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Report to download

Introduction to OLEDs and R&D program of OLED100.eu

by **Stefan Grabowski**
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Organic light-emitting diodes (OLEDs) are efficient light sources with new exciting features. OLEDs can cover large areas, they are extremely thin and can be made on substrates of virtually any shape. This high level of flexibility in terms of design and application makes them highly appealing for lighting designers, manufacturers and consumers. A multitude of colours is available and the quality of the emitted light is high. The spectrum can be tailored such that it resembles the daylight spectrum, for instance. Moreover, as a highly efficient light source, OLEDs have the potential to achieve substantial energy savings. All this makes OLEDs an attractive new type of solid-state lighting that is a compelling candidate to replace conventional lighting systems for large-area illumination.

In the following article the basic principles of OLED technology are presented, and we describe our approach in the OLED100.eu project to achieve the project goals: An efficacy value of 100 lm/W, a lifetime value of 100.000 hours, an OLED size of 100cm×100cm, and a manufacturing process that will produce OLEDs for less than 100€/m^2.

Some basic principles of OLEDs

OLEDs work by electroluminescence similar to their inorganic cousins: When a current is passed through the device, electrons and holes recombine to create light. There are two kinds of material classes of organic LEDs, polymers and small molecules. In OLED100.eu, we prefer small molecules in order to reach our efficacy and lifetime targets. Several layers of organic materials are evaporated onto a supporting substrate pre-coated with conductive ITO. These organic layers have different functionalities like hole injection, hole transport, emission or electron transport as can be seen in the schematic drawing of an OLED in Fig. 1a. On top of these organic layers a metal cathode contact layer (aluminium for instance) is evaporated.

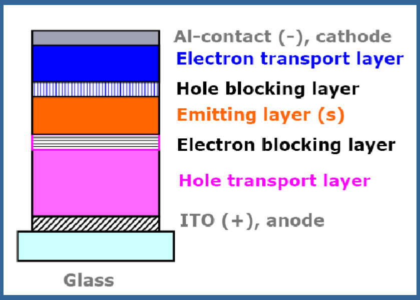

Fig. 1a: Schematic drawing of the layer architecture of an OLED.

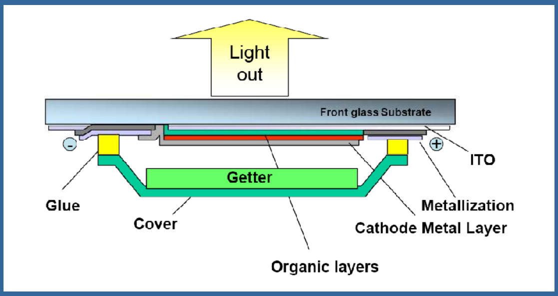

Fig. 1b: Schematic drawing of a complete OLED with encapsulation.

Following this layer deposition, the OLED is encapsulated to protect it from moisture, which would damage the device. The standard package consists of a cavity lid that is glued onto the device. In the cavity is a getter that will take up any moisture that might otherwise reach the OLED (see Fig. 1b).
The OLED is now ready to light up. We run several tests: The I-V-L-curve is measured (a voltage V is applied and the current I and luminance L are recorded, for info on the measurement set-up and conditions see [1]). Furthermore, the emission spectrum and the device lifetime (more precise wording is lumen depreciation) are measured. The lifetime measurements are conducted by applying a constant current to the OLED and monitoring the luminance at given intervals. Since the lifetime of OLEDs is very long nowadays (a few years), one has to measure under accelerated lifetime testing conditions by driving the devices at much higher luminance than the operational target of 1000 cd/m^2. The lifetime at 1000 cd/m^2 is then extrapolated from the measured lifetime values at higher luminance.

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White OLEDs

The emission colour of the OLED is determined by the properties of the emitting molecules. White emission can be achieved by mixing the emission of different molecules, either red (R), green (G), and blue (B) or yellow (Y) and B in one device, an option that is not possible with inorganic LEDs. In practice, R, G, and B-emitting layers are evaporated on top of each other. One can also put different emitters in one layer, for instance R and G to achieve Y. By tuning different parameters (e.g. the structure and composition of the layers) one can chose the emission spectrum and colour point that is desired. In another approach, complete devices with different emission colours are stacked on top of each other. That is, all organic layers of an OLED as shown in Fig. 1 are evaporated, but instead of depositing the top cathode, a special connecting unit is evaporated. Then a second OLED, starting with the hole injection layer is being deposited on top. In practice it is sufficient to deposit two units, a B and a Y emitting one. The advantage of this approach is, since all OLED units emit light, that the total current of the device is reduced and thus the lifetime for a given luminance is better. We are studying both approaches in the OLED100.eu project. (see Fig. 2)

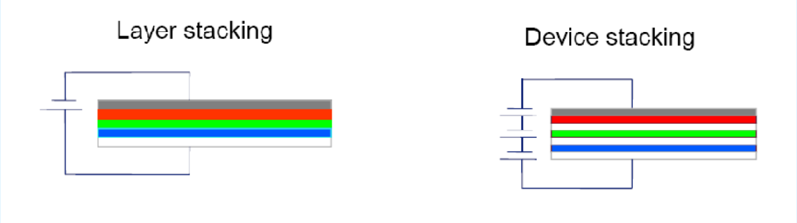

Fig. 2: White OLED in which different emitter layers are evaporated on top of each other in one device (left) and a so-called stacked device in which complete devices are evaporated on top of each other, connected by a special layer system (right). In the stacked device, each sub-unit emits in a different colour to create white emission.

