Design Simulation of Tandem Organic Light Emitting Diode using Efficient Organic Charge Generation Layer

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***Abstract*— Organic Light-Emitting Diodes (OLED) are being used now a day due to their better efficiency, easy fabrication, low power consumption, high stable for future display and lighting application. Tandem OLED is used to enhance the performance of OLED in terms of luminescence and current efficiency as they make use of two or more electroluminescent units that are separated from each other by using charge generation layer (CGL). Here in this paper Tandem OLED is designed using bulk organic hetrojunction of P3HT-PCBM, whose structure is optimized on the basis of thickness and material selection for layers to achieve the enhanced efficiency. According to results the current efficiency and luminance of Tandem OLED is found to be is 34.0336 cd/A at 10 mA/cm^2 and 3403.356 cd/m^2 which is 2.65 times greater than current efficiency and luminance of a single unit device at same current density (12.8154 cd/A and 1281.5364 cd/m^2). Hence charge generation layer of P3HT-PCBM is found to be a promising candidate for design of Tandem OLED.

Keywords—Charge transport, Charge Generation Layer, Efficiency, Organic light emitting diodes

I. INTRODUCTION

Organic Light Emitting Diodes consisting of organic materials is used to generate light, through radiative recombination of electron hole pairs. The efficiency and lifetime of device depends upon materials used in different layers of organic light emitting diodes. Light is emitted through emissive layer which lies in between Electron transport layer (ETL) and Hole transport layer (HTL) when voltage is applied to it. [1]. Now day's organic light emitting diodes are mostly used due to benefits like: low operating voltage, easy fabrication, low power consumption, light weight, flexibility, high stable for future display and lighting application, colour tune ability. [2] - [3]. It is used now a day in flexible and transparent display.

An OLED is categorized in two categories. One made with the help of small organic molecules and second made with the help of organic polymers. Nowadays OLED with organic polymers are being used due to their easy fabrication techniques like inkjet printing etc.

Working of an OLED is similar to LED but the layered structure of an OLED is different than LED. [4]. The OLEDs compete with other light sources due to its greater efficiency but the main focus of the researchers is to increase the stability of the device, enhance its lifetime, and obtain higher electroluminescence at lower current densities. An OLED structure consists of Hole transport layer (HTL), Emissive layer and Electron transport layer (ETL) that are sandwiched between anode and cathode. Sometime blocking layers are used in between to optimize the charge carrier s or exitons generation in the emissive layer. Materials which are used in different layers of an OLED plays an important role in case of efficiency of a device as well as lifetime of a device. Basic structure of an OLED is shown in figure 1.

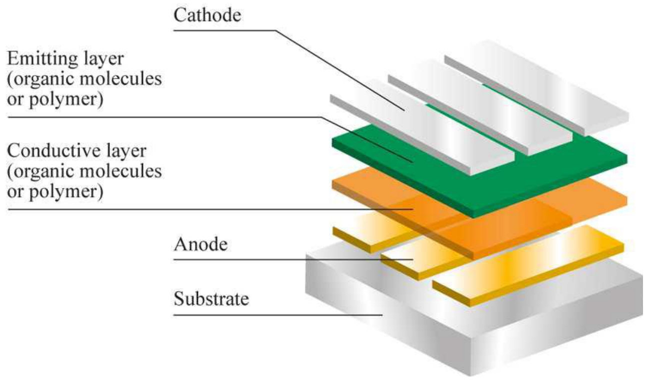

Fig. 1 Basic structure of OLED [3]

The materials that are generally used for making different layers are: Substrate is generally made with plastic, foil or glass. The anode layer generally is composed with indium tin oxide (ITO) as ITO is highly transparent material. For the positively charged electrode high work function is required and the work function of the ITO is very high in comparison to other materials which help easy transfer of holes from HOMO level of anode to the adjacent layer. The cathode layer generally composed with metals such as barium (Ba), calcium (Ca), and aluminum (Al) because these materials have lesser work function as compare to anode which helps the easy electron movement LUMO level of cathode. Materials which generally used for making electron transport layer are PBD, Alq_3, TPBI, LiF, Tio_2 and BCP. Materials which generally used for making hole transport layer are TPD and NPB. They are generally p-type materials. A material which is generally used for emissive layers is made up with organic plastic molecules and polyfluorene. [5] - [7].

