

# Charge conduction study of phosphorescent iridium compounds for organic light-emitting diodes application



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## ABSTRACT

The charge conduction properties of a series of iridium-based compounds for phosphorescent organic light-emitting diodes (OLEDs) have been investigated by thin-film transistor (TFT) technique. These compounds include four homoleptic compounds: Ir(ppy)<sub>3</sub>, Ir(piq)<sub>3</sub>, Ir(Tpa-py)<sub>3</sub>, Ir(Cz-py)<sub>3</sub>, and two heteroleptic compounds Ir(Cz-py)<sub>2</sub>(acac) and Flrpic. Ir(ppy)<sub>3</sub>, Ir(piq)<sub>3</sub> and Flrpic are commercially available compounds, while Ir(Tpa-py)<sub>3</sub>, Ir(Cz-py)<sub>3</sub> and Ir(Cz-py)<sub>2</sub>(acac) are specially designed to test their conductivities with respect to the commercial compounds. In neat films, with the exception of Flrpic, all Ir-compounds possess significant hole transporting capabilities, with hole mobilities in the range of about  $5 \times 10^{-6}$ – $2 \times 10^{-5}$  cm<sup>2</sup> V<sup>-1</sup> s<sup>-1</sup>. Flrpic, however, is non-conducting as revealed by TFT measurements. We further investigate how Ir-compounds modify carrier transport as dopants when they are doped into a phosphorescent host material CBP. The commercial compounds are chosen for the investigation. Small amounts of Ir(ppy)<sub>3</sub> and Ir(piq)<sub>3</sub> (<10%) behave as hole traps when they are doped into CBP. The hole conduction of the doped CBP films can be reduced by as much as 4 orders of magnitude. Percolating conduction of Ir-compounds occurs when the doping concentrations of the Ir-compounds exceed 10%, and the hole mobilities gradually increase as their values reach those of the neat Ir films. In contrast to Ir(ppy)<sub>3</sub> and Ir(piq)<sub>3</sub>, Flrpic does not participate in hole conduction when it is doped into CBP. The hole mobility decreases monotonically as the concentration of Flrpic increases due to the increase of the average charge hopping distance in CBP.

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## 1. Introduction

Organic light-emitting diodes (OLEDs) are now firmly established as key ingredients in high brightness, sharp contrast, ultra-thin, and light-weight displays [1,2]. Commercial products are now available in micro-displays, cell phones, tablets, and large area TV sets. Despite these successes, continuous efforts are still needed in more demanding applications such as in solid-state lighting applications. Among these efforts, the design of high

efficiency phosphorescent light-emitters takes the central stage. Ir(III) phosphors can capture energies from both singlet and triplet excited states, lifting the limit of the internal quantum efficiency to nearly 100% [3]. Besides light-emitting functions, improving charge transporting properties of Ir(III) phosphors via tailoring their structures can be taken as a useful strategy to optimize the OLED efficiency. The incorporation of bulky and hole-transporting arylamine group or carbazole group can reduce the barrier height of hole-injection and enhance the hole-transporting abilities of the resulting Ir(III) phosphors [4]. In a previous report, we employed thin film transistor (TFT) to probe the conductivity of an archetype metal-based phosphorescent compound, tris(2-phenylpyridine)iridium(III) [Ir(ppy)<sub>3</sub>] [5]. We showed that Ir(ppy)<sub>3</sub> is hole conducting, and its hole mobility is of the order of  $2 \times 10^{-5}$  cm<sup>2</sup> V<sup>-1</sup> s<sup>-1</sup>, which is comparable to a common hole

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transporter 4,4'-bis[*N*-(1-naphthyl)-*N*-phenylamino]biphenyl (NPB) under similar measuring conditions. As Ir(ppy)<sub>3</sub> possesses both light-emitting and hole transporting capabilities, incorporating this material into an OLED should allow for device simplification [6–13]. One example of such an effort is to use a neat film of Ir(ppy)<sub>3</sub> as a hole injection layer in an OLED [6]. A more appealing approach is to use Ir(ppy)<sub>3</sub> as a dopant to modulate the hole injection and conduction properties of a wide band gap hole transporter. Lui et al. reported a high efficiency and simplified OLED that uses the Ir(ppy)<sub>3</sub> responsible for hole injection from ITO anode and hole transport in the emissive layer (EML) of CBP [6,7]. Later on, Ma et al. and Kim et al. also demonstrated that the phosphorescent dopants, Ir(ppy)<sub>3</sub> and Ir(ppy)<sub>2</sub>acac, can contribute to the charge transport in EML in OLED, which can reduce the barrier at the interface of HTL and EML, or even replace the hole transporting layer (HTL), such as TAPC and NPB [11–13]. With this approach, simplified OLEDs are demonstrated to have significantly enhanced operational stability without loss of efficiency [13]. To further develop this kind of strategy for device simplification, it is therefore necessary to have more in depth understanding of the charge conduction properties in metal-based phosphorescent compounds.

