

# Quantum computing optimization of charge transport mechanism and luminescence efficiency enhancement in OLED devices

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**Abstract** Organic electroluminescent diodes (OLEDs) have promising applications in display and lighting due to their high efficiency, ultra-thinness, easy bending, and eye protection. However, charge transport imbalance constrains the further improvement of OLED device performance. In this study, the effects of different co-mingled body ratios on the charge transport mechanism of TADF blue materials were investigated using quantum computational methods to enhance the charge transport and luminescence efficiency of white organic light-emitting diodes (WOLEDs). Through the design of ITO/HAT - CN/HATCN/TAPC/DBA - DI: TCTA: 26 dczppy/Tm3PyP26PyB/Liq/Al structure device, system control TCTA: the proportion of 26 dczppy (1-0, 2:1, 1:1, 1:2, 1-0), the influence of the proportion of the blending main body on the carrier equilibrium was studied. The experimental results show that when the ratio of TCTA:26DCzPPy is 1:1, the device performance is optimized, with a maximum brightness of 11,072 cd/m<sup>2</sup>, a maximum external quantum efficiency (EQE) of 22.56%, and a carrier equilibrium factor  $\gamma$  as high as 0.927, which is significantly better than that of devices with other ratios. Single-carrier device studies have shown that an appropriate ratio of the co-mingled body can simultaneously improve the electron and hole transport ability, optimize the carrier injection path, and promote the balanced distribution of carriers in the luminescent layer. It is shown that charge transport can be effectively balanced by regulating the co-mingled body ratio, which provides a theoretical basis and experimental foundation for the design of high-efficiency WOLED devices.

**Index Terms** Quantum computing, organic electroluminescent diode, thermally activated delayed fluorescent material, charge transport, carrier equilibrium, co-mingled body

## I. Introduction

Since its birth, microelectronic technology has greatly promoted the development of society and human progress [1]. Starting from the second half of the 20th century, microelectronics technology has brought new technologies and new media, which have constantly transcended thinking and concepts, refreshing people's cognition of high and new technologies time and again, and at the same time, profoundly changing human's way of life, mode of production, and way of thinking [2], [3]. At present, microelectronics technology has become the core and cornerstone of the information industry, laying a solid foundation for mankind to enter the information age. Compared with microelectronics technology, optoelectronics technology has quietly entered people's lives in another way, appearing in people's vision with a younger and more energetic image [4]-[6].

Due to the universality and breadth of the application of optoelectronics technology, its role in the modernization of information technology also appears to be more and more pivotal, optoelectronics technology has gradually become the basis and key to the survival and development of information technology [7], [8]. We have reason to believe that optoelectronics technology will inevitably set off a revolution in the field of information and become one of the pillars of future information technology. After entering the 21st century, with people's more frequent communication and exchange, the dissemination of information plays a crucial role, and the dissemination of information depends on the display [9]. At this time, as one of the sub-disciplines of optoelectronics technology, information display technology came into being [10]. The development of display technology has greatly improved people's visual ability and information acquisition ability. Especially in today's rapidly changing digital technology, how to obtain more efficient and lightweight display devices has become one of the concerns of people.

In the field of flat panel display, organic electroluminescent diode (OLED) has rapidly become a research hotspot, and it is regarded as one of the new display products with great development potential [11], [12]. OLED technology has many inherent advantages over the current mainstream liquid crystal display (LCD) technology, such as good display effect, thin thickness, low energy consumption, high contrast, good low-temperature resistance, fast

response speed, flexible display and simple preparation process. OLED has many inherent advantages such as thin thickness, low energy consumption, high contrast, good low temperature resistance, fast response time, flexible display and simple preparation process, etc. [13]-[15]. OLED has rapidly gained a place in the field of flat panel display by virtue of its own excellent technical performance and has been gradually developed into many fields such as military, lighting, and civil use, which is related to all aspects of people's practical life. In the military field, it can be used for military map display, military equipment terminal display, etc. [16]. In the field of lighting, it can be used for various color lighting, neon lights, etc. [17]. In the field of civilian display can also be used for cell phones, televisions, computers, car displays, entertainment equipment, medical equipment, etc. [18]-[20]. Nowadays, both emerging products such as personal digital assistants (PDAs), wearable devices, virtual reality devices (VR) and traditional products such as smart phones and tablet PCs have put forward more and more requirements on screen effect and display performance [21], [22]. The OLED display technology has largely met the expectations of people for future display screens and become the most ideal choice among many display devices [23].

