# Luminescence

# Sublimable Cationic Iridium(III) Complexes with 1,10-Phenanthroline Derivatives as Ancillary Ligands for Highly Efficient and Polychromic Electroluminescence

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**Abstract:** A novel series of four sublimable cationic iridium(III) complexes have been prepared with 1,10-phenanthroline derivatives as ancillary ligands and the same negative counter-ion, tetrakis[3,5-bis(trifluoromethyl)phenyl]borate, which has a large steric hindrance and widely dispersed charges, thereby increasing the ionic radii, reducing the electrostatic interaction, and thus improving the volatility. Their structural, photophysical, electrochemical, and thermal properties have been fully characterized. Upon excitation, these

### Introduction

Huge advances in the development of efficient luminescent materials have been the driving force behind the use of organic light-emitting diodes (OLEDs) in full-color flat-panel display technology and lighting sources.<sup>[1]</sup> Heavy-metal compounds, such as ruthenium(II),<sup>[2]</sup> osmium(II),<sup>[3]</sup> iridium(III),<sup>[4,5]</sup> and platinum(II)<sup>[6,7]</sup> complexes, have received considerable attention as superior phosphorescent emitters at room temperature owing to the harvesting of electrogenerated singlet and triplet excitons, with nearly 100% internal guantum efficiency having been achieved. In particular, cyclometalated iridium(III) complexes are by far the most outstanding and versatile family of triplet emitters for OLEDs, which in most cases are neutral.[8-14] In contrast, cationic iridium(III) complexes have unique features, such as facile molecular design and synthesis, excellent redox stability, and highly efficient emission of virtually all colors,<sup>[15,16]</sup> and have emerged as potential phosphorescent materials for OLEDs.[17]

In general, a cationic iridium(III) complex always contains 1) a coordinated iridium(III) cation with the iridium center surrounded by two cyclometalating (CN) ligands and two monodentate or one bidentate neutral chelating ligand and 2) a negative counter-ion to maintain neutrality, for example, tetrafluoroborate ( $BF_4^{-}$ ),<sup>[18]</sup> hexafluorophosphate ( $PF_6^{-}$ ),<sup>[19-21]</sup> or organic anions.<sup>[22,23]</sup> Efforts have focused on developing robust

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Supporting information for this article can be found under http://dx.doi.org/10.1002/chem.201602646. compounds show polychromic emission varying from green to orange in solution, which are blue-shifted in the solid state to different extents due to  $\pi$ - $\pi$  conjugate effects in the ancillary ligands and the resulting molecular aggregation. OLEDs fabricated by vacuum evaporation deposition demonstrated desirable device performance with high efficiency and brightness, exhibiting various electroluminescent colors dependent upon doping concentration.

cationic iridium(III) complexes with tunable luminescence by the chemical modification or molecular design of ligands. Substituted 2-phenylpyridine<sup>[17, 19, 24]</sup> or 1-phenylpyrazole<sup>[25-27]</sup> are the most popular CN ligands, and various neutral ancillary ligands have been exploited, such as bipyridine,<sup>[28-31]</sup> imidazole,<sup>[32, 33]</sup> pyrazole,<sup>[34, 35]</sup> triazole,<sup>[36, 37]</sup> and oxadiazole<sup>[38]</sup> derivatives, which have led to a huge variety of cationic iridium(III) complexes with a wide spectral range of emission from deepblue to near-infrared.

However, the previously reported cationic iridium(III) complexes have seldom been sublimable due to their ionic nature and low vapor pressure, which has severely restricted their application in state-of-the-art OLEDs fabricated by vacuum evaporation deposition. Very recently we demonstrated a feasible strategy for achieving evaporable cationic iridium(III) complexes by introducing negative counter-ions with large steric hindrance and widely dispersed charges, which improves the volatility of the complexes and unlocks the potential of ionic materials for use even in vapor-processed devices.<sup>[39]</sup>

In this work we employed 1,10-phenanthroline derivatives as ancillary ligands and developed a novel series of four sublimable cationic iridium(III) complexes with emission ranging from green to orange. Their photophysical properties, electrochemical behavior, and thermal stability have been fully investigated. Finally, we succeeded in the preparation of OLEDs by the vacuum evaporation deposition of these complexes, achieving highly efficient electroluminescence with a maximum current efficiency of  $16.32 \text{ cd A}^{-1}$  and a brightness of over  $27.1 \times 10^3 \text{ cd m}^{-2}$  with polychromic emission dependent on doping concentration. Our results show that the sublimable cationic iridium(III) complexes feature excellent photo- and electroluminescent properties with emission tunable over a wide-range of colors, and thus are promising phosphorescent emitters for

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use in OLEDs and for creating a novel material system with potential to improve device performance even beyond that reported here.

## **Results and Discussion**

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#### Synthesis and structural characterization

We designed and synthesized four cationic iridium(III) complexes with 1,10-phenanthroline derivatives as ancillary ligands, namely  $[Ir(ppy)_2(dmphen)][BArF_{24}]$  (1),  $[Ir(ppy)_2(dmphen)]$  $[BArF_{24}]$  (2),  $[Ir(ppy)_2(phen)][BArF_{24}]$  (3), and  $[Ir(ppy)_2(bphen)]$  $[BArF_{24}]$  (4, Scheme 1; ppy=2-phenylpyridine, dmphen=2,9-dimethyl-1,10-phenanthroline, dmbphen = 2,9-dimethyl-4,7-diphenyl-1,10-phenanthroline (also named 2,9-dimethyl-batho-



Scheme 1. Chemical structures of 1-4.

phenanthroline), phen = 1,10-phenanthroline, and bphen = 4,7diphenyl-1,10-phenanthroline (also named bathophenanthroline)). We employed [BArF<sub>24</sub>]<sup>-</sup> (tetrakis[3,5-bis(trifluoromethyl)phenyl]borate) as the negative counter-ion, which has a large steric hindrance and widely dispersed charges that effectively increase the ionic radii, reduce the electrostatic interaction, and thus dramatically improve the volatility of 1-4.

