

Shalini Jharia¹,
Pravendra Tyagi²,
Seema Agrawal³

**Study of Structure, Morphological and
Optical Characteristics of
PEDOT:PSS/NPB/Alq₃:DCJTb/Alq₃/Ca
Organic Light Emitting Diode structure**



Abstract

In the research article, optical and electrical feature simulations of organic light-emitting diode (OLED) to comprehend the mechanics of EHP (electron hole pair) recombination and light generation from the OLED. Under simulation, OLED structure based on a heterostructure PEDOT:PSS/NPB/Alq₃:DCJTb/Alq₃/Ca, variations in anode voltage and anode current have been used to study the behavior of excitons linked to EML and ETL. The Holstein model has been used for the Alq₃ (host molecule) and DCJTb (dopant molecule) spectra in electron transport and emissive layers to simulate the spectral features. Förster energy transfer between the host to the dopant materials investigated. Furthermore, this study takes into account the quenching processes associated with dopant concentration and electrodes. As a result, I-V characteristics, Langevin recombination rate, output spectrum power density, luminescent power, spectral luminous flux and spectral radiance are obtained. Based on the results, the operating voltage is around 3.7 V obtained. The proposed OLED has flexible light source for the emission of photons with a wavelength of approximately 560nm. Therefore, this study will provide some theoretical guidance for future development of host-guest materials in OLED.

Keywords: Alq₃: DCJTb, ETL, EML, HTL, Recombination rate, Luminescent power, TCAD silvaco

1. Introduction

Pope and colleagues discovered organic electroluminescence (EL) as light emission [1]. In 1987, Tang et al. introduced a double-layer OLED device with reasonable luminosity at low bias voltage [2]. The structure of OLED is based on the principle of an electroluminescent, made of an active layer sandwich between metallic electrodes where a transparent electrode to emit light. In OLEDs the material with a self-luminous property is used that eliminates the need for a backlight. An active layer is made of small molecules or macro polymers that conduct electricity. This result Organic light-emitting diode (OLED) displays are thin compact, power-efficient, and ideal for portable applications [3]. It requires very little voltage i.e., only 2-10 volts. LCDs and OLEDs have their own merits and demerits they have their strength [4]. An OLED has a broad color range, good contrast, high resolution, (<5um pixel size) inside viewing angle, and low cost of material [5]. Organic materials are used in this LED, which is manufactured without pesticides in an environmentally responsible manner. OLEDs are manufactured in a way that makes it possible to attain a high level of customization. This includes the panel shape, size, and the number of individually programmable segments (including logos for branding). OLED has changed the human lifestyle by offering energy-saving sources with special features such as high contrast, high colour purity, high response speed, low consumption power, etc. It has become a premium technology for display and lighting and is powered by batteries. Due to its wide features, OLED is preferred more in modern lighting [6]. Some advantages of organic devices over other devices, such as LCDs, plasma, and LEDs: better colours and contrast, flexible substrate assembly, a 180-degree viewing angle, green technology (no heavy metal toxicity), fast response time, easy assembly, no infrared and ultraviolet radiation emissions, a high luminous efficiency, a long lifetime, colour purity that is superior, and simple production procedures are required for OLED applications.

¹ Department of Physical Sciences, Banasthali Vidyapith, Banasthali- 304022 Rajasthan, India

² Department of Physical Sciences, Banasthali Vidyapith, Banasthali- 304022 Rajasthan, India

³ Electrical Engineering Department, Rajasthan Technical University, Akelgarh, Kota, India
Corresponding Author Email id: shalinijharia84@gmail.com

Efforts are being made by researchers to create organic light-emitting diodes (OLEDs) with desirable properties such as low operating voltage, good stability, picture quality, durability, and readily available, inexpensive materials [7]. Some of the most recent OLED products to hit the market include bio-sensors, digital cameras, indoor lighting and mobile phones. However, producing OLED with acceptable electrical and optical properties to be employed as a lighting source and huge display panel remains problematic [8]. Various research have been carried using employing approaches to suit the aforementioned parameters of OLEDs. Ritu et al. proposed the OLED by using Alq3 polymer, generally referred to as “tris-(8-hydroxyquinoline)-aluminum” utilized as the ETL (electron transport layer) and emissive layer (EML) of OLEDs [9-10]. Alq3 has emerged as a vital and popular alternative for OLED display devices and systems. Which can readily produce smooth films, and it has numerous unique qualities, like excellent electron mobility and thermal stability. The polymer Alq3 has demonstrated its significance in organic display systems, yet there are still certain disadvantages to the Alq3 layer. For instance, OLEDs with an Alq3 layer may experience device degradation as a result of localized chemical breakdown, leading to diminished performance over time. The previous literature has previously discussed a number of reasons why OLED devices degrade [11-13]. The Alq3-Dy OLED was compared to the pure Alq3 OLED device that was made by Saeed [14]. However, the 4-(dicyanomethylene)-2-t-butyl-6-(1,1,7,7-tetramethyljulolidyl-9-enyl)-DCJTBOLEDs have also made use of -4H-pyran, a derivative of dicyanomethylene-4H-pyran (DCM), to fine-tune their properties. It has been widely used in the manufacturing of red and white OLEDs. Researchers further demonstrate that doping of DCJTB into the rubrene/Alq3 co-host matrix emitting system aids in the prevention of luminescence quenching at high drive voltages [15]. The researchers Liu et al. were able to attain a current efficiency of 4.44 cd/A⁻¹ in DCJTB emission by 2% doping of DCJTB into a bipolar mixed host that included tris(8-hydroxyquinolinato) aluminum(III) (Alq3) and rubrene [16]. Using DCJTB red emitter and 2-methyl-9,10-di(2-naphthyl)anthracene (MADN), Lee et al. [17] developed red OLEDs to achieving the highest current efficiency achieved was 5.42 cm A⁻¹ at 20 mA cm⁻².

