NanoWorld Journal

https://doi.org/10.17756/nwj.2024-s1-025

Research Article

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Study of (NPD/PC60BM/BPhen/TPBi) OLED and its Various Characteristics

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Received: January 03, 2024
Accepted: March 11, 2024
Published: March 14, 2024

Citation: Ritu, Quraishi AM, Kattayat S, Singh J, Alvi PA. 2024. Study of (NPD/PC60BM/BPhen/TPBi) OLED and its Various Characteristics. *NanoWorld J* 10(S1): S138-S142.

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Abstract

This article reports the optimized structure of (NPD/PC60BM/BPhen/TPBi) organic light-emitting diode (OLED) heterostructure having overall size (width) ~ 500 nm and its various characteristics. In the optimized OLED structure, two electron transport layers (ETLs) of the TPBi and BPhen organic polymers have been used for getting higher performance. For the designed OLED structure, energy band diagram, current-voltage (I-V) and current density-voltage (J-V) characteristics, behavior of voltage and current dependent light flux, optical efficiency along with the recombination prefactor have been studied. The turn on voltage is found as ~ 3.5 V, while the optimum value of optical efficiency is obtained at ~ 3 V. The probability with which photons are escaped from the device is found out maximum for 600 - 700 nm wavelength range.

Keywords

PC60BM, Electron transport layers, Electron emissive layer, Light-emitting diode, Organic light-emitting diode

Introduction

In today's scenario the light-emitting diode (LED) technology has had a transformative impact across various sectors, offering energy efficiency, durability, and versatility in lighting and display applications [1-4]. From application point of view, there are several fields such automotive sector, environmental and outdoor lighting; medical and scientific applications, and horticulture, where LED technology is vastly used. LED technology is being improved day by day in several concepts, but there are certain parameters like wide viewing angles, thinner and lighter, better image quality and flexible and curved displays enable the OLED technology better than LED technology [5-8].

OLEDs basically are manufactured of polymeric materials which are considered as disordered organic semiconductors. So far, various OLEDs have been fabricated by using polymer nanocomposites [9-11]. Biodegradable polymer nanocomposites have also played an important role in optoelectronics and electronics [12-14]. In disordered organic semiconductors, electron, and hole mobilities are not constant, in contrast to inorganic semiconductors where these quantities are thought to be constant. In case of organic materials, since holes are more mobile than electrons, electron-hole (e-h) recombination does not take place in the active region of OLED, resulting in better performance. The factors impacting e-h mobilities are temperature, electric field, and type of organic semiconductor. To increase the luminance efficiency and to reduce the voltage at which devices operate, double layer of ETL is required. Introducing an additional ETL layer i.e., TPBi increases usage of exciton and carrier confinement, which enhances the device's efficiency and recombination rate.

The fundamental OLED structure consists of two organic semiconductors, one of which is n-type and is responsible for transporting electrons (considered as ETL), and the other of which is p-type and responsible for transporting holes (considered as HTL: hole transport layer). When the circuit is properly biased, holes from the anode enter the HTL and electrons from the cathode enter the ETL. In the organic semiconductor materials HOMO and LUMO levels are crucial for charge carrier injection. Charge injection in the OLED will improve its performance if these levels match the work-function of the next electrode, leading to large charge carrier's injection and therefore their recombination. The increased mobile e-h charge carrier quenching is a significant problem where it reaches the opposing electrode and is exhausted there. These charge carriers decrease device efficiency since they are ineffective for recombination. Hence, it is necessary to stop these charge carriers from getting to the opposing electrodes which can be done by using double ETL layer and cathode electrodes. Thus, the double ETLs play an important role in improving the OLED performance. Hence, in this work, double ETL layers based on OLED heterostructure has been optimized and studied in context of its various characteristics.

