OLED for Lighting and Signage

Perspectives of Organic Solid State Lighting Towards Commercial Reality

In less than two decades after the fundamental discoveries of organic electroluminescence, Organic Light Emitting Diodes (OLED) have become a commercial reality in display technology. The next revolution is paving the way for business from academic and industrial laboratories to commercial products within next few years: OLEDs as light sources for illumination and signaling. Reported record efficiencies of 110 lm/W for green light and performance targets of ongoing research and development activities focused on white emission indicate the potential of OLEDs to emerge as a solid state lighting source for a wide variety of potential applications, including ambient and technical lighting as well as signage applications, as exit signs or logos.

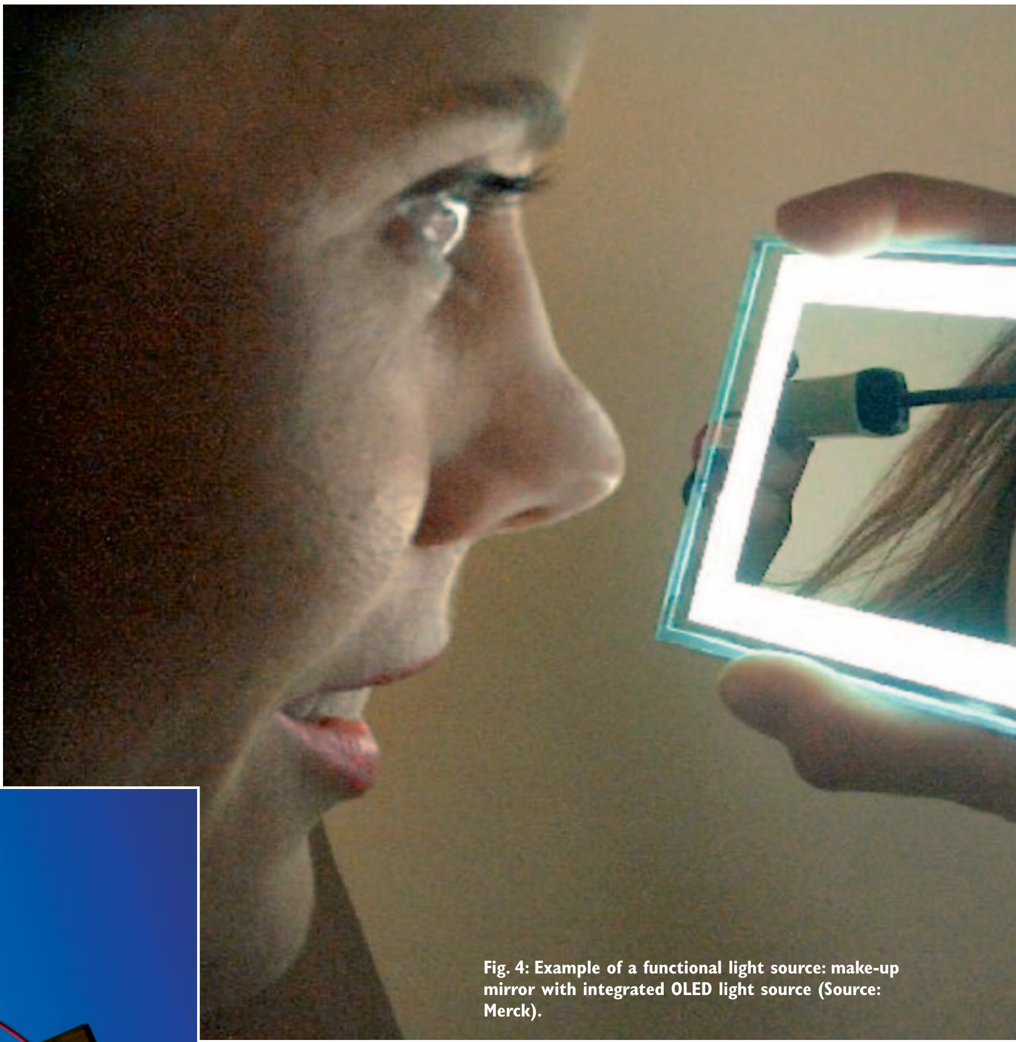

Fig. 4: Example of a functional light source: make-up mirror with integrated OLED light source (Source: Merck).

