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Sublimable cationic Ir(III) phosphor using chlorine as counterion for high-performance monochromatic and white OLEDs

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Lei Ding,^a Chun-Xiu Zang,^b Hui-Ting Mao,^a Guo-Gang Shan,^{*a} Li-Li Wen,^a Hai-Zhu Sun,^{*a} Wen-Fa Xie,^{*b} and Zhong-Min Su^{*ac}

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Different from the previous design strategy, herein, a cationic Ir(III) complex ([(ptbi)₂Ir(bisq)]Cl) with small chlorine as the counterion was synthesized, which realized the formation of solid-film via vacuum-deposited process. The white OLED by employing it as orange-emitting layer achieved excellent performances with brightness of 50122 cd m⁻², CE of 25.5 cd A⁻¹, EQE of 13.1%, accompanied with low CE efficiency roll-off of 4.7%. These are the best results among evaporated cationic Ir(III)-based white OLED reported so far.

Iridium(III) complexes have attracted much attention in the field of optoelectronic and biological media because of their high photoluminescence quantum yield (PLQY), short radiative lifetime, good thermal and photostability, and facile colour tunability across the whole visible spectrum.¹ As superior phosphorescent emitters in organic light-emitting diodes (OLEDs), they achieve internal quantum efficiency of nearly 100% by harvesting both single and triplet excitons.² In comparison with the neutral counterparts, ionic Ir(III) complexes possess unique characteristics such as ease of molecular design, synthesis, and purification as well as good solubility, making them possible to find applications in solution-processed light emitting electrochemical cells (LECs).³ In view of the ionic nature and low vapour pressure, however, conventional cationic Ir(III) complexes seldom realize the formation of film via vacuum evaporation method that has been proved to have high accuracy and stability.⁴ Recently, some efforts have been made to develop sublimable cationic Ir(III) complexes suitable for OLEDs manufacture.⁵ In 2007, Wong et al. reported the first example of sublimable cationic

 ^b. State Key Laboratory on Integrated Optoelectronics, College of Electronic Science and Engineering, Jilin University, Changchun, Jilin 130012, P. R. China
 ^c School of Chemistry & Environmental Engineering, Changchun University of Ir(III) phosphor as emitting layer in multi-layered OLEDs, achieving current efficiency (CE) of 19.7 cd A^{-1} and external quantum efficiency (EQE) of 6.5%.^{5a} More recently, Ma et al. demonstrated a strategy to construct sublimable cationic Ir(III) phosphors by introducing large steric hindrance counter-ions into complexes (**Scheme 1**).^{5b} Despite the great progress achieved, the study on this issue is still in its infancy, and the different molecular design concepts and/or new material systems are highly desired but remain a challenge.

White organic light-emitting diodes (WOLEDs) have drawn much attention due to the immense potential for highly efficient flat-panel displays and solid-state lighting.⁶⁻¹⁰ In 2016, Ma et al. successfully realized the fabrication of ionic Ir(III)based WOLEDs by vacuum evaporation deposition, showing the CE of 3.4 cd A⁻¹ and EQE of 1.8%, respectively.^{5d} However, these device performances are far from satisfaction, which lag behind their neutral counterparts, particularly for maximum brightness and efficiencies. On the other hand, although many reported OLEDs exhibit high efficiencies, they usually undergo a serious efficiency roll-offs at high current densities.⁷ Consequently, it is necessary to fabricate OLEDs with high efficiency and small efficiency roll-off simultaneously. Furthermore, the ENERGY STAR rules that the color rendering index (CRI) of qualified lamps cannot be less than 80 and the saturated red R9 value should be greater than 0.8 These are the important parameters for WOLEDs used for lighting illumination but are usually less reported.

