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An effective thermally activated delayed fluorescence host material for highly efficient blue phosphorescent organic light-emitting diodes with low doping concentration

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Graphical Abstract

Since the host molecule is a TADF material, the T1 state energy can be transferred to the S1 state through reverse intersystem crossing (RISC), and the energy can be 100% transmitted to the object.



Hightlights

- Due to the TADF property of BCz-2SO, the triplet energy can reverse to singlet state and transfer to the phosphor emitter.
- Thanks to the low doping concentration of 1%, the triplet-triplet annihilation can be suppressed and the efficiency roll-off of the device is small.
- The solution-processed blue phosphorescent OLEDs achieved a high brightness of 16537 cd m⁻² and stable EL spectra.

Abstract: A thermally activated delayed fluorescence (TADF) material BCz-2SO has been designed and synthesized as host for blue phosphorescent organic light-emitting diodes (OLEDs). Photophysical studies and theoretical calculations show that the molecule has a small singlet-triplet energy gap (ΔE_{ST}) of 0.345 eV, which is beneficial to the reverse energy transferring between the singlet and triplet state. Thanks to the TADF property, the triplet energy can be transmitted to the singlet state through reverse intersystem crossing (RISC), and then transmitted to the guest through the Förster energy transfer (FET) to achieve 100% utilization of energy. Thus, the triplet–triplet annihilation (TTA) of the blue phosphor can be avoided by the extremely low doping concentration of 1%. By using BCz-2SO as the host of FIrpic, the solution-processed blue phosphorescent device achieves the maximum current efficiency (CE), power efficiency (PE), external quantum efficiency (EQE) and highest brightness of 16.38 cd A⁻¹, 9.04 lm W⁻¹, 7.8% and 16537 cd m⁻², respectively. It demonstrates that one can employ the solution-processed method to prepare the high performance phosphorescent OLEDs using the TADF host material we have developed.

Keywords: blue emission, solution-process, low doping concentration, TADF, organic light-emitting diodes.

1. Introduction

Organic light emitting diodes (OLEDs) with its low cost, high brightness, flexible display, high efficiency, have gradually reached the standard of industrialization,[1-4] OLEDs are a kind of organic materials which can change the electric energy to light energy: the electron and hole

composite exciton through the cathode and anode respectively under the action of electric field, and transfer to the organic light emitting layer through the electron transport layer and the hole transport layer, eventually the energy is exported as photons.[5-8] OLED development goes through three phases: fluorescent OLED, phosphor OLED and thermally activated delayed fluorescent OLED.[9,10] The first generation fluorescent materials have good device stability, but can only use single-state excitons to illuminate, their external quantum efficiencies (EQEs) are generally less than 5% (assuming 20% coupling output of devices).[11-13] To make full use of the triplet excitons, in 1998 Forrest of Princeton university developed the second generation of OLED phosphorescent materials, the inner quantum efficiency of phosphor materials was as much as 100%, because single-state exciton and triplet-state exciton can emit light at the same time.[14,1-3] However, the material was limited by the high price, the serious attenuation of device efficiency.

In order to overcome the shortages of fluorescent materials and phosphorescent materials, Adachi group proposed the concept of thermal activation delay fluorescence (TADF) in 2008--When the singlet and triplet exciton energy difference is very small, triple excitons can be thermally activated and converted to singlet excitons, which then contribute to delayed fluorescence, its theoretical upper limit of internal quantum efficiency is 100%.[15] In 2012, the Adachi group first reported three deep blue TADF materials based on diphenyl sulfone as acceptor, with diphenylamine, tert-butyldiphenylamine and tert-butylcarbazole as donor units, respectively. ΔE_{ST} were 0.54, 0.45 and 0.32 eV, respectively. The theoretical calculations showed that because carbazole has a larger twist angle than diphenylamine and the adjacent benzene ring.[16] The Kido group used bis(phenylsulfonyl)benzene with isomer as the acceptor unit and tert-butylcarbazole as the donor unit. Two compounds were synthesized, which were effectively separated by HOMO and LUMO, ΔE_{ST} was very small.[17] Many of the TADF host molecules currently used for blue phosphorescence have been reported, but few can be prepared by solution-process.