However, it would be challenging for such a low efficiency to meet the demands of industry. Recent work by Zhao et al. describes extremely efficient red-light emitting organic light-emitting diode (OLEDs) fabricated from TCTA host materials doped with DCJTB, using 3P-T2T [18]. Mustafa et al. conducting experimental investigations using solution and thin film techniques, as well as theoretical calculations, the electrical, optical, and spectroscopic properties of the DCJTB molecule were studied [19]. Tau et al. have replaced host material DPF for DCJTB-based red OLEDs [20]. A new study shows that DCJTB organic dye, which has good optical and physical and properties, to use in optoelectronic devices, and it's cheap [21]. There has been evidence that using DCJTB as a dopant in Alq3 polymer significantly alters the material's constant current-voltage properties, charge carriers' mobility (i.e., electrons), and transient electroluminescence property of DCJTB based OLED [22].

The potential for development in OLEDs is not limited to begin the creation of layers of OLED; rather, it is significantly impacted by the anode material employed. Varieties of materials, including modified ITO, PEDOT:PSS, PEDOT:PSS/GO, grapheme and graphene-oxide composite, are employed as anodes. Many researchers are interested in organic optoelectronic devices made of polymers include PEDOT: PSS, which stands for poly(3,4-ethylenedioxythiophene) used as ETL [23]. These polymers are employed in flexible devices and have ability to be mass-produced at a low cost. In organic photoelectric devices, the workfunction of PEDOT: PSS (5.1eV) is higher than that of ITO, hence the energy barrier between PEDOT: PSS and organic energy level is lower than that between ITO and organic layer. Because of the low energy level barrier, hole injection is possible. The visible-range transparency, mechanical flexibility, and thermal stability of PEDOT: PSS films are all quite high. Tiwari et al. investigates different multilayer structure of OLED using PEDOT: PSS/GO Composite Anode [24]. Sharma, G et al. investigated ITO/NPB/Alq3/Alq3:DCJTB/Ag OLED structure to improve its conductivity [25]. Recently Yangyang Guo et al. GO/PEDOT: PSS hybrid anode used to improve its conductivity [26].

In this research using the Atlas silvaco program, the optoelectronic properties of PEDOT:PSS/NPB/Alq3:DCJTB/Alq3/Ca OLED that is based on a single quantum well heterostructure were examined. OLEDs using pure Alq3 as the electron transport layer (ETL) and Alq3:DCJTBas the emitting material (EML) were modeled. The OLED system makes use of three additional layers, a PEDOT: PSS anode, a NPB (N, N'-Di(1-naphthyl)-N, N'-diphenyl-(1,1'-biphenyl)-4,4'-diamine) as the hole transporting layer (HTL), and calcium (Ca) cathode. These layers were placed on a glass substrate, and the performance of these simulated devices was

examined. Proposed OLED shows a considerable improvement in operating voltage, efficiency, and brightness. Research on all these characteristics indicates that OLEDs based on heterostructure systems are effective in emitting bright radiation in the visible spectrum (about 500 nm).

Device structure and Materials

The layered structure and the schematic energy level diagram of OLEDs based on PEDOT:PSS/NPB/Alq₃:DCJT B/Alq₃/Ca structure shown in figure 1(a) and figure 1(b) respectively. Where NPB represents the HTL, Alq₃: DCJT B describes Alq₃ which is EML is utilized as the host material for transient electroluminescence (EL). As a dopant polymer, DCJT B is use. In this case, the great quantum efficiency of the DCJT B is the reason for its adoption as a dopant in the EML [27]. Again, in this setup, the Alq₃ is used as the ETL. This is due to the fact that Alq₃, an organic polymer, exhibits superior stability and film-forming qualities. As a result, Alq₃ has been widely used in EML as a host material in the manufacture of OLEDs, and in order to facilitate the transfer of electrons [28]. Anodes made of PEDOT:PSS and cathodes of Ca are being utilized. The entire thickness of construction of the device measures 120 nm. Table 1 also specified all of the layers that are employed in the OLED construction. Figure 1(b) shows the energy band diagram of the multilayer OLED proposed and consists of a metal cathode and a transparent conducting oxide anode interposed between organic thin layers (HTL, ETL, and EML). Organic materials are known as organic semiconductors because they can conduct electricity, but their conductivity can range from that of an insulator to that of a conductor.

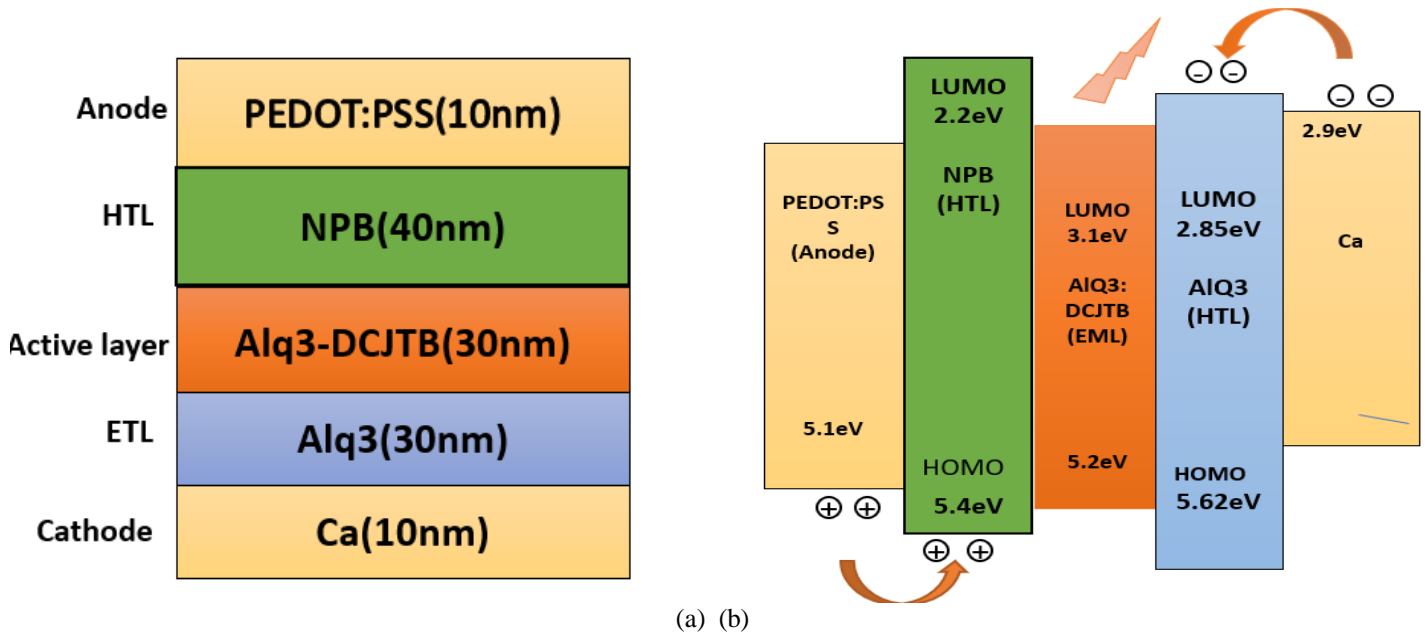


Figure 1(a), (b)The layered structure theschematic energy level diagram of OLEDs based on PEDOT:PSS/NPB/Alq₃:DCJT B/Alq₃/Ca structure

