Making highly efficient white light-emitting diodes

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White organic light-emitting diodes offer a power efficiency, lifetime, and brightness that together constitute a significant advance toward viable devices for lighting.

Light-emitting diodes (LEDs) are used in both displays and illumination applications because they are small, robust, and potentially very efficient. Organic light-emitting diodes (OLEDs) continue to gain attention from the scientific and industrial community. In contrast to their inorganic counterpart, OLEDs are flat and diffuse area light sources with the device thickness being in the range of 1–2mm. Thus far, OLED development has been triggered mainly by applications in the display segment, starting with applications for MP3 music players, mobile phones, and other portable devices. Recently, Sony brought to market the first OLED TV, which indicates that a more general penetration of the display market is close at hand.

OLEDs have not yet entered the lighting market, but that will probably change soon. Already most of the big players in the field are preparing for OLEDs to become ‘the next big thing.’ However, several critical problems need to be solved before widespread use for lighting becomes feasible. Specifically, the lifetimes, power efficiencies, reliability, and cost-effectiveness of white OLEDs must be able to compete with existing lighting technologies.

There are many different approaches to generating white light with OLEDs, some of which we will discuss in this article. In contrast to inorganic LEDs, light of different colors can be generated inside an OLED by mixing different organic emitter molecules in the emission zone. A basic scheme of an OLED device is shown in Figure 1. Glass is usually used as substrate at the moment, although in principle flexible substrates, like polymer or metal foils, could also be selected.

Directly generating multicolored light has several advantages compared to approaches in which blue or UV light is (partly) converted into light of longer wavelengths, as is the case in, for example, fluorescent tubes or white LEDs. Designs that depend on downconversion rely on the availability of suitable phosphors. In contrast, the spectra that can be achieved with OLEDs are free of this constraint, which allows a broader coverage of the visible spectrum, resulting in 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). More important, phosphor-based systems inherently lead to loss of energy as photons are converted to photons of longer wavelengths and lower energy. The principal physical mechanism behind light generation in OLEDs bypasses that energy loss.

Besides the option to combine different emitters, it is also possible to stack two or three OLEDs of different color directly on top of one another. This can easily be achieved using the Novaled PIN OLED technology concept.1 Here, the acronym PIN refers to an OLED structure with a p-doped hole transport layer, an intrinsically conductive emission zone, and an n-doped electron transport layer.2 This type of redox doping, which is comparable to inorganic semiconductor systems, offers two advan-
Figure 2. Typical white OLED spectrum is generated by three different emitters (blue, green, and red). A broad coverage of the visible range results in a very high color-rendering index (CRI). OLED spectra can easily be tuned to achieve different color points and temperatures.

Figure 3. (left) Emission spectrum of the stacked OLED device with and without an optical film on the glass substrate. The device shows a high CRI value of 90 at warm white color coordinates. (right) Power efficiency plotted versus the OLED brightness. For future applications, OLED brightness is expected to be in the range of 500–5000cd/m$^2$.

Advantages. First, the conductivity of the transport layers is increased by more than two orders of magnitude. Second, the charge carrier injection from the electrodes into the organic transport layers is significantly facilitated. The PIN approach has been demonstrated to result in very low operating voltages close to the thermodynamic limit, high power efficiencies, and long lifetimes.

Using a stacked approach, we have reached both a high efficiency and a very long lifetime in a stacked white OLED device. At $(x, y)$ color coordinates of (0.43, 0.44), a power efficiency of 35lm/W and a lifetime of 100,000h, both at a brightness of 1000cd/m$^2$, could be achieved. This combination of extreme longevity with very high power efficiency is a significant step toward creating white OLEDs with performance good enough to enable first applications. The device contains a green and a red unit based on triplet emitters, in combination with a singlet blue emitter unit. The power efficiency of the device decreases only slowly with a higher light output, which is significant for applications that require a high luminous flux (see Figure 3).

Stacked OLED devices based on p- and n-doped transport layers are certainly one very promising approach to reaching a technological breakthrough for white OLEDs in lighting applications. Further improvements of the organic materials, the device architecture, and the optical light outcoupling from the OLED are anticipated, resulting in greater device efficiencies and lifetimes over the coming years.

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References


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