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Solution processed high efficiency blue and white phosphorescent organic light-emitting diodes using a high triplet energy exciton blocking layer

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ABSTRACT

High efficiency solution processed blue and white phosphorescent organic light-emitting diodes (PHOLEDs) were developed using diphenylphosphine oxide-4-(triphenylsilyl)phenyl (TSPO1) as a high triplet energy exciton blocking layer. The solution processed blue and white PHOLEDs showed a high quantum efficiency of 19.4% at 20 cd/m^2 and 12.3% at 119 cd/m^2, respectively, due to the efficient hole and exciton blocking of TSPO1.

1. Introduction

Soluble phosphorescent organic light-emitting diodes (PHOLEDs) have been developed to improve the low quantum efficiency of soluble fluorescent organic light-emitting diodes [1]. Theoretically, the quantum efficiency of OLEDs can be quadrupled using phosphorescent emitting materials instead of fluorescent emitting materials [2]. Therefore, many studies have examined ways of enhancing the quantum efficiency of soluble PHOLEDs.

The most common method to enhance the quantum efficiency of soluble blue PHOLEDs is to manage the host material for the charge balance in the emitting layer. Poly(*N*-vinylcarbazole) (PVK) is used widely as the host material but it has strong hole transport properties and weak electron transport properties [3,4]. Therefore, PVK was mixed with electron transport type host materials for better charge balance [5–10], resulting in a high current efficiency of 22.0 cd/A [5]. On the other hand, the efficiency could not be improved further just by optimizing the host materials in the emitting layer.

The other approach to improve the quantum efficiency of soluble blue PHOLEDs was to use a device structure to confine the triplet excitons in the emitting layer [11–14]. Triplet exciton confinement by high triplet energy exciton blocking materials was reported to be critical to the quantum efficiency of vacuum deposited PHOLEDs [15]. The exciton confining structure was also adopted in soluble PHOLEDs. High triplet energy PVK was effective as a hole transport type exciton blocking layer and several electron transport type exciton blocking layers could increase the quantum efficiency of solution-processed blue PHOLEDs. On the other hand, the efficiency of soluble blue PHOLEDs could not be improved further. The highest efficiency of the solution processed blue PHOLEDs was 15.5% [11]. The most critical problem for the rather low quantum efficiency of soluble blue PHOLEDs was the leakage of the triplet excitons and charges, which degraded the quantum efficiency of soluble blue PHOLEDs. Therefore, it is important to confine the excitons and charges inside the emitting layer to obtain high quantum efficiency in solution-processed blue

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PHOLEDs. A previous report showed that high triplet energy electron transport material improves the quantum efficiency of vacuum-deposited blue PHOLEDs by exciton and charge confinement [16]. The high triplet energy material can also confine excitons and charges inside the emitting layer and enhance the quantum efficiency of soluble blue PHOLEDs.

In this study, a high triplet energy exciton blocking material, diphenylphosphine oxide-4-(triphenylsilyl)phenyl (TSPO1), was deposited on a PVK:FIrpic blue emitting layer and the device performance was investigated. A high quantum efficiency of 19.4% at 20 cd/m^2 was achieved in the soluble blue PHOLEDs using TSPO1 as the electron transport type exciton blocking material. In addition, solution processed three-color white PHOLEDs were also fabricated and a quantum efficiency of 12.3% at 119 cd/m^2 was demonstrated. This study revealed that the solution-processed blue PHOLEDs can show the same quantum efficiency as vacuum deposited blue PHOLEDs by confining the triplet excitons and blocking holes, which could not be realized in other studies. This is the first demonstration of ~20% external quantum efficiency in solution-processed blue PHOLEDs.