Complexes 1-4 were synthesized according to the established three-step procedure used for the preparation of cationic iridium(III) complexes (see Scheme S1 in the Supporting Information). First, the commercially available metal source,  $IrCl_3 \cdot nH_2O$ , was treated with an approximate 50% excess of the ppy ligand to form the cyclometalated iridium(III) dichlorobridged dimer, [Ir(ppy)<sub>2</sub>Cl]<sub>2</sub>, which was then treated with the ancillary ligand (dmphen, dmbphen, phen, or bphen) to produce the corresponding cationic iridium(III) mononuclear complex in high yields as chloride salts. Subsequently, the chloride ion (Cl<sup>-</sup>) was replaced by  $[BArF_{24}]^-$  through a very facile ion-exchange reaction at room temperature. Next, we purified the crude products by column chromatography on silica gel (200-300 mesh) with CH<sub>2</sub>Cl<sub>2</sub> as eluent, and fully characterized them by <sup>1</sup>H and <sup>19</sup>F NMR spectroscopy, ESI mass spectrometry, and elemental analysis (see the Experimental Section).

To further confirm the structural features, we grew single crystals of 1 and 2 from acetone/methanol solution and deter-

(b)

mined their structures by X-ray diffraction crystallography (see Figure 1). In agreement with previous reports,<sup>[40,41]</sup> the coordi-



Figure 1. Single-crystal structures of: a) 1, and b) 2. Thermal ellipsoids are drawn at the 30% probability level. Solvent molecules and hydrogen atoms have been omitted for clarity. The unlabeled atoms are carbon atoms.

nated iridium(III) cations 1 and 2 show distorted octahedral geometries around the iridium center with the two cyclometalating ppy ligands adopting C,C-cis,N,N-trans configurations, and the [BArF<sub>24</sub>]<sup>-</sup> counter-ion exhibits a regular tetrahedron geometry around the boron atom. However, single crystals of 3 and 4 could not be obtained.

#### **Physicochemical properties**

2

The absorption spectra of 1-4 in acetonitrile solution are depicted in Figure 2. In the UV region, the intense absorption bands between 230 and 330 nm correspond to spin-allowed LC (ligand-centered)  $\pi^{-}\pi^{*}$  transitions from the ppy ligands. The quite weak and inconspicuous absorption bands from 350 nm extending to 400 nm have mainly been attributed to <sup>1</sup>MLCT (metal-to-ligand charge transfer), <sup>1</sup>LLCT (ligand-to-ligand charge transfer), <sup>3</sup>MLCT, <sup>3</sup>LLCT, and LC  ${}^{3}\pi \rightarrow \pi^{*}$  transitions. The LLCT transitions have been ascribed to the promotion of electrons from the phenyl groups of the ppy ligands to the phenanthroline-type ancillary ligands. Owing to the strong spinorbit coupling induced by the heavy iridium atom, the spinforbidden  $^3\text{MLCT}$ ,  $^3\text{LLCT}$ , and LC  $^3\pi{\rightarrow}\pi^*$  transitions also have significant intensity.[42,43]

Upon excitation ( $\lambda_{ex} = 380$  nm), complexes **1–4** show polychromic photoluminescence (PL) varying from green to orange

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(a)



Figure 2. Absorption spectra of 1-4 in CH<sub>3</sub>CN solution. Inset shows the normalized absorbance in the region 360-400 nm.

in solution. As shown in Table 1, the peak wavelengths of 1 and 2 are about 40 nm shorter than those of 3 and 4, respectively, due to the introduction of the electron-donating methyl groups into the phenanthroline-type ancillary ligands. In comparison with 1 and 3, the PL spectra of 2 and 4, respectively, are red-shifted by 10 nm, probably because of the intramolecular strong  $\pi$ - $\pi$  conjugation between the pendant phenyl groups and the phenanthroline-type ancillary ligands. On the other hand, the pendant phenyl groups also cause intermolecular  $\pi$ - $\pi$  conjugation effects and therefore greater molecular aggregation in 2 and 4, thereby leading to lower photoluminescence quantum yields (PLQYs) than observed for 1 and 3.

Figure 3 shows the PL spectra of 1–4 at different concentrations in various solvents, namely acetonitrile (CH<sub>3</sub>CN), tetrahydrofuran (THF), and dichloromethane (CH<sub>2</sub>Cl<sub>2</sub>). The structureless and broad spectra of 1–4 indicate that their emissive excited states have much more <sup>3</sup>MLCT or <sup>3</sup>LLCT than LC <sup>3</sup> $\pi \rightarrow \pi^*$ character.<sup>[44,45]</sup> We can also see that the least polar solvent



Figure 3. PL spectra of 1–4 at concentrations of: a)  $10^{-3}$ , and b)  $10^{-5}\, M$  in CH\_3CN, THF, and CH\_2Cl\_2, respectively.

 $(CH_2CI_2)$  causes a clear blue shift of the PL spectra, probably because it is less effective at stabilizing the polar excited states of these emitters. The peak wavelengths of **1** in  $10^{-3}$  M CH<sub>3</sub>CN, THF, and CH<sub>2</sub>CI<sub>2</sub> solution are located at 547, 542, and 533 nm, and are blue-shifted to 539, 536, and 528 nm in more dilute