The rapid development of microelectronics and optoelectronics technology has greatly changed the way of life and production of human beings. As a branch of optoelectronics technology display technology, which organic electroluminescent diode (OLED) has become one of the most promising new display products because of its advantages of good display effect, thin thickness, low energy consumption, high contrast, fast response speed, and flexible display. In particular, white organic light-emitting diode (WOLED) has a promising application in the field of health solid-state lighting and full-color display. However, charge transport imbalance in OLED devices has become a key factor limiting their performance. Thermally activated delayed fluorescence (TADF) materials are an important way to improve the luminescence efficiency of OLEDs due to their ability to utilize both single-linear and three-linear excitons, which can theoretically achieve 100% internal quantum efficiency. In this study, a quantum computational approach was adopted to achieve the regulation of charge transport balance by optimizing the device structure and the doping ratio of the co-mingled body TCTA:26DCzPPy for the TADF blue-lighting material DBA-DI. Firstly, devices with multifunctional layer structures were designed and prepared to achieve efficient carrier injection and confinement; secondly, the effects of five different blending body ratios on carrier injection and transport were systematically investigated; thirdly, with the help of single-hole device and single-electron device tests, the regulatory mechanisms of the doping ratios on the carrier mobility and the equilibrium factor were analyzed in-depth; lastly, the optimized device structures and doping ratios were verified. In enhancing the charge transport and luminescence efficiency of WOLEDs. Through a multi-level and multi-angle study, this paper reveals the regulation mechanism of the co-doped body ratio on the performance of OLED devices, which provides theoretical guidance and experimental basis for the design of high-efficiency and long-life OLEDs.

## II. Structure and working principle of OLED devices

The development of information display technology has gone through three stages: cathode ray tube (CRT), liquid crystal display (LCD) and plasma display (PDP), and organic electroluminescent devices (OLEDs). At present, OLED display technology has been widely used in a variety of display and lighting end products.

### II. A. Basic structure

Organic electroluminescent device is a kind of electrode injection type device, its structure is mainly used in the anode and cathode according to a certain order to insert each organic functional layer of the sandwich structure. The anode is commonly used is indium tin oxide, cathode materials generally have a lower function of the metal such as calcium, magnesium, barium, lithium, pot and so on. Organic electroluminescent device multi-layer structure, which LUMO for the organic layer of the lowest unoccupied molecular orbitals, similar to the conduction band in the inorganic semiconductor, HOMO for the highest occupied molecular orbitals, similar to the valence band in the inorganic semiconductor. In the transparent electrode on the growth of organic materials and then growth of cathode materials will constitute an organic electroluminescent device. Under the applied voltage, electrons and holes are injected into the lowest unoccupied molecular orbital, LUMO, and the highest occupied molecular orbital, HOMO, of the organic material, respectively. Electrons and holes in the electric field under the action of the charge transport layer migration, in the light-emitting materials meet and bound to each other after the formation of excitons, exciton radiation back to the excitation of the energy in the form of photons are released, thus forming a light-emitting. According to the number of different organic functional layers contained therein, they are usually divided into single-layer, double-layer, triple-layer and multi-layer structures, and the basic structure of organic electroluminescent devices is shown in Figure 1.