Fig. 1: Monochrome OLEDs have already surpassed the efficiency of the light bulb (Source: Novaled)

Introduction

Imagine, you gently wake-up each morning, cause your ceiling lits up in the most marvelous nature like morning colors. Imagine, you switch on your window as light source once the sunset begins. Or that you change the atmosphere of your living room by simply tuning the ceiling light color to your mood.
All these new kind of light designers whishes will become truth by using high-brightness OLEDs as light sources. But also in today's domain of the traditional light bulb solid-state lighting will find its place due to the higher efficiency and light quality.
Solid-state lighting means the direct conversion on electrical energy into light enabled by inorganic or organic materials. This market is currently dominated by inorganic high brightness LED's with an annual turnover of above

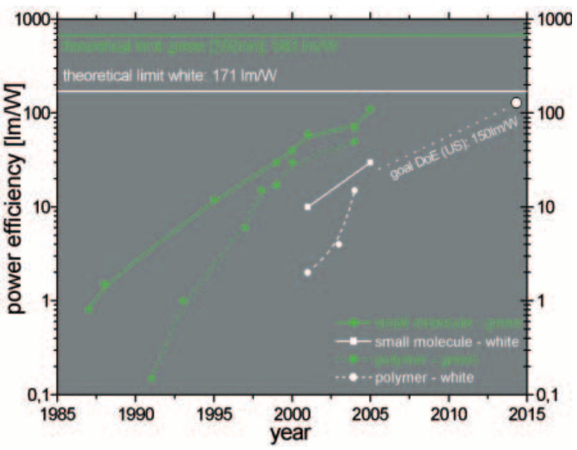

Fig. 2: Efficiency records over time for green and white emitting OLED. Graph showing data for small molecule and polymer technology. Some of latest results include optics for external outcoupling typically enhancing efficiency by 1.5–2 times. Due to non standarized measurements, published scientific archievements are not always comparable. (source: Merck)

€ 1.5 billion. Until 2010 this segment is expected to realize an annual growth rate of >20 % resulting in overall market greater than € 5 billion [1].

OLEDs are thin-film devices coated on glass or in future even different substrates. In this sense they are the first intrinsically flat large area light source, which offer a whole new range of applications. Organic light emitting diodes could be found in a variety of commercial applications by 2010, including signage applications ranging from emissive logos or exit signs, covering ambient lighting in architectural applications or functional lighting, like backlights for LCD displays.

OLED Fundamentals

OLEDs work by the principle of electroluminescence. Positive and negative electronic charges are injected respectively from anode and cathode into a stack of organic layers of several tens of nanometers in thickness. The voltage applied is in the range of a few Volts only. When migrating through the organics, these charges eventually recombine by forming an exciton. This exciton can release its excitation energy into a photon with a certain probability. The higher this probability the more efficient the OLED device will be. Internal quantum efficiencies close to the theoretical limited have already been proven in research laboratories.

Two OLED technologies are coexisting, currently: so-called small molecule based sm-OLEDs are manufactured by evaporating several layers of low molecular weight organic materials in vacuum processes. In the second technology, long-chain OLED polymers are deposited as solutions on the substrate using printing methods.

OLEDs are now being commercialized in small-size self-emissive displays. This differentiates OLEDs from LCD displays, which need additional background illumination. OLED display market is estimated to rise to $ 615 million in 2005 [2].

But OLEDs have a much greater potential than displays only. Worldwide research is ongoing to create high-brightness, high efficiency and long life white OLEDs for lighting and signage. White light can be generated by several approaches, including the down-conversion of a blue emitting OLED by organic or inorganic phosphors, white light generated within a stack sequence of blue, green and red emitting layers or even intrinsically white emitting layers. Superior light quality with very high Color Rendering Index (CRI>90) will be realized.

Achievements

Less than two decades have passed since the fundamental invention of organic electroluminescence [3, 4], and tremendous progress in both, science and technology, has been achieved.

Fig. 2 displays the "historical" evolution of record values in power efficiency (lm/W) of OLEDs for green and lighting quality white. While the small molecule history started as early as 1987, polymer electroluminescence was discovered only in 1990. Record efficiencies for phosphorescent green are for small molecules 110 lm/W (incl. outcoupling) [5] and polymer 50 lm/W (without outcoupling) [6]. For white, which became reality only in 2000, the efficiency benchmark of incandescence lamps (13 lm/W) has been beaten by both technologies. Small molecule devices recently demonstrated up to 25 lm/W [7 – Novaled results of 25 lm/W where archieved at typical lighting brightness of 1000 Cd/m^2 and for non-RGB structured devices and can therefore be considered good reference for future lighting devices] [8, 9]. Polymer status is at 15 lm/W [10]. White OLED with >50 lm/W are expected to be demonstrated in research laboratories in the next two years.