| Table 1   | Table 1. Photophysical properties, electrochemical behavior and thermal stability of 1–4. |   |   |             |  |             |  |               |   |  |  |  |  |
|---|---|---|---|-------------|--|-------------|--|---------------|---|--|--|--|--|
| Absorption<br>$\lambda_{abs} \text{ [nm]}(\varepsilon \text{ [x 10}^4 \text{ m}^{-1} \text{ cm}^{-1} \text{])}^{[a]}$ |   | Emission in different solvents $\lambda_{\rm PL} \; [\rm nm] \; (10^{-5} \; {\rm m})^{\rm (b)} \; \; \lambda_{\rm PL} \; [\rm nm] \; (10^{-3} \; {\rm m})^{\rm (b)} \; \; \varphi \; (\tau \; [\mu s])^{\rm (c)}$ |   |             | Emission in solid states $\lambda_{PL} \; [nm]^{[d]} \; \; \varphi \; (\tau \; [\mu s])^{[e]}$ |             | $\begin{array}{c} \text{Redox} \\ E_{\text{ox}} \left[ V \right] \left( E_{\text{HOMO}} \right)^{[f]}  E_{\text{red}} \left[ V \right] \left( E_{\text{LUMO}} \right)^{[f]} \end{array}$ |               | Δ7 <sub>5%</sub><br>[°C] <sup>[g]</sup> |  |  |  |  |
| 1   | 269 (5.28)<br>367 (0.56)  | 539 (CH₃CN)<br>536 (THF)<br>528 (CH₂Cl₂)  | 547 (CH₃CN)<br>542 (THF)<br>533 (CH₂Cl₂)  | 0.34 (0.89) | 522 (neat film)<br>513 (PMMA)  | 0.34 (0.96) | 0.94 (-5.74)   | -1.92 (-2.88) | 320                                     |  |  |  |  |
| 2   | 254 (5.87)<br>374 (0.97)  | 553 (CH <sub>3</sub> CN)<br>549 (THF)<br>539 (CH <sub>2</sub> Cl <sub>2</sub> )   | 559 (CH <sub>3</sub> CN)<br>555 (THF)<br>545 (CH <sub>2</sub> Cl <sub>2</sub> ) | 0.28 (3.47) | 539 (neat film)<br>522 (PMMA)  | 0.33 (1.49) | 0.94 (-5.74)   | -1.93 (-2.87) | 362                                     |  |  |  |  |
| 3   | 267 (5.79)<br>369 (0.69)  | 583 (CH <sub>3</sub> CN)<br>581 (THF)<br>569 (CH <sub>2</sub> Cl <sub>2</sub> )   | 589 (CH <sub>3</sub> CN)<br>585 (THF)<br>574 (CH <sub>2</sub> Cl <sub>2</sub> ) | 0.36 (0.69) | 550 (neat film)<br>537 (PMMA)  | 0.58 (0.91) | 0.86 (-5.66)   | -1.86 (-2.94) | 356                                     |  |  |  |  |
| 4   | 270 (5.98)<br>369 (1.25)  | 593 (CH <sub>3</sub> CN)<br>588 (THF)<br>576 (CH <sub>2</sub> Cl <sub>2</sub> )   | 599 (CH <sub>3</sub> CN)<br>595 (THF)<br>580 (CH <sub>2</sub> Cl <sub>2</sub> ) | 0.30 (0.82) | 566 (neat film)<br>550 (PMMA)  | 0.53 (0.88) | 0.86 (-5.66)   | -1.85 (-2.95) | 356                                     |  |  |  |  |

[a] In CH<sub>3</sub>CN solution ( $10^{-5}$  m),  $\varepsilon$  denotes the molar extinction coefficient. [b] PL emission in different solvents at concentrations of  $10^{-5}$  or  $10^{-3}$  m. [c] In nitrogen-saturated CH<sub>3</sub>CN solution ( $10^{-5}$  m);  $\varphi$  measured versus quinine hydrogen sulfate with  $\varphi_{reference} = 0.545$  in 1 m H<sub>2</sub>SO<sub>4</sub> ( $10^{-5}$  m). [d] PL wavelength in neat film or 5 wt% doped PMMA film, about 100 nm thick prepared by spin coating from 1,2-dichloroethane. [e] PLQYs measured in neat film. [f] In degassed DMF solution,  $E_{HOMO}$  is the energy of the HOMO and  $E_{LUMO}$  is the energy of the LUMO. [g] The temperature of 5% weight reduction measured under a flow of dry nitrogen gas at a heating rate of  $10^{\circ}$ Cmin<sup>-1</sup>.

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solution  $(10^{-5} \,\text{m})$ , respectively, due to reduced molecular aggregation. Analogous phenomena are also found in the PL spectra of **2–4**, as tabulated in Table 1.

As depicted in Figure 4, in a 5 wt% doped poly(methyl methacrylate) (PMMA) film, 1-4 clearly show shorter PL wave-



Figure 4. PL spectra of 1–4 in neat film and 5 wt %<sup>-1</sup> doped PMMA film.

lengths of 513, 522, 537, and 550 nm, respectively, owing to the lower polarity of PMMA compared with the solvent molecules. Compared with those in PMMA film, the PL spectra of 1-4 in neat film exhibit bathochromic shifts; this is because the coordinated iridium(III) cations and negative counter-ions are separated in 5 wt% doped PMMA film, but in close proximity and bonded to each other in neat film leading to a distinct molecular aggregation. Complex 1 shows green phosphorescence with a peak wavelength at 513 nm in 5 wt% doped PMMA film, which is red-shifted to 522 nm in neat film (Table 1). Similarly, the peak wavelengths for 2-4 in PMMA film are in the range 522-550 nm, and are bathochromically shifted to 539-566 nm in neat film. Note that the PLQYs of 2 and 4 are a little smaller than those of 1 or 3 in neat film, respectively, which also indicates stronger intermolecular  $\pi$ - $\pi$  conjugation effects, although overall the molecular aggregation and concentration quenching are effectively reduced by the weak intermolecular interaction resulting from the large steric hindrance of the [BArF<sub>24</sub>]<sup>-</sup> counter-ion.<sup>[46]</sup> Interestingly, the lifetimes of 1, 3, and 4 are shorter than 1 µs both in nitrogen-saturated CH<sub>3</sub>CN solution and in neat film, whereas the lifetimes of **2** are quite long, that is, 3.47  $\mu$ s in CH<sub>3</sub>CN and 1.49  $\mu$ s in neat film. However, the underlying causes of this odd phenomenon are still unknown and need further investigation.

The electrochemistry of **1–4** was then probed by cyclic voltammetry in nitrogen-saturated *N*,*N*-dimethylformamide solution (see Figure S1 in the Supporting Information). Complexes **1** and **2** show similar redox properties with an oxidation potential of 0.94 V and a reduction peak of around -1.92 V. In comparison, the oxidation potentials of **3** and **4** are a little smaller (0.86 V), whereas their reduction potentials are higher (ca. -1.85 V), which suggests a wider energy gap between their highest-occupied molecular orbitals (HOMO) and lowestoccupied molecular orbitals (LUMO). In addition, thermogravimetric analysis (TGA) under a flow of dry nitrogen gas demonstrated the good thermal stability of **1–4** with 5% weight reduction temperatures over 320°C (see Figure S2 in the Supporting Information). The structures of **1–4** determined in the pristine state and after vacuum sublimation are quite similar (see the Experimental Section and Figures S3– S10), thereby confirming their superior sublimability without any observable decomposition, which is consistent with our previous work and enables the fabrication of devices by vacuum evaporation deposition.<sup>[39]</sup>

#### Electroluminescence

To investigate the electroluminescent (EL) behavior of **1–4**, we fabricated and evaluated OLEDs with the following structure: ITO/NPB (40 nm)/EML (20 nm)/TPBi (30 nm)/Mg:Ag (150 nm)/Ag (50 nm). ITO represents indium tin oxide, NPB (*N*,*N*'-di-1-naphthyl-*N*,*N*'-diphenylbenzidine) was used for hole injection, the EML (emitting material layer) consists of a host matrix and a single dopant, TPBi (1,3,5-tris(1-phenyl-1*H*-benzo[*d*]imidazol-2-yl)benzene) was inserted as a hole-blocking layer, and Mg:Ag/Ag served as the cathode. The molecular structures and a schematic energy level diagram of the above OLED material are shown in Figure 5.

