The 27th Iranian Conference on Optics and Photonics (ICOP 2021), and the 13th Iranian Conference on Photonics Engineering and Technology (ICPET 2021). University of Sistan and Baluchestan, Zahedan, Iran, Feb. 2-4, 2021

کد مقاله : ۱-۲۴۵۶-۱۰-A

تاثیر ضخامت های ماده TPD بر روی عملکرد دیودهای نورگسیل آلی

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چکیده–در این پژوهش تاثیر ضخامتهای ماده (۴۰ nm، ۵۳nm، ۶۰ nm، ۹۴nm و ۱۰۵nm)TPD به عنوان لایه انتقال دهنده حفره بر روی عملکرد دیودهای نورگسیل آلی مورد بررسی قرار می گیرد. به منظور ساخت دیودهای نورگسیل آلی از روش تبخیر گرمایی استفاده شده است و مشخص شده است که اگر ضخامت TPD از ۴۰ nm به ۵۳nm و سپس به ۶۰ nm، ۹۴nm و ۱۰۵nm افزایش یابد، مشخصات چگالی جریان-لومینسانس-ولتاژ برای ضخامت ۵۳nm در ولتاژهای پایین تر و برای ضخامتهای دیگر در ولتاژهای بالاتر ظاهر می شوند. ولتاژ عملکرد و ولتاژ تحریک برای ضخامت ۹۴nm بیشترین مقدار است و با تغییر ضخامت TPD از ۶۰ nm به ۱۰۵nm ، ۴۰ nm و ۵۳nm بترتیب کاهش می یابد. همچنین ضخامت TPD بر روی مشخصات بازده جریان و بازده توان دیودهای نورگسیل آلی تاثیر می گذارد بطوریکه این کمیتها بترتیب برای ضخامت های ۶۰ nm و ۹۴nm مربوط به ضخامت TPD بیشینه می باشند.

کلید واژه- بازده، لومینسانس، ماده آلی، ولتاژ عملکرد

Influence of TPD thicknesses on the performance of organic light-emitting diodes (OLEDs)

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Abstract- In the present work, the influence of the N,N' –Bis(3-methylphenyl)-N,N' –bis(phenyl) benzidine (TPD)-like diamine thicknesses (40nm, 53nm, 60nm, 94nm and 105nm), as a hole transport layer (HTL) on the performance of organic light-emitting diodes (OLEDs) has been investigated. For fabrication of the OLED devices, thermal evaporation method has been used and it is revealed that if the thickness of TPD increases from 40 nm to 53nm and then to 60nm, 94nm and 105 nm, the current density-luminance-voltage characteristics for TPD thickness of 53nm (at voltages lower than 15 V) appear at lower voltages and for other thicknesses appear at higher voltages. So that the driving voltage and operating voltage are the highest for TPD thickness of 94nm and these quantities are decreasing for TPD thickness from 60nm to 105nm, 40nm and 53nm respectively. Also the thickness of TPD affects on current efficiency and power efficiency characteristics of OLED devices, So that these quantities are the highest for devices with TPD thickness of 60nm and 94 nm respectively.

Keywords: Efficiency, Luminance, Organic material, Operating voltage

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1. Introduction

Organic light emitting diodes ($OLED_S$) have attracted much attention in recent decays after the discovery of Tang and van slyke in 1987, So that many attempts have been done for increasing their luminance and efficiency because of appealing characteristics such as light weight, flexibility, fast response time, wide viewing angle and mechanical flexibility. The devices fabricated by Tang were two layer OLEDs (TPD as HTL and tris-(8-hydroxyquinoline) aluminum(Alq_3) as emitting layer (EML) and electron-transport layer (ETL))[1]. In OLEDs, the recombination process of electrons and holes injected from electrodes makes it possible light emission from the EML. Thus moreover the organic material itself the thickness of organic layer affects on the device performance [2]. In most cases, the OLED device thickness is about 100 nm which leads to the lower driving and operating voltage of about lower than 10 V. Also this low thickness leads to better performance of OLED device in the view of operating and driving voltage but the presence of defects in organic materials leads to the instability and short lifetime for this thin device. Therefore despite higher driving and operating voltage, thick devices have been extensively investigated during the last years. However despite these investigations, their efficiency and lifetime are critical topics. Thus, a low driving voltage that strongly is related to the charge balancing of electrons and holes in an emitting layer of OLED, has been considered as one of the most important parameter for improvement the OLED performance [3]. With notice to the relations of current efficiency (η_c= L/J) and power efficiency (η_P= πL/JV= $\pi\eta_c$/V) which relates these quantities to the luminance (L), current density (J) and operating voltage (V), the charge balancing leads to higher current efficiency, lower operating voltage(*V*) and higher power efficiency, for practical applications[4]. Also with notice to these relations, with considering the nearly constant current efficiency (η_c), the power efficiency (η_P) increases for lower thicknesses of device because this leads to the lower driving voltage (V). However, in practice it is essential to optimize the different layers of the OLED device to obtain higher power efficiency due to existence of leakage current that originates from lowering layer thickness [5]. Another point in OLED devices is to use of the Indium tin oxide (ITO) with work function (WF) of 4.4eV to 4.7eV as transparent conductive anode, metal halides like liteum fluoride (LiF) as electron injection layer (EIL) between cathode and electron transport layers (ETL_S) and optical interference for optimization of the OLED devices[6-8].

