# New iridium complex as high-efficiency red phosphorescent emitter in polymer light-emitting devices<sup>†</sup>

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A new heteroleptic iridium complex  $Ir(1-piq)_2pt$  with 1-phenylisoquinoline and 3-(pyridin-2'-yl)-1*H*-1,2,4-triazole was synthesized and characterized. The complex was incorporated into phosphorescent polymer light-emitting devices using polyhedral oligomeric silsesquioxaneterminated polyfluorene (PFO-poss) as a host polymer doped with 30% of electron transport materials 2-(4-biphenylyl)-5-(4-*tert*-butylphenyl)-1,3,4-oxadiazole (PBD). Red electrophosphorescence was observed with a peak emission at 605 nm. The highest-efficiency polymer light-emitting diode was achieved with PFO-poss doped with 2% Ir(1-piq)<sub>2</sub>pt. An external quantum efficiency of 10.4% and a luminous efficiency of 9.4 cd  $A^{-1}$  were obtained at 10.8 mA cm<sup>-2</sup>. These values were found to be 7.67% and 5.99 cd  $A^{-1}$  at 100 mA cm<sup>-2</sup>.

# Introduction

Organic/polymer light emitting diodes (O/PLEDs) have attracted considerable interest among academic and industrial communities because of their potential applications in full-color flat panel displays.<sup>1,2</sup> Great progress has been made mainly through the synthesis of efficient lumophores and the development of improved device structures.<sup>3–6</sup>

The strong spin–orbit coupling caused by heavy metal ions (Os, Ir, Pt) incorporated in the complexes results in efficient intersystem crossing from the singlet to the triplet excited state. These organometallic complexes are highly suitable for phosphorescent light emitting devices due to their relatively short excited state lifetime, high photoluminescence efficiencies and excellent color tunability. Mixing of the singlet and triplet excited states not only removes the spin-forbidden nature of the radiative relaxation of the triplet state but also significantly shortens the triplet state lifetime. Triplet–triplet annihilation is more effectively suppressed because of the shorter lifetime of the triplet-excited state. These devices implement efficient phosphorescent dopants as the light-emitting medium capable of harvesting light from both singlet and triplet excitons to reach an internal quantum efficiency of 100%.<sup>7,8</sup>

By optimizing the molecular structure of the dopants and the energy transfer process, high external and power efficiencies have been obtained from the green to the red spectral region.<sup>9–12</sup> Due to their extremely high efficiency and wavelength tunability over the entire visible spectrum, great efforts have been devoted to the design, synthesis and characterization of cyclometalated iridium complexes. It was found that the synthesis of homoleptic cyclometalated iridium

complexes was difficult and tedious.<sup>13,14</sup> Heteroleptic cyclometalated iridium complexes possess comparable properties and device performance.4,15 These complexes have two cyclometalated ligands and a single bidentate, monoanionic ancillary ligand. In general, the ancillary ligands are β-diketones. The emission color from the complex is dependent on the choice of cyclometalating ligand, ranging from blue to red. The power efficiency and external quantum efficiency of a device fabricated with Ir(piq)<sub>3</sub> as a dopant in a multilayer structure<sup>12</sup> are 8.0 lm  $W^{-1}$  and 10.3% at 100 cd m<sup>-2</sup> and 6.3 lm  $W^{-1}$  and 9.6% at 300 cd m<sup>-2</sup>. However, the condition for the synthesis of heteroleptic cyclometalated iridium complexes is much milder. Hughes and Bryce<sup>16</sup> and Jenekhe et al.<sup>17</sup> reviewed and pointed out that the high efficiency is related to the electron-transporting nature of the pt ancillary ligand. A pyrazolyl-borate ligand<sup>18</sup> and a triazolyl pyridine ligand<sup>19</sup> were reported to be ancillary ligands, which can be used to prepare "real blue" heteroleptic cyclometalated iridium complexes. PLEDs have the potential to be used for large area displays, which can be made from the solution. Ir(III) cyclometalated complexes are receiving great attention as efficient phosphor dopants in polymer matrices for applications in the area of organic light-emitting diode devices (OLEDs).<sup>20-23</sup> Gong et al. reported high-efficiency red emission of  $QE_{ext} = 5\%$  ph/el and LE = 7.2 cd A<sup>-1</sup> with the maximum of 600 nm by doping tris(2,5-bis-2'-(9',9'-dihexylfluorene)pyridine)iridium(III) [Ir(HFP)<sub>3</sub>] into PVK : PBD (40%).<sup>24</sup> The external quantum efficiencies of polymer light emitting diodes (PLEDs) based on the phosphorescent dye doped into the polymer host are still much lower than those of small molecule-based OLEDs. Our previous work on red polymer devices has involved the use of polymers PVK and PFO as the host materials doped with PBD and obtained saturated red phosphorescent PLEDs with external quantum efficiency up to 12%.25