The maintained slope of improvement in Fig. 2 gives reason to belief, that commercial OLED lamps with power efficiencies of >20 lm/W could be realized within a few years serving as light sources for signaling and ambient lighting. But also general lighting applications, targeting for 50 lm/W, appear to be reality before end of this decade.

With respect to light sources one of the unique characteristics of OLEDs is their close-to lambertian emission characteristic. Luminance (measured in Cd/m_) is equal for all viewing angles. Fig. 3 shows a luminance measurement of a typical OLED device, proving homogeneous light density distribution within less than ± 5 %. Deviations from lamebrain characteristics can be expected only for very high incident angles.

Not only material research is the driving force in OLED development; also light management plays a key role in current research programs. In simple OLED designs, only 20–30 % of the light generated in the emissive layer can escape the device. Control and modification of light guiding in the inner stack of the OLED has the potential to enhance outcoupling efficiency by a factor of 2.

Fig. 4 shows a photograph of an OLED with outcoupling structures enhancing the total efficiency.

Manufacturing technologies represent another field of development activities. The 1st generation equipment for both vacuum and solution based processes, has proven OLED manufacturability under mass production environments for small-size displays. The 2nd generation equipment is being developed and tested worldwide with the targets to enhance tact time, machine-uptime, material yield, process stability, manufacturability and device performance in order to significantly reduce manufacturing cost and improve manufacturability.

Government Support

Governments worldwide support the development of solid-state lighting via research grant programs as the stakes are high. In the US, the Department of Energy (DOE) is investing yearly about $ 30 million on programs in Solid-state Lighting [11]. The European Commission spends via their framework programs several million euro yearly for research projects like Olla [12] and Rolled [13]. In Germany, the Bundesministerium für Bildung und Forschung (BMBF) is currently launching a 100 million Euro programme over the next five years for development of OLED lighting and displays [14]. New players in Asia see their chances in this emerging market. Chinese and Japanese governments support developments via grants to get a pole position in this race.

Challenges and Outlook

Research results shown above look already very promising, but there are still many scientific and technical challenges on the road to commercial success to be overcome. All traditional lighting firms and some new entrants are on their way to develop OLED lighting systems, supported by university groups and research institutes.

The main challenges for OLEDs general lighting market introduction are to raise the efficiency for white devices above 50 lm/W, while at the same time lowering the total device costs by 1–2 orders of magnitude. Material research and production equipment development must therefore go in hand in hand. New high volume throughput technologies, for making the ultra thin organic layers with very high precision, are under investigation. For solution based OLED devices the final vision is role-to-role processing involving printing technologies.

Market Introduction

But fast market introduction requires more. For full for customer acceptance, standardization of OLED lighting technology will be essential. As the technology is still in its infancy, the standards have still to be set.
Therefore a long way is still to go, before OLED technology will find its place in general lighting applications. First products can be expected to be commercialized in the signaling and ambient lighting market or for functional light sources. In the mean time, the development and capacity for large area OLEDs will be ramped up and is expected to hit the market from 2010 onwards.

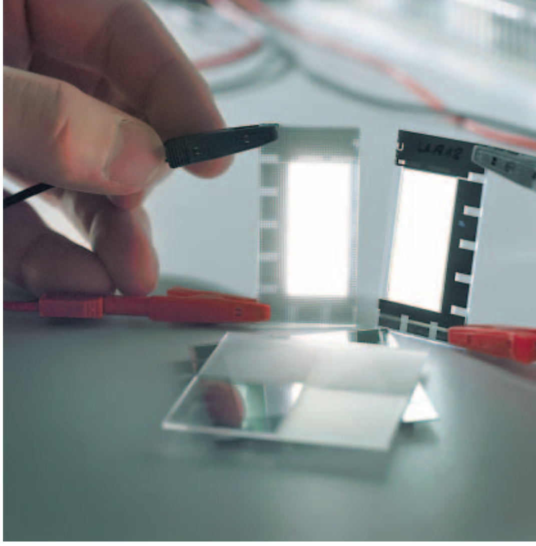

Fig. 3: Additional light outcoupling structures make OLEDs up to two times more efficient. (Source: Philips Lighting)

References

A list of references is available from the authors.

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