To enhance the performance of OLED in terms of luminescence and current efficiency an advance OLED structure known as Tandem OLED is being used these days.

II. TANDEM ORGANIC LIGHT EMITTING DIODE

As the conventional OLED make use of single electroluminescent unit to emit light therefore its life time reduced as they need at higher current densities to achieve high luminescence. Tandem OLEDs made with two or more electroluminescent units that are placed over one another and separated with the help of CGL have gained much attention due to their ability to achieve same luminance at much smaller current densities in contrast to conventional OLEDs.[8] - [9].

The tandem OLEDs are widely used now a days as it provides higher operational lifetime, superior current efficiency and luminance as compared to the conventional OLEDs. With the increase in the electroluminescence stacked layer the electroluminescence intensity can be increased linearly even at the fixed current density. Thus high current efficiency and electroluminescence efficiency can be obtained by using tandem OLEDs. The intermediate connector linking between two adjacent electroluminescence layers is the key factor of tandem OLEDs. The CGL in tandem OLEDs consist of a bilayered structure with various materials, including, an organic–metal (or metal oxide) bilayered, an organic–organic bilayered or a metal–metal (or metal oxide) bilayered or organic hetrojunctions or organic photovoltaic CGL. For the commonly used CGLs with an organic–metal oxide bilayered, transition metal oxides (TMOs) such as tungsten trioxide (WO3), molybdenum tri-oxide (MoO3), and vanadium oxide (V2O5), are widely incorporated adjacent to the hole transport layer (HTL) of the neighboring emission unit. [10]. The drawback of using CGL with metal oxides can react with the negative charges present in the adjacent ETL and make complexes. Therefore CGLs with organic hetrojunctions are widely incorporated.

III. EXPERIMENTAL DESIGN DETAILS

In this paper we made three structures to show effectiveness of proposed CGL of P3HT-PCBM. First structure is a simple OLED device, second structure is a Tandem OLED device made by using bulk hetrojunction CGL of P3HT-PCBM and the third structure is a Tandem OLED device made by using metal oxide CGL layer. The detail structure of these devices is given in Table 1. The detail in these structures: Top layer is ITO because the outcoupling of light is calculated through the ITO layer on the top of the stack. Here ITO is used as anode in the structure and the thickness of the ITO is optimized as 100 nm. Then HTL, emissive layer and ETL inserted in the structure. In this structure of OLED we take NPB as hole transport layer and a thickness of NPB is optimized as 30 nm, BAlq as emissive layer and the thickness of BAlq is optimized as 20 nm, and Alq_3 as electron transport layer and the thickness of Alq_3 is optimized as 30nm. Aluminum (Al) is used as cathode in the structure and the thickness of the Al is optimized as 100 nm. In the second structure of Tandem OLED two single units are connected through P3HTPCBM having 6 nm thickness. In the third structure of Tandem OLED two single units are connected through Zno/Wo3 having 6 nm thicknesses.

Table 1. Proposed layer structure

Device	Layers
Device A	ITO(100nm)/NPB(30nm)/BAlq(20nm)/Alq3(30nm)/Al (100nm)
Device B	ITO(100nm)/NPB(30nm)/BAlq(20nm)/Alq3(30nm)/ P3HTPCBM(6nm)/NPB(30nm)/BAlq(20nm)/Alq3 (30nm)/Al(100nm)
Device C	ITO(100nm)/NPB(30nm)/BAlq(20nm)/Alq3(30nm)/ Zno(3nm)/Wo3 (3nm)/NPB(30nm)/BAlq(20nm)/Alq3 (30nm)/Al(100nm)

