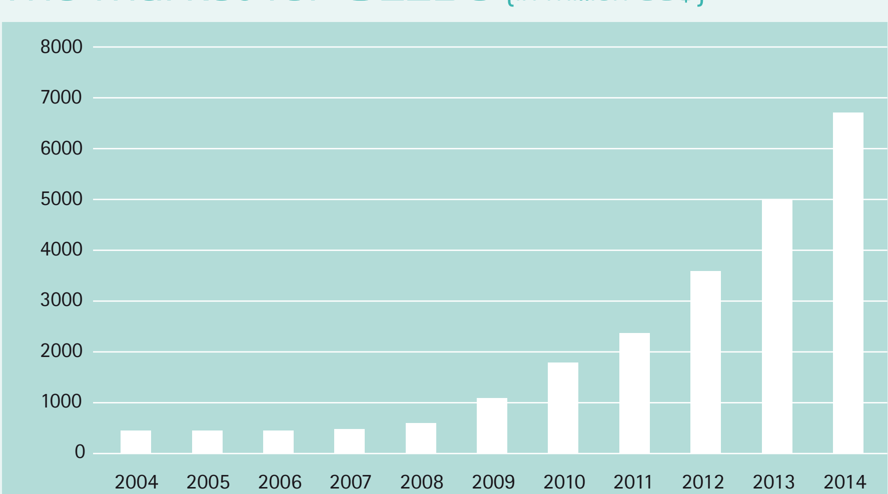
for the organic light-emitting diodes' enhanced performance. Firstly, the scientists embossed the Makrofol® layer with a special surface structure to create a landscape of mountains and valleys measuring just a few micrometers in height. This uneven surface ensures that the light beams are reflected, but that a large share of the light reaches the outside nonetheless. Secondly, the Bayer material specialists equipped the polycarbonate foil with scattering additives - tiny, transparent particles that increase the scattering effect of the film. The particles achieve this by playing ping-pong with the light beams, constantly changing the angle of reflection until much of the light reaches the outside. "What is important here is that the transparent polymers have a different refractive index so that the beams of light are significantly diffracted," adds Pudleiner. In combination, the two effects make the OLEDs shine brighter.

Polycarbonate film increases the energy efficiency of OLEDs

The film also improves the color fidelity. "Without the film, the illuminating surface appears to be a slightly different color depending on the angle it is viewed from – a visual effect that is due to the inner structure of the OLEDs. With the film, the surface appears homogenous from every angle," explains Krummacher.

The Makrofol® layer helps to coax more light out of the OLEDs, thus enhancing their energy efficiency. The same light yield now requires less voltage – and that saves electricity. This also increases the life span of the organic molecules and thus the service life of the entire light-emitting diode. "The stability of the emitter substances is heavily dependent on current/voltage intensity during operation," explains Krummacher. At the same time, the robust Makrofol® film also provides excellent shatter protection for the surface-emitting light sources.

The market for OLEDs (in million US$)



Source: IntertechPira

The prospects for OLEDs are bright: the trend in lighting technology is towards large-surface, decorative illumination. This is leading to a boom in the market for OLEDs for illumination and displays. The industry is working at top speed to develop more economical manufacturing procedures for the miracle light source.

Light art: the surface-lit OLEDs open up completely new design opportunities for lamps and light elements to designers and interior architects.

Bayer researchers are already working on the next generation of decoupling films for OLEDs. To this end, they want to make the film even thinner. In the laboratory, the Makrolon® layer can already be reduced to 100 micrometers, just a third of its current thickness. The film known as Makrofol® TP228 is designed to do even more than that, however. "The film can be dyed and partially or fully printed in order to adapt the light effects of an illuminated OLED lamp to customers' wishes," says Pudleiner. Thanks to an anti-dust function, particles of dust will no longer cling to the surface either. The future of illumination has already dawned in Bayer's laboratories – and tried-and-proven Bayer Makrolon® plastic will help organic molecules shine even more efficiently and cost-effectively in the future. The OLED experts at Bayer MaterialScience and Osram will continue working side by side on efficient production processes and optimized materials to make these thin lighting panels fit for the future.

Interview

Brighter, more efficient and longer-lasting

Dr. Benjamin Krummacher is a product developer for OLEDs at Osram in Regensburg. *research* spoke with him about the new lighting tiles and future lighting concepts.

When will organic light-emitting diodes (OLEDs) replace the LEDs currently available?

Together, the two technologies have the potential to overtake existing light sources. But OLEDs and LEDs are not competitors. Each of them has a different set of strengths that complement each other perfectly and can be easily combined. The LED is ideal as a bright point-light source. OLEDs, on the other hand, provide a diffuse surface-emitting light. This also opens the door to entirely new design concepts, such as window panes that shine in the dark.

How do OLEDs compare with current conventional light sources like light bulbs, halogen lamps and energy-saving lamps?

OLEDs are significantly more efficient than normal light bulbs, which produce an output of 12 to 15 lumens (unit for luminous flux) per watt. The first commercially available organic light-emitting diode, the Orbeos® lighting panel from Osram, introduced to market in late 2009, can generate a luminous flux of approximately 25 lumens per watt. That is comparable with contemporary halogen lamps. In the lab, we have already built OLEDs that are three times as efficient. Our current goal is 100 lumens per watt.

What is the most important benefit that OLEDs offer?

In addition to the myriad design and application possibilities, the long service life of organic light-emitting diodes makes them especially attractive. They last some 5,000 hours – approximately five times as long as conventional light bulbs. Even then, the OLEDs shine with at least half of their original brightness while light bulbs simply burn out.

What are the biggest challenges facing the new lighting technology?

The OLED is the "Formula One" of light sources, but there are numerous remaining hurdles to clear on the way to commercialization for the mass market. The longevity and efficiency of the materials must be optimized. The process chain must also be fine-tuned in order to reduce production costs. The market has to gradually gain momentum first. In addition, modern lighting technologies are placing new demands on households and the electrical infrastructure. The amount of voltage needed is steadily decreasing. LEDs and OLEDs can be operated on just three to four volts. At the moment, this necessitates additional ballasts to adapt the main voltage of approximately 220 volts for these light sources. We are working on developing new standards here as well.

www.research.bayer.com/oled
Further information on the topic of OLEDs