Our previous work has focused on the design of cationic Ir(III) complexes as sensors, and excellent emitting layer for LECs, et al. Herein, we obtained cationic Ir(III) complex that can be vacuum evaporated by introducing a small volume counterion such as Cl⁻ (**Scheme 1**). Employing it as the emitting-layer, monochromatic orange-emitting OLED exhibits excellent performance with a maximum CE of 17.8 cd A⁻¹ and EQE of 10.5%. Optimized WOLED shows a maximum brightness of 50122 cd m⁻², a maximum CE of 25.5 cd A⁻¹, EQE of 13.1% and tiny CE efficiency roll-off of 4.7%, all of which are the best results of the reported cationic Ir(III)-based WOLED by now. The resulting WOLED well satisfy the premise of colour

^{a.} Institute of Functional Material Chemistry and National & Local United Engineering Lab for Power Battery, Faculty of Chemistry, Northeast Normal University, Changchun 130024, P. R. China E-mail:shangg187@nenu.edu.cn (G. G. Shan), sunhz335@nenu.edu.cn (H. Z. Sun), zmsu@nenu.edu.cn (Z. M. Su)

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purity stipulated by the ENERGY STAR with CRI of 80 and R9 > 0.

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[(ptbi)₂Ir(bisq)]Cl was easily synthesized with a high yield of 68%. [(ptbi)₂Ir(bisq)]Cl realized outstanding thermal stability with high decomposition temperature of 337 °C, and no glass transition peak was observed on its DSC curve (Figs. S1 and S2, ESI⁺). In addition, the ¹H-NMR measurements before and after vapor deposition were carried out (Fig. S3, ESI⁺). The data suggested that [(ptbi)₂Ir(bisq)]Cl barely decomposed during the vacuum evaporation, demonstrating its good sublimability.



Fig. 1 Ultraviolet-visible absorption and PL spectra of **[(ptbi)**₂**Ir(bisq)]CI** in acetonitrile solution (10⁻⁵ M) and neat film at 298 K. Inset: luminescence photographs of **[(ptbi)**₂**Ir(bisq)]CI** in acetonitrile solution and neat film.

Absorption and photoluminescent (PL) spectra of [(ptbi)2lr(bisq)]Cl at room temperature (R.T.) are presented in Fig. 1. The strong absorption bands ranging from 200 to 325 nm are ascribed to spin-allowed ${}^{1}\pi-\pi^{*}$ transitions from the ligands, while the weaker bands from 325 nm extending to 475 nm are attributed to metal-to-ligand charge-transfer (¹MLCT), ligand-to-ligand charge-transfer (¹LLCT), ³MLCT, ³LLCT and ³LC ${}^{3}\pi$ - π^{*} transitions.⁹ As shown in **Fig. 1**, the PL spectra of [(ptbi)2lr(bisq)]Cl in acetonitrile solution and neat film measured at R.T. show similar peak position of 608 and 610 nm, respectively. The broad and structureless PL spectra indicate that its emissive excited state predominantly results from ³MLCT and/or ³LLCT rather than ³LC ³ π - π *characters.¹⁰ In addition, there is no significant change in emission spectrum for the spin-coated film and evaporated film, as shown in Fig. S4. The broad full width at half maximum (FWHM) of both solution and neat film are about 94 nm and 85 nm, showing its