In this paper, 1-phenylisoquinoline (1-piq) is chosen as the cyclometalating ligand, and an ancillary ligand 3-(pyridin-2'-yl)-1*H*-1,2,4-triazole (pt) is synthesized. A corresponding

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heteroleptic iridium complex from this ligand was synthesized and characterized. By using the new heteroleptic iridium complex as a guest and polyfluorene as a host, high-efficiency red phosphorescent polymer light-emitting devices were obtained. In comparison, we also synthesized a homoleptic iridium complex  $Ir(1-piq)_3$ . The devices doped with the homoleptic iridium complex are also demonstrated.

# Experimental

### Measurement and characterization

The <sup>1</sup>H NMR and <sup>13</sup>C NMR spectra were collected on a Bruker DRX 400 spectrometer in deuterated chloroform solution operating respectively at 400 or 100 MHz, with tetramethylsilane as reference. Elemental analyses were performed on a Vario EL elemental analysis instrument (Elementar Co.). EI-MS were recorded on a LCQ DECA XP Liquid Chromatograph-Mass Spectrometer (Thremo Group) and UV-visible absorption spectra were recorded on a HP 8453 UV-Vis spectrophotometer. Cyclic voltammetry was carried out on a CHI660A electrochemical workstation in a solution of tetrabutylammonium hexafluorophosphate (Bu<sub>4</sub>NPF<sub>6</sub>) (0.1 M) in dichloromethane at a scan rate of 10 mV s<sup>-1</sup> at room temperature under argon protection. A platinum electrode was used as the working electrode. A Pt wire was used as the counter electrode, and a saturated calomel electrode was used as the reference electrode.

## Syntheses

**Reagents.** All reagents and solvents were obtained from Aldrich, Acros, and TCI Chemical Co. and used as received. Tetrakis(triphenylphosphine)palladium was stored in an atmosphere of dry argon. The ligands 1-phenylisoquinoline  $(1-piq)^{26}$  and 3-(pyridin-2'-yl)-1*H*-1,2,4-triazole  $(pt)^{27}$  were synthesized according to the literature.

**N-Phenethyl benzamide** (1). Benzoyl chloride(28.10 g, 0.20 mol) was dropped into a mixture of phenethylamine (24.20 g, 0.20 mol) and triethylamine (20.20 g, 0.2 mol) in 300 mL dichloromethane. The mixture was stirred at room temperature for 4 hours. After being washed with water, 5% hydrochloric acid and water, the organic layer was dried with anhydrous magnesium sulfate. The product obtained was purified by recrystallization from ethyl acetate to form white crystals of **3** (37.3 g, 83.3%). GC-MS (225, M<sup>+</sup>).

**l-Phenyl-3,4-dihydroisoquinoline (2).** 22.51 g (0.1 mol) of **1** were dissolved in 40 mL of xylene.  $P_2O_5$  (28.60 g, 0.1 mol) and POCl<sub>3</sub> (80 mL) were added *via* stirring, and the mixture was heated to reflux and held at that temperature for 3 hours. Then the solution was allowed to cool to room temperature. The solvent was decanted, and the residual solid was carefully triturated to neutrality with 10% sodium hydroxide solution. The resultant aqueous mixture was dried with anhydrous magnesium sulfate. Evaporating the solvent formed a brown–yellow oily crude product. Further purification by silica gel column using ethyl acetate–dichloromethane (1 : 10)

as an elute formed a pale yellow oil (17.11g, 82.4%). <sup>1</sup>H NMR (CDCl<sub>3</sub>, 400 MHz):  $\delta_{\rm H}$ (ppm) 7.60–7.58 (dd, 2 H), 7.41–7.40 (m, 4 H), 7.26–7.21 (m, 3 H), 3.86–3.82 (t, 2 H), 2.80–2.77 (t, 2 H). GC-MS: *m*/*z* 207 (M<sup>+</sup>).

