

Highly Efficient White PIN OLEDs for Lighting Applications

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During the last number of years, organic light emitting diodes (OLEDs) have gained constantly increasing attention in the scientific and industrial community. So far the OLED development was mainly triggered by applications in the display segment, where the technology allows for ultra-thin displays elements with a very high color gamut. With an increasing number of OLED displays in the mobile phone prime segment and the introduction of the first TV by Sony, the XEL-1, the technology succeeded in gaining a foothold in this market.

For lighting the unique technical features of OLEDs are expected to result in a fundamental paradigm shift rather than an evolutionary development as observed for the transition from LCD to OLED displays. OLEDs are ultrathin area light sources that are potentially flexible, can be produced with almost any color and white OLEDs show very high color rendering properties. Furthermore they are fully dimmable, can be switched on and off without any time delay and already exhibit good energy efficiencies and very long lifetimes. Most OLEDs will be manufactured with one reflective electrode, so the devices will be mirror-like when they are switched off. However, it is also possible to have transparent OLEDs, which could be used as lighting elements in windows, screens or room dividers.

Due to these unique design options, OLEDs will enter the market through high price segment and design-led applications. A first product was already launched in April this year by Ingo Maurer, who designed a desktop lamp using some white light OLED panels from Osram. Even though this lamp is only a pioneer product with only a small number of devices being produced, it will be a progenitor for several OLED based lighting items becoming visible in the market in the near future. Within a timeframe of five to 10 years, OLED will also develop into a serious contender for market share in the general lighting segment.

Organic light emitting diodes differ from their inorganic counterparts in several ways, even though the basic principle - light generation in a solid state semiconductor by recombination of electrons and holes - is the same. OLEDs are made from organic semiconductor materials, i.e. molecular, carbon based substances, which form amorphous layers rather than well-defined crystal lattices. Therefore, the conductivity of organic semiconductors is usually several orders of magnitude lower than for inorganic materials. On the other hand the layers are not fragile and brittle but flexible.

Using redox doping by special donor and acceptor molecules, the well-known PIN concept of LEDs can be applied in OLEDs, which helps to increase the conductivity of the hole- and electron transporting layers dramatically. By using this PIN concept, organic light emitting diodes can reach the same low driving voltages as inorganic ones.

In contrast to inorganic LEDs, OLEDs are area light sources; the organic compounds can be easily deposited on large areas through thermal evaporation in a vacuum. Being an area light source, the heat generated inside the device is not focused on a small volume as it is the case in LEDs; therefore heat dissipation is not a practical problem for OLEDs. During standard operation the self-heating of an OLED is limited to only a few degrees.

A certain disadvantage over LEDs, is the fact that the OLED brightness

(i.e. light intensity per area, cd/m^2) cannot be increased too much and the very high brightness levels that are reached in LEDs are not feasible with their organic equivalents. Therefore, the light output in OLED applications is mainly increased by larger device areas, i.e. the light output is proportional to the device size.

Because of these basic differences, OLEDs and inorganic LEDs address different market segments - large area light sources, e.g. ceiling lamps, for OLEDs and high light output point sources, e.g. spotlights, for LEDs. A basic scheme of an OLED device is shown in Figure 1.

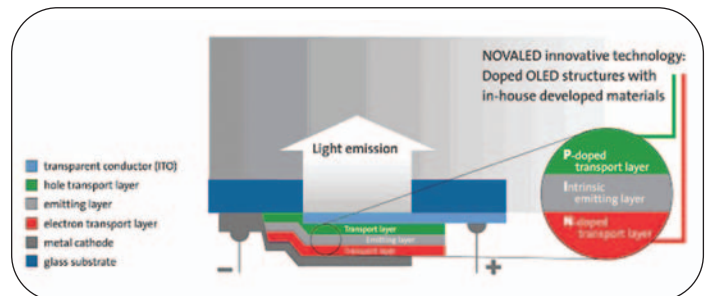


Figure 1. In an OLED device holes and electrons are injected into a stack of organic layers, which are sandwiched between usually a transparent Indium-Tin-Oxide (ITO) electrode and a metal electrode. Electrons and holes recombine in the emission zone of the device, which contains organic emitter dyes. Here, excitons are formed by the combining charge carriers, which eventually decay and emit visible light. Glass is mostly used as substrate at the moment, however, in principle, flexible substrates like polymer or metal foils could also be selected.

There are various different approaches to generate white light with OLEDs. In contrast to white inorganic LEDs and also fluorescent lamps, the different colors of the white light are not generated through the conversion of blue or UV light through phosphors. In the case of OLEDs, it is possible to generate light of different colors directly inside the device by mixing different organic emitter molecules, e.g. of red, green and blue emission color, in the emission zone.

The approach to directly emit light from emitters with different colors has several advantages as compared to approaches in which blue or UV light is (partly) converted into light of higher wavelengths. The spectrum that can be achieved with OLEDs does not depend on the availability of suitable phosphors, which allows for a broader coverage of the visible spectrum resulting in a better light quality and a higher color rendering index (CRI). Figure 2 shows a typical white OLED spectrum generated by three different emitters (blue, green and red).