Fig. 2(a) shows the schematic diagram of the simple OLED, Fig. 2(b) shows the schematic diagram of bulk hetrojunction Tandem OLED, Fig. 2(c) shows the chemical structure of PCBM, Fig. 2(d) shows the chemical structure of P3HT,
Fig. 2(e) shows the schematic diagram of metal oxide Tandem OLED

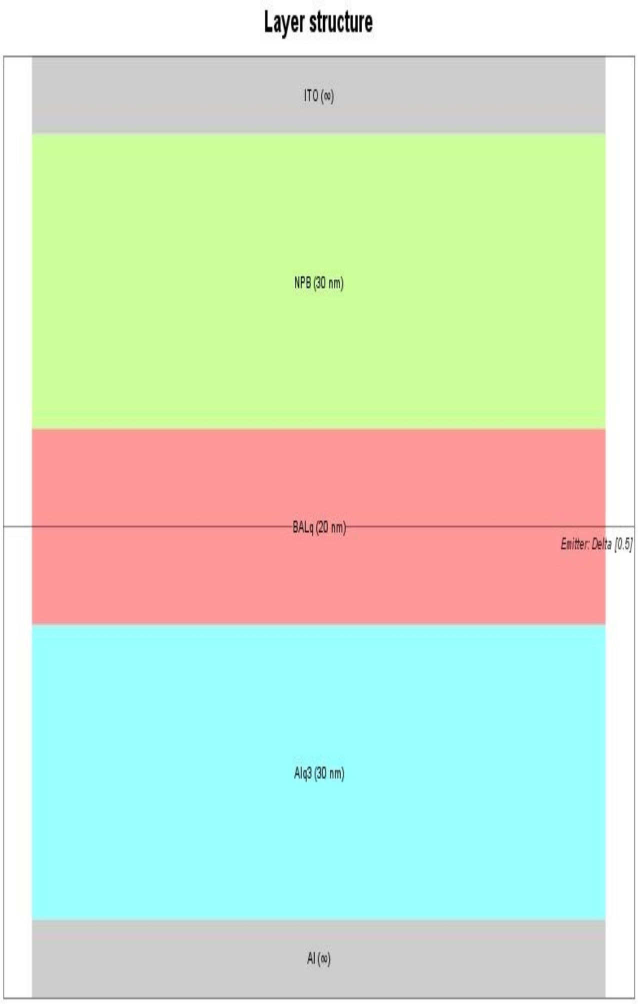

Fig. 2(a) Schematic diagram of Device A

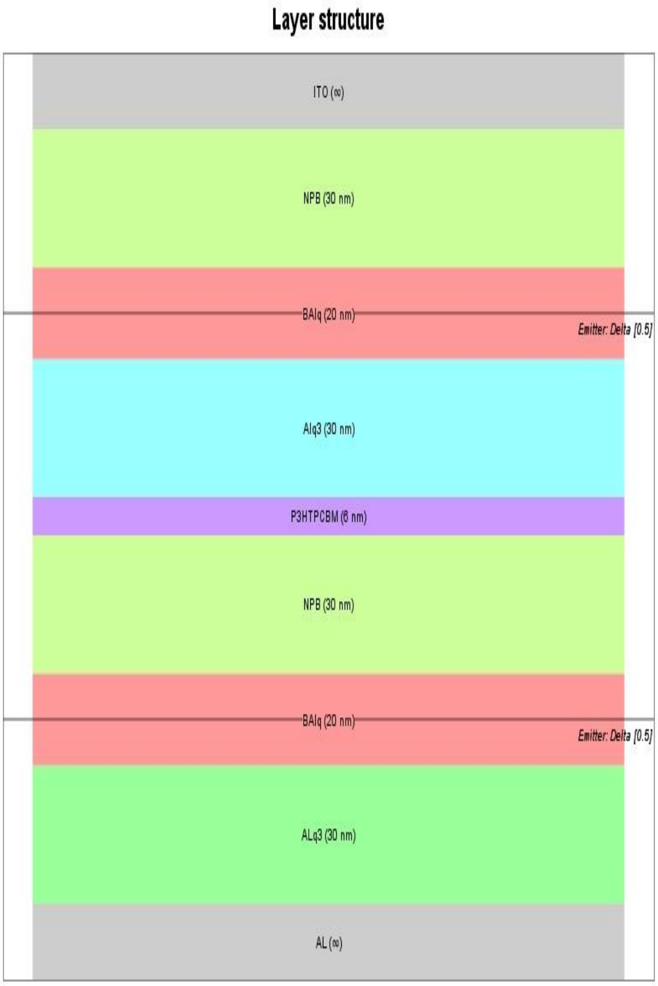

Fig. 2(b) Schematic diagram of Device B

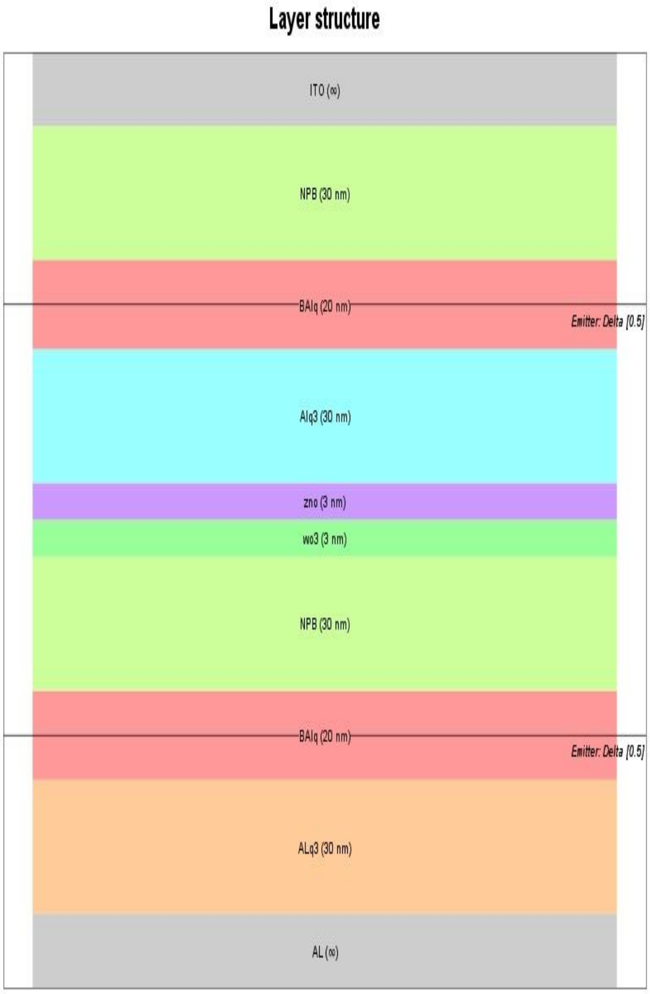

Fig. 2(e) Schematic diagram of Device C

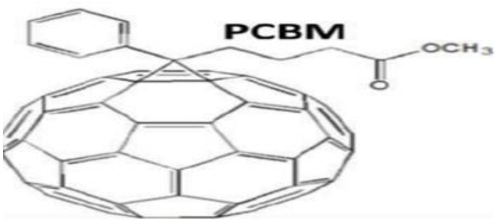

Fig. 2(c) Chemical structure of PCBM

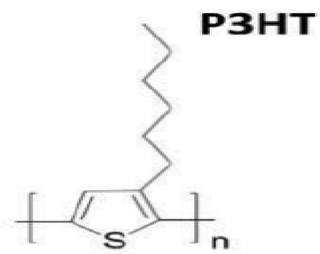

Fig. 2(d) Chemical structure of P3HT

IV. RESULT ANALYSIS