First, we utilized a pyridine-containing bipolar host material, 26DCzPPy (2,6-bis[3-(9H-carbazol-9-yl)phenyl]pyridine), with a triplet energy ( $E_{T}$ ) of 2.71 eV for the OLEDs based on 1 and 2.<sup>[47]</sup> The energy alignments in Figure 5 indicate an efficient exothermic energy transfer from the triplet state of 26DCzPPy to the triplet state of 1 or 2 and an excellent triplet energy confinement of the emitters. Figures S11 and S12 in the Supporting Information show the current density and luminance versus voltage (J-V and L-V) characteristics of the OLEDs based on 1 and 2 with different doping ratios, respectively. We found that both J and L decrease with increasing concentration of 1 or 2, due to the electron trapping of ionic materials.<sup>[17]</sup> Through optimization, we attained green emission with high brightness values of  $12.4 \times 10^3$  and  $10.3 \times 10^3$  cd m<sup>-2</sup> for the OLEDs based on 1 and 2, respectively, whereas the maximum current efficiency (CE) is somewhat low (see Tables 2 and 3). To improve the efficiency of the OLEDs based on 2, we elected another host material, DIC-TRZ (2,4-diphenyl-6-(12-phenylindolo[2,3-a]carbazol-11-yl)-1,3,5-triazine), with thermally activated delayed fluorescence (TADF) and an even higher  $E_{T}$  of 3.0 eV, which can prevent the energy transfer of triplet excitons from the emitters back to the host material more effectively.<sup>[48]</sup> Finally, we obtained highly efficient OLEDs based on 2 with a highest CE of 11.30 cd A<sup>-1</sup> and a maximum luminance of  $17.9 \times 10^3$  cd m<sup>-2</sup> for a doping ratio of 4 mol% (see Figure S13 in the Supporting Information).

Moreover, it is noteworthy that the OLEDs based on 1 and 2 show concentration-dependent polychromic EL spectra, as shown in Figure 6a–c. As the doping concentration increases from 4 to 20 mol%, the EL wavelengths of the OLEDs based on 2 are red-shifted from 528 to 544 nm, that is, they have a wide range of emission of 16 nm, whereas those of the OLEDs based on 1 vary by only 6 nm. Analogous phenomena

4





Figure 5. Molecular structures and schematic energy level diagram for the materials used in the fabrication of OLEDs.

| Table 2. Performance summary of OLEDs based on 1.   |  |                             |                            |                        |  |  |                                   |  |  |
|---|--|-----------------------------|----------------------------|------------------------|--|--|-----------------------------------|--|--|
| EML composition   | $\lambda_{PL} \; [nm]^{\scriptscriptstyle{[a]}}$ | $V_{\rm on}  [V]^{\rm [b]}$ | Max CE $[cd A^{-1}]^{[c]}$ | EQE [%] <sup>[d]</sup> | Max $L [10^3 \text{ cd m}^{-2}]^{[e]}$ | $\lambda_{\text{EL}} \left[ \text{nm}  ight]^{\text{(f)}}$ | CIE ( <i>x,y</i> ) <sup>[g]</sup> |  |  |
| 26DCzPPy  | 391  | 7.0                         | 0.60                       | 0.77                   | 5.3                                    | 436  | (0.16,0.10)                       |  |  |
| 26DCzPPy: 4 mol% 1  | 508  | 6.7                         | 3.32                       | 1.17                   | 10.0                                   | 512  | (0.28,0.52)                       |  |  |
| 26DCzPPy: 8 mol % 1   | 512  | 6.8                         | 3.30                       | 1.17                   | 10.2                                   | 514  | (0.28,0.52)                       |  |  |
| 26DCzPPy: 12 mol% 1   | 514  | 8.2                         | 3.41                       | 1.20                   | 11.1                                   | 514  | (0.30,0.52)                       |  |  |
| 26DCzPPy: 16 mol % 1  | 517  | 8.7                         | 3.20                       | 1.12                   | 12.4                                   | 516  | (0.31,0.53)                       |  |  |
| 26DCzPPy: 20 mol% 1   | 518  | 8.8                         | 3.13                       | 1.09                   | 12.2                                   | 518  | (0.31,0.53)                       |  |  |
| [a] $\lambda_{PL} = PL$ wavelength of the corresponding EML. [b] $V_{on} = turn$ -on voltage to reach a luminance of 1 cdm <sup>-2</sup> . [c] CE = current efficiency. [d] EQE = external quantum efficiency. [e] $L = luminance$ . [f] $\lambda_{EL} = EL$ wavelength. [g] CIE = Commission Internationale de l'Elairage. |  |                             |                            |                        |  |  |                                   |  |  |

| Table 3. Performance summary of OLEDs based on 2. |  |   |                            |                        |  |                              |                                   |  |  |
|---|--|---|----------------------------|------------------------|--|------------------------------|-----------------------------------|--|--|
| EML composition                                   | $\lambda_{PL} \; [nm]^{\scriptscriptstyle{[a]}}$ | $V_{\rm on} \left[ {\rm V}  ight]^{ m [b]}$ | Max CE $[cd A^{-1}]^{[c]}$ | EQE [%] <sup>[d]</sup> | Max $L [10^3 \text{ cd m}^{-2}]^{[e]}$ | $\lambda_{EL} \; [nm]^{[f]}$ | CIE ( <i>x,y</i> ) <sup>[g]</sup> |  |  |
| 26DCzPPy  | 391  | 7.0   | 0.60                       | 0.77                   | 5.3                                    | 436                          | (0.16,0.10)                       |  |  |
| 26DCzPPy: 4 mol % 2                               | 528  | 7.9   | 3.25                       | 1.15                   | 9.7                                    | 528                          | (0.37,0.53)                       |  |  |
| 26DCzPPy: 8 mol % 2                               | 529  | 8.0   | 3.01                       | 1.07                   | 9.9                                    | 532                          | (0.37,0.53)                       |  |  |
| 26DCzPPy: 12 mol% 2                               | 533  | 8.8   | 2.74                       | 0.97                   | 9.5                                    | 534                          | (0.38,0.54)                       |  |  |
| 26DCzPPy: 16 mol% 2                               | 536  | 9.0   | 2.78                       | 0.97                   | 9.4                                    | 538                          | (0.38,0.54)                       |  |  |
| 26DCzPPy: 20 mol % 2                              | 538  | 9.7   | 2.74                       | 0.89                   | 10.3                                   | 544                          | (0.40,0.51)                       |  |  |
| DIC-TRZ   | 510  | 6.6   | 1.63                       | 0.62                   | 7.5                                    | 518                          | (0.33,0.49)                       |  |  |
| DIC-TRZ: 4 mol % 2                                | 530  | 5.7   | 11.30                      | 3.74                   | 17.9                                   | 528                          | (0.37,0.56)                       |  |  |
| DIC-TRZ: 6 mol % 2                                | 532  | 6.2   | 10.61                      | 3.51                   | 14.2                                   | 530                          | (0.38,0.56)                       |  |  |
| DIC-TRZ: 8 mol % 2                                | 534  | 6.4   | 7.44                       | 2.40                   | 16.3                                   | 532                          | (0.38,0.56)                       |  |  |
| DIC-TRZ: 12 mol % 2                               | 535  | 6.8   | 6.51                       | 2.11                   | 14.4                                   | 538                          | (0.38,0.56)                       |  |  |
| DIC-TRZ: 20 mol % 2                               | 537  | 7.5   | 5.95                       | 2.15                   | 10.2                                   | 544                          | (0.40,0.51)                       |  |  |

