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Four times lifetime improvement of blue phosphorescent organic light-emitting diodes by managing recombination zone

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ABSTRACT

Lifetime of blue phosphorescent organic light-emitting diodes (OLEDs) was improved by suppressing a recombination zone shift using a high triplet energy exciton blocking layer. Host material of the emitting layer was inserted as the exciton blocking layer between a hole transport layer and an emitting layer, and the exciton blocking layer kept the recombination zone near hole transport layer side without significant emission zone change during lifetime test. The suppressed recombination zone shift improved the lifetime of the blue phosphorescent OLED by four times.

1. Introduction

Blue phosphorescent organic light-emitting diodes (OLEDs) have been studied for more than decade to enhance low quantum efficiency of blue fluorescent OLEDs because theoretical quantum efficiency of phosphorescent OLEDs is four times higher than that of fluorescent OLEDs [1]. State of the art quantum efficiency of phosphorescent OLEDs is already over 30% compared with ~10% of the fluorescent OLEDs [2–6]. However, the lifetime of the blue phosphorescent OLEDs is still a challenge and current lifetime level of the phosphorescent OLEDs is much shorter than that of fluorescent OLEDs [7,8,14–20].

There have been several approaches to extend the lifetime of the blue phosphorescent OLEDs. One approach was to apply stable blue triplet emitters developed using phenylimidazole type ligands [9–11]. Several phenylimidazole ligand based triplet emitters have been studied and provided much longer lifetime than traditional phenylpyridine ligand based triplet emitters. Another approach was to control emission zone of the blue phosphorescent OLEDs [8]. A device structure employing a graded doping structure in the emitting layer could extend the lifetime of the blue device by widening the emission zone of the device. Other than these, a stable hole transport type exciton blocking material could also improve the lifetime of the blue phosphorescent device by suppressed triplet exciton quenching and good hole injection [12]. However, the lifetime of the blue phosphorescent device is still very short and further understanding about the approach to increase the lifetime of the blue device is essential.

Herein, we demonstrate lifetime improvement of blue phosphorescent device by suppressing recombination zone shift during continuous driving of the device via managing exciton blocking layer in contact with a hole transport layer. The exciton blocking layer suppressed recombination zone shift from hole transport layer side to electron transport layer side through retarded hole injection, which extended the lifetime of the blue phosphorescent device by reducing triplet exciton quenching by the electron transport layer.

2. Experimental

Blue phosphorescent devices for lifetime measurement had the following device stack structure.

ITO/DNTPD (60 nm)/BPBPA (30 nm)/mCBP (x nm)/mCBP:Ir(dbi)$_3$ (30 nm)/LG201 (35 nm)/LiF (1 nm)/Al (200 nm).

ITO was indium tin oxide, DNTPD was N,N′-diphenyl-N,N'-bis-[4-(phenyl-m-tolyl-amino)-phenyl]-biphenyl-4,4'-diamine, BPBPA was N,N,N′N'-tetra[(1,1'-biphenyl)-4-yl]-(1,1'-biphenyl)-4,4'-diamine, mCBP was 3,3-di(9H-carbazol-9-yl)biphenyl, and Ir(dbi)$_3$ was tris[1-(2,4-diisopropyldibenzo[b,d]furan-3-yl)-2-phenylimidazole] iridium(III). Thicknesses of the mCBP exciton blocking layer were 0, 10 and

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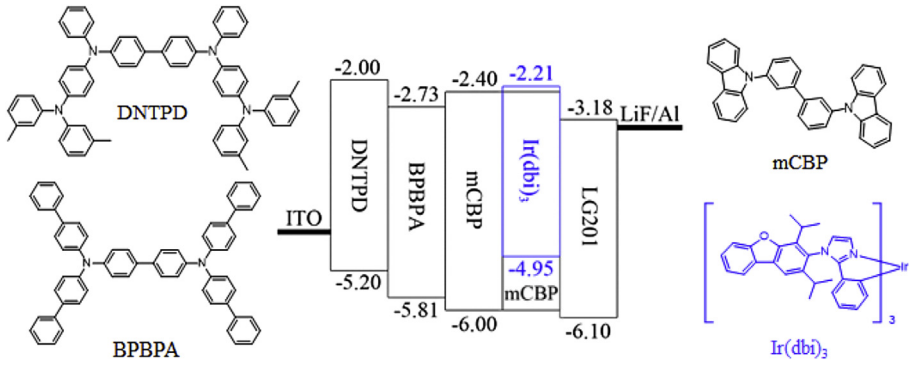

Fig. 1. Device structure and chemical structure of organic materials.