**I-Phenylisoquinoline (3).** 17.01 g (0.082 mol) of **2** were dissolved in 50 mL 1,2,4-trimethylbenzene, and 1.75 g of 10% Pd/C (2% mol) were added, and the mixture refluxed for 3 h at 190 °C in N<sub>2</sub>. The black power was filtered and washed with dichloromethane several times. Volatiles were removed to leave a yellow liquid, which was stored at 4 °C for 1 h, with a yellow solid being separated out. The product was purified by recrystallization from petroleum ether to form white crystals (12.30 g, 73%). <sup>1</sup>H NMR (CDCl<sub>3</sub>, 400 MHz): δ<sub>H</sub>(ppm) 8.60–8.59 (d, 1 H), 8.10–8.08 (d, 1 H), 7.87–7.85 (d, 1 H), 7.70–7.67 (m, 3 H), 7.65–7.62 (t, 1 H), 7.54–7.46 (m, 4 H). GC-MS: *m*/*z* 205 (M<sup>+</sup>).

**3-(Pyridin-2-yl)-1***H***-1,2,4-triazole (4).** 5.00 g of 2-cyanopyridine were added to 20 ml of methanol and then added to 10 ml of a methanol solution of sodium methoxide (25 wt%), and the resulting solution was stirred at a room temperature for 1 hour. 5 ml of acetic acid were added to the solution dropwise, and 10 g of formylhydrazide were added and stirred at room temperature for 1 hour to precipitate a white crystal. The crystal was separated *via* filtration, 50 ml of toluene was added into it, and the resulting mixture was stirred under reflux for 3 hours. The mixture was then cooled to room temperature and the solvent was removed to obtain a white solid (4.01 g, 57.0%). <sup>1</sup>H NMR (CDCl<sub>3</sub>, 400 MHz):  $\delta_{\rm H}$ (ppm) 15–14 (br s, 1 H), 8.70–8.68 (d, 1 H), 8.27 (s, 1 H), 8.10–8.08 (d, 1 H), 7.98– 7.94 (m, 1 H), 7.50–7.47 (m, 1 H).

[Ir(1-piq)<sub>2</sub>Cl]<sub>2</sub>, tetrakis(l-phenylisoquinoline-*C*2,*N'*)( $\mu$ -chlorobridged)diiridium(III). Iridium trichloride hydrate (1.318 g, 3.8 mmol) was combined with 1.915 g (9.4 mmol) of 3, dissolved in a mixture of 20 mL 2-ethoxyethanol and water (3 : 1), and refluxed for 24 h in N<sub>2</sub>. The solution was cooled to room temperature, and the deep-red precipitate was collected on a glass filter frit. The precipitate was washed with 95% ethanol and ethyl ether to form a dark-red power (2.134 g, 90%), which was used directly for the next step without purification.<sup>20</sup>

Ir(1-piq)<sub>3</sub>, tris(1-phenylisoquinoline-C2,N')iridium(III). [Ir(1piq)<sub>2</sub>Cl]<sub>2</sub> (0.508 g, 0.4 mmol), **3** (0.328 g, 1.6 mmol), acetyl acetone (0.081 g, 0.8 mmol) and triethylamine ((0.080 g, 0.8 mmol) were dissolved in 50 mL of glycol. The solution was refluxed under nitrogen for 48 h. After cooling the reaction mixture to room temperature, 10 mL of 1 M aqueous hydrochloric acid was added to the solution, resulting in precipitation of the product. Then the product was filtered, washed with water and ethyl ether, and dried at 100 °C in vacuum. The purification of the product was carried out by silica gel column chromatography with CH<sub>2</sub>Cl<sub>2</sub> as an eluent to obtain a red powder (0.193 g, 30%). <sup>1</sup>H NMR (CDCl<sub>3</sub>, 400 MHz):  $\delta_{\rm H}$ (ppm) 8.94 (m, 3 H), 8.18 (d, 3 H), 7.71 (m, 3 H), 7.62 (m, 6 H), 7.33 (d, 3 H), 7.09 (d, 3 H), 6.94–6.99 (m, 6 H), 6.84 (t, 3 H). Anal. Calcd for C<sub>45</sub>H<sub>30</sub>IrN<sub>3</sub>: C, 67.14, H, 3.76, N, 5.22. Found: C, 67.24, H, 3.59, N, 5.18%. EIMS: m/z 805 (M + 1)<sup>+</sup>.