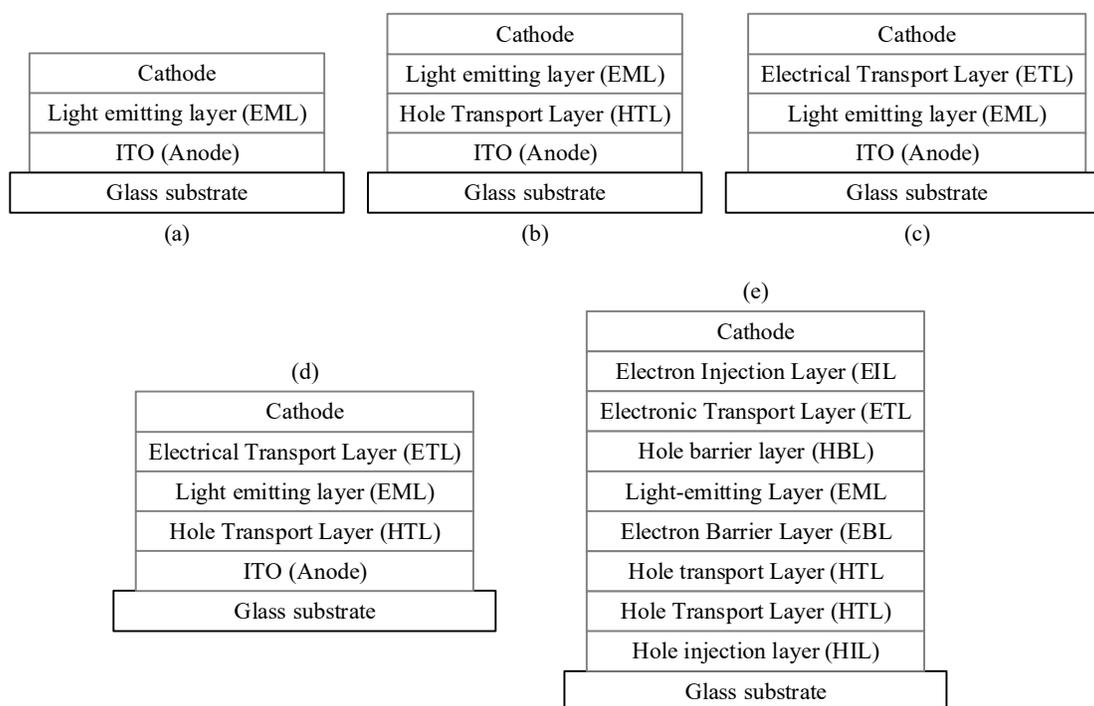


Figure 1: Basic Structure of OLED

### II. A. 1) Single layer OLED structure

The monolayer OLED structure is one of the simplest structures, as shown in Fig. (a), which is composed of an anode, a light-emitting layer, and a cathode, and is most common in polymer electroluminescent devices. The monolayer device structure has and only has a light-emitting layer composed of one or several light-emitting materials, and the thickness of the light-emitting layer is usually about 100 nm.

### II. A. 2) Bilayer OLED structure

Double-layer OLED can be divided into two types according to the light-emitting layer of organic materials on the electron and hole transport capacity: one as shown in Figure (b), the structure is mainly characterized by the light-emitting layer of organic materials with better electron transport properties, so you need to add a layer of hole transport material between the anode and the light-emitting layer in order to balance the rate of injection of holes and electrons into the light-emitting layer. At the same time, the added hole transport material on the electron also plays a certain role in blocking, to ensure that the injected holes and electrons in the light-emitting layer can be effectively compounded. The second is shown in Figure (c), the main feature of the structure is that the light-emitting layer of organic materials with good hole transport properties, between the cathode and the light-emitting layer to add a layer of electron transport material to avoid the occurrence of the electrode / light-emitting layer interface of the exciton burst phenomenon, so that the light-emitting region of the device is very well shifted to the light-emitting layer.

### II. A. 3) Triple OLED structure

As shown in (d), i.e., it contains both electron transport layer, light emitting layer and hole transport layer between cathode and anode, and each of the three organic layers has its own role. In a three-layer OLED device, by optimizing the transport characteristics and thickness of the two carrier transport layers, hole and electron, etc., devices with excellent performance can be obtained more accurately and more easily. Currently, the three-layer structure of OLEDs is the most common device structure.

### II. A. 4) Multilayer OLED structures

Multilayer OLEDs are shown in Fig. (e) to further improve the performance of the device. The purpose of adding an electron or hole injection layer is to lower the energy level barrier for carrier injection, making it easier to inject carriers into the carrier transport layer and also lowering the start-up voltage. The purpose of adding an electron or hole blocking layer is to block carriers that are not complexed in the light-emitting layer to avoid the formation of leakage currents as well as to improve the charge complexation region. However, the increase in the organic functional layers of multilayer OLEDs makes the device structure complex, and the large number of layers also

means an increase in the difficulty of preparation and the cost of materials, which affects the practical application of OLEDs.

### II. B. Principles of operation

Organic electroluminescence refers to the phenomenon that organic materials emit light under the excitation of an electric current or electric field. The organic electroluminescence process can be roughly divided into five parts, the specific process shown in Figure 2.