In this paper we used different materials to make three devices. In Device A we used ITO as an anode and the work function of an ITO layer is 4.8ev, NPB used as HTL and the HOMO and LUMO level of NPB is 5.5ev and 2.4ev, BAlq used as emissive layer and the HOMO and LUMO level of BAlq is 5.9ev and 2.9ev, Alq_3 used as ETL and the HOMO and LUMO level of Alq_3 is 5.7ev and 3.1ev and Al used as cathode and the work function of the cathode is 4.3ev. Homo level of NPB and BAlq is nearly same. The difference of homo levels between two NPB/BALq 0.2 eV so holes can easily transfer to the emissive layer, and LUMO level of ALq_3 and BALq is nearly same. The difference between homo levels of two ALq_3/BALq 0.2 eV so electrons can easily transfer through Alq_3 to emissive layer. When electrons and holes reaches at the emissive layer then the recombination of electrons and holes pairs take place and after recombination of electron hole pair exciton is generated hence light is generated as output. The maximum current efficiency through device A is 12.8154 cd/A , luminance is 1281.5364cd/m^2 and EQE Lambertian is 0.755. Fig. 3(a), Fig. 3(b) and Fig. 3(c) shows the current efficiency graph , luminance graph and EQE Lambertian graph of device A respectively.

Fig. 3(a) Device A current efficiency graph

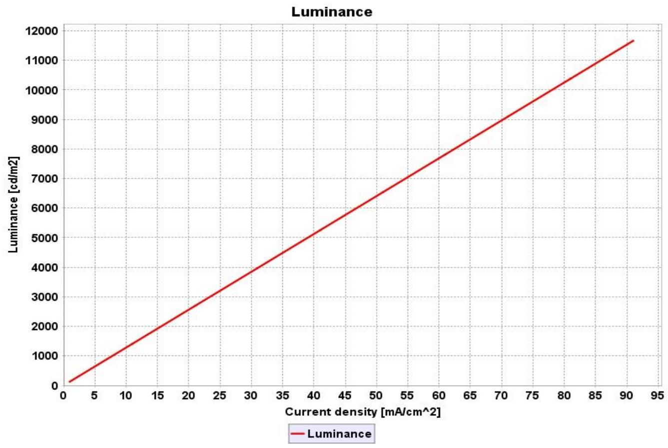

Fig. 3(b) Device A luminance graph

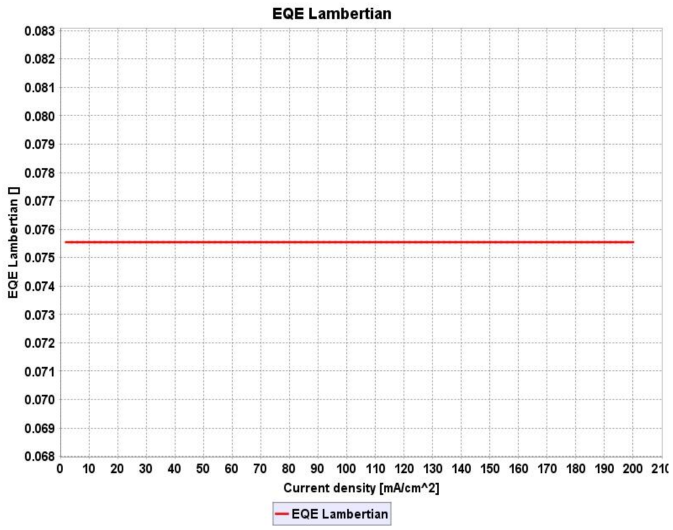

Fig. 3(c) Device A EQE Lambertian graph

Device B is a Tandem device as shown in Fig. 2(b). In this device P3HT PCBM is used as CGL. The maximum current efficiency through device B is 34.0336 cd/A, luminance is 3403.356 cd/m^2 and EQE Lambertian is 0.2466. Fig. 4(a), Fig. 4(b) and Fig. 4(c) shows the current efficiency graph, luminance graph and EQE Lambertian graph of device B respectively.