According to Figure 1(b) to transfer the holes from the anode to the emissive layer. HOMO (Highest occupied molecular orbit) of HTL receives the holes inserted from the anode. It is located between the emissive layer and the anode layer. Similarly, the cathode (Ca) injects electrons into the LUMO (Lowest occupied molecular orbit) of ETL, which is located between the cathode and the active layer. The device emits photons of a specific energy through the process of recombination of electrons from the ETL and holes from the HTL in the active layer, which occurs when an external potential is applied across it. DCJT B doped with emissive layer, which helps to reduce electron mobility. The work function of outer layer (cathode and anode) is crucial to an OLED's operation [29]. To reduce operating voltage, the cathode work function must be lower than that of the anode. The emissive layer is the part of the device that generates light. It is the area where electrical energy is transformed into light. The ETL facilitates electron transport to the emissive layer, whereas the HTL facilitates hole transport to the emissive layer. The energy band diagram suggests that the PEDOT:PSS/NPB/Alq₃:DCJT B/Alq₃/Ca OLED has

aheterostructure of single quantum well with an EML that is similar to a quantum well area, which is the active region.

Table1:Material parameter specifications of proposed PEDOT:PSS/NPB/Alq3:DCJTb/Alq3/Ca OLED structure.

Parameters	Alq3(ETL)	Alq3:DCJTb(EML)	NPB(HTL)	PEDOT:PSS(Anode)	Ca(Cathode)
Thickness(nm)	30	30	40	-	-
Acceptor density, N_A (cm^{-3})	2×10^{19}	2×10^{19}	2×10^{19}	-	-
Donor density, N_D (cm^{-3})	2×10^{19}	2×10^{19}	2×10^{19}	-	-
Dielectric permittivity, ϵ_r	3	3.1	3.5	-	-
Electron affinity, χ (eV)	3	3	2.31	-	-
Bandgap, E_g (eV)	2.7	2.7	3	-	-
Electron mobility μ_n (cm^2/Vs)	1.5×10^{-07}	1.5×10^{-07}	6.9×10^{-06}	-	-
Hole mobility, μ_p (cm^2/Vs)	9.16×10^{-10}	9.16×10^{-10}	2.60×10^{-04}	-	-
Workfunction(eV)				5.13	2.90

4. Simulation Results and Discussions

The heterostructure of OLED device was designed using the ATLAS tool from silvaco, an OLED meshing structure consisting of a number of grid points. The Langevin recombination distribution inside OLED structure in TCAD Tony plot is illustrated in figure 2.

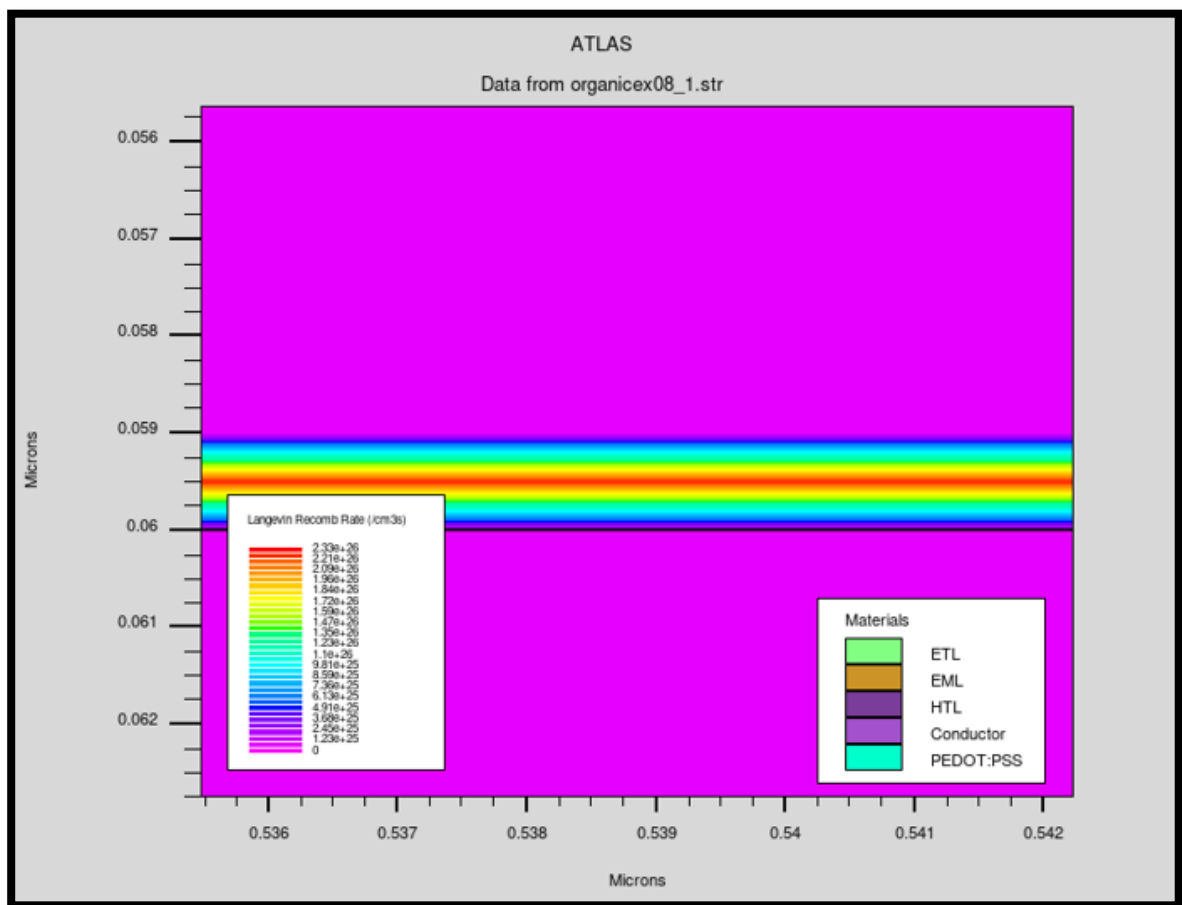


Figure 2: The Langevin recombination rate

The Langevin recombination coefficient models their combination rate to be optical only. The rate of Langevin recombination is $2.33 \times 10^{26} \text{ cm}^{-3} \text{ s}^{-1}$ as shown in Figure 2. And Figure 3 shows the recombination rate in microns along the device in relation to the distance traversed by the device.