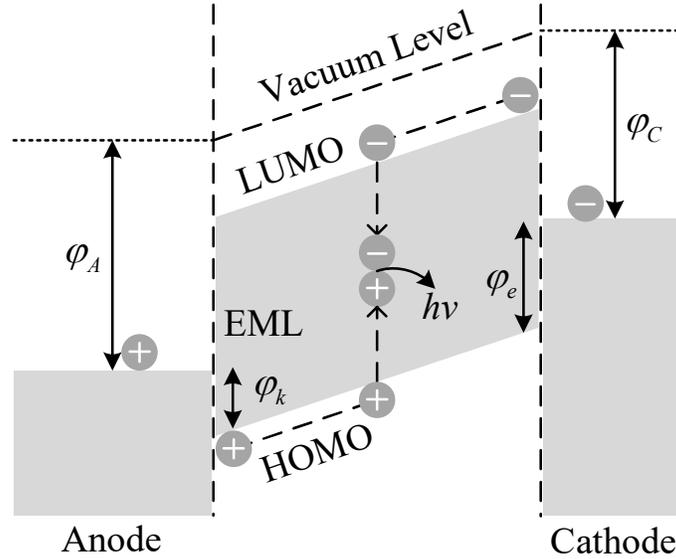


Figure 2: Organic electroluminescence mechanism

#### II. B. 1) Carrier injection

Driven by an applied electric field, electrons and holes are injected from the cathode and anode, respectively, into the organic emissive layer (EML), with the electrons going into the lowest unoccupied orbital (LUMO) of the organics, and the holes being injected into the highest occupied orbital (HOMO) of the organics. In the process of carrier injection holes and electrons are injected from the electrodes into the emissive layer must overcome the injection barrier. Currently, there is no well-established theory to explain the mechanism of carrier injection. The more recognized ones are the space charge confinement hot electron emission injection theory and the FN tunneling injection theory.

The space charge-limited hot electron emission injection theory suggests that a significant portion of the semiconductor has a large thermal motion energy that can cross the contact potential barrier and be emitted from one side to the other. The current density versus electric field relationship can be expressed by the following equation:

$$J_{RS} = AT^2 \exp\left(-\frac{\varphi_B - \beta_{RS} \sqrt{F}}{k_B T}\right) \quad (1)$$

where  $T$  - temperature, K.  $A = \frac{4\pi q m_n^* k^2}{h^3}$ , known as Richardson's constant,  $q$  is the elementary charge  $m_n^*$  refers to the effective mass of the electron and is assumed to be equal to the free electron mass  $m_0$ ,  $h$  is Planck's constant.  $\varphi_B$  - is the injected potential barrier when the electric field is zero, eV.  $k_B$  - is the Boltzmann constant.  $\beta_{RS} = \sqrt{q^3 / 4\pi\epsilon\epsilon_0}$ ,  $\epsilon_0$  is the vacuum dielectric constant,  $\epsilon$  is the relative permittivity.  $F$  - electric field strength, equal to  $V/q$ ,  $V$  is the voltage. From Eq. (1), the hot electron emission injection current is determined by the electric field and the injection barrier and is temperature dependent.

Carrier injection at high electric field can be explained by applying the FN tunneling theory. The current density equation is as follows:

$$J_{FN} = \frac{A^* q^2 F^2}{\varphi_B \alpha^2 k_B^2} \exp\left(-\frac{2\kappa\varphi_B^{3/2}}{3QF}\right) \quad (2)$$

where  $a$  - is  $\frac{4\pi\sqrt{2m^*}}{h}$ ,  $k$  - is a parameter that depends on the shape of the potential barrier,  $\varphi_B$  -- is the potential barrier height.

The FN tunneling theory ignores the Coulomb force and only considers the tunneling effect of the delta potential barrier, and the magnitude of the injected current is determined by the injected potential barrier; the lower the barrier, the easier the carriers are injected and the higher the current.

### II. B. 2) Carrier migration

The process in which carriers are injected into the luminescent layer and then transported to the positive and negative electrodes, respectively, under the action of an applied electric field. It is generally believed that in organic solids, the intermolecular orbitals are less overlapped, the electrons are localized, and the carrier migration takes place in a hopping manner. The migration of charged carriers may occur in three ways: the two carriers meet, the two carriers do not meet, and the carriers are inactivated by capture by impurities or defects.

The balance of carrier injection and transport is a key factor affecting the performance in the interim. As it stands, most polymers are  $p$ -type semiconducting materials with unbalanced hole and electron transport. From the point of view of material synthesis, synthesizing materials with bipolar transport properties can help to improve the transport properties of holes and electrons.

### II. B. 3) Generation of excitons

When electrons and holes are injected from the cathode and anode into the light-emitting layer, they move toward each other under the electric field, and when they reach a certain region of encounter, "electron-hole bound pairs" are formed under the attractive force, i.e., excitons. According to the different angular momentum of the coupling formation, the formation of excitons can be divided into single-line excitons (total spin angular momentum is zero) and three-line excitons (total spin angular momentum is not zero).

### II. B. 4) Energy transfer

After the exciton is formed, it will continuously diffuse and migrate in the emission layer by free diffusion until it returns to the ground state. In the process of returning to the ground state, three ways are usually taken: a forward jump, an unassisted jump, and an energy transfer. Energy transfer is also an important pathway for the deactivation of excited state molecules and usually occurs between an excited state molecule and a ground state molecule. The interaction between the two transfers the excited state energy unaided to the ground state molecule, leaving it in the excited state, and the acceptor molecule leaps to produce light. White light devices and organic electrogenic phosphorescent devices are most often realized based on host-guest doping systems, and thus the energy transfer process has an important impact on the luminescence performance of the devices.