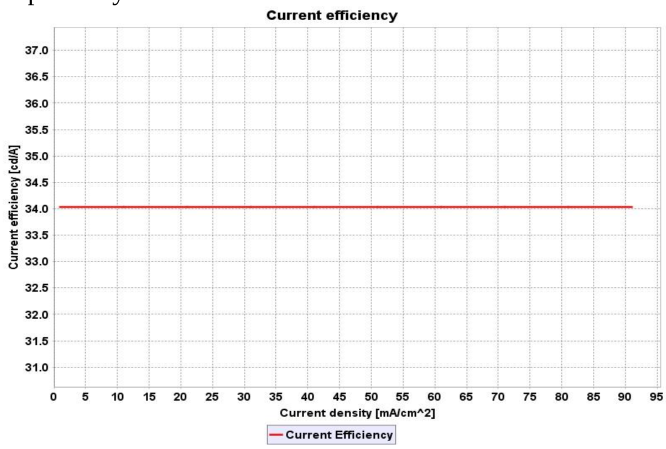

Fig. 4(a) Device B current efficiency graph

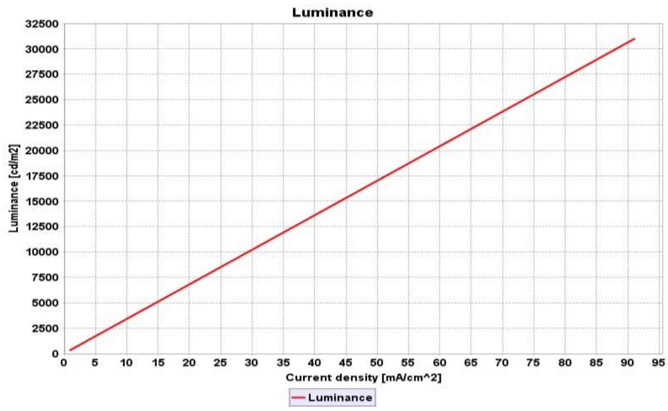

Fig. 4(b) Device B luminance graph

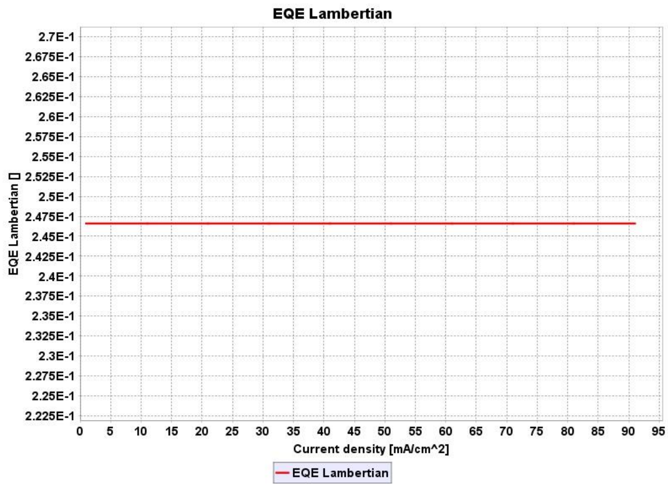

Fig. 4(c) Device B EQE Lambertian graph

Device C is a Tandem device as shown in Fig.2 (e). In this device Zno, $W0_3$ is used as CGL. The maximum current efficiency through device C is 31.9636 cd/A, luminance is 3196.3573 cd/m^2 and EQE Lambertian is 0.2315.