Experimentation

OLED structure and energy band diagram

In figure 1, the optimized layer structure of (NPD/PC60BM/BPhen/TPBi) heterostructure OLED has been illustrated, while the energy band diagram of the designed OLED has been shown in figure 2. The working of illustrated OLED in figure 1 is like that of conventional p-n junction diode (inorganic LED). Generally, the OLEDS are assigned as solid-state lightning devices which are made up of different organic electroluminescent materials. In the presented OLED structure, lithium fluoride (LiF) and aluminum (Al) is considered as ~ 50 nm and have been used as cathodes and indium tin oxide ITO (ITO, 150 nm) having high work function and transparency is used as anode [15]. The popular low work function cathode material known as LiF/Al can dramatically lower the barrier height. Electrons and holes are generated at cathode and anode terminal of the OLED device, respectively. The order of different layers sandwiched between anode (ITO) and two cathode (LiF and Al) electrodes: HTL, electron emissive layer (EML), two ETLs.

N,N′-Di(1-naphthyl)-N,N′-diphenyl-(1,1′-biphenyl)-4,4′-diamine (NPD or NPB) of thickness 40 nm is used as HTL plays a vital role in conducting holes and blocking electron. PC60BM (thickness ~ 40 nm) i.e., 3′H-cyclopropa fullerene-C60-Ih-3′-butanoic acid 3′-phenyl methyl ester is used as an EML. The overall size of the designed OLED is ~ 500 nm. The 500 nm width of OLEDs is significant because it corresponds to the green wavelength, which is an essential element in achieving vibrant colors and accurate displays. This

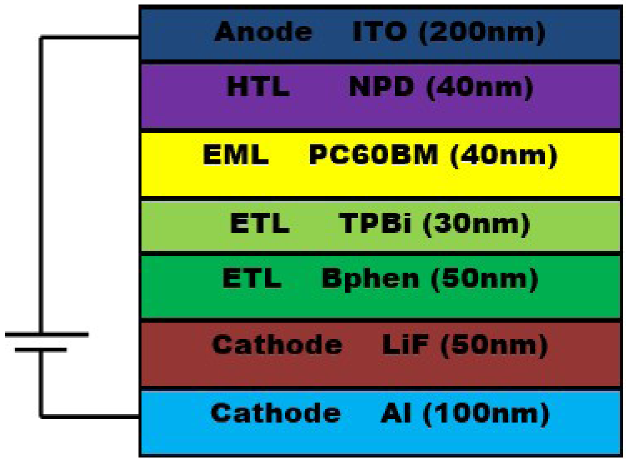

Figure 1: Layer structure of (NPD/PC60BM/BPhen/TPBi) heterostructure OLED.

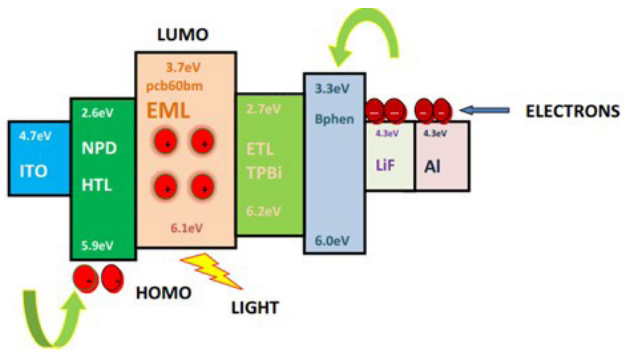

Figure 2: Energy band diagram of (NPD/PC60BM/BPhen/TPBi) heterostructure OLED.

wavelength is of utmost importance in the RGB color paradigm, as it facilitates the production of a broad range of colors and the establishment of well-balanced white light. OLED displays guarantee visual comfort and energy efficiency by optimizing emission at 500 nm, rendering them suitable for a wide range of applications including smartphones, televisions, and monitors. The ability to precisely regulate the emission at this wavelength significantly improves the overall functionality of OLED technology, providing users with a visually captivating and unified experience across various devices. Thus, in view of the above fact, the size of OLEDs plays a pivotal role in driving cutting-edge technology across multiple domains. In the realm of consumer electronics, the flexibility and compact nature of OLED displays are instrumental in shaping the design of foldable smartphones, wearable devices, and ultra-thin laptops.