potential to be fabricated WOLEDs with high CRI in with blue-emitting and green-emitting combination materials.¹¹ PL spectrum of [(ptbi)₂Ir(bisq)]Cl measured at 77 K exhibits a maximum emission peak at 580 nm (Fig. S5, ESI+). Because solvent reorganization in solution at 77 K cannot stabilize the CT states,¹² the energy level of the transition increases,¹³ leading to the blue-shifted emission of about 20 nm compared with that at R.T.. The emission lifetimes ($\tau_{\rm p}$) of [(ptbi)₂Ir(bisq)]Cl are 0.67 and 0.86 µs in the solution and film, respectively, as shown in Table S1. The shorter lifetimes indicate that [(ptbi)2lr(bisq)]Cl may suppress the serious triplet-triplet annihilation (TTA) effect¹⁴ and improve the transition efficiency from singlet to triplet state.¹⁵ Interestingly, PLQY of [(ptbi)2Ir(bisq)]Cl in solution is 17.8%, while it increases to 32.4% in neat film, which is as twice times as that in acetonitrile (10⁻⁵ M). From the radiative (k_r) and nonradiative (k_{nr}) rate constants data shown in Table S1, k_r increases and k_{nr} decreases after film formation, which are responsible for the higher PLQY of [(ptbi), lr(bisq)]Cl in neat film.¹⁶ It is clear that the emission of [(ptbi)₂Ir(bisq)]Cl in the solution is weak, however, PLQY is enhanced in the solid state, probably due to its inherent aggregation-induced phosphorescent emission (AIPE) effect.¹⁷ In order to estimate the electron density distributions and energy levels of the orbitals, theoretical calculations of [(ptbi)2lr(bisq)]Cl were performed. The highest occupied molecular orbital (HOMO) and lowest unoccupied molecular orbital (LUMO) levels and distributions of [(ptbi)2lr(bisq)]Cl are shown in Fig. S6 (ESI+). For [(ptbi)2lr(bisq)]Cl, the HOMO (-5.81 eV) is localized on the Ir(III) atom and main ligands, whereas the LUMO (-2.70 eV) is distributed over the whole ancillary ligand with a small part on the Ir(III) atom. The triplet excited state (T₁) was calculated to understand the transition characteristic. As shown in Fig. S6 (ESI⁺) and Table S2, it is found that T₁ of [(ptbi)₂Ir(bisg)]Cl is from HOMO-2 to LUMO transition with a contribution of approximately 78%. The orbital analysis indicates that the T₁ emission of [(ptbi)2lr(bisq)]Cl contains a mixture of ³LLCT and ³MLCT transitions, which agrees well with the photophysical results discussed above.

Cyclic voltammetry (CV) measurements were also recorded to explore its electrochemical property (Table S1). The peak appeared at 0.37 V is attributed to the oxidation of the Ir(III)

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Table 1 EL performances for monochromatic and white OLEDs

Device	a) V _{turn-on}	CE ^{b), c)}	PE ^{b), c)}	EQE ^{b), C)}	Efficiency roll-offs			L _{max} ^{d)}	CIE	CRI ^{e)}	R9 ^{e)}
	[V]	$[cd A^{-1}]$	$[\text{Im W}^{-1}]$	[%]		[%]		[cd m ⁻²]	[(x, y)]		
					CE	PE	EQE				
monochromatic	3.3	17.8/14.4	15.4/8.4	10.5/8.4	19.1	45.5	20.0	25035	(0.60,0.40)	/	/
W4	3.6	25.5/24.3	17.3/13.2	13.1/12.2	4.7	23.7	7.0	50122	(0.49,0.45)	80	4

a) Measured at 1 cd m⁻². b) Maximum efficiencies. c) Efficiencies of the devices at 1000 cd m⁻². d) Maximum luminance. e) Values of the devices at 7 V

metal cationic site $[Ir(III) \rightarrow Ir(IV)]$.¹⁸ Consequently, the HOMO of $[(ptbi)_2 Ir(bisq)]CI$ is determined to be -5.17 eV. LUMO is -2.83 eV, calculating from the HOMO energy level and the absorption spectrum. These electrochemical data provide the useful information to design and fabricate devices.

To investigate the potential of the cationic Ir(III) complex in the device performance, vacuum deposition-processed OLED was fabricated by using [(ptbi)2Ir(bisq)]Cl as the dopant. The structure of OLED is ITO/MoO₃ (3 nm)/TAPC (35 nm)/TCTA (5 nm)/DCzPPy: [(ptbi)2lr(bisq)]Cl (10%, 20 nm)/TmPyPB (40 nm)/LiF (0.5 nm)/Mg:Ag (Fig. 2a). Herein, MoO₃, TAPC, TCTA, TmPyPB, LiF and DCzPPy (2,6-bis(3-(9H-carbazol-9-yl)phenyl)pyridine) were employed as hole-injecting layer, holetransporting layer, electron-blocking layer, electrontransporting layer, electron-injecting layer and host material, respectively. The corresponding EL data are depicted in Table 1. The morphology of both non-doped evaporated film and doped evaporated film were also tested by atomic force microscope (AFM). As shown in AFM images (Fig. S7, in ESI), they exhibit no special aggregation behaviors with the root mean square (RMS) values of 0.747 nm and 0.507 nm for nondoped and doped evaporated film, respectively.