[a]  $\lambda_{PL} = PL$  wavelength of the corresponding EML. [b]  $V_{on} = turn-on$  voltage to reach a luminance of 1 cd m<sup>-2</sup>. [c] CE = current efficiency. [d] EQE = external quantum efficiency. [e] L = luminance. [f]  $\lambda_{EL} =$  EL wavelength. [g] CIE = Commission Internationale de l'Elairage.

can also be observed in the PL spectra of the corresponding EMLs. This effect probably arises because, compared with 1, the  $\pi$ - $\pi$  conjugation effects between the pendant phenyl groups and 1,10-phenathroline in the ancillary dmbphen ligand of 2 cause stronger molecular aggregation.

Similarly, the OLEDs based on 3 and 4 also exhibit EL spectra dependent on their doping ratios in the DIC-TRZ host matrix (Tables 4 and 5). As the concentration increases from 4 to 20 mol%, the EL wavelengths of the OLEDs based on 3 vary from 538 to 549 nm with an 11 nm bathochromic shift (Fig-

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Figure 6. PL and EL spectra of: a, b) OLEDs based on 1 and 2 with the 26DCzPPy host, and c-e) OLEDs based on 2-4 with the DIC-TRZ host.

| Table 4. Performance summary of OLEDs based on 3.   |  |                                |   |                        |  |  |                                   |  |  |
|---|--|--------------------------------|---|------------------------|--|--|-----------------------------------|--|--|
| EML composition   | $\lambda_{PL} \; [nm]^{\scriptscriptstyle{[a]}}$ | <i>V</i> on [V] <sup>[b]</sup> | Max CE [cd A <sup>-1</sup> ] <sup>[c]</sup> | EQE [%] <sup>[d]</sup> | Max $L [10^3 \text{ cd m}^{-2}]^{[e]}$ | $\lambda_{\scriptscriptstyle EL}  [nm]^{\scriptscriptstyle (f)}$ | CIE ( <i>x,y</i> ) <sup>[g]</sup> |  |  |
| DIC-TRZ   | 510  | 6.6                            | 1.63  | 0.62                   | 7.5                                    | 518  | (0.33,0.49)                       |  |  |
| DIC-TRZ: 4 mol % 3  | 539  | 4.5                            | 8.79  | 2.87                   | 22.2                                   | 538  | (0.38,0.56)                       |  |  |
| DIC-TRZ: 8 mol % 3  | 544  | 5.4                            | 9.41  | 3.05                   | 22.4                                   | 544  | (0.39,0.54)                       |  |  |
| DIC-TRZ: 12 mol % 3   | 545  | 5.3                            | 9.15  | 3.03                   | 22.2                                   | 545  | (0.39,0.53)                       |  |  |
| DIC-TRZ: 16 mol % 3   | 547  | 5.7                            | 3.89  | 1.29                   | 15.4                                   | 546  | (0.39,0.55)                       |  |  |
| DIC-TRZ: 20 mol % 3   | 548  | 6.9                            | 2.87  | 0.98                   | 11.8                                   | 549  | (0.40,0.53)                       |  |  |
| [a] 1. Di uuruslaarth of the coveranding FMI [b] // ture on ustance to yearth the luminance of 1 of m <sup>-2</sup> [s] (C. surrant officiance [d] FOC external |  |                                |   |                        |  |  |                                   |  |  |

[a]  $\lambda_{PL} = PL$  wavelength of the corresponding EML. [b]  $V_{on} = \text{turn-on voltage to reach the luminance of 1 cd m^{-2}. [c] <math>CE = \text{current efficiency. [d] } EQE = \text{external quantum efficiency. [e] } L = \text{luminance. [f] } \lambda_{EL} = EL$  wavelength. [g] CIE = Commission Internationale de l'Elairage.

| Table 5. Performance summary of OLEDs based on 4. |   |                             |   |                        |  |  |                                   |  |  |
|---|---|-----------------------------|---|------------------------|--|--|-----------------------------------|--|--|
| EML composition                                   | $\lambda_{	extsf{PL}}  [	extsf{nm}]^{	extsf{a}]}$ | $V_{\rm on}  [V]^{\rm [b]}$ | Max CE [cd A <sup>-1</sup> ] <sup>[c]</sup> | EQE [%] <sup>[d]</sup> | Max $L [10^3 \text{ cd m}^{-2}]^{[e]}$ | $\lambda_{\scriptscriptstyle EL}  [nm]^{\scriptscriptstyle (f)}$ | CIE ( <i>x,y</i> ) <sup>[g]</sup> |  |  |
| DIC-TRZ   | 510   | 6.6                         | 1.63  | 0.62                   | 7.5                                    | 518  | (0.33,0.49)                       |  |  |
| DIC-TRZ: 4 mol % 4                                | 538   | 5.0                         | 16.32                                       | 5.10                   | > 27.1                                 | 542  | (0.39,0.56)                       |  |  |
| DIC-TRZ: 8 mol % 4                                | 540   | 5.9                         | 14.96                                       | 4.69                   | > 27.1                                 | 544  | (0.40,0.56)                       |  |  |
| DIC-TRZ: 12 mol % 4                               | 549   | 6.0                         | 7.44  | 2.41                   | 15.6                                   | 547  | (0.42,0.55)                       |  |  |
| DIC-TRZ: 16 mol % 4                               | 559   | 8.9                         | 3.90  | 1.30                   | 8.3                                    | 552  | (0.43,0.54)                       |  |  |
| DIC-TRZ: 20 mol % 4                               | 561   | 9.3                         | 5.49  | 1.93                   | 9.5                                    | 558  | (0.43,0.54)                       |  |  |