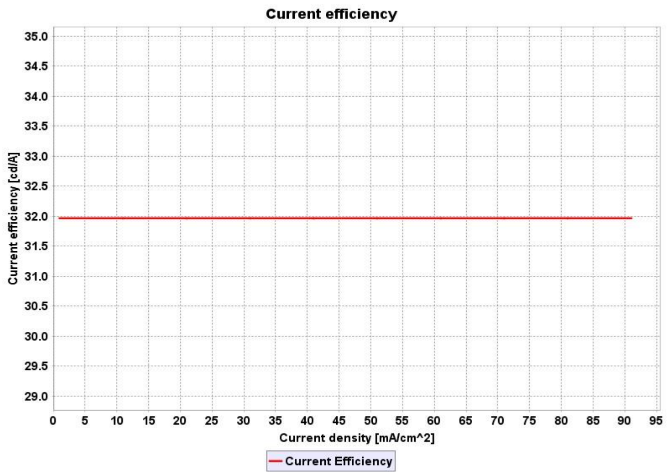

Fig. 5(a) Device C current efficiency graph

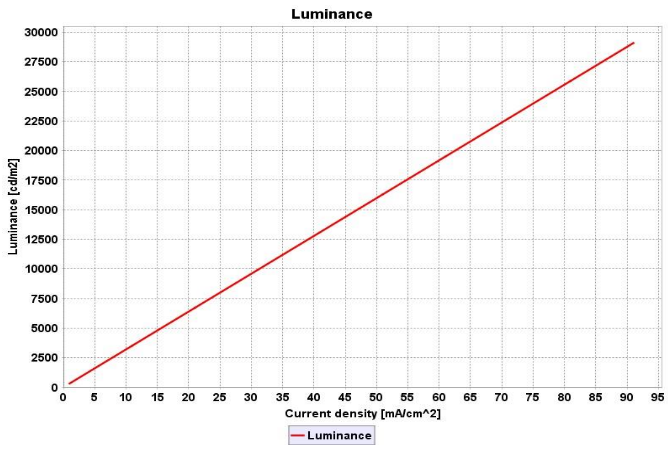

Fig. 5(b) Device C luminance graph

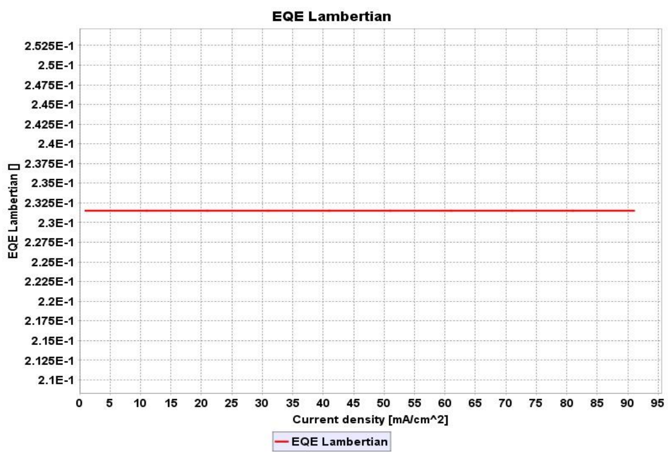

Fig. 5(c) Device C EQE Lambertian graph

Current efficiency of this structure is less as compared to device B because oxide layers reacts with the negative charges present in the ETL layer and make complexes hence the performance of the device is deteriorates. Fig. 5(a), Fig. 5(b) and Fig. 5(c) shows the current efficiency graph, luminance graph and EQE Lambertian graph of device C respectively.

V. RESULT COMPARISION

In this paper we have three devices. Table 2 shows the detailed results of all three devices and Fig. 6 shows the comparison of these three devices on the basis of devices current efficiency, luminance and EQE Lambertian. In all three devices when we used P3HT-PCBM as CGL layer then the current efficiency as well as luminance is found to be maximum. From the above results and discussion device B using P3HT-PCBM as CGL is found to be very efficient device.

