Bright prospects for organic-LED lighting

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Improved device designs will boost the efficiency of white organic light emitters to exceed that of conventional lighting sources.

Many fascinating and novel forms of illumination could be realized using organic LEDs (OLEDs), including glass windows that are transparent during the day and emit light at night, and light-emitting wallpaper or tiles. OLEDs are also extremely power efficient. Their most important benchmark is their luminous efficacy, which reaches—or even exceeds—that of conventional lighting technologies such as incandescent lamps, compact fluorescent lamps (CFLs), or fluorescent tubes.

CFLs have found widespread acceptance in the residential sector: more than half of all households in the European Union use CFLs. Nevertheless, a large amount of energy can still be saved if the remaining incandescent lamps are replaced by energy-saving lighting. To become a viable alternative to conventional light sources, OLEDs have to reach a luminous efficacy greater than 60 or 90 lm/W to beat CFLs or become more efficient than fluorescent tubes, respectively. To hit these targets, we recently used two approaches for fabricating highly efficient white OLEDs, based on all-phosphorescent and triplet-harvesting setups.

Our white, all-phosphorescent OLED consists of charge-transport, electron- and hole-blocking, and emission layers, each only several nanometers thick (see Figure 1). Holes and electrons are injected into the device at the transparent indium tin oxide anode and silver cathode, respectively. They are transported by the charge-transport layers on either side toward the emission layers, where the electrons and holes meet and form electron-hole pairs (excitons) that can recombine radiatively and emit light. To avoid electrons or holes drifting through the entire emission layer without forming excitons, charge-blocking layers confine all injected charge carriers to the emission layer.

Organic dyes usually emit only in limited parts of the visible spectrum. White emission that covers the full visible spectrum can only be generated by an emission mixture from several different dyes. In our setup, we include three different emission layers, each emitting at a different wavelength (red, green, and blue). There are two types of emitters, fluorescent and phosphorescent. The former can only emit light from their singlet state, while the latter can also harvest energy from the triplet state. Since three times as many triplets as singlets form in the emission layer, the highest efficiency can be obtained with phosphorescent emitters.

The OLED’s layer design leads to highly efficient devices (see Figure 2). At 1000 cd/m², we obtain an efficacy as high

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as 90lm/W based on a pyramidal outcoupling structure. This clearly exceeds the efficiency of CFLs, thus showing the potential of the all-phosphorescent approach. However, there are two aspects that need further improvement. The color point of the emitted light, (0.41, 0.49) in the chromaticity diagram defined by the International Commission on Illumination, is off the Planckian locus (implying an intrinsically different color from those emitted by the ubiquitous incandescent light bulbs), and the diode lifetime is rather short (1–2h). Both shortcomings could be avoided by employing a deep-blue, stable phosphorescent emitter. However, such a light source is not available at present.

In an alternative approach, phosphorescent blue emitters can be replaced by fluorescent light sources, while still retaining the possibility of reaching 100% internal efficiency. To avoid losses through unused triplets formed on the blue emitter, a blue dye with a high triplet level can be used. This allows transfer of unused triplets to the phosphorescent red emitter, where they can recombine and emit light.

The stack design of our triplet-harvesting OLED is shown in Figure 3. The recombination zone is marked by a yellow box. Excitons can be formed in the green or blue layers. The green emitter is a phosphorescent dye and all resulting excitons will generate light. In contrast, the blue emitter is fluorescent, so that only the singlets will generate light. However, the triplets formed in the blue layer can diffuse toward the red layer, where they can be harvested. Thus, a balanced white spectrum with contributions from red, green, and blue emitters is achieved.

Figure 4. Quantum efficiency (circles: right y axis) and luminous efficacy (squares: left y axis) of the triplet-harvesting approach. Open symbols represent values without outcoupling enhancement, while half-filled symbols include an outcoupling foil.

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possible and—most importantly—all generated excitons can be harvested and generate light. In principle, achieving an internal efficiency of nearly 100% is possible.

The external luminous efficacy and quantum efficiency obtained with this setup are shown in Figure 4. Without outcoupling enhancement, external quantum efficiencies are obtained of approximately 10% at 1000cd/m$^2$. Use of an outcoupling foil increases the quantum efficiency and luminous efficacy to approximately 13% and 27lm/W, respectively.

In summary, white OLEDs have become a powerful technology, combining high luminous efficacy with good color quality and novel design options. At present, our team’s further efforts focus on development of stable blue phosphorescent emitters and of concepts that avoid using a phosphorescent blue, such as the triplet-harvesting approach.

This work received funding from the European Community’s Sixth and Seventh Framework Programmes through grants IST-2002-004607 (OLLA) and FP7-224122 (OLED100.eu).

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