

White Organic Light-Emitting Diodes for Solid-State Lighting

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Organic light-emitting diodes (OLEDs) have attracted intensive interests since the first report by Tang and coworkers in 1987.¹ Research over the past two decades has made great progress on efficient fabrication of blue, green and red OLEDs into matrix displays.² In 2007, a commercial available 11-inch diagonal, 3 mm-thick OLED television was released by Sony in Japan.³ However, the white OLEDs haven't been fully studied until the recent decade due to the difficulties in acquiring high purity white light with high efficiency.⁴ Besides the potential application in back light unit of flat panel displays, white OLEDs are expected to be used as the alternative lighting sources for general solid-state lighting.⁵

The employment of phosphorescent materials in white OLEDs fabrication is one of the most important progresses for the current research.⁶ Those phosphorescent materials are iridium or platinum complex, which are doped with the host molecules to form the emissive layer.⁵ Under electrical injection, the energy can be transferred from both singlet and triplet excitons of the host molecules to the triplet state of the phosphorescent guest molecules, followed by charge trapping and recombination, where phosphorescence forms.⁷ In this way, the internal quantum efficiency can reach 100% which corresponds to a fourfold increase to those fluorescent counterparts, since they can only harvest singlet excitons.⁸

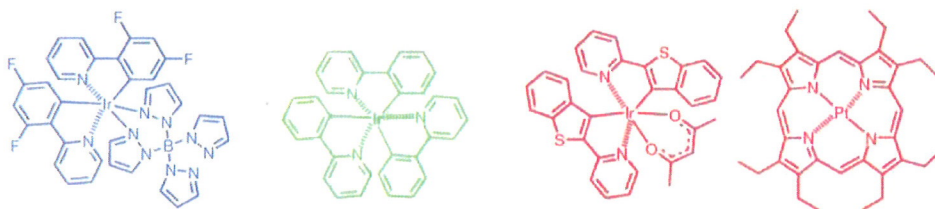


Figure 1. Phosphorescent molecules⁵

More challenges of white OLEDs research are based on the designing device architectures. The challenges originate from the difficulties to synthesize a single molecule to efficiently emit over the entire visible spectrum, so complicated architectures are required for producing white light.⁴ Multiple dopants have been added to fulfill the goal. It is demonstrated that white light can be acquired with OLEDs with either fluorescent or phosphorescent multiple emissive layers.^{9, 10} Apparently, the OLED with phosphorescent multiple emissive layers provides a much higher external quantum efficiency.¹⁰ The device structure can be further simplified by simultaneously co-dope three phosphorescent emitting dopants into a wide energy gap host.¹¹ Because there is only one emissive layer in this OLED, the thickness of the device can be hugely decreased and the efficiency can be significantly increased. However, such wide energy gap always causes short operational lifetimes for blue electrophosphorescent part that limit the total lifetime for all-phosphor-doped white OLEDs. This can be avoided by a new white OLED architecture that uses a fluorescent emitting dopant to harness all electrically generated high energy singlet excitons for blue emission, and phosphorescent dopants to harvest the remainder of lower-energy triplet excitons for green and red emission.¹² This architecture takes

advantage of the high color stability of blue fluorescent dopant and the 100% internal quantum efficiency of other phosphorescent dopants. In addition, by changing the host and guest molecules, the device structures can be further simplified¹³ and the external quantum efficiency can be increased to 20.3%, representing the most efficient white OLED so far.¹⁴

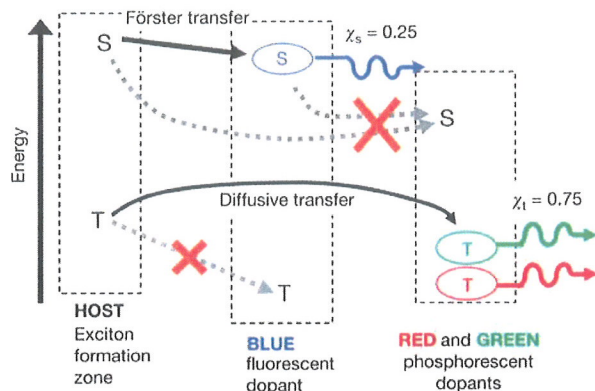


Figure 2. Energy transfer in the fluorescent/phosphorescent white OLED¹²

According to U.S. Department of Energy (DOE)'s report, lighting consumes about 765 TWh of electricity each year in the United States, or nearly 30% of all electricity produced for building. In terms of total energy consumption, it is about 22% of all the electricity produced.¹⁵ Among all possible light sources, low efficient incandescent lamps still account for 42% of the total electricity consumption. DOE anticipates that the employment of highly efficient solid-state lighting devices, including white OLEDs and LEDs, will decrease national energy consumption by 29% and accumulate energy savings of \$125 billion by 2025.⁴ However, the device cost remains a significant challenge towards the commercial usages of white OLEDs. The future research would focus on either finding a high-throughput manufacturing process that is capable of making such structures with good yield and at very low cost or using what we have learned to simplify the OLED structure without sacrificing performance.

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