The injection and transportation of holes has significant influence on the performance of OLED devices. Thus in this manuscript, the influence of the HTL thickness (thin layer or thick layer) on this subject and in conclusion on the performance of these devices has been investigated. For this purpose, the OLED devices with the structure of ITO/TPD (40, 53, 60, 94,105nm) /Alq_3 (60nm)/LiF(0.5nm)/Al(100nm) have been fabricated with thermal evaporation method and various characteristics such as current density, luminance, operating voltage, driving voltage, current efficiency and power efficiency have been measured and calculated.

2.Materials and Methods

This research work has been done in February and March months of 2018 year in NANO electronic and thin film laboratories of the Department of Physic, Faculty of Basic Science, University of Mazandaran, Babolsar, Iran and Department of Physic, Faculty of Science, Ferdowsi University of Mashhad, Iran respectively.

2.1 Materials

For this research, the TPD (HTL) and Alq_3 (ETL) organic materials have been provided from Sigma Aldrich Company and have been used as received.

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Also inorganic materials such as LiF (EIL) and Al (cathode) and ITO glasses (anode) are provided from other company.

2.2 Fabrication Methods

The ITO glasses with a sheet resistance of about $20\Omega/cm^2$, are etched by using zinc powder and hydrochloric acid to define the anode electrode pattern and then cleaned using ultrasonic baths of detergent, acetone, ethanol, and deionized (DI) water for 10 min respectively, followed with drying by high purity nitrogen gas. The OLED devices have been fabricated, without breaking vacuum for TPD and Alq_3, by using successive vacuum-depositions and with little breaking vacuum for LiF and Al on top of the indium tin oxide (ITO) substrates. For this purpose the Edward coating system has been used. The deposition rate for organic materials (TPD and Alq_3) was 0.2-0.8 A˚/s at pressure of 1×10^{-6}mbar for vacuum chamber, while this rate for inorganic materials such as LiF and Al was 0.1 and 1-5 A˚/s respectively[9-11].

2.3 Measuring Methods

For measuring of the different layers thicknesses a quartz crystal sensor has been used. The current density- luminance -voltage (J-L-V) characteristics of the devices were measured using a computer-controlled digital I-V meter with model of TRUE RMS PROVA 903 and light meter with model of YK-2005 LX in ordinary conditions. The driving voltage at any given current density and operating voltage at any given luminance are obtained from the J-L-V characteristics. Also current efficiency (η_c) and power efficiency (η_p) of the OLED devices are calculated as $\eta_c = \frac{L}{J}$ and $\eta_p = \frac{\pi}{V}\eta_c$ respectively.

3. Results and Discussions

3.1Current density-luminance-voltage results

Current density-luminance-voltage (J-L-V) quantities for OLED structures (Fig.1) are presented in Figs.2 and 3 respectively. From these figures, it is observed that when the thickness of TPD increases from 40 nm to 53nm and then to 60nm, 94nm and 105 nm, For TPD with thickness of 53nm (at voltages lower than 15 V), the current density-voltage and luminance-voltage curves shift to lower voltage while for other thicknesses these curves shift to higher voltages. The shift value for TPD thickness of 94 nm is the highest and for TPD thickness of 105 nm is the lowest.

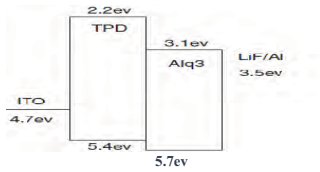

Fig.1 Band structure of the investigated OLED devices: ITO/TPD/Alq_3/LiF/Al

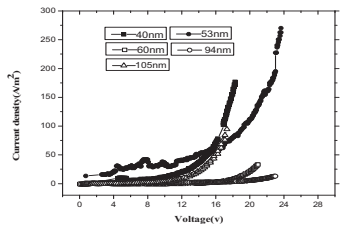

Fig.2 Current density-voltage characteristic of the OLED structures for various thicknesses of TPD

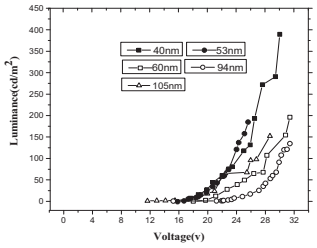

Fig.3 Luminance -voltage characteristics of the OLED structures for various thicknesses of TPD.