[a]  $\lambda_{PL} = PL$  wavelength of the corresponding EML. [b]  $V_{on} = turn-on$  voltage to reach a luminance of 1 cd m<sup>-2</sup>. [c] CE = current efficiency. [d] EQE = external quantum efficiency. [e] L = luminance. [f]  $\lambda_{EL} = EL$  wavelength. [g] CIE = Commission Internationale de l'Elairage.

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ure 6d), whereas those of the OLEDs based on **4** show a larger variation of 16 nm between 542 and 558 nm (Figure 6e). We attained yellow-emitting devices of **3** with a maximum CE of 9.41 cdA<sup>-1</sup> and a brightness of  $22.4 \times 10^3$  cdm<sup>-2</sup> by doping with 8 mol% of **3** (see Figure S14 in the Supporting Information), whereas the OLEDs based on **4** show a better performance with a CE of 16.32 cdA<sup>-1</sup> and a brightness in excess of  $27.1 \times 10^3$  cdm<sup>-2</sup> with 4 mol% doping of **4** (see Figure S15).

## Conclusions

A novel series of four sublimable cationic iridium(III) complexes **1–4** with 1,10-phenanthroline derivatives as ancillary ligands have been designed, synthesized, and fully characterized. Highly efficient and polychromic vacuum-evaporated OLEDs prepared from complexes **1–4** were fabricated and evaluated; superior device performance was achieved for green to yellow

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emission. Bathochromic shifts dependent on the doping concentration of these new phosphorescent materials were also demonstrated and explained by the  $\pi$ - $\pi$  conjugation effects of the 1,10-phenanthroline-type ancillary ligands and the resulting molecular aggregation. Our work provides new insight into both the photo- and electroluminescent characterization of cationic iridium(III) complexes and reveals a new family of sub-limable ionic phosphorescent materials with immense potential for state-of-the-art organic electronic devices in full-color displays and solid-state lighting.

## **Experimental Section**

#### Methods

Solvents were purchased from commercial sources and used as received unless otherwise stated. ESI mass spectrometry was performed with a Thermo Electron Corporation Finnigan LTQ. <sup>1</sup>H NMR and <sup>19</sup>F NMR spectra were recorded with a JOEL JNM-ECA600 NMR spectrometer. Single-crystal X-ray characterization was performed on a Bruker SMART APEX charge-coupled device (CCD) diffractometer equipped with graphite monochromatized MoK $\alpha$  radiation. The absorption and PL spectra were performed with a UV/Vis spectrophotometer (Agilent 8453) and a fluorospectrophotometer (Jobin Yvon, FluoroMax-3), respectively. The excited state lifetimes were measured on a transient spectrofluorimeter (Edinburgh Instruments, FLSP920) with time-correlated single-photon counting technique at the peak emitting wavelength. PLQYs in degassed CH<sub>3</sub>CN solution (1 × 10<sup>-5</sup> M) were calculated with quinine sulfate ( $\varphi$  = 0.545 in 1 M H<sub>2</sub>SO<sub>4</sub>) as the reference. PLQYs in neat films were measured at the excitation wavelength of 400 nm by using a Quantaurus-QY C11347-11. Cyclic voltammetry was performed on a Princeton Applied Research potentiostat/galvanostat model 283 voltammetric analyzer in degassed N,N-dimethylformamide solution  $(1 \times 10^{-3} \text{ M})$ at a scan rate of 100 mVs<sup>-1</sup> with a platinum plate as the working electrode, a silver wire as the pseudo-reference electrode and a platinum wire as the counter electrode. The supporting electrolyte was tetrabutylammonium perchlorate (0.04 g mL<sup>-1</sup>) and ferrocene was selected as the internal standard.

#### Synthesis and characterization

Synthesis and characterization of 1: The dichloro-bridged diiridium complex [Ir(ppy)<sub>2</sub>Cl]<sub>2</sub> (0.9953 g, 0.928 mmol) and dmphen ligand (0.4048 g, 1.863 mmol) were dissolved in 1,2-ethanediol (60 mL). Then the mixture was heated at reflux at 150  $^\circ\text{C}$  in a Schlenk tube for 16 h under an argon atmosphere to form a yellow solution. After cooling to room temperature, Na[BArF<sub>24</sub>] (1.8043 g, 2.036 mmol) was slowly added to the reaction mixture under stirring. The product was then extracted with CH<sub>2</sub>Cl<sub>2</sub> and dried under vacuum at 60 °C overnight. The crude product was purified by column chromatography on silica gel (200-300 mesh) with CH<sub>2</sub>Cl<sub>2</sub> as the eluent, to yield a yellow powder (2.1852 g, 1.390 mmol). Yield: 75%. In the pristine state: <sup>1</sup>H NMR (600 MHz,  $[D_6]DMSO) \delta = 8.72$  (d, J=8.3 Hz, 2 H), 8.24 (d, J=8.2 Hz, 2 H), 8.20 (s, 2H), 7.88 (dd, J=11.4, 4.2 Hz, 2H), 7.84 (d, J=7.6 Hz, 2H), 7.80 (d, J=8.3 Hz, 2 H), 7.70 (s, 4 H), 7.61 (s, 8 H), 7.58 (d, J=5.7 Hz, 2 H), 6.99 (dd, J=9.7, 3.6 Hz, 2 H), 6.92 (t, J=7.5 Hz, 2 H), 6.76 (t, J= 7.5 Hz, 2 H), 6.04 (d, J=7.6 Hz, 2 H), 2.03 ppm (s, 6 H); <sup>19</sup>F NMR (600 MHz, [D<sub>6</sub>]DMSO):  $\delta = -61.55$  ppm (s, 24 F); MS (ESI): m/z: calcd for C<sub>36</sub>H<sub>28</sub>IrN<sub>4</sub>: 709.19 [M-BArF<sub>24</sub>]<sup>+</sup>; found: 709.19; calcd for C<sub>32</sub>H<sub>12</sub>BF<sub>24</sub>: 863.06 [M-lr(ppy)<sub>2</sub>(dmphen)]<sup>-</sup>; found: 863.07. After