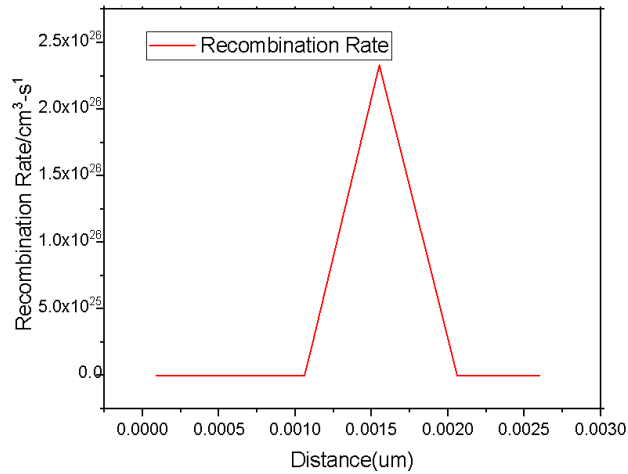


Figure 3: Langevin recombination rate with respect to distance along the device

Figure 4 depicts the electrical characteristics of OLED based on a single quantum well heterostructure and displays the current-voltage performance where operating voltage clearly shows a big improvement. Also displays the simulated current (I) - voltage (V) characteristics. The current conduction is characterized by a robust, nearly exponential increase as bias voltage increases. The threshold voltage is found $\sim 3.7\text{V}$ from this characteristic. In this OLED, the I-V characteristic is determined by both the interfaces, PEDOT:PSS/NPB and Ca/Alq₃. Electrons are the predominant carriers on the ETL/Ca side, while holes are the main carriers on the HTL/PEDOT:PSS side. The turn-on voltage is thus caused by the majority carriers, which include both electrons and holes. In addition, adjusting these interface barriers allows you to modify the turn-on voltage. At higher operating anode voltages, minority carriers can play a large part in the total current, and so the contribution of minority carriers to the total current increases.

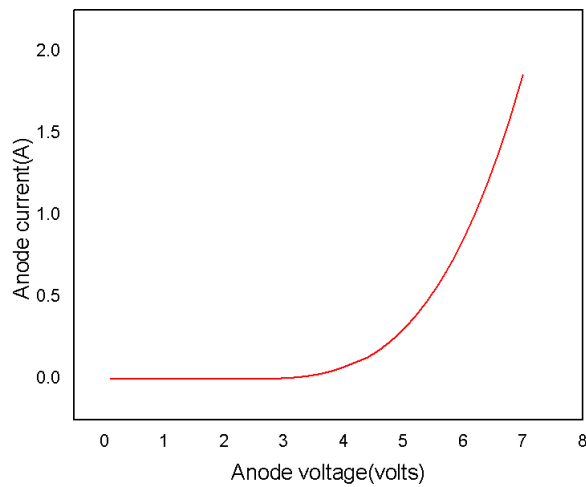


Figure 4. Voltage-Current characteristic of PEDOT:PSS/NPB/Alq₃:DCJT/Alq₃/Ca OLED.

The OLEDs based on the electroluminescence where the energy of electrical is transformed into optical energy through a series of connected processes that involve the two mechanisms: First, charge carriers are injected and transported. Second, strongly bonded electron-hole pairs (EHPs), sometimes known as "excitons," are formed. When these excitons undergo radiative recombination, the radiative energy is emitted as visible light. When these excitons undergo radiative recombination, the radiative energy is released as visible light.

In majority of the studies on OLEDs, the behavior of excitons is not given much attention. This is the reason that excitonic devices are still in their early stages of development when compared to optoelectronic devices. The efficiency of device largely depends on formation, utilization and decay mechanism of these excitons. However, in Figure 5, the changes in excitons of the EML (emissive layer) material may be observed as the anode voltage and anode current change. Figure 5(a) shows that the EML excitons react exponentially to the anode voltage, whereas Figure 5(b) shows that they react linearly to the anode current. Nonetheless, regardless of anode voltage or current, the excitons of dopant material (DCJTb) of EML grow faster than the excitons of host material (Alq3) of EML. The action of excitons of the dopant (DCJTb) with variation in anode voltage or current demonstrates that it is the ideal material to use as a dopant in the host material of the EML. In the same way, Figure 6 shows the change in exciton development in ETL material under different anode voltage and current conditions. Again, increasing the anode voltage increases the growth of ETL excitons exponentially, whereas increasing the anode current causes these excitons to expand linearly, as seen in Fig.7 (a, b). Nevertheless, regardless of the anode voltage and current, there is a continuous difference in density between ETL and EML excitons, as shown in Figure 5 and Figure 6.