In this work, a TADF luminescent molecule BCz-2SO with a small singlet-triplet energy gap was designed and synthesized. Its UV absorption and fluorescence emission spectra showed blue luminescence, its turn-on voltage is 5.17 V, and the energy gap is 0.345 eV, TGA and DSC show that it has good stability and can be used for the preparation of device. As a host material, a blue phosphorescent device was prepared by solution-process, and its current efficiency (CE),

luminous efficiency (PE), external quantum efficiency (EQE) and highest brightness are measured as 16.38 cd A⁻¹, 9.04 lm W⁻¹, 7.8% and 16537 cd m⁻². It has to be said that TADF's special energy transfer mode not only enables 100% utilization of energy, but also achieves low device efficiency roll-off. In addition, since BCz-2SO has a small ΔE_{ST} , the energy is transferred more efficiently between the host and guest, it is sufficient to do only one percent doping when preparing the device, which contributes to energy and resource savings.

2. Experimental section

General Information

All the organic materials are purchased from various sources and used as received. ¹H NMR and ¹³C HMR spectra are measured by a BRUKER AMX 300 or 500 MHz instrument. Thermogravimetric analysis (TGA) and differential scanning calorimetry (DSC) curves are recorded on a Netzsch simultaneous thermal analyzer (STA) system (STA 409PC) and DSC 2910 modulated calorimeter under a dry nitrogen gas flow at a heating rate of 10°Cmin⁻¹. The film surface morphology is performed by the AFM (Seiko Instruments, SPA-400). Cyclic voltammetry (CV) is performed on a CHI750C voltammetric analyzer. The UV-Vis absorption spectra of the compound is acquired by a SHIMADZU UV-2450. The PL spectra is measured and the integrating sphere is purged with flowing nitrogen during the entire measuring process. The BRUKER DALTONICS Matrix-assisted laser desorptionionization time-of-flight mass spectrometry (MALDI-TOF-MS) is used to measure molecular masses. The photoluminescence emission spectra is obtained by a HORIBA FLUOROMAX-4 and liquid nitrogen is placed into the optical Dewar flask for low temperature (77 K) photophysical measurements.

Computational details

The geometrical and electronic properties of BCz-2SO were performed with the Gaussian 03 program package. The calculation was optimized at the B3LYP/6-31G(d) level of theory. The molecular orbitals were visualized using Gaussview.

Device fabrication

The OLED device was prepared on indium-tin oxide (ITO) substrates that had been templated.

The ITO substrate was repeatedly washed with deionized water, acetone and absolute ethanol, dried, and treated with UV and ozone for 15 minutes. Then the ITO substrate was placed in a spin-coating machine. On the suction cup, spin-on PEDOT:PSS was rotated at a speed of 3500 r/min for 40 seconds. And PEDOT: PSS was dissolved in chlorobenzene at a concentration ratio of 1:1 and then annealed at 140 °C. After 15 minutes, the ITO substrate was transferred to a nitrogen-filled glove box, and the luminescent layer BCz-2SO:FIrpic was spin-coated on ITO at 3500 r/min for 40 seconds (The solution concentration in the luminescent layer was 8.0 mg/mL, the concentration of FIrpic is 2.8mg/mL). After the spin coating was completed, the ITO substrate was annealed at 80 °C for 30 minutes. Finally, the electron injecting layer TPBi and the aluminum electrode were sequentially vapor-deposited on the ITO substrate by thermal evaporation, and the degree of vacuum in the vapor deposition process was maintained at 2×10^{-6} Torr.

Preparation of AFM test film

The ITO substrate was repeatedly washed with deionized water, acetone and absolute ethanol, dried, and treated with ultraviolet light and ozone for 15 minutes. The ITO substrate was placed on the spinner of the spin-coating machine. Spin-coated PEDOT:PSS was rotated at a speed of 3,500 r/min for 40 seconds, then annealed at 140°C for 15 minutes, then ITO The substrate was transferred to a nitrogen-filled glove box, and the BCz-2SO dichloroethane solution was spin-coated on ITO at a solution concentration of 8.0 mg/mL. After spin coating, the ITO substrate was annealed at 80°C for 30 minutes.

2.1. Synthesis

Synthesis of 3-(9H-carbazol-6-yl)-9H-carbazole (M1).