To enhance the efficiency and electronic injection of the optimal device, the TPBi (30 nm) i.e., 1,3,5-Tris(1-phenyl-1Hbenzimidazol-2-yl) benzene and Bphen (50 nm) i.e., 4,7-Diphenyl-1,10-phenanthroline or Bathophenanthroline are used as ETLs between the EML (PC60BM) and cathodes (LiF/Al). The electrons from cathode (LiF/Al) electrodes are transported to PC60BM layer with the help of ETL (TPBi/Bphen) (Figure 2). Similarly, the holes from ITO are transported to PC60BM with the help of NPD or NPB. Singlet and triplet excitons are generated in the active region (in emitter layer) due to recombination of electrons and holes. Excitons release their energy in the form of photons light from the active layer.

The wavelength of light emitted depend on the emitter material i.e., PC60BM (40 nm). OLEDs having an additional ETL layer of TPBi decrease the energy barrier between Bphen and PC60BM, enhance the e-h balance and prevent quenching of excitons at the interface of Bphen and PC60BM; prevent aggregation of electron and holes on the thin film. The materials used for designing ETLs heterostructure based OLED are having high intrinsic mobility tunable morphology and excellent electrical conductivity. With sub-monolayer quantities of LiF deposited on the surface, the effective work-function of Al is drastically reduced [16, 17]. As reported earlier, with the double ETLs the device the current efficiency and luminance of the OLEDs have been enhanced [18]. Regarding performance improvement, it's crucial to have balanced charge transport and injection ensure that the created excitons are used for emission instead of charge storage at the interface (i.e., quenching) to obtain high efficiency in OLEDs.

Results and Discussion

To obtain the I-V characteristics, the voltage is applied between anode and cathode terminals of the OLED device. The terminal connection is shown in figure 1; the I-V characteristic is shown in figure 3. Current is not obtained in OLED till 3.5 V. Further increase in the voltage results in the exponential increase of current (in nA) due to the recombination of e-h pairs in the active layer. Thus, the value of turn on voltage for heterostructure based AL/LiF/Bphen/PC60BM/NPD/ITO OLED is approximated as 3.5 V. The current behavior is found nearly exponential increasing after turning on voltage, as shown in above figure 3. With the help of interface barriers present between the electrodes, the value of turn-on voltage can be controlled. Because of double ETL layer, the value of turn on voltage is reduced significantly. The J-V characteristic is shown in figure 4. The J-V characteristic shows the relationship between the applied voltage through AL/LiF/Bphen/PC60BM/NPD/ITO OLED and the corresponding current density across it. From figure 4, after the turn on voltage there is exponential increase of current density with the applied voltage which completely agrees with the I-V characteristics of OLED.

The light flux is computed as a function of voltage, as shown in above figure 5a. Light flux starts to increase after 2.5 V. Beyond this voltage, light flux increases exponential with the increase in applied voltage. The light flux is also computed as a function of current density, as shown in above figure 5b. As the value of current density is increased beyond 100 (A/m^2) there is a linear increase in the value of light coming out from the unit area of AL/LiF/Bphen/PC60BM/NPD/ITO device. ETL and HTL layers play a major role in transporting electrons and holes from the electrodes to EML. The formation of e-h pairs i.e., excitons is occurred in the EML. In figure 6, the e-h generation rate is plotted against the layer position (nm).

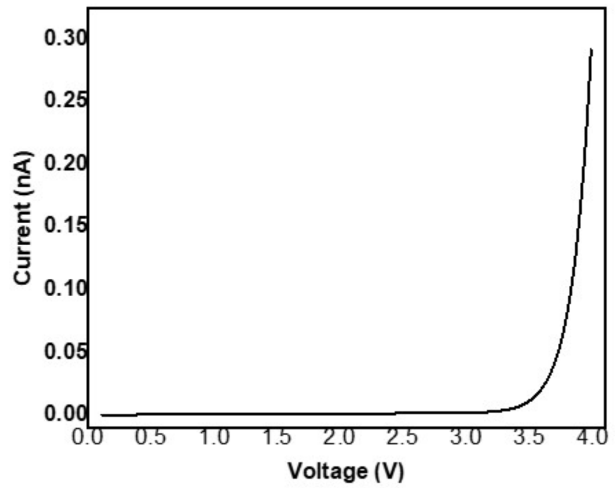

Figure 3: I-V characteristics of (NPD/PC60BM/BPhen/TPBi) heterostructure OLED.

