



# Deep blue phosphorescent organic light-emitting diodes with excellent external quantum efficiency

Jungeun Park<sup>a</sup>, Hankook Oh<sup>a</sup>, Sihyun Oh<sup>a</sup>, Jinho Kim<sup>a</sup>, Hyun Jin Park<sup>b</sup>, Oh Young Kim<sup>b</sup>, Jun Yeob Lee<sup>b,\*</sup>, Youngjin Kang<sup>a,\*</sup>

<sup>a</sup> Department of Chemistry & Division of Science Education, Kangwon National University, 200-701 Chuncheon, Republic of Korea

<sup>b</sup> Department of Polymer Science & Engineering, Dankook University, Yongin, Gyeonggi-do 448-701, Republic of Korea

## ARTICLE INFO

### Article history:

Received 1 July 2013

Received in revised form 8 September 2013

Accepted 11 September 2013

Available online 10 October 2013

### Keywords:

Phosphorescent organic light-emitting diodes (PHOLEDs)

Heteroleptic iridium(III) complex

Deep-blue triplet emitter

External quantum efficiency

## ABSTRACT

Highly efficient deep blue phosphorescent organic light-emitting diodes (PHOLEDs) using two heteroleptic iridium compounds, (dfppy)<sub>2</sub>Ir(acac) and (dfppy)<sub>2</sub>Ir(dpm), as a dopant and 9-(3-(9H-carbazol-9-yl)phenyl)-9H-carbazol-3-yl)diphenylphosphine oxide as a host material have been developed. The electroluminescent device of (dfppy)<sub>2</sub>Ir(dpm) at the doping level of 3 wt% shows the best performance with external quantum efficiency of 18.5–20.4% at the brightness of 100–1000 cd/m<sup>2</sup> and the color coordinate of (0.14,0.18) at 1000 cd/m<sup>2</sup>.

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## 1. Introduction

Deep-blue phosphorescent Ir(III) compounds have been the subject of great interest in recent years due to their versatile applications in a wide array of fields such as flat panel displays and solid state lighting [1]. In particular, much focus has been directed to C<sup>N</sup> chelated ligand based Ir(III) compounds due to their high thermal and electrochemical stability, easily tunable energy gaps, and high photoluminescence quantum efficiency attributed to the short life time of their excited state [2]. However, few blue phosphorescent iridium compounds show truly high external quantum efficiency (EQE) when compared to standard green and red devices, because of the large energy gap of blue phosphors as well as the elevated energy of their triplet state [3].

Development of a series of efficient blue phosphorescent iridium derivatives and the device optimization using these compound is in high demand in both the display and lighting industries but is a greatly challenging task that has been an ongoing challenge [4]. Over 20% of EQE of blue phosphorescence has been achieved mainly by combination of newly developed host or hole-blocking materials and well known dopants such as iridium(III) bis[(4,6-difluorophenyl)pyridinato-N,C<sup>2'</sup>]picolate (FIrpic), iridium(III)bis(4',6'-difluorophenylpyridinato)tetrakis(1-pyrazolyl)borate(Fir6) and iridium(III)bis((3,5-difluoro-4-cyanophenyl)pyridine)picolate (FCNIRpic), etc [5]. However, few accounts have been reported of EQE exceeding 20% of efficiency by the modification of device configuration [1a,6]. Although efforts into increasing EQE have mainly focused on developing appropriate hosts, continuous demand for the development of blue phosphorescent compounds together with device optimization remains a challenge that must be overcome until now.

We have recently developed a new blue iridium(III) compound with high quantum efficiency by using a fluorinated bipyridine (dfppy) ligand instead of

\* Corresponding authors. Tel.: +82 332506737; fax: +82 332429598 (Y. Kang).

E-mail addresses: [leej17@dankook.ac.kr](mailto:leej17@dankook.ac.kr) (J.Y. Lee), [kangy@kangwon.ac.kr](mailto:kangy@kangwon.ac.kr) (Y. Kang).

phenylpyridine [7]. These molecules have the general formula of  $\text{Ir}(\text{C}^{\wedge}\text{N})_2(\text{L}^{\wedge}\text{X})$  where  $\text{C}^{\wedge}\text{N}$  = 2',6'-difluoro-2,3'-bipyridine (dfppy), and  $\text{L}^{\wedge}\text{X}$  = ancillary ligand such as picolinate (**1**), acetylacetonate (**2**) and dipivaloylmethanate (**3**), as shown in chart 1.

These heteroleptic iridium compounds are considered to be an ideal emitter for blue phosphorescence because of their high photoluminescent quantum efficiency. Therefore, we have previously fabricated double-layer electroluminescent devices using compounds **1–3** as a dopant. These EL devices showed pure blue color with moderate efficiency (EQE: 10–15%) [7b]. However, the optimization of device condition is still needed because the lack of energy transfer between host and dopant and exciton confinement in emitting layer was observed in this structure. This fact prompted us to further investigate excellent device optimization.