Increasing light emission and OLED lifetime

OLED efficiency depends on both, the materials and the device structure. Materials are chosen to optimise the charge carrier mobility as well as exciton recombintion, and careful attention is paid to the energy level differences between different materials so that carriers do not pile up at the interface between different materials.

In all organic molecules there are energy states with angular momentum 0 (spin singlet states) and three times as many states with angular momentum 1 (spin triplet states). In singlet emitters (also called fluorescent emitters) light emission occurs due to a transition from a singlet level to the ground state. There is no light emission allowed from the triplet states since the momentum has to be conserved for radiative transitions, and the luminous recombination efficiency is limited to only 25% of the available charge carriers. The situation is different in phosphorescent emitters. Special dopant molecules permit momentum conserving luminescent transitions from singlet as well as triplet states. On these emitters every electron-hole pair creates a photon. A classic example of a phosphorescent emitter is the green emitting fac-tris(2-phenylpyridine)-iridium, whose short name is $Ir(ppy)_3$. Phosphorescent emitters therefore have higher efficiencies than fluorecent emitters. However, since the lifetime of phosphorescent blue emitters is currently still very short, we are looking into the so-called hybrid approach, i.e., the use of fluorescent B together with phosphorescent R and G to make white OLEDs.

With this approach efficient devices with lifetime values of several 10.000 hours have been achieved already. To further improve the lifetime, one has to use more stable organic materials but also optimize the device architecture.

Getting emitted light out of the diode

Optimizing the device architecture will increase the amount of light that is being generated in the device. Another important aspect is how to get this light out of the device. The organic layers have a high refractive index of about 1.8. The light that is being emitted there has to enter the glass substrate with a refractive index of about 1.5. At the OLED/glass interface total reflection can occur, which results in some of the light being reflected back into the organic layer. The same can happen for the light that has reached the glass substrate and is now facing the interface glass/air with a transition from a refractive index of 1.5 to 1.0. Snell's law teaches that every light beam that is hitting the interface at an angle of 41.8° or larger will be reflected back.

A straightforward improvement is obtained by integrating light-scattering particles into the substrate or by introducing out-coupling structures like pyramids or half lenses at the interface to air. These ensure that light, which would hit the surface at an angle under which total reflection occurs now encounter a smaller angle and can escape from the substrate into air. Even if some light beams cannot escape the first time, they reach the glass surface under a different angle when they approach it a second time after they are reflected back from the top cathode and then be able to escape into air.

Light out-coupling is a powerful means that increases the amount of emitted light without changing the operating voltage of the OLED and thereby increasing the device efficiency: When more light is coming out of the device, the OLED can be operated at a lower driving voltage and current to obtain a luminance level of 1000 cd/m^2 in air, which leads to an improved lifetime.

Making larger area OLEDs

There are two main challenges to increase the emitting surface area of OLEDs. The first is defects. The greater the area, the greater is the chance of having a defect that could kill the whole device. In OLED100.eu we are therefore working on short-resistant architectures and short-detection methods to make the devices more reliable. The second challenge is the delivery of identical current density to all parts of the device in order to assure uniform luminance over the entire device area. We are developing shunt metal lines that distribute the current more evenly over large areas. Such a shunt line structure can be seen in the OLED in Fig. 3.

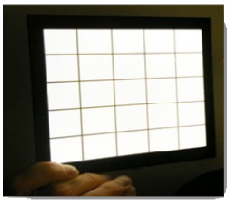

Fig. 3: Large-area OLED with shunt line structure that ensures a homogeneous emission. Courtesy of Philips Lighting.

Reducing the manufacturing price

Another goal of OLED100.eu is to develop alternative manufacturing process steps that have the potential to reduce the manufacturing cost of an OLED to 100€/m^2 or below. We are developing printing processes for the shunt lines and the ITO, which are potentially less expensive. Other attempts of reducing the cost are targeting the encapsulation.

With these approaches we are tackling our goals to make highly efficient OLEDs with an efficacy value of 100 lm/W, to make long-lived OLEDs that work for 100.000 h, to make large-area tiled 100cm×100cm lighting modules and to develop processes that reduce the manufacturing cost below 100€/m^2. With these specifications OLEDs then have efficacy values comparable to the most efficient fluorescent tubes (which have about 90 lm/W) and lifetime values comparable to LEDs (currently about 70.000 h), all that combined with a large emission area.