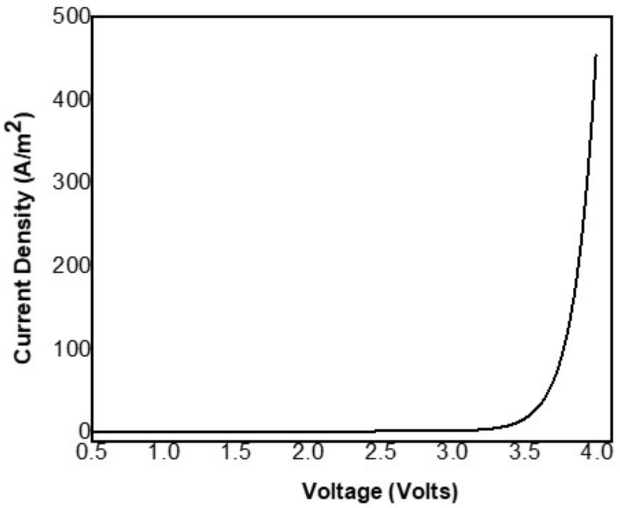

Figure 4: J-V characteristics of (NPD/PC60BM/BPhen/TPBi) heterostructure OLED.

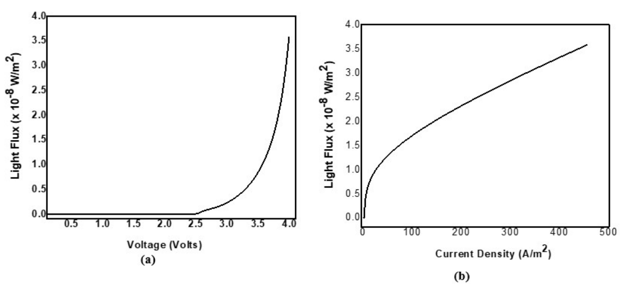

Figure 5: Behavior of **(a)** voltage and **(b)** current dependent light flux of (NPD/PC60BM/BPhen/TPBi) heterostructure OLED.

The ultimate amount of e-h generation rate can be seen along the layers position range 250 - 300 nm i.e., at the position of EML as shown in figure 6.

The optical efficiency % corresponding to applied voltage has been calculated and shown in figure 7. For designing an

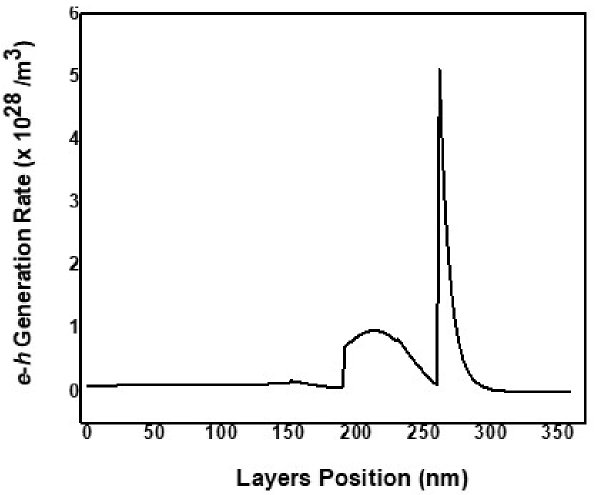

Figure 6: e-h concentration along the layers position of (NPD/PC60BM/BPhen/TPBi) heterostructure OLED.

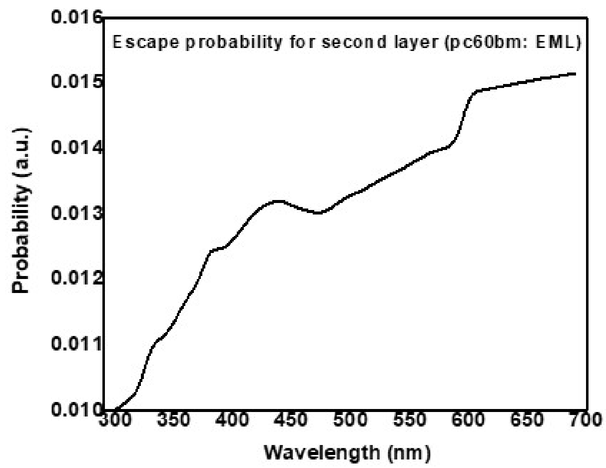

Figure 8: Emission probability of (NPD/PC60BM/BPhen/TPBi) heterostructure OLED.