Table 2: Detailed results

Device	Current efficiency (cd/A)	Luminance (cd/m^2)	EQE Lambertian
Device	12.8154	1281.5364	0.0755
Device	34.0336	3403.356	0.2466
Device	31.9636	3196.3573	0.2315

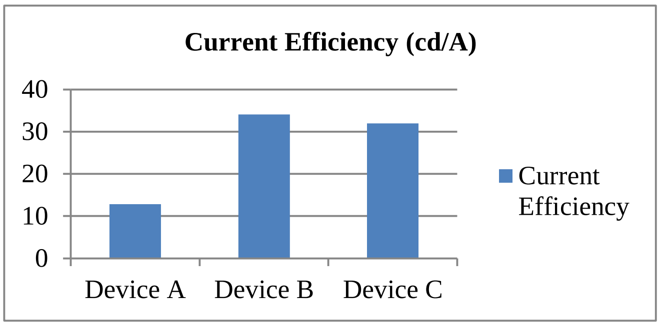

Fig. 6 (a) Current efficiency graph

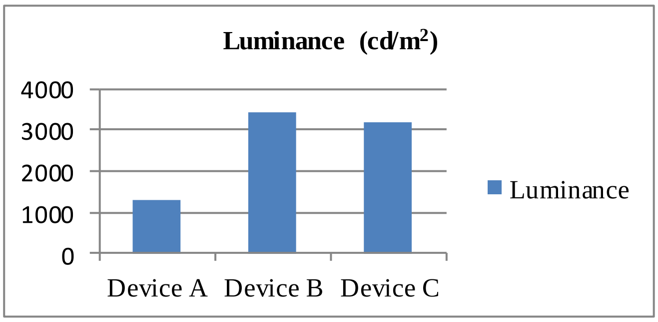

Fig. 6 (b) Luminance graph

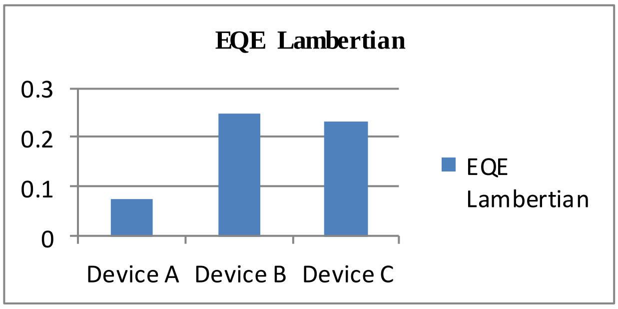

Fig. 6 (c) EQE Lambertian graph

As found from above, Device B with P3HT-PCBM as CGL shows maximum current efficiency and luminance as compared with Device A and Device C. We compare the efficiency, luminance and EQE Lambertian of different devices at 15mA/cm^2 current density. The current efficiency at 15mA/cm^2 current density of device A is 12.8154 cd/A, device B is 34.0336 cd/A and device C is 31.9636 cd/A. The luminance at 15mA/cm^2 current density of device A is 2000 Cd/m^2, device B is 5000cd/m^2 and device C is 5000cd/m^2. The EQE Lambertian at 15mA/cm^2 current density of device A is 0.0755, device B is 0.2466 and device C is 0.2315. By comparing both current efficiency and luminance we can say that device B is better in term of current efficiency and luminance in contrast to device A and device C because the drawback of device C used CGL with metal oxides can react with the negative charges present in the adjacent ETL and make complexes. Therefore CGLs with organic hetrojunctions are widely incorporated.

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VI. CONCLUSION

In this paper we have proposed tandem device using P3HT-PCBM as CGL. The maximum current efficiency and luminance of single emitting unit device A is found to be 12.8154 cd/A and 1281.5364 cd/m^2 at 10 mA/cm^2. The maximum current efficiency and luminance of proposed Tandem device B is found to be 34.0336 cd/A and 3403.356 Cd/m^2 at same current density. The current efficiency of device B is 62.34% increased as compared to device A. The luminance of device B is 62.34% increase as compare to device A whereas current efficiency and luminance of device C is found to be 31.9636 cd/A and 3196.3573 cd/m^2. The current efficiency of device C is 59.91 % increased as compared to device A. The luminance of device C is 59.90 % increased as compared to device A. Hence maximum current efficiency and luminance is obtained when P3HT-PCBM is used as CGL.

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