### II. B. 5) Electroluminescence

Excited state energy is deactivated by single or triple excitation to produce photons and release light energy. A single excited state governs the deactivation to produce photons, i.e., electroluminescence, and a triple excited state governs the deactivation to produce photons, i.e., electroluminescence. Conventional devices emit light from the anode side. For single-linear-state fluorescent light-emitting devices, the upper limit of the internal quantum efficiency of the device is for electroluminescent devices, both single-linear-state and triple-linear-state excitons can be utilized, and the theoretical internal quantum efficiency is 100%.

## III. Experimental design

White organic light-emitting diodes (WOLEDs) have attracted the attention of people from all over the world due to their high efficiency, ultra-thinness, ease of curvature, and eye protection, and the rising wave of applications in areas such as healthy solid-state lighting and full-color displays. In order to realize high-performance WOLEDs, phosphorescent and thermally activated delayed fluorescent (TADF) materials are widely used. Therefore, in this paper, we optimize the device structure of TADF blue light materials and optimize the doping ratio of each body in combination with the co-blended body structure in order to enhance the charge transport and luminescence efficiency of white organic light-emitting diodes (WOLEDs).

### III. A. Experimental materials

Since functional materials have different frontier orbitals, the modification and selection of body and carrier transport materials are very important for the design of OLEDs. Considering its excellent carrier injection and transport capabilities, energy level alignment between the injection and transport layers is needed to enable fast electron/hole injection into the organic emission layer, balance the electron/hole transport rate, and control the exciton complex region, so as to stabilize and improve the device performance more effectively. The materials involved in this experiment are all commercially available and can be directly used for device fabrication without further purification.

In designing the device structure, 1,4,5,8,9,11-hexaazabenzonitrile (HAT-CN) is able to better facilitate hole injection. Meanwhile, 4,4'-cyclohexylbis[N,N-bis(4-methylphenyl)aniline] (TAPC) and 1,3,5-tris(6-(3-(pyridin-3-yl)phenyl)pyridin-2-yl) (Tm3PyP26PyB) are utilized as a hole-transporting layer (HTL) and an electron-transporting layer (ETL) due to their respective high hole and high electron mobility and can be used as a hole-transporting layer (HTL) due to their respective The lowest unoccupied molecular orbital (LUMO) and highest occupied molecular orbital (HOMO) energy levels are at (-1.8 eV), (-6.5 eV) and can be used as electron blocking layer (EBL) and hole blocking layer (HBL). The blue TADF material 5-(5,9-dioxa-13b-boronaphtho[3,2,1-de]anthracen-7-yl)-10,15-diphenyl-10,15-dihydro-5H-diindolo[3,2-a:3',2'-c]carbazole (DBA-DI) can be doped into a 4,4',4'-tris(carbazol-9-yl)trisbenzenamine (TCTA) and 9,9'-(2,6-pyridinediylidenebis-3,1-phenylene)bis-9H-carbazole (26DCzPPy) within a mixed body.

### III. B. Test equipment

#### (1) IVL Test Equipment

The current density-voltage-brightness (J-V-B) curves measured for OLED devices consist of a Keithley 2400 programmable power meter and a PR655 SpectraScan Photometer inspection system. Working in the darkroom environment, through the power meter and electrical control detection system measurement, according to the measured data to analyze and calculate the device luminous efficiency, brightness can be accurate to 0.5 cd m<sup>-2</sup>, efficiency can be accurate to 0.1 cd A<sup>-1</sup>.

#### (2) Transient EL test system

OLED device transient EL luminescence test system, purchased from South Korea McScience test system (McScience 6200), the system is divided into the host cabinet and the darkroom, designed to distinguish different time photoluminescence transient response characteristics. It consists of a darkroom, a power supply unit, a current amplification adapter, an oscilloscope, a pulse transmitter, and a computer mainframe.

## IV. Results and discussion

Using quantum chemical calculations, exploring the ratio of different body structures can further optimize the balance of carriers inside the blue devices, which helps to enhance the charge transport and luminescence efficiency performance of WOLEDs. The detailed device structures are ITO/HAT-CN(8 nm)/HATCN(0.2 wt%):TAPC(40 nm)/TAPC(10 nm)/DBA-DI(20 wt%):TCTA:26DCzPPy(x:y)(10 nm)/Tm3PyP26PyB(50 nm)/Liq(1 nm)/Al(100 nm). Where x:y=1:0, 2:1, 1:1, 1:2, 0:1 correspond to devices A1-A5, respectively.