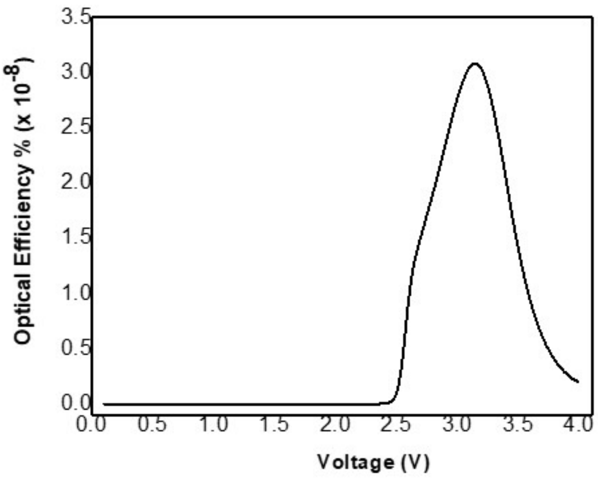

Figure 7: Voltage dependent optical efficiency of (NPD/PC60BM/BPhen/TPBi) heterostructure OLED.

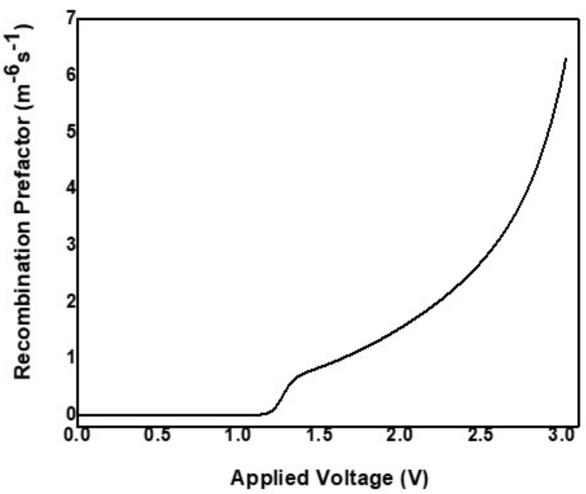

Figure 9: Recombination prefactor of (NPD/PC60BM/BPhen/TPBi) heterostructure OLED.

efficient OLED, the study of optical simulations is essential [19]. The optical efficiency of an AL/LiF/Bphen/PC60BM/NPD/ITO OLED is measured as a function of applied voltage between the electrodes. Optical efficiency is used to measure the quantity of light emitted from the OLED device. The optimum value of optical efficiency is obtained at ~ 3 V of OLED and agreed with the results shown in figure 5a.

The escape probability is computed as a function of wavelength and plotted figure 8. The emitted light from the AL/LiF/Bphen/PC60BM/NPD/ITO device is found in the visible region. The probability with which photons are escaped from the device is found out maximum for 600 - 700 nm wavelength range photons. The recombination prefactor of AL/LiF/Bphen/PC60BM/NPD/ITO OLED denotes the rate at which e-h pairs are recombining. It is simulated by using Auger recombination model. It is found out to be increase exponential after 1.5 V (Figure 9).

Conclusion

Optimization and simulation of the (NPD/PC60BM/BPhen/TPBi) OLED heterostructure has been performed successfully to get its various characteristics such as I-V and J-V characteristics, behavior of voltage and current dependent light flux, optical efficiency along with the recombination prefactor. In the optimized OLED structure, two ETLs of the TPBi and BPhen organic polymers have been used for getting higher performance. For the optimized OLED structure, the turn on voltage is found as ~ 3.5 V, while the optimum value of optical efficiency is obtained at ~ 3 V. The probability of emission of photons is found out maximum for wavelength range of 600 - 700 nm.

Acknowledgments

Ritu and P.A. Alvi acknowledge for their work to the DST, govt. of India for providing the research support through CURIE project funded to Banasthali Vidyapith.

Conflict of Interest

None.

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