3-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)-9H-carbazole (1.52 g, 5 mmol), 3-bromo-9Hcarbazole (1.23 g, 5 mmol), K₂CO₃ (2.09 g, 15 mmol), pd(pph₃)₄ (0.029 g, 0.025 mmol) are added into a round-bottom flask (100 mL), then adding the mixture of toluene (18 mL), ethanol (9 mL) and ultrapure water (3 mL) under N₂, the mixture is stirred to reflux overnight at 78 °C. After completion of the reaction, the solution is separated by rotary evaporator, methylene chloride is added to the residue solid and the organic layer is dried over Na₂SO₄, then concentrated in vacuo.[18] The residue solid is purified by column chromatography to give the product as yellow solid powder (1.198 g, 72.2%): ¹H NMR (500 MHz, DMSO): δ 11.26 (s, 2H), 8.50 (s, 2H), 8.34–8.31(m, 2H), 7.91–7.88 (m, 2H), 7.59–7.46 (m, 6H), 7.30–7.25 (m, 2H). EI MS (m/z): 333.35, calcd for C₂₄H₁₆N₂, 332.13.

Synthesis of (4-bromophenyl)(phenyl)sulfane (M2).

3-bromobenzenethiol (3.78 g, 20 mmol), 1-iodobenzene (6.12 g, 30 mmol), K₂CO₃ (8.34 g, 60 mmol), CuI (0.576 g, 4 mmol), and 1,10-phenanthroline (0.792 g, 4 mmol) are mixed in DMSO (15 mL), the solution is stirred for 24 h under N₂. Then cooled to room temperature and extracted with methylene chloride and water. The extracted organic layer is dried with Na₂SO₄ and evaporated under vacuum.[19] The resulting crude product is purified by silica-gel column chromatography to give the product as white solid powder (3.96 g, 74.8%): ¹H NMR (500 MHz, CDCl₃) δ (ppm) 7.41 (s, 2H), 7.39 (s, 2H), 7.16 (dd, J =8.2, 2.7 Hz, 5H). EI MS (m/z): 265.74, calcd for C₁₂H₉BrS, 265.96.

Synthesis of 1-(4-bromophenylsulfonyl)benzene (M3).

(4-bromophenyl) (phenyl) sulfane (2.65 g, 10 mmol), Hydrogen peroxide (30 mL) are mixed in acetic acid (100 mL), then the solution is stirred for 2 h at 120°C A large amount of water is added to the reaction system, stirring and white solid is precipitated and filtered. The solid layer is dissolved in dichloromethane and neutralized with sodium bicarbonate. At last, anhydrous sodium sulfate is added to remove water and evaporated under vacuum.[19] The crude product is purified by column chromatography on silica-gel to give the desired product as white solid powder (2.44 g, 82.1%): ¹H NMR (500 MHz, CDCl₃) δ (ppm) 7.93 – 7.89 (m, 2H), 7.81 – 7.75 (m, 2H), 7.66 – 7.59 (m, 2H), 7.56 (dd, J = 6.0, 3.9 Hz, 1H), 7.53 – 7.46 (m, 2H). EI MS (m/z): 295.85, calcd for C₁₂H₉BrO₂S, 297.95.

Synthesis of

9-(4-(phenylsulfonyl)phenyl)-3-(9-(4-(phenylsulfonyl)phenyl)-9H-carbazol-6-yl)-9H-carbazol e (BCz-2SO).

3-(9H-carbazol-6-yl)-9H-carbazole (0.5 g, 5 mmol), 1-(4-bromophenylsulfonyl) benzene (1.125 g, 12 mmol), potassium carbonate (1.25 g, 30 mmol), cuprous iodide (0.11 g, 2 mmol), 1,10-phenanthroline (0.06 g, 2 mmol) are dissolved in 30 mL of N,N-dimethylformamide (DMF) under N₂, stirring for 24 h under 160 °C. After completion of the reaction, dichloromethane and water are added to the cooled mixture. The organic layer is separated and dried over Na₂SO₄, then concentrated in vacuo. The residue solid is purified by column chromatography to give the product as pale yellow solid (2.08 g, 62.3%): ¹H NMR (500 MHz, CDCl₃, δ): 8.43 (s, 2H), 8.27–8.19 (m, 6H), 8.09 (d, J = 7.4 Hz, 4H), 7.82 (d, J = 8.5 Hz, 4H), 7.77 (dd, J = 8.5, 1.6 Hz, 2H), 7.67 (t, J = 7.4 Hz, 2H), 7.62 (t, J = 7.6 Hz, 4H), 7.56 (d, J = 8.5 Hz, 2H), 7.51–7.44 (m, 4H), 7.37 (t, J = 7.3 Hz, 2H). ¹³C NMR (500 MHz, CDCl₃, δ): 144.2, 143.7, 141.4, 138.6, 138.2, 137.6, 137.1, 133.5, 128.9, 128.5, 127.6, 127.1, 126.8, 124.5, 123.9, 121.5, 116.6, 115.6, 109.1. EI MS (m/z): 764.16, calcd for C₄₈H₃₂N₂O₄S₂, 764.18.