### IV. A. Optimize the proportion of co-mingled subjects

Figure 3 shows the J-V-B spectrogram of the TADF blue light-emitting single component, the current density and luminous brightness of the device increases gradually with the increase in voltage, it can be seen according to the trend of the luminescence of the device A3 is better than other devices can achieve a higher brightness, and with the increase in voltage the increase in current density still maintains a moderate value. When the mixing theme ratio is appropriate, the luminescent layer of the guest molecule increases more hole-electron pairs can be consumed through the main body to the guest energy transfer pathway, reducing the difficulty of carrier injection and improve the transmission capacity. Therefore, under 1:1 doping concentration, the luminescent layer can capture more carriers for luminescence more efficiently, which is more favorable for carrier injection, and thus improves the efficiency of the device. At the same time, the appropriate doping concentration improves the injection efficiency and distribution uniformity of carriers, and the appropriate doping concentration reduces the energy migration process of the body in the light-emitting layer, which improves the carrier complex probability and luminescence efficiency, leading to a higher luminance.

The EL performance optimized by the ratio of the blue light body structure is shown in Table 1, with a denoting the maximum brightness (B), b denoting the maximum current efficiency (CE), c denoting the maximum power efficiency (PE), d denoting the maximum exoquantum efficiency (EQE), e denoting the exoquantum efficiency at

1000 cdm<sup>-2</sup>, and  $f$  denoting the peak spectral value at 1000 cdm<sup>-2</sup>. When the doping ratio of the mixed-subject system was 1:1 (device A3), the blue device obtained was turned on at 2.5 V, and its maximum brightness, CE, PE, and EQE were 11072 cdm<sup>-2</sup>, 50.57 cdA<sup>-1</sup>, 60.22 lmW<sup>-1</sup>, and 22.56%, respectively.

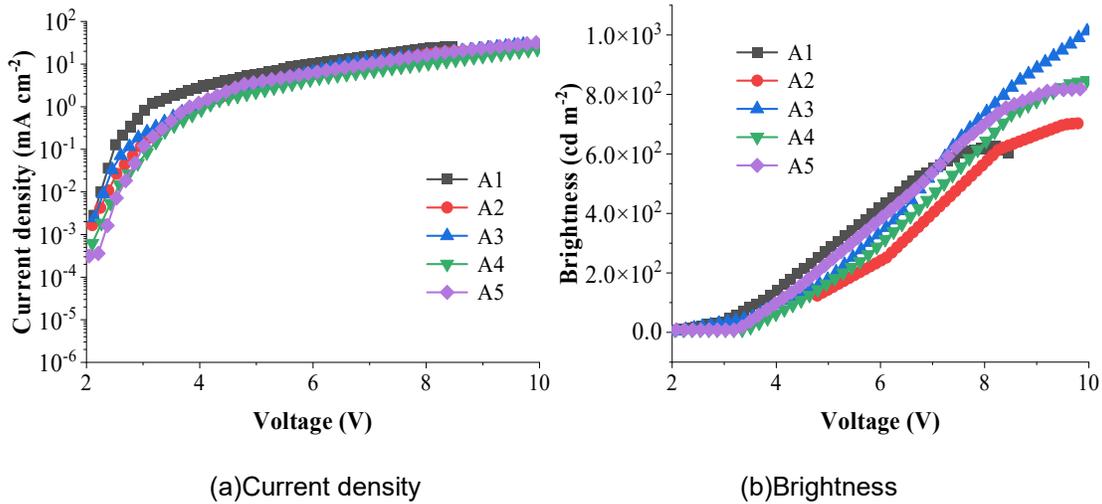


Figure 3: J-V-B spectra of TADF blue emissive unit devices

Table 1: EL Performance of Blue Light Host Structure Ratio Optimization

Device	V <sub>turn-on</sub> (V)	Maximum				EQE <sub>e</sub> (%) (1000 cd m <sup>2</sup> )	Peak $f$
		B <sub>a</sub> (cd m <sup>2</sup> )	CE <sub>b</sub> (cd A <sup>-1</sup> )	PE <sub>c</sub> (lm W <sup>-1</sup> )	EQE <sub>d</sub> (%)		
A1	2.5	6744	38.91	44.17	18.79	7.28	474
A2	2.6	7726	42.51	50.82	21.91	7.45	474
A3	2.5	11072	50.57	60.22	22.56	12.69	485
A4	2.6	9133	45.08	51.07	21.05	10.53	481
A5	2.7	8724	37.62	41.15	17.66	11.41	481

The brightness power curves and brightness luminescence curves of the devices are shown in Figs. 4 and 5. It can be observed that the WOLEDs show the highest efficiency when the mixing concentration ratio is 1:1 (device A3), and the efficiency of the device gradually decreases as the guest concentration continues to increase or decrease. However, the rolling down of the efficiency of the devices at all five concentrations is small, which is attributed to the fact that the body has a bipolar transport characteristic that contributes to the balance of carriers in the luminescent layer, and carrier complexation occurs throughout the luminescent layer.