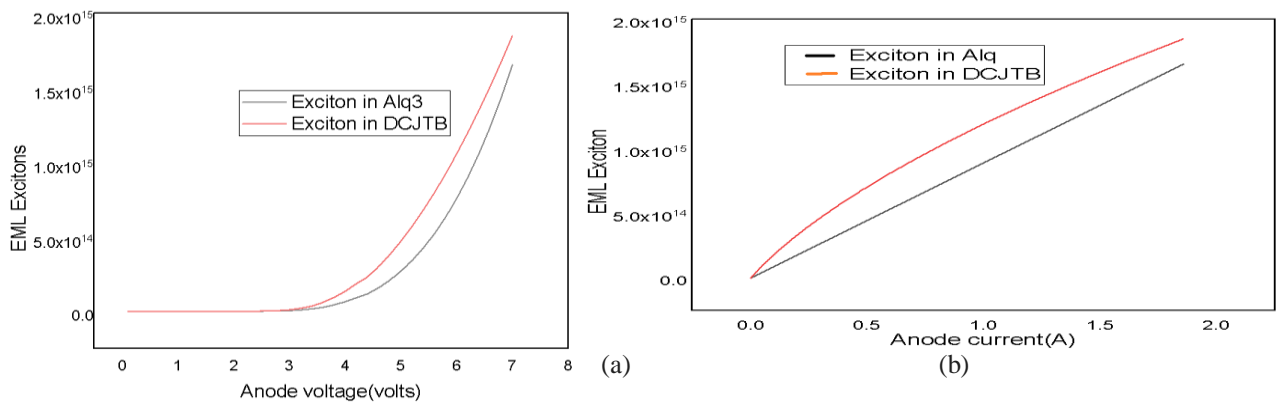


Figure 5(a),(b). EML excitons in ITO/NPB/Alq₃:DCJTb/Alq₃/Ag OLED.

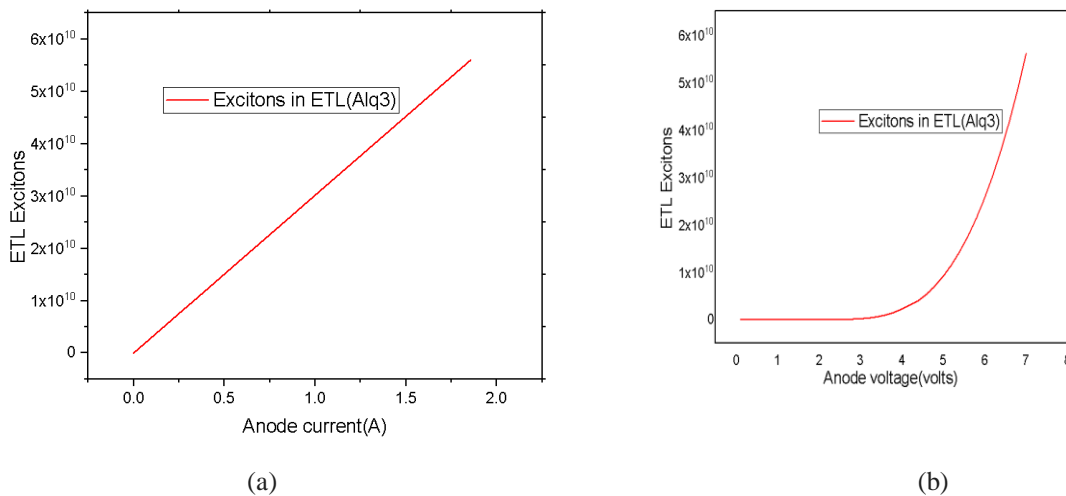


Figure 6(a),(b). ETL excitons in ITO/NPB/Alq₃:DCJTb/Alq₃/Ag OLED.

The luminescent power of the OLED has also been investigated in relation to the anode voltage and current. In figure 7 (a, b & c), we can see the optimized light-emitting diode (OLED) P-V and P-I curves. See Fig. 7 (a) and (b) for the luminous power exponentially varies with anode voltage and linear response to current. This indicates that the intended OLED begins to glow at approximately 4 V. After that, the luminescent power increases exponentially as the anode voltage continues to rise. The OLED power is around mW at the turn-on voltage (~4 V), whereas the higher voltage needed for full brightness is approximately 30mW. Figure 7(c) also shows the luminous power vs. cathode current. It was discovered that the luminous power of the OLED decreases linearly with the cathode current.