From Fig. 2b, [(ptbi)2lr(bisq)]Cl-based OLED shows orange emission peak at 589 and 622 nm, with CIE coordinates of (0.60, 0.40). Similar to EL spectrum, the PL spectrum of [(ptbi), lr(bisq)]Cl in the co-evaporated film is peaked at 590 and 623 nm, indicating that the complete charge and/or energy transfer occurs from the host to the [(ptbi)2lr(bisq)]Cl upon excitation (Fig. S8, ESI⁺). An obviously blue-shifted emission of 20 nm from the PL spectrum in neat film is observed, which is probably caused by rigidochromic effect as its dominant ³MLCT excited-state characteristic.¹⁹ The monochromatic device exhibits maximum luminance (L_{max}) of 25035 cd m⁻², a maximum CE of 17.8 cd A⁻¹, power efficiency (PE) of 15.4 lm W⁻ ¹, and EQE of 10.5%. Although the efficiency decrease at brightness of 1000 cd m⁻², it still remains CE of 14.4 cd A⁻¹, PE of 8.4 lm W⁻¹, respectively. [(ptbi)₂lr(bisq)]Cl exhibits excellent EL performance in comparison with reported cationic Ir(III)based monochromatic OLEDs, which will be in favor of its potential to construct WOLEDs (Table S3, ESI+).

To validate this issue, we fabricated WOLEDs by using [(ptbi)₂lr(bisq)]Cl as the complementary emitter in combination with blue-emitting FIrpic and green-emitting Ir(ppy)₃. The device structure is ITO/MOO₃ (3 nm)/TAPC (35

nm)/TCTA (5 nm)/DCzPPy: [**(ptbi)**₂**Ir(bisq)**]**CI** (10%, O nm)/DCzPPy:Ir(ppy)₃ (10%, G nm)/DCzPPy:FIrpic (10% B nm)/TmPyPB (40 nm)/LiF(0.5 nm)/Ag:Mg (Fig. S9). Generally, the excellent WOLEDs will have high efficiency, low efficiency roll-off and high CRI, etc. To obtain WOLEDs with high performance that install above parameters together, herein, device structures were systematically optimized by adjusting thickness of each emitting layer.





Fig. S10 (ESI⁺) shows the electroluminescent properties for **W1-W3** and corresponding device parameters are depicted in Table S4 (ESI⁺). From device **W1** to **W3**, the thickness of FIrpic layer is changed from 25 nm to 17 nm. After optimization, **W3** shows negligible efficiency roll-off of 2.7% at 1000 cd m⁻², which indicates that thinner FIrpic layer facilitates the electron-transport. According to schematic energy-level diagram of WOLEDs (**Fig. 3a**), electrons and holes are effectively confined within the EML and the main carrier recombination zone is located at the interface between orange and green emitting layers. Thereby, it is believed that WOLEDs performances will be further enhanced via ingeniously adjusting the orange and green emitting layers simultaneously.

More obvious enhancements in efficiency can be obtained after optimization of device architectures. All electroluminescent properties are summarized in **Fig. 3** and **Table 1**. As shown in **Fig. 3**, a starting voltage of 3.6 V, a maximum brightness of 50122 cd m⁻², a maximum CE of 25.5 cd A^{-1} , a maximum PE of 17.3 lm W⁻¹ and EQE of 13.1% are realized in **W4**. At luminance of 1000 cd m⁻², **W4** has a

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decrease in efficiency due to TTA effect and field-induced quenching effect, but it still remains CE of 24.3 cd A⁻¹, PE of 13.2 lm W⁻¹ and EQE of 12.2%. This is the highest reported efficiency of WOLEDs based on cationic Ir(III) complexes (Table S5). Furthermore, because of the broad FWHM of [(**ptbi**)₂Ir(**bisq**)]CI, the obtained CRI of WOLEDs are 80 and R9 are greater than 0.