Herein, we report systematic evaluation of electroluminescence (EL) characteristics when compound **2** or **3** is employed as a dopant in phosphorescent organic light-emitting diodes (PHOLEDs). To our knowledge, the external quantum efficiency of this compound is notably superior to previously reported blue iridium phosphors of different sorts, and is one of few highly achieved results for materials with 20% EQE using a 1,3-bis(*N*-carbazolyl)benzene (mCP) or 9-(3-(9H-carbazol-9-yl)phenyl)-9H-carbazol-3-yl)diphenylphosphine oxide (mCPPO1) host.

## 2. Experimental

Two iridium(III) compound **2**, **3** and host material (mCPPO1) were synthesized according to previous reports [7b,8]. The device structure used in this work was indium tin oxide (ITO, 50 nm)/poly(3,4-ethylenedioxythiophene):poly(styrenesulfonate) (PEDOT:PSS, 60 nm)/4,4'-cyclohexylidenebis[*N,N*-bis(4-methylphenyl)aniline] (TAPC, 20 nm)/mCP (10 nm)/host:dopant **2** or **3** (25 nm)/TSPO1 (35 nm)/LiF (1 nm)/Al (200 nm). The host materials in the emitting layer were mCP and mCPPO1. Doping concentrations of dopant **2** and **3** were 3%, 5% and 10%. The doping concentration of dopant **2** and **3** was controlled by changing the deposition rate of host and dopant materials. The PEDOT:PSS hole injection layer was formed by spin coating process and other materials were deposited by

vacuum thermal evaporation. All devices were encapsulated with a glass lid to protect the devices from moisture and oxygen. Device performances were measured using Keithley 2400 source measurement unit and CS1000 spectroradiometer.

## 3. Results and discussion

The dopant **2** and **3** were originally developed as deep blue phosphorescent emitters and gave moderate quantum efficiency of 10–15%. However, triplet excitons could not be effectively confined and charge balance in the emitting layer was not optimized in our previous work in spite of deep blue emission color [7b]. Therefore, we designed a device architecture which can improve charge balance and confine triplet excitons and charges in the emitting layer. Based on our previous investigation, the HOMO energy of complex **1** is 6.49 eV. While the HOMO energies of **2** and **3** are 5.89 and 5.88 eV, respectively. Host materials generally require wider energy gaps and deeper HOMO levels than deep blue emitters. Therefore, complex **2** and **3** are employed as emitters in this study because of their narrow energy gaps and high-lying HOMO energy relative to mCP and mCPPO1 hosts.

As the triplet energy of the dopant **2** and **3** was 2.76 and 2.74 eV, high triplet energy mCP (2.90 eV) and diphenylphosphine oxide-4-(triphenylsilyl)phenyl (TSPO1, 3.39 eV) were used as hole transport type and electron transport type exciton blocking materials, respectively. The two exciton blocking materials can confine triplet excitons inside an emitting layer and can improve the device performances of the dopant **2** and **3**. In addition, holes and electrons can also be confined in the emitting layer due to energy barrier for charge leakage. High triplet energy mCP and mCPPO1 were selected as host materials to optimize energy transfer and charge balance in the emitting layer. The high triplet energy of mCP (2.90 eV) and mCPPO1 (3.00 eV) hosts can induce efficient energy transfer to blue triplet emitters. In particular, the mCPP1 host can also balance holes and electrons in the emitting layer due to bipolar charge transport properties[8].

Deep blue PHOLEDs were fabricated using dopant **2** and **3** to optimize the device performances. Doping concentration of dopant **2** and **3** were changed from 3% to 10% and

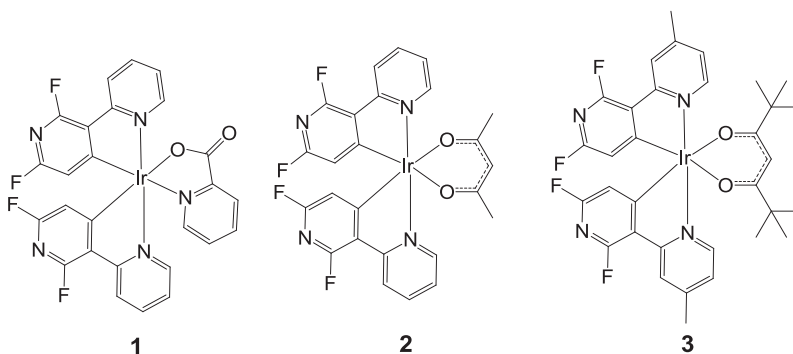


Chart 1. Molecular structure of deep blue iridium complexes **1**, **2** and **3**.

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