Recent Research Highlights in Blue Fluorescent Emitters in Organic Light-Emitting Diodes

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Organic light emitting diodes (OLEDs) received much attention from both academia and industry as the next-generation flat panel displays. However, to produce high quality OLEDs, there are still many challenges to overcome. Especially, in full color OLEDs, the intrinsic wide band gap of the blue emitting materials results in inferior efficiency compared to those of green and red emitting materials. Therefore, extensive research efforts have been devoted to develop efficient blue emitting materials. This review briefly summarizes the basics of OLEDs and introduces highlights of research efforts in blue-emitting materials.

Keywords: Organic light emitting diodes, OLEDs blue emitting material, \(\pi\)-conjugated organic materials, Electroluminescence

1. Introduction

Organic light emitting diodes (OLEDs) are optical electronic devices based on the photoluminescent properties of \(\pi\)-conjugated organic materials. During past two decades, the study of OLEDs has received much attention from both academia and industry as next-generation flat panel displays because of their remarkable advantages such as self-emitting, high brightness, full-color emission, low driving voltage and fast response time[1,2]. Recently, OLED technology was successfully commercialized by some major display companies and mainly applied to small electronics like mobile phones and digital cameras. However, to produce high quality OLED, there are still many challenges to overcome. Especially, in full color OLEDs, the intrinsic wide band gap of the blue emitting materials results in inferior efficiency compared to those of green and red emitting materials. Therefore, in recent years, many research efforts have been devoted to develop efficient blue emitting materials. This review briefly summarizes basics of OLED and introduces research highlights in blue-emitting materials.

2. Working principle of OLED

A typical OLED is composed of few nanometer thickness thin layer of OLED material placed between two electrodes. One of two electrodes should be transparent, so that the light which is created passes through when applying a voltage[3]. OLED materials are \(\pi\)-conjugated organic small molecules which are able to generate electroluminescence (EL). EL is a phenomenon in which the light of specific wavelength is created from the exciton made by electrons and holes injected into the thin film of organic material through cathode and anode (see Figure 1). Since discovery of EL from a single crystal of anthracene by Pope et al in 1963, OLED was firstly demonstrated by Heilbrich et al and Mehrink et al in 1965[4,5]. After that, numerous conjugated organic molecules have been synthesized and reported to exhibit EL ranging from red to green and blue to realize full-color flat panel displays to date.

In order to fabricate full color OLED displays, red[6-7], green[8-9] and blue-light emitters[10,11] with high EL efficiencies,
3. Research Highlight in Blue Fluorescent Emitters

Blue emitting materials exhibit low efficiencies and short device lifetimes because a wide band gap of the materials are generally mismatched with the HOMO (highest occupied molecular orbital) and LUMO (lowest unoccupied molecular orbital) levels of the other hole and electron transporting layer in OLED device[11]. For the reason, there has been tremendous interests to develop blue emitting materials with pure and highly efficient[12,13]. Efforts to achieve highly efficient blue emitting materials have sought to 1) control the emission wavelength by managing the properties of the $\pi$-conjugation system in molecules that have high quantum efficiencies, such as anthracene, fluorine and pyrene (see Figure 2) 2) reduce packing between molecules and limit emission quenching by introducing bulky side groups. These methods enhance the purity and stability of the blue materials with high photon conversion efficiencies[14-16].