Fig. 3 (a) Energy level diagram of WOLED (b) EL spectra of W4 (c) Currentvoltage-luminance (*J-V-L*) (d) EQE, PE, CE curves. Insert of Fig.3b is EL image of W4

To further check the feasibility of such system, we replaced 1-phenyl-2-p-tolyl-1H-benzo[d]imidazole (ptbi) with 2-(4-tertbutylphenyl)-1-phenyl-1*H*-benzo[d]imidazole (tbpbi), and synthesized other structurally similar cationic Ir(III) complex, [(tbpbi)2lr(bisq)]Cl (Fig. S11, ESI⁺). The thermal stability of [(tbpbi)2Ir(bisq)]Cl and the relevant test results are summarized in the supporting information (Figs. S12 and S13, ESI⁺). All results indicate that [(tbpbi)₂Ir(bisq)]Cl can also be vacuum evaporated. We tried to gain insight into the solidpacking by culturing their single-crystal structures but failed. It is hypothesized that the chlorine counterion may form the special interactions with emissive cation part, which can improve its volatility to some context. To verify our hypothesis, [(tbpbi)2lr(bisq)]PF6 with hexafluorophosphate as counterion was synthesized and its ¹H-NMR data before and after vapor deposition have been measured. Similar to reported cationic Ir(III)complex. the results demonstrate that [(tbpbi)2lr(bisq)]PF6 suffers from unsatisfactory volatility (Fig. S14, ESI⁺). Therefore, we speculate that the small chlorine counterion might play very important role in enhancing the volatility for studied cationic Ir(III) complexes. The more clear reason is undergoing in our lab.

In summary, we synthesized one novel sublimable orange emitting cationic Ir(III) complex **[(ptbi)₂Ir(bisq)]CI** using chlorine as counterion. An orange-emitting OLED with CE of 17.8 cd A⁻¹ and a high EQE of 10.5% was successfully fabricated by vacuum evaporation deposition. Employing it as orangeemitting layer, obtained WOLEDs achieve a maximum brightness of 50122 cd m⁻², and a maximum CE of 25.5 cd A⁻¹, EQE of 13.1 % with tiny efficiency roll-off of 4.7%. As far as we know, this is the highest reported efficiency of WOLEDs based on sublimable cationic Ir(III) complexes. The results reported here will open a new avenue to construct efficient sublimable cationic Ir(III) complexes in future.

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Conflicts of interest

There are no conflicts to declare.