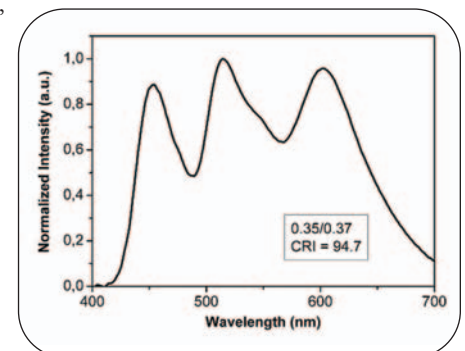


Figure 2. Typical white OLED spectrum generated by three different emitters (blue, green and red). A broad coverage of the visible range is achieved resulting in a very high color rendering index. OLED spectra can be easily tuned to achieve different color points and temperatures.

the case when blue or UV photons get converted into photons of longer wavelengths and lower energy.

However, critical issues remain to be solved before widespread use for such applications becomes feasible: white OLEDs need to be able to compete with existing lighting technologies with respect to lifetimes, power efficiencies, reliability and cost effectiveness. Figure 3 shows an overview of the power efficiency development of OLEDs during recent years. As can be seen, the efficiency development follows a very steep curve that strikingly resembles how LED efficiencies have developed to become the highly efficient solid state light sources they are today.

Assuming that the efficiencies will further increase

during the next years, it is to be expected that white OLEDs will become competitive with the best lighting technologies that are currently available on the market. Efficiency improvements will mainly be made in two areas:

- Through improved emitter materials, where, especially in blue the current level is not satisfactory both regarding the excitation conversion efficiency as well as the durability of the emitter molecules.
- Through improvements of the light extraction from the OLEDs, as currently between 50 percent and 80 percent of the light is still trapped in the device. Even though organic materials are in principle better suited to extract the light, as the refractive index of organic compounds is smaller than for inorganic semiconductors, the large area nature of the diodes requires some new technologies in this respect. Especially the substrates, currently mostly glass, will have to be engineered to allow more light to escape from the diode.

Finally, the driving voltage is also a critical parameter for the OLED efficiency. However, here the PIN technology already allows for driving voltages that are relatively close to the thermodynamic limits. Nevertheless, improved p- and n-dopants as well as transport materials might give rise to some small efficiency improvements in the future.

The current performance level of white OLEDs already allows for first applications. Early in 2007, Konica-Minolta announced that it managed to achieve a power efficiency of 64 lm/W with a white OLED device along with a lifetime of 10,000 hours. Also in 2007, Novald AG announced a high efficiency and a very long lifetime in a white OLED device; at color coordinates x, y of 0,43/0,44, a power efficiency of 38 lm/W and a lifetime of 100,000 hours, all at a brightness of 1,000 cd/m², were achieved. Here an efficiency level comparable to conventional Halogen lamps is reached with a lifetime that far exceeds most alternative existing lighting technologies.

For a red light emitting OLED, Novald could even announce a lifetime of 1 million hours in 2007. This value means that in principle such an OLED device would need about 100 years to drop to 50 percent of its initial luminance level when driven at 1,000 cd/m² initial

luminance. Even though it certainly is a huge challenge to realize such extraordinary lifetimes in a product including electronics and encapsulation; OLED technology clearly demonstrates that it has the potential to develop into a “mount-and-forget” solution in the future.

Another big challenge for the OLED lighting industry is clearly the mass manufacturing of devices in large quantity and high yields at low prices. Here, we currently see a lot of activities by different players in the market to align OLED manufacturers, tool makers, substrate suppliers and technology providers. Different innovative production concepts are being investigated, e.g. inline manufacturing on large area glass substrates or roll-to-roll processing on flexible substrates like steel. Furthermore improved electrode structures, substrates and encapsulation methods are being developed, which will help to bring the production yield up and make large area devices more easily accessible.

Also the public funding efforts in the big markets Europe, the US and the Far East indicate how seriously the current activities are directed toward spawning an OLED lighting industry in the next decade.

Dr. Sven Murano obtained his Ph.D. in Physical Chemistry after studies at ETH Zürich, Case Western Reserve University, Cleveland, and Philipps University Marburg. His thesis on the optoelectronic properties of uniaxially aligned discotic liquid crystals was supported by the German Merit Foundation (Studienstiftung des Deutschen Volkes). He joined Novald in March 2004. He can be reached at sven.murano@novald.com.

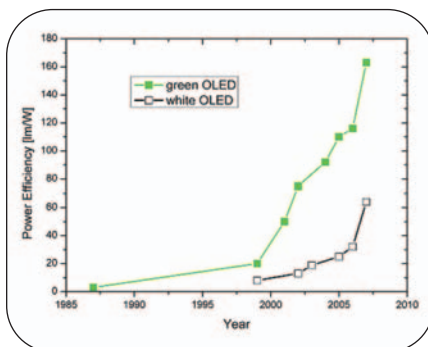



Figure 3. Power efficiency development of green and white OLED device.

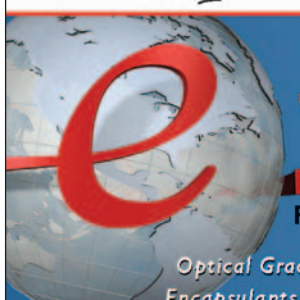
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