 $Ir(1-piq)_2pt$ , bis(l-phenylisoquinoline-C2, N')iridium(III)(3-(pyridin-2'-yl)-1,2,4-triazole). The solution of 4 (0.206 g, 1.4 mmol) and sodium methoxide (0.088 g, 1.6 mmol) in anhydrous ethanol was heated to 50 °C for 1 hour. A mixture of [Ir(1-piq)<sub>2</sub>Cl]<sub>2</sub> 0.502 g (0.4 mmol) in 10 mL dichloromethane was dropped into the reaction solution. Then the reacting mixture was refluxed for 3 hours and cooled down to room temperature. 50 mL of water and 30 mL of dichloromethane were added. The organic phase was separated and washed with water, and was dried with anhydrous magnesium sulfate. Further purification by silica gel column chromatography using acetone–dichloromethane (1:1) as an eluent gave red power (0.302 g, 52%). <sup>1</sup>H NMR (CDCl<sub>3</sub>, 400 MHz):  $\delta$ (ppm) 8.97-8.95 (t, 1 H), 8.92-8.90 (t, 1 H), 8.45 (s, 1 H), 8.25-8.21 (t, 2 H), 8.17-8.16 (d, 1 H), 7.84-7.79 (m, 3 H), 7.70-7.67 (m, 4 H), 7.62-7.55 (d, 1 H), 7.41-7.40 (d, 1 H), 7.25-7.24 (d, 1 H), 7.18-7.16 (d, 1 H), 7.06-7.02 (m, 3 H), 6.99-6.79 (m, 2 H), 6.42-6.40 (d, 1 H), 6.39–6.37 (d, 1 H). <sup>13</sup>C NMR (CDCl<sub>3</sub>, 100 MHz): δ(ppm) 169.52, 169.27, 162.03, 157.92, 154.64, 152.74, 152.06, 149.55, 146.48, 145.16, 142.14, 140.75, 138.13, 136.85, 136.50, 132.88, 132.24, 130.96, 130.84, 130.28, 130.04, 127.98, 127.85, 127.36, 127.24, 126.98, 126.85, 126.38, 126.14, 124.17, 121.33, 121.18, 121.08, 120.37. Anal. Calcd for C<sub>37</sub>H<sub>25</sub>IrN<sub>6</sub>: C, 59.58, H, 3.39, N, 11.27. Found: C, 59.51, H, 3.50, N, 11.12%. EIMS: m/z 747 (M + 1)<sup>+</sup>.

### Device fabrication and characterization

The molecular structures of the compounds involved in this device study are shown in Scheme 2. PFO (poss) was purchased from American Dye Sources Inc. PBD was purchased



lr(1-piq)<sub>2</sub>pt

Scheme 1 Synthetic route for iridium complexes.



Scheme 2 Molecular structures used for device fabrication.

from Aldrich. Device configuration is ITO/PEDOT/PVK/ blends/Ba/Al. A 40 nm PVK film was placed between the ITO/PEDOT and the emitting layer to facilitate the hole injection. A thin layer of Ba with a 200 nm Al capping layer was used as the cathode. The thickness of the Ir complex– polymer blend was 70–80 nm in all cases.

The fabrication of electrophosphorescent devices was carried out by following the standard procedure below. A 70 nm thick layer of poly(ethylenedioxythiophene) : poly(styrene sulfonic acid) (PEDOT : PSS, Baytron P 4083, purchased from Bayer AG) was spin cast onto pre-cleaned ITO-glass substrates. Then, a 40 nm thick layer of PVK was spin cast on the top of PEDOT. A mixture of the iridium complex with (PFO(poss) + PBD) was spin cast from the solution in chlorobenzene. A profilometer (Tencor Alfa-Step 500) was used to determine the thickness of the films. Layer thickness during thermal deposition was monitored upon deposition by using a crystal thickness monitor (Sycon). Device fabrication was carried out in a controlled dry-box (Vacuum Atmosphere Co.) in N2 circulation. Current density (I)-voltage (V)-luminance (L) data were collected using a Keithley 236 source measurement unit and a calibrated silicon photodiode. Absolute PL efficiencies were measured in an integrating sphere (IS-080, Labsphere) under the 325 nm line of a HeCd laser. External EL quantum efficiencies (EQE) were obtained by measuring thhe total light output in all directions in an integrating sphere (IS-080, Labsphere). The luminance (cd  $m^{-2}$ ) was measured by a Si photodiode, and calibrated by using a PR-705 SpectraScan Spectrophotometer (Photo Research). Photoluminescence (PL) spectra and electroluminescence (EL) spectra were recorded using a CCD spectrophotometer (Instaspec 4, Oriel).