Notes and references

- a) H. Na and T. S. Teets, J. Am. Chem. Soc., 2018, 140, 6353; b) R.
 D. Costa, E. Orti, H. J. Bolink, F. Monti, G. Accorsi, N. Armaroli, Angew. Chem. Int. Ed. 2012, 51, 8178.
- P. T. Chou and Y. Chi, *Chem. Eur. J.*, 2007, **13**, 380; b) T. Zhang, C.
 Shi, C. Zhao, Z. Wu, J. Chen, Z. Xie, D. Ma, *ACS Appl. Mater. Interfaces* 2018, **10**, 8148.
- 3 M. Lenes, G. Garcia-Belmonte, D. Tordera, A. Pertegás, J. Bisquert, H. J. Bolink, Adv. Funct. Mater., 2011, 21, 1581.
- 4 a) Y. Zhang , J. Lee , S. R. Forrest , *Nat. Commun.* 2014, *5*, 5008; b)
 M. Sessolo, D. Tordera, H. J. Bolink, *ACS Appl. Mater. Interfaces* 2013, *5*, 630.
- 5 a) W. Y. Wong, G. J. Zhou, X. M. Yu, H. S. Kwok and Z. Lin, Adv. Funct. Mater., 2007, **17**, 315; b) D. Ma, Y. Qiu and L. Duan, Adv. Funct. Mater., 2016, **26**, 3438; c) F. Zhang, Y. Guan, S. Wang, S. Li, F. Zhang, Y. Feng, S. Chen, G. Cao and B. Zhai, Dyes Pigments, 2016, **130**, 1; d) D. Ma, L. Duan and Y. Qiu, J. Mater. Chem. C, 2016, **4**, 5051.
- 6 a) B. W. D'Andrade and S. R. Forrest, Adv. Mater., 2004, 16, 1585;
 b) S. Wang, Q. Yang, B. Zhang, L. Zhao, D. Xia, J. Ding, Z. Xie, L. Wang, Adv. Optical Mater., 2017, 5, 1700514.
- 7 a) R. Cui, W. Liu, L. Zhou, X. Zhao, Y. Jiang, Y. Zheng, H. Zhang, J. Mater. Chem. C, 2017, 5, 2066; b) Z. Wang, X.-L. Li, Z. Ma, X. Cai, C. Cai, S.-J. Su, Adv. Funct. Mater., 2018, 28, 1706922.
- M. Du, Y. Feng, D. Zhu, T. Peng, Y. Liu, Y. Wang, M. R. Bryce, *Adv. Mater.*, 2016, 28, 5963; b) H. Cao, G. Shan, X. Wen, H. Sun, Z. Su, R. Zhong, W. Xie, P. Li, D. Zhu, *J. Mater. Chem. C*, 2013, 1, 7371.
- 9 M. K. Nazeeruddin, R. Humphry-Baker, D. Berner, S. Rivier, L. Zuppiroli, M. Graetzel, J. Am. Chem. Soc., 2003, 125, 8790.
- a) M. G. Colombo, H. U. Guedel, *Inorg. Chem.* 1993, **32**, 3081; b)
 S. G. Nelson, C. Zhu, X. Shen, *J. Am. Chem. Soc.*, 2004, **126**, 14.
- 11 P. Tao, W.-L. Li, J. Zhang, S. Guo, Q. Zhao, H. Wang, B. Wei, S.-J. Liu, X.-H. Zhou, Q. Yu, B.-S. Xu, W. Huang, *Adv. Funct. Mater.*, 2016, **26**, 881.
- 12 D. Ma, T. Tsuboi, Y. Qiu, L. Duan, Adv. Mater., 2017, 29, 1603253
- 13 A. B. Tamayo, S. Garon, T. Sajoto, P. I. Djurovich, I. M. Tsyba, R. Bau, M. E. Thompson, *Inorg. Chem.*, 2005, **44**, 8723.
- 14 a) Y.-M. Jing, F.-Z. Wang, Y.-X. Zheng, J.-L. Zuo, J. Mater. Chem. C, 2017, 5, 3714; b) B. Jiang, C. Zhao, X. Ning, C. Zhong, D. Ma and C. Yang, Adv. Optical Mater., 2018, 1800108.
- 15 a) Y. C. Zhu, L. Zhou, H. Y. Li, Q. L. Xu, M. Y. Teng, Y. X. Zheng, J. L. Zuo, H. J. Zhang, X. Z. You, *Adv. Mater.*, 2011, **23**, 4041; b) C. L. Ho, Q. Wang, C. S. Lam, W. Y. Wong, D. Ma, L. Wang, Z. Q. Gao, C. H. Chen, K. W. Cheah and Z. Lin, *Chem. Asian J*, 2009, **4**, 89.
- 16 J.-L. Liao, P. Rajakannu, P. Gnanasekaran, S.-R. Tsai, C.-H. Lin, S.-H. Liu, C.-H. Chang, G.-H. Lee, P.-T. Chou, Z.-N. Chen and Y. Chi, *Adv. Optical Mater.*, 2018, **6**, 1800083.
- 17 a) Q. Zhao, L. Li, F. Li, M. Yu, Z. Liu, T. Yi and C. Huang, *Chem. Commun.*, 2008, 685; b) Y. You, H. S. Huh, K. S. Kim, S. W. Lee, D. Kim and S. Y. Park, *Chem. Commun.*, 2008, 3998.
- 18 A. B. Tamayo, B. D. Alleyne, P. I. Djurovich, S. Lamansky, I. Tsyba, N. N. Ho, R. Bau and M. E. Thompson, *J. Am. Chem. Soc.*, 2003, 125, 7377.
- 19 H. Cao, H. Sun, Y. Yin, X. Wen, G. Shan, Z. Su, R. Zhong, W. Xie, P. Li and D. Zhu, *J. Mater. Chem. C*, 2014, **2**, 2150.

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