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vacuum sublimation: <sup>1</sup>H NMR (600 MHz, [D<sub>6</sub>]DMSO)  $\delta$  = 8.73 (d, J = 8.3 Hz, 2H), 8.24 (t, J=8.1 Hz, 2H), 8.21 (s, 2H), 7.88 (t, J=7.8 Hz, 2H), 7.85 (d, J=7.8 Hz, 2H), 7.80 (d, J=8.3 Hz, 2H), 7.68 (s, 4H), 7.62 (s, 8H), 7.59 (d, J=5.7 Hz, 2H), 7.00 (t, J=6.6 Hz, 2H), 6.93 (t, J=7.5 Hz, 2H), 6.77 (t, J=7.4 Hz, 2H), 6.06 (d, J=7.6 Hz, 2H), 2.05 ppm (s, 6H); <sup>19</sup>F NMR (600 MHz, [D<sub>6</sub>]DMSO)  $\delta$  = -62.08 ppm (s, 24 F); MS (ESI): *m/z*: calcd for C<sub>36</sub>H<sub>28</sub>IrN<sub>4</sub>: 709.19 [*M*-BArF<sub>24</sub>]<sup>+</sup>; found: 709.19; calcd for C<sub>32</sub>H<sub>12</sub>BF<sub>24</sub>: 863.06 [*M*-Ir(ppy)<sub>2</sub>(dmphen)]<sup>-</sup>; found: 863.06; elemental analysis calcd (%) for C<sub>68</sub>H<sub>40</sub>BF<sub>24</sub>IrN<sub>4</sub>: C 51.95, H 2.56, N 3.56; found: C 51.89, H 2.60, N 3.56.

A single crystal of 1 was grown from an acetone/methanol mixed solution and characterized by X-ray crystallography. Space group P-1, a=13.5997(15), b=18.476(2), c=25.972(3) Å, a=86.694(4),  $\beta=87.006(4)$ ,  $\gamma=73.370(4)^{\circ}$ , V=6238.0(12) Å<sup>3</sup>, Z=4,  $d_{calcd}=1.674$  g cm<sup>-3</sup>,  $R_1=0.0479$ ,  $\omega R_2=0.0843$  for 21163 observed reflections [ $l \ge 2\sigma(l)$ ] (CCDC 1477554).

Synthesis and characterization of 2: The synthesis route to 2 was quite similar to that used for the synthesis of 1, except that dmphen was replaced by dmbphen as the ancillary ligand. Yield: 78%. In the pristine state: <sup>1</sup>H NMR (600 MHz, [D<sub>6</sub>]DMSO):  $\delta$  = 8.28 (d, J = 8.1 Hz, 2H), 8.03 (s, 2H), 7.93 (t, J = 7.3 Hz, 2H), 7.86 (d, J =7.7 Hz, 2 H), 7.84 (s, 2 H), 7.75 (d, J=5.6 Hz, 2 H), 7.69 (s, 4 H), 7.62 (s, 10 H), 7.61 (s, 8 H), 7.08 (t, J=6.4 Hz, 2 H), 6.93 (t, J=7.4 Hz, 2 H), 6.78 (t, J=7.4 Hz, 2H), 6.07 (d, J=7.6 Hz, 2H), 2.10 ppm (s, 6H); <sup>19</sup>F NMR (600 MHz, [D<sub>6</sub>]DMSO):  $\delta = -61.57$  ppm (s, 24 F); MS (ESI): *m*/*z*: calcd for C<sub>48</sub>H<sub>36</sub>IrN<sub>4</sub>: 861.26 [*M*-BArF<sub>24</sub>]<sup>+</sup>; found: 861.26; calcd for  $C_{32}H_{12}BF_{24}$ : 863.06  $[M-lr(ppy)_2(dmbphen)]^-$ ; found: 863.07. After vacuum sublimation: <sup>1</sup>H NMR (600 MHz, [D<sub>6</sub>]DMSO):  $\delta$  = 8.29 (d, J=8.2 Hz, 2 H), 8.04 (s, 2 H), 7.94 (t, J=7.8 Hz, 2 H), 7.88 (d, J= 7.8 Hz, 2 H), 7.85 (s, 2 H), 7.77 (d, J=5.7 Hz, 2 H), 7.70 (s, 4 H), 7.63 (s, 10 H), 7.60 (s, 8 H), 7.10 (t, J=6.6 Hz, 2 H), 6.94 (t, J=7.5 Hz, 2 H), 6.79 (t, J=7.4 Hz, 2 H), 6.09 (d, J=7.7 Hz, 2 H), 2.12 ppm (s, 6 H); <sup>19</sup>F NMR (600 MHz, [D<sub>6</sub>]DMSO):  $\delta = -61.91$  ppm (s, 24 F); MS (ESI): *m*/*z*: calcd for C<sub>48</sub>H<sub>36</sub>IrN<sub>4</sub>: 861.26 [*M*-BArF<sub>24</sub>]<sup>+</sup>; found: 861.26; calcd for C<sub>32</sub>H<sub>12</sub>BF<sub>24</sub>: 863.06 [*M*-lr(ppy)<sub>2</sub>(dmbphen)]<sup>-</sup>; found: 863.06; elemental analysis calcd (%) for C<sub>80</sub>H<sub>48</sub>BF<sub>24</sub>IrN<sub>4</sub>: C 55.73, H 2.81, N 3.25; found: C 55.69, H 2.80, N 3.30.

A single crystal of **2** was grown from an acetone/methanol mixed solution and characterized by X-ray crystallography. Space group *P*1, *a*=14.162(3), *b*=14.191(3), *c*=18.008(4) Å, *a*=107.27(3), *β*=110.08(3),  $\gamma$ =100.28(3)°, *V*=3083.0(11) Å<sup>3</sup>, *Z*=2, *d*<sub>calcd</sub>=1.663 g cm<sup>-3</sup>, *R*<sub>1</sub>=0.0583,  $\omega R_2$ =0.1601 for 22333 observed reflections [ $l \ge 2\sigma(l)$ ] (CCDC 1482351).