# **Results and discussion**

# Syntheses of ligands and iridium complexes

The cyclometalating ligand (1-piq) and the ancillary ligand (pt) were synthesized according to the literature.<sup>24,25</sup> Homoleptic complex  $Ir(1-piq)_3$  was prepared by the reaction of the dimer with an excess of 1-piq in glycol under reflux. Following the improved method, a slightly better yield and milder conditions were created. The yield of this reaction was reported to be  $27\%^{12}$  using tris(acetylacetonato)iridium,  $Ir(acac)_3$ , with an excess of 1-piq in glycerol under reflux.



**Fig. 1** Absorption of Ir complex neat film and PL of host (PFO-PBD (30%)).

Since the ancillary ligand **4** possesses two possible coordinated N atoms, there may arise two different iridium complexes, a charged complex with a protonated ligand and a neutral complex with a deprotonated one; only the latter is our target product. We first deprotonated pt with sodium methoxide before mixing it with the chloride-bridged iridium dimer in order to preferably obtain the neutral complex. The yield obtained by this method is significantly enhanced, reaching 52%.

Fig. 1 shows the normalized absorption of neat iridium complexes and their photoluminescence (PL) spectra in thin films blended into PFO(poss)-PBD (30%) host on quartz substrates. The intense absorption band around 250-350 nm can be assigned to a spin allowed  $\pi - \pi^*$  transition on the cyclometalated ligands, and the broad absorption band with lower energy (450–500 nm) is typical of spin-allowed metal to ligand charge-transfer <sup>1</sup>MLCT and <sup>3</sup>MLCT transitions, as described previously.<sup>13</sup> Table 1 summarizes the absorption bands of the complexes. The 450 nm peak for Ir(1-piq)<sub>2</sub>pt is blue-shifted compared with that at 486 nm for Ir(1-piq)<sub>3</sub>. This indicates that the introduction of the 1,2,4-triazole group into the ancillary ligand has an influence on the absorption properties of the corresponding iridium complex. There is good overlap between the fluorescence spectrum of PFO-PBD 30% and the metal-ligand charge transfer MLCT absorption band of iridium complexes. This overlap should enable efficient Förester energy transfer from the singlet-excited state in the host to the MLCT band of the guest. Fast intersystem crossing to the triplet state of the subsequent emission from this state is a built-in feature.

The electrochemical properties of the complexes were studied. CV (cyclic voltammetry) scans of  $Ir(1-piq)_2pt$  and  $Ir(1-piq)_3$  are shown in Fig. 2. For  $Ir(1-piq)_2pt$ , the



Fig. 2 Cyclic voltammograms of Ir complexes: (a)  $Ir(1-piq)_2pt$ ; (b)  $Ir(1-piq)_3$  (scan rate: 10 mV s<sup>-1</sup>, solvent: dichloromethane).

quasi-reversible oxidation and reduction waves were recorded at 0.91 V and -1.39 V, respectively. Similarly, for Ir(1-piq)<sub>3</sub>, we recorded an oxidation wave at 0.59 V and a reduction wave at -1.43 V. The HOMO and LUMO levels were estimated from the oxidation potential according to an empirical formula.<sup>28</sup>

The optical band gap is estimated from the onset of the absorption edge (MLCT) of the thin film. All the data are listed in Table 1. CV data indicate that the replacement of a piq ligand by pt leads to a significant lowering of the HOMO level towards vacuum level. At the same time, the energy gap from the electrochemically determined value is much larger than that of the optical band gap estimated above. This is probably due to the interface dipole effect on modifying the energy barriers between electrodes and organic materials.<sup>29</sup>

#### **Electroluminescent properties**

Fig. 3(a) shows the normalized electroluminescence (EL) spectra of Ir(1-piq)<sub>2</sub>pt-doped PFO(poss)-PBD(30%) devices with different dopant concentrations. EL emission is