References

[1] "OLLA White Paper on the Necessity of Luminous Efficacy Measurement Standardisation of OLED Light Sources", can be downloaded from OLLA-project website www.olla-project.org (scroll to bottom).

OLED100.eu International Summer School on OLEDs

From June 2nd to June 8th, 2009 OLED100.eu, in association with the Polish Supramolecular Chemistry Network, and the Institute of Physical Chemistry of the Polish Academy of Sciences organized an International Summer School on OLEDs : **"ORGANIC ELECTRONICS: FROM LAB TO HOME"** which took place at the Conference Centre Krutyn, in the Masurian Lake District, Poland .

The school was fully subscribed. With 67 students and 18 lecturers there was not a single empty seat in the class room. The 3-day scientific programme included the following presentations:

Dr. Arvid Hunze (Siemens/Germany): Device physics of (white) OLEDs for lighting

Prof. Takao Someya (Tokyo University/Japan):
- OTFT Basics: Electronic transport properties of pentacene films and transistor channels
- OTFT Applications: Ambient electronics using printed organic transistors - From E-skins to power sheets

Prof. Peter Strohriegl (University of Bayreuth/Germany):
- Materials for organic electronics
- Materials for phosphorescent OLEDs

Prof. Chihaya Adachi (Kyushu University/Japan):
- Control of molecular aggregation aiming for high performance OLEDs
- Challenges for organic semiconductor laser diodes

Prof. Reinder Coehoorn (Philips Research & TU Eindhoven/The Netherlands): The development of an experimentally validated OLED device model

Dr. Herbert Boerner (Philips Research/Germany): Triplet excitons in OLEDs

Dr. Wilfried Pohl (Bartenbach LichtLabor/ Austria): Application-oriented view on lamps

Dr. Kristian O. Sylvester-Hvid, (Risø National Laboratory for Sustainable Energy/Denmark):
- Polymer/molecular solar cells from a molecular point of view – a chemist's view.
- Polymer/molecular solar cells from a device point of view – a physicist's view
- Recent progress in polymer based PV

Dr. Karsten Walzer (Heliatek/Germany): Design and properties of pin-type small-molecule solar cells

Dr. Michael Hoffmann (Fraunhofer IPMS/Germany):
- Technology of OLEDs for lighting: Backplanes and layouts
- Technology of OLEDs for lighting: Production and characterization

Dr. Mike Hack (Universal Display Corp./U.S.A.):
- Status and future for high efficiency phosphorescent OLED displays
- Opportunities and challenges for flexible OLED displays
- Status and future for high efficiency phosphorescent OLED solid state lighting

Dr. Klaus Schmidt (PolyIC/Germany): Organic field effect transistors and their applications in RFID-systems

Prof. Kristiaan Neyts (Gent University/Belgium)
- Light emission from planar OLEDs
- Improving light outcoupling from OLEDs

Dr. Ton van Mol (Holst Centre TNO/The Netherlands): Flexible OLEDs

Dr. Dietmar Keiper (Aixtron/Germany): Organic vapour phase deposition (OVPD)

Fig. 1: The classroom was full

Developing technologies to produce
efficient OLED products for exploitation
by the European lighting industry.

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OLED100.eu International Summer School on OLEDs

The programme also included Scientific Consulting Sessions which took place after dinner . Enthusiastic participants had the opportunity to learn more on topics presented during the day by the lecturers. A poster session was also organized on June 6 in the afternoon .

Fig.1: T. Someya consulting session

Fig. 2: P. Strohriegel consulting session

Fig. 3: Poster discussions

Leisure activities included a bonfire evening, a canoe afternoon and an excursion to the sanctuary Święta Lipka.

Fig.1: Picnic bonfire

Fig. 2: Teacher and student working together

Fig. 3: The sanctuary Święta Lipka

Aesthetical perception case study on OLEDs ready for download

Large-area OLEDs are a novel kind of light source, which offer a large variety of design options. This refers to really free design parameters such as shape, size and emission colour, but also to technology enforced parameters such as off-state appearance and shunt line structures. However, little is known about the acceptance of the potential end-users concerning these features. Which OLED tile shape is preferred and which colour temperature?

OLED100.eu consortium partner Bartenbach LichtLabor has conducted an aesthetical perception case study in which test subjects were questioned about their likes and dislikes with regards to OLEDs. A report that covers aspects like OLED tile size and shape, colour temperature and off-state appearance (mirror-like or milky) has been compiled and is ready for download from our website **www.oled100.eu.**

Office room model for aesthetical perception case study with ceiling consisting of square (left), hexagonal (middle), and ornamental-type OLED tiles.