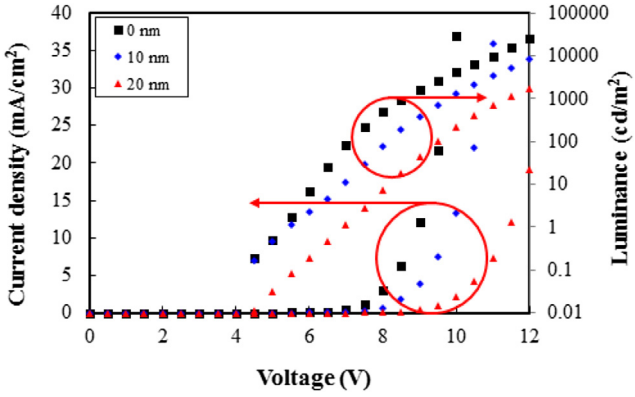

Fig. 2. Current density–voltage–luminance curves of blue phosphorescent OLEDs. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

20 nm. Device structure and chemical structure of organic materials used in this work are shown in Fig. 1.

Emission zone monitoring device had a red sensing layer inside the mCBP:Ir(dbi)$_3$ emitting layer. Total thickness of the emitting layer was 30 nm including the mCBP:Ir(dbi)$_3$ emitting layer (28 nm) and mCBP:tris[1-phenylisoquinolinato-N,C^2] iridium(III) (Ir(piq)$_3$) sensing layer (2 nm). Location of the sensing layer was 5 nm, 14 nm and 23 nm from the hole transport layer. The emission zone was traced with the Ir(piq)$_3$ intensity while collecting lifetime data.

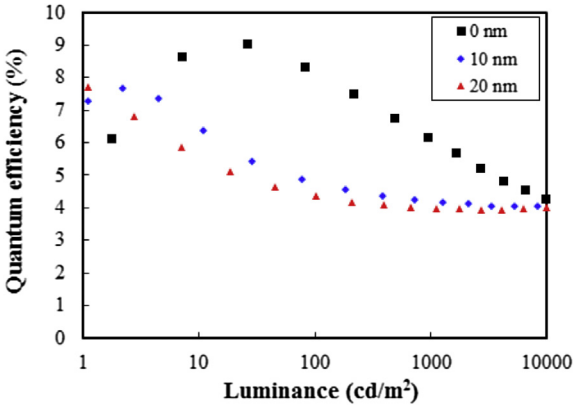

Fig. 3. Quantum efficiency–luminance curves of blue phosphorescent OLEDs. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Detailed device characterization methods were reported in our early work [12,13] and the lifetime data of the device were collected from the lifetime measurement system with Si photodiode as a light intensity detector.

3. Results and discussion

Blue phosphorescent OLEDs require high triplet energy exciton blocking layer in contact with a blue emitting layer to avoid a loss of triplet excitons. However, it is difficult to apply stable high triplet energy exciton blocking layer between the blue emitting layer and electron transport layer because most electron carrying high triplet energy materials are unstable and gives rise to fast decay of luminance within short time range. Therefore, the blue phosphorescent OLEDs studied in this work had the exciton blocking layer only between the blue emitting layer and hole transport layer without any exciton blocking layer in contact with the electron transport layer. The absence of the exciton blocking layer may decrease device efficiency when the emission zone is close to electron transport layer, which suggests that the emission zone of the mCBP:Ir(dbi)$_3$ device has a great influence on the lifetime of the device. A mCBP exciton blocking layer at the interface between BPBPA and mCBP:Ir(dbi)$_3$ was inserted to block exciton quenching of Ir(dbi)$_3$ by BPBPA and to reduce emission zone movement to electron transport layer side during lifetime measurement because triplet excitons would be quenched by low triplet energy electron transport layer.

Three devices with the mCBP exciton blocking layer at thicknesses of 0, 10 and 20 nm were prepared and electro-optical properties of the blue devices were compared in Fig. 2. The mCBP

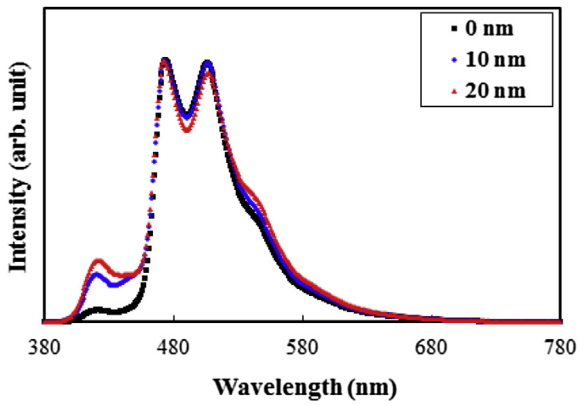

Fig. 4. EL spectra of blue phosphorescent OLEDs. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)