4,4-Bis(2,2-diphenylvinyl)-1,1'-biphenyl (DPVBi), the most famous blue emitting material, was first reported by Hosokawa at Idemitsu Kosan in 1995[17]. Device made with ITO / CuPc (20 nm) / TPD (60 nm) / DPVBi (40 nm) / Alq3 (30 nm) / Mg:Ag (9:1, 200 nm)[19]. The device showed 3.5 cd/A in efficiency and coordinates of (0.15, 0.23) in CIE. Remarkably, the device recorded 4000 hours of device life-time under initial luminance condition of 636 cd/m, but in practice, low glass transition temperature of ADN (95 °C) and poor film morphology limited its possibility in use as a real manufacturing product. Accordingly, TBADN bearing t-butyl unit was proposed[20]. Introduction of t-butyl unit enabled to improve morphology of the film but donating effect of t-butyl unit resulted in a red shift of photoluminescence (PL), bringing difficulty in materialization of pure blue color. Besides, reduction of carrier mobility by t-butyl unit was observed. To make up these demerits, finally, 2-Methyl-9,10-di-naphthalen-2-yl-anthracene (MADN) which has a methyl unit at 2 position of anthracene unit of ADN was proposed. High glass transition temperature (120 °C) and good film morphology of MADN allowed excellent deep blue color in color coordinates of (0.15, 0.10)[21].

S. A. Jenekhe et al. have synthesized a series of highly fluorescent blue-emitting n-type oligomers based on a 6,6'-bis(4-phenylquinoline) core. Simple bilayer OLEDs, which is without ETL layer, employing the oligoquinolines as the emissive and electron-transport materials were found to have stable blue EL with high efficiencies and excellent blue color CIE coordinates (see Figure 3). OLEDs made from the oligoquinoline with biphenyl end groups, B2PPQ, in particular, had the highest efficiencies (7.12 cd/A, EQE 6.56% at 1175 cd/m²) in non-doped device. These results demonstrate that the new oligoquinolines are very promising blue emitters and electron-transport materials for developing high-efficiency OLEDs with a simple architecture[22].

P-type non-doped OLED materials have also been developed. Tao et al. designed anthracene derivatives with triphenylamine in side group to help hole injection (see Figure 4). The compounds, which is anthracene-triphenylamine derivative exhibit strong blue emission with...
quantum yields of 0.44~0.48 and maximum efficiency of 7.9 cd/A in non-doped device. Remarkably, Hole transporting layer (HTL)-free two-layer device architecture allows higher powder efficiency compared to other non-doped fluorescent blue OLEDs (~6.8 lm/W)[23].

Recently, Jiang et al. suggested multifunctional fluorine-based oligomers with spiro-annulated carbazole (see Figure 5). Nobility of this work is to minimize undesired suppression of EL caused by the photo/thermal oxidation at 9-position of fluorine unit to ketonic defect by introducing spiro-linkage in chemical structure using carbazole-cored ladder-type molecules. Authors expected that implantation of carbazole provided improved hole injection and transportation. Furthermore the spiro-configuration would effectively impede the intermolecular $\pi-\pi$ interactions and consequently lead to the amorphous morphology of a ladder-type molecule[24].

J. W. Park et al. have described new blue emission materials based on a type of dual core concept (see Figure 6). These chromophore materials with orthogonally bonded dual cores exhibited stronger fluorescence and electroluminescence with about two times higher external quantum efficiency (EQE) values and two times longer blue emission lifetimes than their single core counterparts. One of the dual core derivatives, TP-AP-TP, exhibited an ELmax value of 456 nm and a high luminance EQE of 7.51% when used in a non-doped EL device. A device based on TP-AP-TP showed twice the lifetime of a device based on the commercialized material, 2-methyl-9,10-bis(naphthalen-2-yl) anthracene (MADN)[10].

### 4. Conclusions and outlook

In this article, we briefly summarized fundamentals of OLED and introduced recent research highlights in blue-emitting materials. So far, as mentioned above, current research activities have mainly centered on development of economical and durable fluorescent emitters with high emitting quantum yield and stability to commercialize OLED displays. However, in the future, the solution process such as roll-to-roll and ink-jet has to be achieved to produce large area, flexible OLED display and lighting. A related material also has to be developed. These efforts are very crucial research fields to cut production cost of next generation high performance OLED displays.

### References

1. C. L. Ho and W. Y. Wong, Small-molecular blue phosphorescent