Synthesis and characterization of 3: The synthesis route of 3 was quite similar to that used for the synthesis of 1, except that dmphen was replaced by phen as the ancillary ligand. Yield: 77%. In the pristine state: <sup>1</sup>H NMR (600 MHz, [D<sub>6</sub>]DMSO):  $\delta$  = 8.87 (d, J = 8.2 Hz, 2 H), 8.35 (s, 2 H), 8.23 (d, J=8.2 Hz, 2 H), 8.18 (d, J=8.2 Hz, 2H), 8.02 (dd, J=8.1, 5.1 Hz, 2H), 7.93 (d, J=7.8 Hz, 2H), 7.84 (t, J=7.8 Hz, 2H), 7.65 (s, 4H), 7.59 (s, 8H), 7.43 (d, J=5.7 Hz, 2H), 7.03 (t, J=7.5 Hz, 2H), 6.94 (dt, J=14.8, 7.0 Hz, 4H), 6.27 ppm (d,  $J\!=\!7.5$  Hz, 2 H);  $^{19}\text{F}$  NMR (600 MHz, [D\_6]DMSO):  $\delta\!=\!-61.62$  ppm (s, 24 F); MS (ESI): *m/z*: calcd for C<sub>34</sub>H<sub>24</sub>IrN<sub>4</sub>: 681.16 [*M*-BArF<sub>24</sub>]<sup>+</sup>; found: 681.16; calcd for C<sub>32</sub>H<sub>12</sub>BF<sub>24</sub>: 863.06 [*M*-lr(ppy)<sub>2</sub>(phen)]<sup>-</sup>; found: 863.07. After vacuum sublimation: <sup>1</sup>H NMR (600 MHz,  $[D_6]DMSO$ ):  $\delta = 8.90$  (d, J = 8.3 Hz, 2 H), 8.39 (s, 2 H), 8.26 (d, J =8.2 Hz, 2 H), 8.22 (d, J=4.9 Hz, 2 H), 8.06 (dd, J=8.1, 5.1 Hz, 2 H), 7.96 (d, J=7.8 Hz, 2H), 7.87 (t, J=7.8 Hz, 2H), 7.69 (s, 4H), 7.62 (s, 8H), 7.47 (d, J=5.7 Hz, 2H), 7.06 (t, J=7.5 Hz, 2H), 6.97 (dt, J= 15.0, 6.8 Hz, 4 H), 6.31 ppm (d, J=7.5 Hz, 2 H); <sup>19</sup>F NMR (600 MHz,  $[D_6]DMSO$ :  $\delta = -61.90$  ppm (s, 24 F); MS (ESI): m/z: calcd for C<sub>34</sub>H<sub>24</sub>IrN<sub>4</sub>: 681.16 [*M*-BArF<sub>24</sub>]<sup>+</sup>; found: 681.16; calcd for C<sub>32</sub>H<sub>12</sub>BF<sub>24</sub>: 863.06  $[M-Ir(ppy)_2(phen)]^-$ ; found: 863.06; elemental analysis

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calcd (%) for  $C_{66}H_{36}BF_{24}IrN_4$ : C 51.34, H 2.35, N 3.63; found: C 51.37, H 2.36, N 3.62.

Synthesis and characterization of 4: The synthesis route of 4 was quite similar to that used for the synthesis of 1, except that dmphen was replaced by bphen as the ancillary ligand. Yield: 80%. In the pristine state:<sup>1</sup>H NMR (600 MHz, [D<sub>6</sub>]DMSO):  $\delta$  = 8.30 (t, J = 6.2 Hz, 4 H), 8.22 (s, 4 H), 8.06 (d, J=5.3 Hz, 2 H), 7.98 (d, J=7.6 Hz, 2H), 7.94-7.90 (m, 2H), 7.72 (s, 4H), 7.69-7.63 (m, 8H), 7.62 (s, 8H), 7.61 (s, 2H), 7.10-7.05 (m, 4H), 6.97 (t, J=7.4 Hz, 2H), 6.31 ppm (d, J=7.4 Hz, 2 H);  $^{19}\text{F}$  NMR (600 MHz, [D<sub>6</sub>]DMSO)  $\delta\!=\!-61.77$  ppm (s, 24 F); MS (ESI): m/z: calcd for  $C_{46}H_{32}IrN_4$ : 833.23  $[M-BArF_{24}]^+$ ; found: 833.23; calcd for C<sub>32</sub>H<sub>12</sub>BF<sub>24</sub>: 863.06 [M-lr(ppy)<sub>2</sub>(bphen)]<sup>-</sup>; found: 863.06. After vacuum sublimation: <sup>1</sup>H NMR (600 MHz,  $[D_6]DMSO$ : $\delta = 8.31$  (t, J = 6.0 Hz, 4H), 8.23 (s, 4H), 8.06 (d, J =5.3 Hz, 2 H), 7.98 (d, J=7.8 Hz, 2 H), 7.92 (t, J=7.8 Hz, 2 H), 7.71-7.58 (m, 22H), 7.08 (t, J=7.8 Hz, 2H), 6.98 (t, J=7.4 Hz, 2H), 6.33 ppm (d, J=7.5 Hz, 2H);  $^{19}{\rm F}$  NMR (600 MHz, [D\_6]DMSO)  $\delta\!=$ -61.91 ppm (s, 24 F); MS (ESI): m/z: calcd for C<sub>46</sub>H<sub>32</sub>IrN<sub>4</sub>: 833.23 py)<sub>2</sub>(bphen)]<sup>-</sup>; found: 863.06; elemental analysis calcd (%) for C<sub>78</sub>H<sub>44</sub>BF<sub>24</sub>IrN<sub>4</sub>: C 55.23, H 2.61, N 3.30; found: C 55.33, H 2.61, N 3.31.

CCDC CCDC 1477554 (1) and 1482351 (2) contain the supplementary crystallographic data for this paper. These data can be obtained free of charge from The Cambridge Crystallographic Data Centre.

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# **FULL PAPER**

Simply sublime! A novel series of sublimable cationic iridium(III) complexes with 1,10-phenanthroline derivatives as ancillary ligands and the same bulky negative counter-ion have been prepared and used to fabricate highly efficient polychromic OLEDs by vacuum evaporation deposition (see figure). This work provides a new and promising material system containing evaporable charged phosphorescent emitters for use in organic electronics.



#### Luminescence

D. Ma, C. Zhang, Y. Qiu, L. Duan\*

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Sublimable Cationic Iridium(III) Complexes with 1,10-Phenanthroline Derivatives as Ancillary Ligands for Highly Efficient and Polychromic Electroluminescence