2. Experimental

The basic device configuration of indium thin oxide (ITO)/poly-3,4-ethylenedioxythiophene:polystyrenesulfonate (PEDOT:PSS, 60 nm)/PVK: iridium(III) bis(4,6-(di-fluorophenyl)-pyridinato-*N*,C′) picolinate (FIrpic) (66 nm, 15%)/TSPO1(x nm)/LiF (1 nm)/Al (100 nm) was used to evaluate the TSPO1 as the exciton blocking material for solution processed blue PHOLEDs. The thicknesses of the TSPO1 were 25, 30, 35 and 40 nm. The device structure of the white PHOLEDs was ITO/PEDOT:PSS (60 nm)/PVK:FIrpic: tris[2-(p-tolyl)pridine]iridium(III)(Ir(mppy)$_3$): iridium(III) bis(2-phenylquinoline) acetylacetonate (Ir(pq)$_2$acac) (70 nm, 15%, *x*%, 0.5%)/TSPO1 (30 nm)/LiF (1 nm)/Al (100 nm). The doping concentrations of the Ir(mppy)$_3$ in the white PHOLEDs were 1% and 0.3%. Fig. 1 shows the chemical structure of TSPO1 and the device structures of blue and white PHOLEDs. The PVK emitting layer was spin coated from toluene solution at a concentration of 1.5 wt%. The spin coated PVK layer was baked at 80 °C from 20 min to remove the residual solvent. TSPO1 was deposited by vacuum evaporation. The current density (*J*)–voltage (*V*)–luminance (*L*) characteristics and electroluminescence (EL) spectra of the devices were measured using a Keithley 2400 source measurement unit and a Minolta CS 1000 A spectroradiometer. The Lambertian distribution of light emission was observed in all devices and the quantum efficiency was calculated based on the Lambertian distribution of light emission.

3. Results and discussion

A high triplet energy and deep highest occupied molecular orbital (HOMO) level of the electron transport materials are important for confining the holes and triplet excitons inside the emitting layer. The TSPO1 has a high triplet energy of 3.36 eV and a HOMO level of 6.79 eV [16]. The triplet energy of the TSPO1 was much higher than

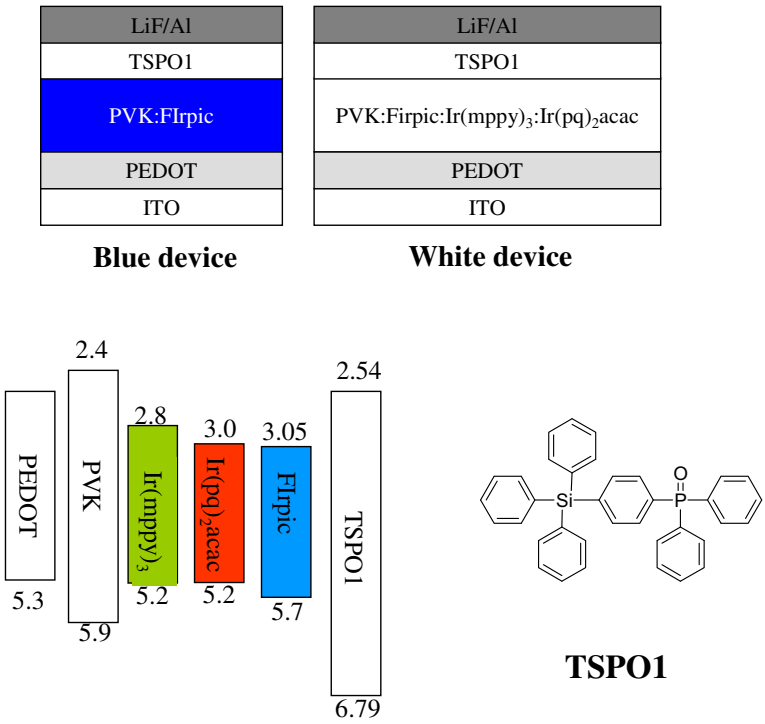

Fig. 1. Device structures of the blue and white PHOLEDs. Energy level diagram of the PHOLEDs is also shown in this figure.