This means that (as shown in Figs.4 and 5), the driving voltage at a specific value for current density and operating voltage at a specific value for luminance are the highest for TPD thickness of 94nm and these quantities are decreasing for TPD thickness from 60nm to 105nm, 40nm and

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53nm respectively, so that, the device with TPD thickness of 53nm has the lowest driving and operating voltages among these devices.

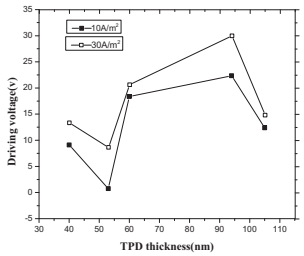

Fig.4 The driving voltage of OLEDs in terms of TPD thickness at two value for current density(J=10,30A/m^2)

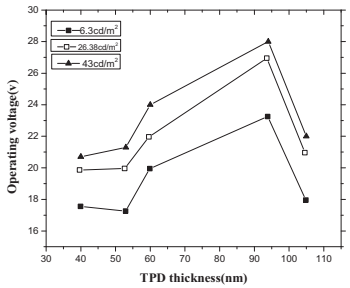

Fig.5 The operating voltage of OLEDs in terms of TPD thickness at three value for luminance (L=6.3,26.38,43cd/m^2).

3.2 Current efficiency and power efficiency results

Current efficiency and power efficiency characteristics of OLED structures (Fig.6) show that with varying the TPD thicknesses from 40 nm to 53nm and 60nm, the current efficiency increases dramatically while after that decreases for TPD thickness varying from 60 nm to 94 nm and 105 nm. Thus the maximum current efficiency occurs for OLED device with TPD thickness of 60 nm. The current efficiency of OLED with TPD thickness of 94nm is higher than OLEDs with TPD thicknesses of 40, 53 and 105nm but is lower than OLED with TPD thickness of 60nm. In the case of power efficiency, it should be noticed that with increasing the TPD thickness from 40 nm, to 53 nm, 60 nm, 94 nm and 105 nm, this quantity shows increasing and decreasing variations periodically, So that the maximum power efficiency occurs for OLED devices with TPD thickness of 94 nm.

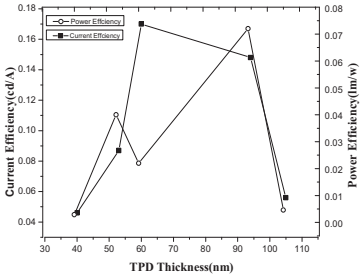

Fig.6 current efficiency and power efficiency quantities for OLED structures.

3.3 Discussions

For discuss about these results we consider that the lowest unoccupied molecular orbital (LUMO) levels of Alq_3 and TPD are 3.1ev and 2.2ev respectively, thus with insertion of the TPD as HTL, electrons accumulate between the TPD/Alq_3 interfaces. This phenomena leads to creation of local electric field inside the TPD layer and enhancement of the holes injection into the HTL can be obtained. Also With notice to the high hole mobility (1.5×10^{-3} cm^2 V^{-1} s^{-1}) in TPD and its highest occupied molecular orbital (HOMO=−5.4eV) level, the efficient hole injection from ITO anode to this layer would be possible. Therefore, the insertion of TPD (53nm) as HTL leads to shift of the J-V and L-V curves toward lower voltages with respect to TPD (40 nm). But for thicker TPD layers (105 nm, 60 nm, and 94 nm), the decreasing of the local electric field, leads to decreasing of the hole injection and shift of the J-V and L-V curves toward higher voltages, respectively[12-15]. Another point is unbalanced carriers transportation due to unequal holes mobility in TPD with electrons mobility in Alq_3 which affects on the current efficiency and power efficiency of the OLED devices. With increasing the TPD thickness due to the decreasing of the electric field inside the HTL and

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increasing the operating voltage and driving voltage the hole injection was reduced. In conclusion the balance situation of charge carriers is improved and leads to the better OLED performance for TPD thickness of 94nm from the point of current efficiency and power efficiency view[16-19].

4. Conclusion

From this study, it is revealed that with increasing the TPD thickness from 40 nm to 53nm and then to 60nm, 94nm and 105 nm, at first for TPD with thickness of 53nm (at voltages lower than 15 V), the current density-luminance-voltage curves shift to lower voltages while for other thicknesses these curves shift to higher voltages. The shift value for TPD thickness of 94 nm is the highest and for TPD thickness of 105 nm is the lowest. Also the thickness of TPD affects on current efficiency and power efficiency characteristics of OLED devices, So that these quantities are the highest for devices with TPD thickness of 60nm and 94 nm respectively.

Acknowledgments

This study discovered the effects of thin and thick TPD layers as holes transport material on the performance of OLED devices based on Alq_3 emitting layer that can be beneficial for the future of OLED devices. This study will help the researchers to uncover the critical areas of OLED devices that many researchers were not able to explore. Thus a new theory on the effects of HTL thickness may be arrived at.

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