(a) K₂CO₃, pd(pph₃)₄, toluene, ethanol, ultrapure water; (b) K₂CO₃, CuI, 1,10-phenanthroline, DMSO; (c) Hydrogen peroxide, Acetic acid; (d) Potassium carbonate, Cuprous iodide, 1,10-phenanthroline, DMF.

Scheme 1. Synthetic routes of BCz-2SO and related molecular formulas.

3. Results and discussion

3.1. Synthesis and characterization

The synthesis routes of the BCz-2SO are shown in Scheme 1, and the detailed synthetic procedures are described in the Experimental Section. BCz-2SO is synthesized in four steps using 3-bromobenzenethiol and 3-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)-9H-carbazole as raw material, and all compounds are further confirmed by NMR spectroscopy.

3.2. Thermal analysis

In order to determine the thermal properties of BCz-2SO, thermogravimetric analysis (TGA) and differential scanning calorimetry (DSC) analyses are performed under a nitrogen atmosphere at a heating rate of 10 °C min⁻¹. It is found that the compound exhibits excellent thermal stability with high decomposition temperatures (T_d , defined at the temperature that the materials show a 5% weight loss) around 450 °C, while the glass transition temperature (T_g) is 160 °C. It turns out that BCz-2SO has high thermal stability and suitability, which are of great significance for the fabrication of devices. The results are shown in Fig. 1.



Fig. 1. TGA and DSC curves for BCz-2SO recorded at a heating rate of 10 $^\circ$ C min⁻¹ under N₂.

In order to determine the film forming ability and morphological stability of BCz-2SO, we test its AFM images of the spin-coated thin films, as shown in Fig. 2. It can be seen that there is no agglomeration structure basically and its root-mean-square (RMS) roughness value is 0.359 nm , which indicates that BCz-2SO has good film forming performance and stable morphology, which is conducive to the preparation of devices.



Fig. 2. AFM topographic images of BCz-2SO.

3.3. Theoretical calculations

The electrical and geometric properties of BCz-2SO are studied by density functional theory calculation (DFT) at a B3LYP/6-31G(d) level for the geometry optimization. As shown in Fig. 3, the HOMO is localized on two carbazole unit and the LUMO is localized on sulfoxide unit. From the figure we can draw that the small overlap between the HOMO and LUMO which indicates the strong charge transfer character and small electron exchange energy, and this ensures its TADF feature. The geometries of the host shows that the BCz unit is significantly twisted, resulting in a non-planar structure in each molecule. In addition, we use the optimized structure of S0 for DFT calculation and obtained that the singlet state value and triplet state value are 3.2973eV and 2.9520eV, respectively. The value of ΔE_{ST} is 0.345eV, which is obtained by subtracting the energies of the triplet and singlet states that is corresponding to the above results.



Fig. 3. Molecular structure, optimized geometry and HOMO and LUMO distribution of BCz-2SO.

3.4. Electrochemical properties

In order to investigate the frontier orbital energy levels of the compound, the oxidation initiation potential of the compound is measured by cyclic voltammetry (CV). Using tetrabutylammonium

Hexafluorophosphate (TBAPF6) as the supporting electrolyte and ferrocene as the internal standard in anhydrous DMF for cathodic scan and in CH_2Cl_2 for anodic scan. According to the Fig. 4, the initial oxidation potential of the compound (E_{ox}) can be observed that is 0.95 eV. The HOMO and the LUMO energy levels of the compound are calculated from the following two formulas by combining the energy gap calculated by ultraviolet absorption.

$$HOMO = - (E_{ox} - 0.40 + 4.8) eV$$

$$LUMO = HOMO - Eg$$

The calculated results are the HOMO value of -5.352 eV and LUMO value of -5.695 eV. The relevant physical properties of BCz-2SO are listed in Table 1.



Fig. 4. Cyclic voltammograms of the compound.