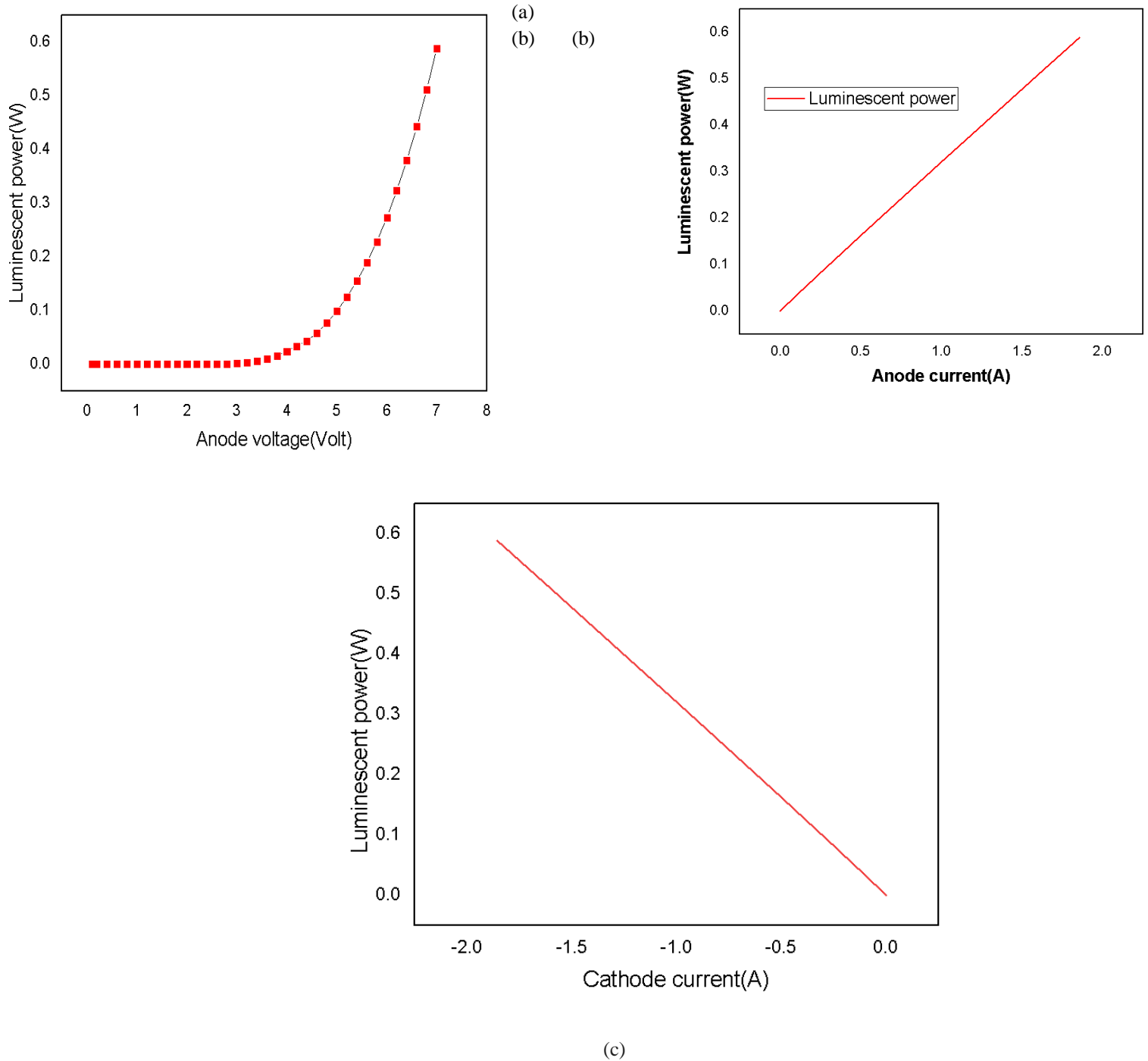


Figure 7. (a) Characteristics of Luminescent Power versus with anode voltage (b) Luminescent power with anode current (c) Luminescent power with cathode current

An additional evaluation of the PEDOT:PSS/NPB/Alq3:DCJTb/Alq3/Ca OLED was performed to better understand its spectrum behavior. The output spectrum power density of the OLED is displayed in Fig. 8(a). According to Fig. 8(a), the best output spectrum power density is received when the energy is around 2.1eV. Additionally, a hump has emerged, equivalent to energy of 2.4eV.

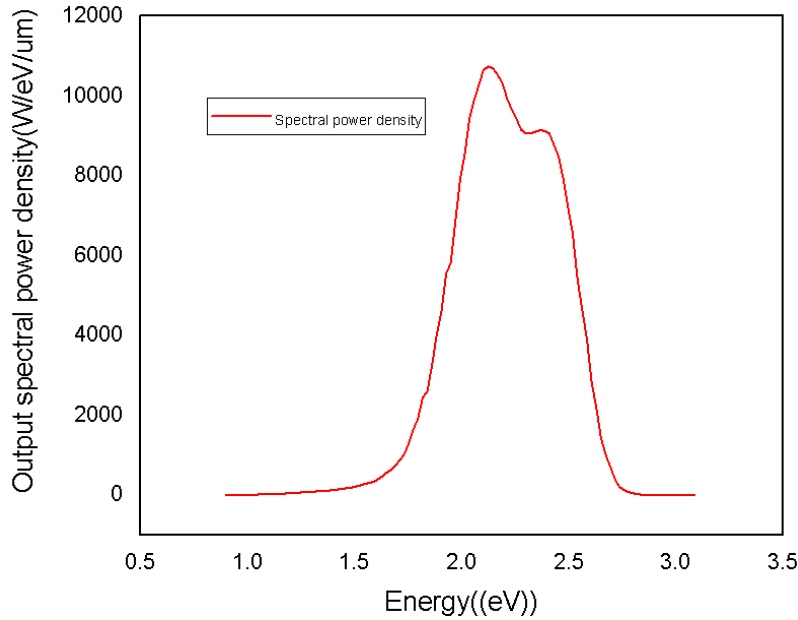


Figure 8. Output spectrum power density as function of energy

These wavelengths correlate to the green and yellow/orange colors. Because the maximum output spectrum power density is found with a strong peak at approximately 585 nm, it will dominate over 520 nm. Because of this, the radiation that this OLED will produce will have an orangey-yellow hue. The intensity change in the output spectrum power density at 585 and 520 nm may attribute to variation in exciton density.

Figure 9 (a, b) shows a similar trend of fluctuation in spectral radiance and source PL (photo luminescence). The plot of the computed spectral radiance with respect to wavelength can be seen in Figure 9(a).

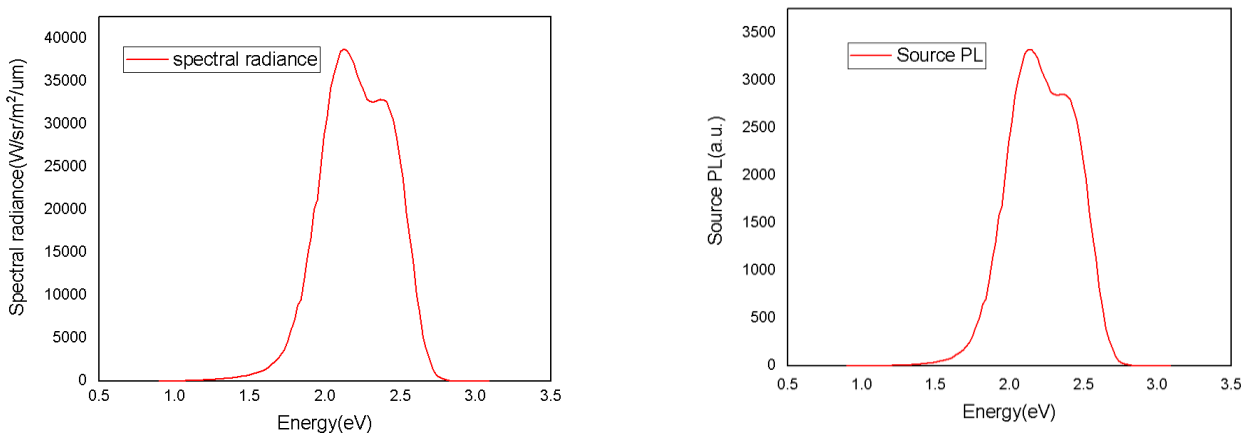


Figure 9. (a) Spectral radiance and (b) Source PL of ITO/NPB/Alq3:DCJTb/Alq3/Ag OLED as a function of wavelength.