Table 1 Physical property of the complexes

Compound	Absorbance/nm <sup>a</sup>	Absorbance/nm <sup>b</sup>	HOMO <sup>c</sup> /eV	LUMO <sup>c</sup> /eV	Energy gap/eV	$E_{\rm opt}^{\ \ d}/{\rm eV}$
Ir(1-piq) <sub>2</sub> pt Ir(1-piq) <sub>3</sub>	236, 290, 341, 451 230, 280, 423	307, 357, 449 252, 303, 350, 454, 486	-5.31 -4.99	-2.99 -2.97	2.32 2.02	2.09 2.05
<sup><i>a</i></sup> CH <sub>2</sub> Cl <sub>2</sub> solution. <sup><i>b</i></sup> Neat film from CH <sub>2</sub> Cl <sub>2</sub> solution. <sup><i>c</i></sup> Calculated from the empirical formulae $E_{\text{HOMO}} = -e(E_{\text{ox}} + 4.4)$ , $E_{\text{LUMO}} = -e(E_{\text{re}} + 4.4)$ .						



Fig. 3 (a) EL spectra of the devices from  $Ir(1-piq)_2pt$  doped into PFO(poss)-PBD in different doping concentrations; (b) comparison of EL and PL spectra of devices doped with 2%  $Ir(1-piq)_2pt$ .

dominated by the  $Ir(1-piq)_2pt$  emission peak at 605 nm. No host (PFO (poss)-PBD) emission was observed even at dopant concentration as low as 2% (w/w). In Fig. 3(b), we compare EL and PL spectra from the film of 2%  $Ir(1-piq)_2pt$ -doped PFO(poss)-PBD (30%). We note that the photoluminescence profile is identical with the EL emission and consists exclusively of an emission which has its peak at 605 nm and results from the triplet emission due to  $Ir(1-piq)_2pt$ . The results indicate that energy transfer from host singlets to the  $Ir(1-piq)_2pt$  complex is very efficient for  $Ir(1-piq)_2pt$ -doped PFO(poss)-PBD (30%).<sup>30</sup>

PL spectra of  $Ir(1-piq)_3$  (Fig. 4b) show a significant contribution from the host at low dopant concentrations, although the EL emission profiles of  $Ir(1-piq)_3$  devices show no host emission from low dopant concentration (2 wt%) (Fig. 4). It seems to indicate that energy transfer from the PFO host to  $Ir(1-piq)_3$  complex is less efficient than that to the  $Ir(1-piq)_2pt$  complex.



Fig. 4 (a) EL spectra of the devices from  $Ir(1-piq)_3$  doped into PFO(poss)-PBD in different doping concentrations; (b) comparison of EL and PL spectra of devices doped with 2%  $Ir(1-piq)_3$ .



Fig. 5 Luminance and external quantum efficiency of devices from 2% Ir complexes doped into PFO(poss)-PBD: (a) Ir(1-piq)<sub>2</sub>pt; (b) Ir(1-piq)<sub>3</sub>.

Fig. 5 shows the luminance and external quantum efficiency vs. current density characteristics of devices fabricated with 2% Ir(1-piq)<sub>2</sub>pt and Ir(1-piq)<sub>3</sub> doped into the PFO host. With the same device configuration, the Ir(1-piq)<sub>2</sub>pt device (Fig. 5a) shows much higher efficiency than the Ir(1-piq)<sub>3</sub> device (Fig. 5b).

An external quantum efficiency of 10.4% and a luminous efficiency of 9.4 cd  $A^{-1}$  with luminance of 330 cd m<sup>-2</sup> was achieved at 10.8 mA cm<sup>-2</sup> for Ir(1-piq)<sub>2</sub>pt devices, among the highest for red-emitting polymer phosphorescent devices. Device performance slightly decreases with increasing current density and remains as high as 7.7% and 6.0 cd  $A^{-1}$  at a current density of 100 mA cm<sup>-2</sup>. The device with Ir(1-piq)<sub>3</sub> complexes shows much less external quantum efficiency, as reported previously for devices from this complex. The highest efficiency of 3.9% at 11 mA cm<sup>-2</sup> was reached from the device doped with 2% complex. The operating voltage for Ir(1-piq)<sub>3</sub> is slightly less than that for the Ir(1-piq)<sub>2</sub>pt device. The high efficiency obtained is probably due to the fact that the ancillary ligand including the 1,2,4-triazole group affects the electronic structure because of its electro-transporting nature.

# Conclusion

A new heteroleptic iridium complex Ir(1-piq)<sub>2</sub>pt was synthesized and characterized. High-efficiency red phosphorescent polymer light-emitting devices based on the iridium complex were also demonstrated. The results indicate that the design of chemical structure of the ligand is important for the device performance.

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