3.5. Photophysical properties

The photophysical properties of the molecule are studied by UV-visible absorption spectrum, fluorescence emission spectrum and low temperature phosphor spectrum under nitrogen condition. Fig. 5(a) shows the UV-vis absorption spectra, PL spectra and Phosphorescence spectra of BCz-2SO film (77 K) in toluene. The triplet energies (E_T) of BCz-2SO determined by the phosphorescence spectra at 77 K is 2.9108 eV. In addition, according to the fluorescence spectrum in toluene, the singlet energies (E_S) is calculated, giving a value of 3.5068 eV. It can be seen that the triplet state and the singlet state energy obtained by the experiment are consistent with the

theoretical values. Fig. 5(b) shows room-temperature emission spectra of the molecule in the pure film state, as shown in the figure, the position of the largest emission peak is at around 460 nm which indicates that BCz-2SO is a blue luminescent material.

To further investigate the photophysical properties, the room temperature normalized UV-vis absorption spectra and PL spectra of BCz-2SO are measured in different solutions. According to the theoretical calculation of the excited state, it can be seen that the compound has the charge transfer (CT) state and the local excitation (LE) state, so the solvation effect test is carried out -- the absorption and emission spectra of the compound are tested in n-hexane, toluene, dichloromethane (DCM) and N,N-dimethylformamide (DMF), respectively. As shown in Fig. 6(a) and Fig. 6(b), the UV absorption spectrum of the compound does not change much with the position of the different absorption peaks of the solvent, but with the polarity of the solvent increases, the emission spectrum of the compound red shifts--the position of the emission peak gradually moves to the right. This solvation behavior is due to the intramolecular charge transfer (ICT) of the carbazole donor to the diphenyl sulfone receptor, which has a large dipole moment in the excited state, and the interaction of the compound with the solvent is enhanced in the polar solvent. The energy is reduced in a more stable excited state, resulting in a red shift in the emission spectrum.

In order to prove the ICT effect within the molecule, UV-absorption and fluorescence spectra of the molecule are tested in different solutions to study the changes of molecular dipole moment under excitation state, and the relationship between directional polarization of solvent and Stokes shift is explored by lippert-mataga equation:

$$\Delta v = v_{abs} - v_f \cong \frac{2(\Delta \mu)^2}{hca^3} \Delta f(\varepsilon, n) + A \tag{1}$$

$$\Delta f(\varepsilon, n) = \frac{\varepsilon - 1}{2\varepsilon + 1} - \frac{n^2 - 1}{2n^2 + 1}$$
(2)

In the above formulas, ε and n are the static dielectric constant and refractive index of the solvent, respectively. Δv refers to the Stokes shift between absorption and fluorescence, h means the Planck's constant, a is the solute cavity radius, and c represents the velocity of light.[20] Fig. 6(c) shows the function curve of Δv and f (ε , n). According to formula (1), the slope value is 16363

cm⁻¹, related spectral data are in Table 2, with the above slope, the dipole moment is calculated to be 12 D, such a large dipole moment also proves that there is indeed an intramolecular charge transfer between the donor and the acceptor.



Fig. 5. (a) UV-vis absorption spectra, PL spectra and Phosphorescence spectra of BCz-2SO film (77K) in toluene ;



(b) Room-temperature emission spectra of solid BCz-2SO.

Fig. 6. (a) The room temperature normalized UV–vis absorption spectra indifferent solutions ; (b) PL spectra of BCz-2SO in different solvents; (c) Lipperte–Mataga plot of BCz-2SO in various solutions.

3.6. Electroluminescence properties

Since BCz-2SO has a high triplet energy level and is typical blue light in the film state, the compound is used as a host material of blue phosphorescence. In order to test whether BCz-2SO can be used as a solution-processed host, we prepare a single-layer blue phosphorescent device based on FIrpic. The relative energy level of the material is shown in Fig. 7. As can be seen from the figure, since the host material is a TADF molecule, the triplet energy can be returned to the singlet state through RISC, which may explain why the host and the guest can still transfer energy through the Forst form at a doping concentration of 1% and why the device roll-off is small. The structure of the device: ITO/ PEDOT: PSS (40 nm)/ host: FIrpic (1 wt%, 60 nm)/ TPBI (40 nm)/ LiF(1 nm)/ Al(100 nm). ITO is the anode, PEDOT is the hole injection layer, TPBI is the electron transport layer and Al is the cathode. Fig. 8 shows the current density-voltage-luminance plot(J-V-L), current density versus luminous efficiency, and brightness vs. power efficiency. The main features of the device are listed in Table 3. It can be seen from the figure that the device has a turn-on voltage of 5.17 V, a maximum luminous efficiency of 16.38 cd A⁻¹, and a maximum power efficiency of 9.04 lm W⁻¹.



Fig. 7. Schematic energy-level diagram of the device and the molecular structures of the emitter.