This contribution looks into the hole conduction in a series of Ir-based phosphorescent compounds that have been applied in OLEDs. They include homoleptic Ir(ppy)<sub>3</sub>, Ir(piq)<sub>3</sub>, Ir(Tpa-py)<sub>3</sub>, Ir(Cz-py)<sub>3</sub>, and heteroleptic Ir(Cz-py)<sub>2</sub>(acac) and Flrpic. The chemical structures of all compounds are shown in Fig. 1. Ir(ppy)<sub>3</sub>, Ir(piq)<sub>3</sub> and Flrpic are commercially available compounds, while Ir(Tpa-py)<sub>3</sub>, Ir(Cz-py)<sub>3</sub> and Ir(Cz-py)<sub>2</sub>(acac) are specially designed to test their conductivities with respect to the commercial compounds. Ir(ppy)<sub>3</sub> and Ir(piq)<sub>3</sub> employ phenylpyridines as the hole conducting units. Ir(Cz-py)<sub>3</sub> and Ir(Cz-py)<sub>2</sub>(acac) possess a carbazole moiety while Ir(Tpa-py)<sub>3</sub> possesses a triphenylamine moiety. Hole mobilities of these compounds were evaluated by TFT

technique. In addition, we selected three of the commercial materials, namely, Ir(ppy)<sub>3</sub>, Ir(piq)<sub>3</sub> and Flrpic, and doped these Ir compounds into 4,4'-*N,N'*-dicarbazole-biphenyl (CBP), which is a popular charge transporting host used in phosphorescent OLEDs [14], and observed how the hole mobilities change as the dopant concentration varies.

## 2. Experimental details

Ir(ppy)<sub>3</sub>, Ir(piq)<sub>3</sub> and Flrpic were obtained from Lumtec Inc. and were used as received. Ir(Tpa-py)<sub>3</sub>, Ir(Cz-py)<sub>3</sub> and Ir(Cz-py)<sub>2</sub>(acac) were synthesized and purified according to the procedures outlined in the literature [15–17]. TFT technique (top-contact configuration) was used to study the hole transporting properties of the neat or doped CBP films [18,19]. A thermally grown SiO<sub>2</sub> (~300 nm) on a p<sup>+</sup> Si wafer was used as the substrate. The substrate was cleaned by de-ionized water and acetone followed by the UV ozone treatment [20]. Then 100 nm of CBP neat film and doped CBP films were thermally evaporated onto the SiO<sub>2</sub> layer at a base pressure of 10<sup>-6</sup> torr. The deposition rate was controlled at 0.5 Å/s. Following the organic film, the patterned source (S) and drain (D) electrodes consisted of a thin layer (20 nm) of MoO<sub>x</sub> followed by 100 nm of gold thermally deposited through a shadow mask with channel length (L) and width (W) defined by 50 μm and 9 mm, respectively.

## 3. Results and discussions

Fig. 2 shows the TFT output characteristics of the neat films of CBP, Ir(ppy)<sub>3</sub>, Ir(piq)<sub>3</sub>, Ir(Tpa-py)<sub>3</sub>, Ir(Cz-py)<sub>3</sub> and Ir(Cz-py)<sub>2</sub>(acac) films at room temperature (292 K). They all have well-defined p-type TFT current–voltage characteristics. A clear linear region

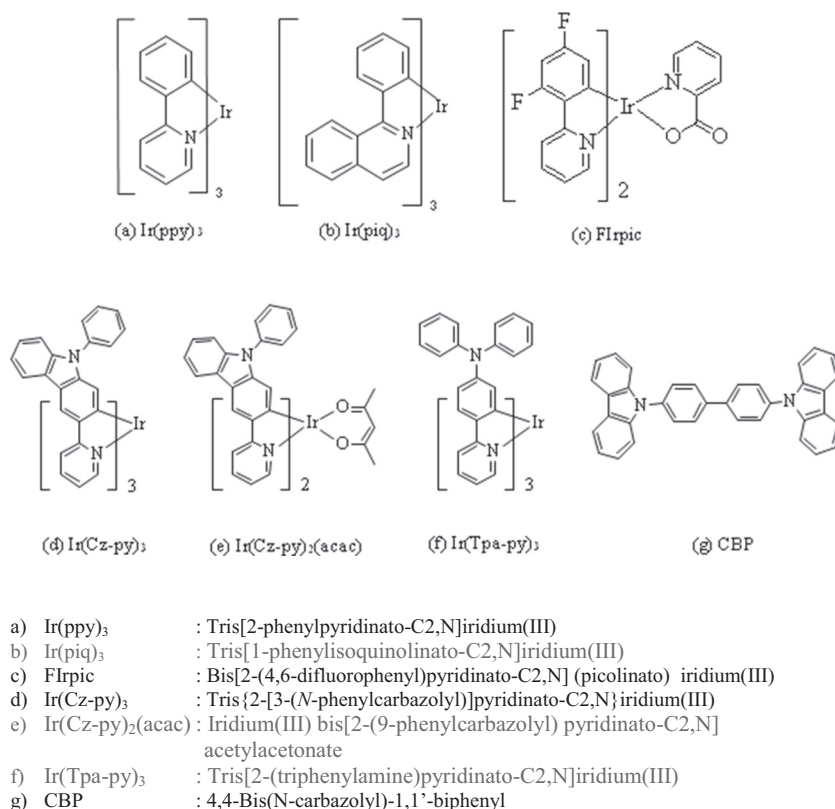


Fig. 1. Full names and chemical structures of Ir compounds for conductivity investigation.

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