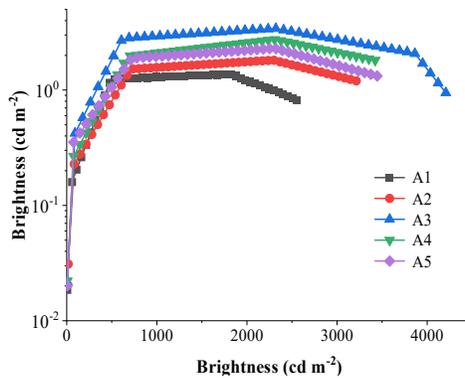


Figure 4: Brightness power efficiency profile

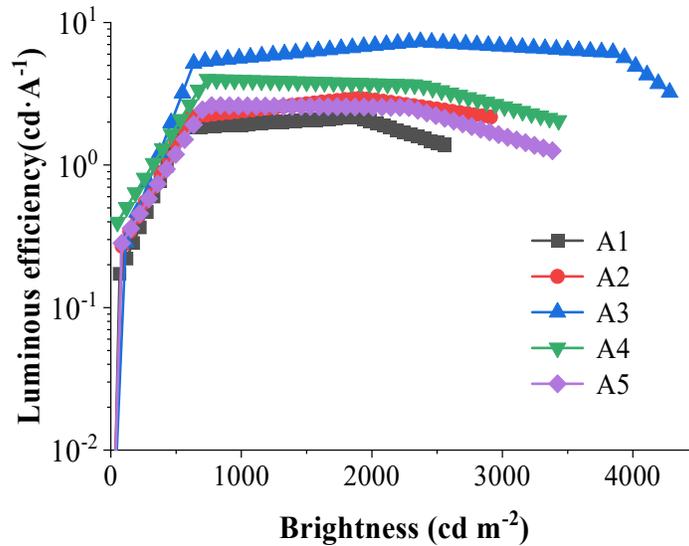
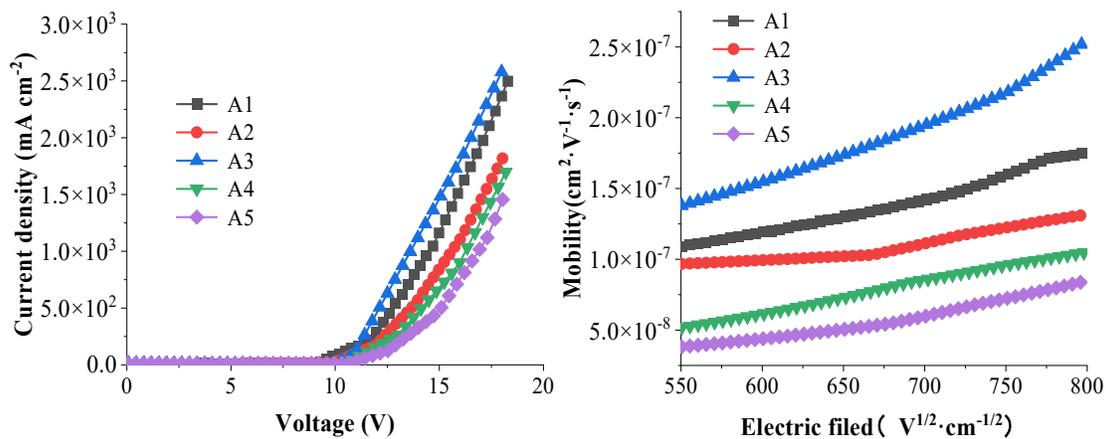