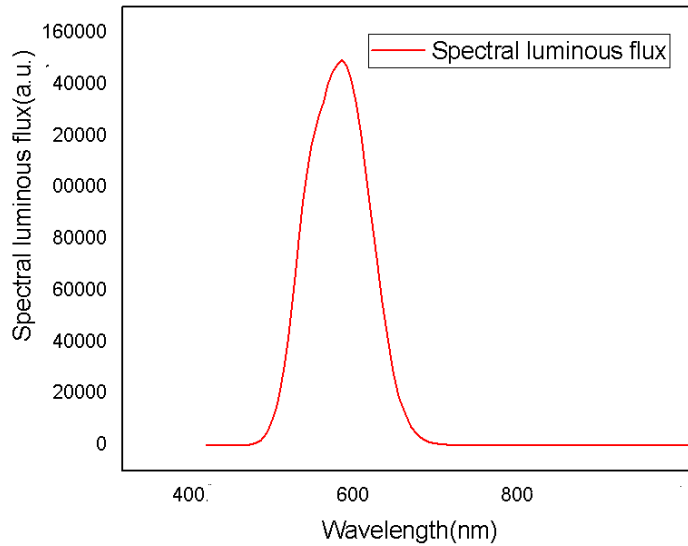
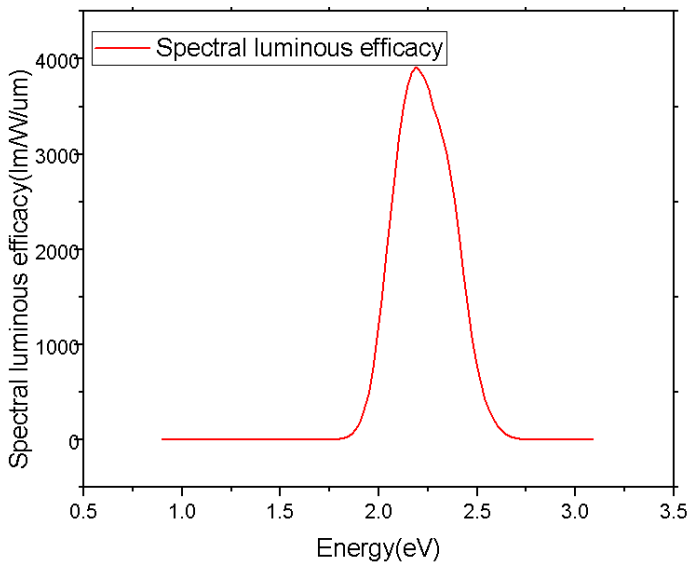
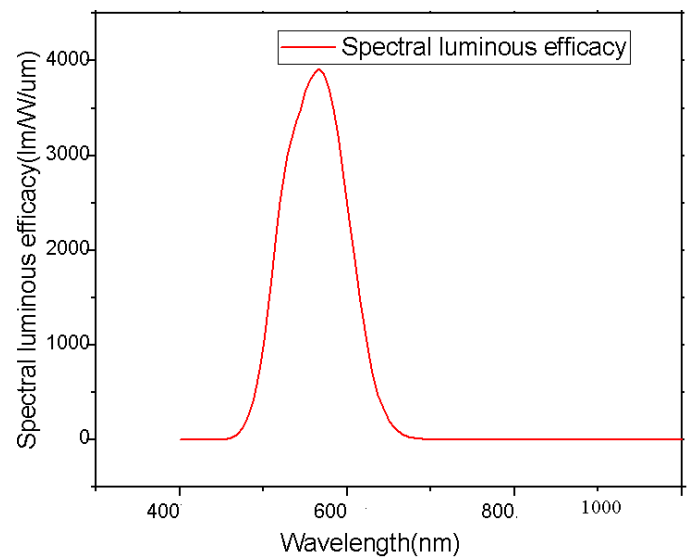


Figure 10. Spectral luminous flux of PEDOT:PSS/NPB/Alq₃:DCJTBA/Alq₃/CaOLED.

Figure 10 depicts the spectral luminous flux of proposed OLED. The peak luminous flux in the visible zone, which is associated with a yellow/orange color, is approximately 565 nm, as seen in Fig. 10. The PEDOT:PSS/NPB/Alq₃:DCJTBA/Alq₃/Ca OLED is well-suited for producing yellow light, as shown by the normalized intensity in the illustration of Figure 10



(a)



(b)

Figure 11(a), (b) OLED spectral luminescence efficacy

Figure 11 shows OLED spectral luminescence efficacy measures how well an OLED turns electrical power into visible light at different wavelengths. It is critical for assessing OLED performance, especially color purity, energy efficiency, and brightness. Figure 11(a) illustrated that spectral luminescence efficacy in OLEDs is directly related to photon energy, as different wavelengths correlate to different energy level at around 2.0–2.5 eV and 500–600 nm, green photons strike a compromise between efficiency and luminous efficacy as shown in Figure 12(b), and

the peak spectral efficacy is observed at approximately 585 nm, and the peak hump is observed at around 520 nm.

Conclusion

A detailed analysis of optical and electronics properties of PEDOT:PSS/NPB/Alq3/Alq3:DCJTb/Ca heterostructure based OLED presented. The choice of host to be employed in a guest-host matrix for the Alq3 emitter Alq3:DCJTb is presented. The excitons that are created in EML and ETL under different anode voltage and current conditions were investigated through this study. The Holstein model was utilized to investigate Alq3 and DCJTb spectra in ETL and EML. The simulation results showed that the designed OLED had an operating voltage of approximately 4 V and the maximum luminous flux was attained in the visible region at around 565 nm, which is a yellow/orange color. As a result, it is advised that contacts with matching injection capabilities be utilized for constructing efficient OLEDs, even if it requires a modest increase in the turn-on voltage. Research on all these characteristics indicates that OLEDs based on heterostructure are effective in emitting bright radiation in the visible spectrum (about 500 nm).