Fig. 8. (a) Current density–voltage–luminance (J–V–L) characteristics; (b) Luminouce efficiency (hollow) as a function of current density. Inset: Power efficiency (solid) as a function of brightness.

The EL spectrum and EQE of the device are shown in Fig. 9(a). The EQE reaches 7.8% at 3.15 mA cm⁻². It is worth noting that the doping concentration is only 1%, because BCz-2SO as the luminescent host material has a small ΔE_{ST} that is beneficial to the RISC between the singlet and the triplet.[21,22] The related mechanism diagram is shown in Fig. 10. This figure shows the energy transferring between the T₁ state and S₁ state and the host and guest. It also can be seen from the EL diagram that the device exhibits a typical blue light emission of 476 nm, where comes from the guest FIrpic, indicating that the energy is completely transferred from the host material to the guest material, which also shows that using BCz-2SO as the host of the blue phosphorescent device luminescent layer is feasible. Fig. 9(b) also tests the EL spectra at different voltages and it can be seen that as the voltage increases, the overall trend is the electroluminescence intensity enhancing. At the same time, with the voltage increasing, the spectral position does not change significantly, indicating the stability of electroluminescence. EL performances of the device are listed in Table 3.



Fig. 9. (a) Dependence of EQE on current density for the device. Inset: EL spectrum of the blue-emitting device;

(b) EL spectrum of blue-emitting devices measured at different voltages



Fig. 10. Energy transfer mechanism diagram of the device.

4. Conclusion

In summary, we designed and synthesized a TADF luminescent molecule BCz-2SO by using carbazole group and diphenyl sulfone segment, and characterized its series of properties. TGA and DSC showed that it has good stability and can be used for the preparation of device, absorption and emission spectra of the device showed that it has typical blue light emission, and a blue phosphorescent light-emitting diode was constructed as a host material. A blue phosphorescent OLED which can be used for solution preparation was prepared, and the CE, PE, EQE and highest brightness of the device were 16.38 cd A⁻¹, 9.04 lm W⁻¹, 7.8% and 16537 cd m⁻², respectively. It is demonstrated our study enriches the field of blue phosphorescent OLEDs that can be used in solution processing. At the same time, due to its special energy transfer mechanism and small ΔEst,

it is only necessary to do very little to achieve the desired effect when preparing the device, which is of great significance in saving energy resources.

Conflict of interest statement

We declare that we have no financial and personal relationships with other people or organizations that can inappropriately influence our work, there is no professional

or other personal interest of any nature or kind in any product, service and/or company that could be construed as influencing the position presented in, or the review of, the manuscript entitled, " An effective thermally activated delayed fluorescence host material for highly efficient blue phosphorescent organic light-emitting diodes with low doping concentration".

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	$\lambda_{abs}{}^1\!(nm)$	$\lambda_{em}^{1}(nm)$	HOMO ² (eV)	LUMO ² (eV)	$\Delta E_{ST}^{3}(eV)$	T_d ⁴ / T_g (°C)
BCz-2SO	241, 288, 334	410	-5.352	-5.695	0.345	450/160

Table 1. Physical properties of BCz-2SO.

¹ Measured in CH2Cl2 solution at 300K. ² The difference between S1 and T1. ³ Estimated from the onset of fluorescence and phosphorescence spectrum. ⁴ Td, corresponding to 5% weight loss.

Table 2. Spectral properties of BCz-2SO in different Solvents BCz-2SO solvents $\Delta f^{1}(\epsilon, n)$ $\Delta V ^{4}(cm^{-1})$ $\Lambda_{abs}^{2}(nm)$ $\Lambda f^{3}(nm)$ 0.0012 380 291, 347 2503 n-hexane 0.014 241, 288, 339 410 5108 toluene DCM 0.217 260, 293, 342 444 6717 DMF 0.274 241, 288, 339 484 8837

 $^1\Delta f$ is the orientation polarizability parameter of the solvent. $^2\lambda_{abs}$ is absorption wavelength. $^3\lambda f$ is fluorescent

wavelength. ${}^{4}\Delta V$ is the Stokes shift.

Device	$V_{on}(V)$	EQE _{max} (%)	CE_{max} (cd A^{-1})	PE_{max} ($lm W^{-1}$)	$\lambda_{max}\left(nm ight)$	B _{max} (cd m ⁻²)
BCz-2SO	5.17	7.8	16.38	9.04	476	16537

Table 3. EL performances of the device using BCz-2SO as host.