Figure 5: Brightness luminous efficiency profile

**IV. B. Effects on carrier injection**

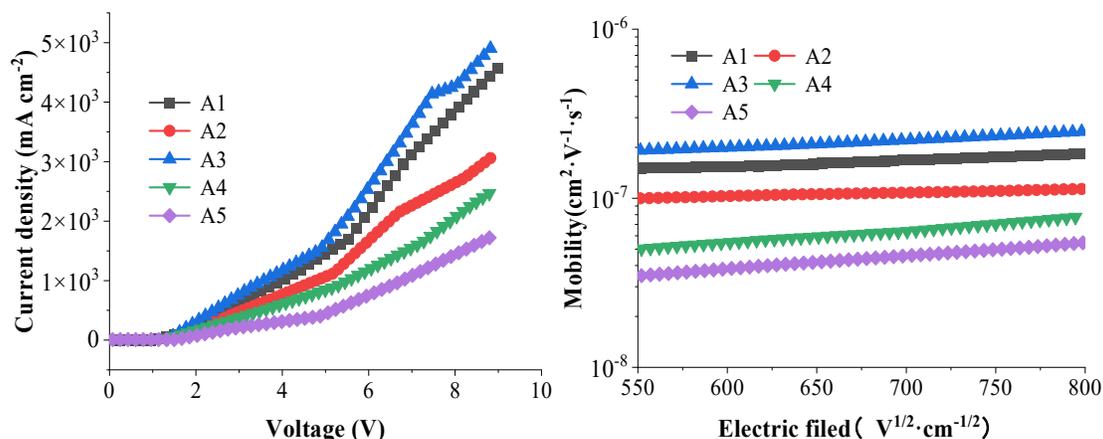
In order to investigate the effect of different doping concentrations on the carrier injection of the devices, single-hole devices structured as ITO/PEDOT : PSS(40nm)/EML(40nm)/MoO3(10nm)/Al(70nm) and single-electron devices structured as ITO/Zno(40nm)/EML(40nm)/Bphen(30nm)/LiF(0.5 nm)/Al (70 nm) single-electron devices, and their electrical properties were tested, and the mobility of holes and electrons and the carrier balance factor  $\gamma$  were calculated at different concentrations. Figures 6(a) and (c) show the current density-voltage (J-V) characteristics of single-carrier devices at each concentration ratio, and Figures 6(b) and (d) show the carrier mobility at different electric field strengths. As can be seen from the figure, the carrier mobility and current density are enhanced with the increase of the doping ratio of the mixed body, which means that the addition of the blue TADF material provides a new energy transfer channel to promote the carrier transport more efficiently. The carrier equilibrium factors  $\gamma$  for the five concentration ratios of devices A1-A5 are 0.768, 0.892, 0.927, 0.864, and 0.745, respectively. It is seen that  $\gamma$  is the closest to 1 under the 1:1 doping concentration ratio, which is the reason for the high efficiency.

The above analysis shows that the TCTA:26DCzPPy (1:1) co-doped body system is capable of confining and balancing carriers at lower voltages, optimizing charge transport and luminescence efficiency enhancement in OLED devices.



(a)Current density of single hole device

(b)Carrier mobility of single hole device



(c) Current density of single electron device

(d) Carrier mobility of single electron device

Figure 6: The effect of different doping concentrations on the injection of the device

## V. Conclusion

In this study, the effects of the co-mingled body ratio on the charge transport mechanism and luminescence efficiency of TADF blue light materials were systematically investigated by quantum computational methods. It was shown that in the ITO/HAT-CN(8 nm)/HATCN(0.2 wt%):TAPC(40 nm)/TAPC(10 nm)/DBA-DI(20 wt%):TCTA:26DCzPPy(x:y)(10 nm)/Tm3PyP26PyB(50 nm)/Liq(1 nm)/Al(100 nm) structure, the device performance is optimized when the ratio of TCTA:26DCzPPy is 1:1. At this ratio, the device has a low start-up voltage of 2.5 V and achieves a maximum brightness, current efficiency, power efficiency and external quantum efficiency of 11072 cd/m<sup>2</sup>, 50.57 cd/A, 60.22 lm/W and 22.56%, respectively. The single-carrier device test shows that the carrier balance factor  $\gamma$  reaches 0.927 when the co-mixed body ratio is 1:1, indicating that the injection and transport of electrons and holes reach an optimal equilibrium state. The external quantum efficiencies of the devices at 1000 cd/m<sup>2</sup> with different mixing ratios are 7.28%, 7.45%, 12.69%, 10.53% and 11.41%, respectively, confirming the significant effect of the co-mixing body ratio on the efficiency roll-off of the devices. The carrier mobility test shows that the appropriate co-mingled body ratio can simultaneously improve the migration of electrons and holes, create more energy transfer channels, and thus improve the efficiency of carrier utilization. This study not only reveals the role of the co-mixed body ratio in regulating the charge transport mechanism, but also provides a practical strategy for the design of high-performance WOLEDs. Through the precise regulation of the carrier balance factor and the optimization of the co-mingled body ratio, the efficient management of charge transport is achieved, which provides new ideas and methods for the performance enhancement of OLED devices.

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