Reference

- [1] Pope, M., Kallmann, H.P., Magnante, P., 1963. Electroluminescence in organic crystals. *J. Chem. Phys.*, 38, 2042–2043.
- [2] Tang, C.W., VanSlyke, V.A., 1987. Organic Electroluminescent Diodes. *Appl. Phys. Lett.*, 51, 913
- [3] Burroughes, J.H., Bradley, D.D.C., Brown, A.R., Marks, R.N., Mackay, K., Friend, R.H., Burns, P.L., Homes, A.B., 1990. Light-Emitting Diodes Based on Conjugated Polymers. *Nature*, 347, 539
- [4] Yang, X., Zhou, G., Wong, W.-Y., 2015. Functionalization of Phosphorescent Emitters and Their Host Materials by Main-Group Elements for Phosphorescent Organic Light-Emitting Devices. *Chem. Soc. Rev.* 44, 8484– 8575.
- [5] Liu, B., Gao, D., Wang, J, Wang, X., Wang, L., Zou, J., Ning, H., Peng, J., 2015. Progress of White Organic Light Emitting Diodes. *Acta Phys. Chim. Sin.* 31, 1823–1852.
- [6] Imane., Anass., Zakaria., Mohammed., 2023. Simulation and analysis of electro-optical characteristics of organic compounds in organic light emitting diode(OLEDs). *Organic article*, 7(3), 8-23
- [7] Schwartz, G., Reineke, S., Rosenow, T.C., et al., 2009. Triplet harvesting in hybrid white organic Light-Emitting diodes. *Advanced Functional Materials.* 19(9), 1319-1333.
- [8] Kuei, C.Y., Tsai, W.L., Tong, B., et al., 2016. Bis-tridentate Ir (III) complexes with nearly unitary RGB phosphorescence and organic light-emitting diodes with external quantum efficiency exceeding 31%. *Advanced Materials.* 28(14), 2795-2800.
- [9] Xie, G., Meng, Y., Wu, F., Tao, C., Zhang, D., Liu, M., ... & Zhao, Y. (2008). Very low turn-on voltage and high brightness tris-(8-hydroxyquinoline) aluminum-based organic light-emitting diodes with a MoOx p-doping layer. *Applied Physics Letters*, 92(9).
- [10] Ritu, Quraishi, A. M., Kattayat, S., Muqri, A. K., Hashmi, S. Z., Ezzeldien, M., ... & Alvi, P. A. (2023). Optimization of NPD/Alq3/TPBi/Bphen OLED structure and investigation of electrical characteristics along with allied parameters. *Optical and Quantum Electronics*, 55(8), 698. [10].
- [11] J. McElvain, H. Antoniadis, M.R. Hueschen, J.N. Miller, D.M. Roitman, J.R. Sheets, R.L. Moon, Formation and growth of black spots in organic light-emitting diodes, *J. Appl. Phys.* 80 (1996) 6002
- [12] So, F., & Kondakov, D. (2010). Degradation mechanisms in small-molecule and polymer organic light-emitting diodes. *Advanced Materials*, 22(34), 3762-3777.
- [13] Aziz, H., & Popovic, Z. D. (2004). Degradation phenomena in small-molecule organic light-emitting devices. *Chemistry of Materials*, 16(23), 4522-4532.
- [14] Saeed, A., Alshahrie, A., & Salah, N. (2020). Fabrication of highly efficient organic light-emitting diode based on dysprosium-incorporated tris-(8-hydroxyquinoline) aluminum. *Journal of Materials Science: Materials in Electronics*, 31, 22179-22189.

- [15] Kang, H. Y., & Lee, C. (2004). Electroluminescence properties of organic light-emitting diodes with a red dye doped into Alq₃: rubrene mixed host.
- [16] Lee, Y. G. et al. Comparison of two cohost systems for doped red organic light-emitting devices in an effort to improve the efficiency and the lifetime. *Organic Electronics* 9, 339–346 (2008).
- [17] Liu, T. H., Iou, C. Y. & Chen, C. H. Doped red organic electroluminescent devices based on a cohost emitter system. *Appl. Phys. Lett.* 83, 5241–5243 (2003).
- [18] B. Zhao, T. Zhang, B. Chu, et al., Highly efficient red OLEDs using DCJTb as the dopant and delayed fluorescent exciplex as the host, *Sci. Rep.* 5 (2015) 10697.
- [19] Mustafa Kurban, Bayram Gündüz, Physical and optical properties of DCJTb dye for OLED display applications: experimental and theoretical investigation, *J. Mol. Struct.* 1137 (2017) 403–411.
- [20] Tao, S., Niu, L., Yu, J., Jiang, Y., & Zhang, X. (2010). High-performance organic red-light-emitting device based on DCJTb and a new host material. *Journal of luminescence*, 130(1), 70-73.
- [21] Friend, R. H., Gymer, R. W., Holmes, A. B., Burroughes, J. H., Marks, R. N., Taliani, C. D. D. C., ... & Salaneck, W. R. (1999). Electroluminescence in conjugated polymers. *Nature*, 397(6715), 121-128.
- [22] Chen, J., & Ma, D. (2004). Effect of dye concentration on the charge carrier transport in molecularly doped organic light-emitting diodes. *Journal of applied physics*, 95(10), 5778-5781.
- [23] Gueye, M. N., Carella, A., Faure-Vincent, J., Demadrille, R., & Simonato, J. P. (2020). Progress in understanding structure and transport properties of PEDOT-based materials: A critical review. *Progress in Materials Science*, 108, 100616.
- [24] Tiwari, A., & Kumar, B. (2020, February). Investigation of Different Layer OLED Structure based upon PEDOT: PSS/GO Composite Anode. In *2020 International Conference on Electrical and Electronics Engineering (ICE3)* (pp. 583-587). IEEE
- [25] Sharma, G., Hashmi, S. Z., Kumar, U., Kattayat, S., Ahmad, M. A., Kumar, S., ... & Alvi, P. A. (2020). Optical and electronic characteristics of ITO/NPB/Alq₃: DCJTb/Alq₃/Ag heterostructure based organic light emitting diode. *Optik*, 223, 165572.
- [26] Guo, Y., Li, X., Li, B., & Wang, W. (2024). Hybrid electrode interface modification enhances OLEDs performance. *Optical Materials Express*, 14(4), 972-982.
- [27] Liu, T. H., Iou, C. Y., & Chen, C. H. (2005). Development of highly stable organic electroluminescent devices with a doped co-host emitter system. *Current Applied Physics*, 5(3), 218-221.
- [28] Tang, C. W., VanSlyke, S. A., & Chen, C. H. (1989). Electroluminescence of doped organic thin films. *Journal of applied physics*, 65(9), 3610-3616.
- [29] ShaliniJharia&Pravendra Tyagi, (2024), Investigation the effect of anode workfunction on the optoelectronics performance of Organic Light Emitting Diode, Research and Reviews, *Journal of Physics*, 13(02), 27-37