Tandem OLED Simulation Design using efficient charge generation layer

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***Abstract*—**this paper presents the design simulation of Tandem OLED for the enhanced efficiency. The performance of Tandem device is better than the single emissive unit as it is composed of two or more electroluminescent (EL) units that are separated by the Charge generation layer (CGL). In this paper, Efficient CGL of CSF2/C60/CuPc/PEDOT-PSS is proposed to enhance the performance of the Tandem OLED, which is the key component for charge generation and carrier injection into the adjacent emissive units. The main focus of this work is on the increased current efficiency and luminance of the device. To obtain the desired current efficiency the design is optimized at different levels. According to the results obtained after simulation the current efficiency (mA/cm^2) and luminance (mA/cm^2) is 24.6356 and 116.3251 respectively, which is approximately 49.49% and 68% higher than the current efficiency and luminance of single emissive unit OLED at the same current density. Tandem Oled provides greater advantages over the conventional OLED some of them are the longer lifetime of the device, higher performance and higher luminance at small current densities.

Keywords- *OLED; Charge Generation Layer; Charge transport; Efficiency improvement*

I. INTRODUCTION

Due to sources depletion caused by high consumption and usage.–The resources are vanishing from the earth and in future it is almost impossible for the habitat to survive in the absence of the resources. With the advancement in the modern world and population, the resources are depleted to a greater extent by us. Thus it is the major problem which is arising in the modern world. Many resources that have been depleted are non renewable resources, namely coal, wood, petrol, diesel, gas etc. Thus this problem has leaded the scientists to develop and utilize more and more of the renewable resources that can be used for great centuries and there would be no threat for the human existence without the resources. Renewable resources are the resources that can be reproduced or replenished by natural activities like biological reproduction or other processes that take place in the environment. Renewable resources are important aspect for the sustainability. These resources have gained an increased attention in the recent past years due to the rising cost and non availability of the non renewable resources. Many renewable resources that are used are water, geothermal, biomass, solar energy etc. As the name suggests Geo implies earth and warm means heat consequently geothermal vitality is a sustainable wellspring of vitality that gives warm from the earth. Biomass or biofuels are the sources of energy that provides energy from the living organisms. The main interest of the scientists is in the field of the organic solar cells and OLEDs. Both solar cells and oleds are the major advancement in the field of the renewable resource technologies. Awesome work is still done keeping in mind the end goal to make SOLAR CELLS and OLEDS more work proficient. Natural opto-electronic gadgets including natural resounding burrowing diodes, OLEDs, natural phototransistors, natural photovoltaic cells, and natural photograph finders have shaped an immense zone of research.

II. OLED

OLEDs were developed in 1987.OLEDs are the devices that generates light when external voltage is applied. Organic light emitting diodes comprises of the layers mainly- A substrate, an emissive layer where the light is generated after the recombination of electrons and holes, a cathode that is used to inject the electrons into the emissive layer, layers of organic material called as HTL and ETL,A transparent anode that injects the holes into emissive layer when exposed to the electric current. Additional layers can be used in order to further optimize the charge carriers or exitons generation in the emissive layer these layers are Hole injection layer (HIL), hole blocking layer (HBL), electron injection layer (EIL), electron blocking layer (EBL) An OLED is a solid state semiconductor gadget that comprises of a leading layer and an emissive layer, all together sandwiched between two electrodes and placed on a substrate. The thickness of OLED varies from 100 to 500nm [1]. The OLEDs were developed to compete with other light sources in the market since OLEDs provides greater efficiency but still the further research is carried out in order to increase the stability of the device and enhance its lifetime. The main focus in this field is to obtain higher electroluminescence or higher brightness even at lower current densities. To reduce the operational voltage of OLED a double layered structure with hole-transport and electron-transport material is used; to improve the OLED performance and the researches have been carried out to identify the distinct functionalities of the various materials [2]. OLEDs give high electroluminescence proficiency and it can be fabricated on different substrates, therefore it is generally utilized as a part of level board show and strong state lighting innovation [3]. In commercial OLEDs the anode used is basically the thin layer of tin-doped indium oxide (ITO), that is conductive, transparent and colorless, OLED provides various advantages like low cost, large scale fabrication, fast response etc. [4] . But due to the presence of the loss channels that are substrate mode, evanescent mode and waveguide mode only 20% of the generated radiation is out-coupled and rest of it is lost. Thus to design a highly efficient OLED multilayered structure is proposed which can be used to control the radiative recombination and hence exitons are confined to the emissive layer only [5]. Light emission in simple OLED can be explained as follows- Across the cathode and anode a potential difference i.e. voltage is applied to light up the OLED. The cathode gets the electrons from control source and anode loses them or gets openings when the power begins to flow. The emissive layer becomes negatively charged since electrons are added by power source, and the conducting layer becomes positively charged since holes are added, the holes being more mobile than the electrons, thus they jump across the boundary. That is moves from conductive layer to the emissive layer. The electron and holes recombine with each other and release energy in the form of the light called as the photon. This process happens multiple times in OLED thus producing continuous light for as long as the current keeps flowing. Fig.1 show the structure of the conventional OLED which contains cathode, emissive layer conductive layer, anode and substrate.

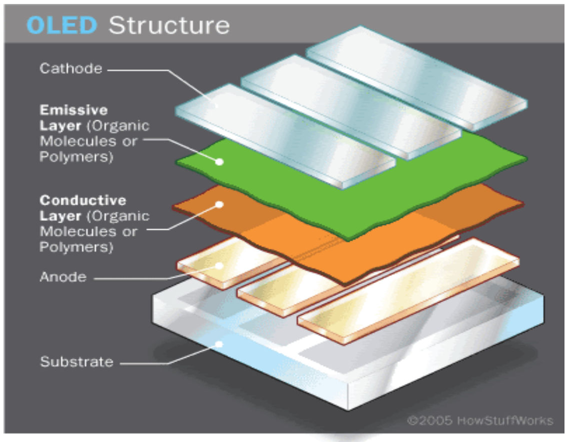

Fig.1: Conventional OLED structure[1]

A more advanced structure called Tandem OLED are widely used nowadays for the enhanced performance.

III. TANDEM OLED

As compared to the conventional OLED's the tandem OLED have gathered a great attentions due to their superior current efficiency, operational lifetime and luminance. Multiple electroluminescent units (EL) are present in tandem oled which are electrically connected in series and are connected via intermediate connecting layers. With the number of stacked EL units the intensity of EL increases linearly. Thus by using the tandem oled structure high efficiency, and longer operational lifetime can be achieved at reduced the current density as compared to the simple OLED. For tandem oled to work efficiently the intermediate connectors used to connect two adjacent EL units are the key factors. The intermediate connecting layers that are used must facilitate effective electron injection and Hole blocking into the adjoining ETL of one connected EL unit, and holes injection and electron blocking into the HTL of other adjacent EL unit. Thus the greater efficiency can be obtained. For the higher performance of the tandem OLED, it is required to understand the properties of intermediate connectors. They should have high electrical conductivity for minimum electrical loss and must possess operational stability [6].The intermediate connectors usually are the bilayers of organic-metal oxide, metal-metal oxide or organic-organic heterojunction. Mainly charge generation units are employed for connecting two EL units. The operational voltage of the tandem oled is nearly twice as compared to the simple oled having single EL unit. A Tandem OLED normally consists of two electrodes namely cathode and anode, double or triple EL units, and intermediate connectors namely CGL that connects various EL units together. Different types of intermediate connectors works according to the device structure. Due to the "multi photon emission" effect the tandems OLEDs have the potential to achieve over 100% internal quantum efficiency (IQE).

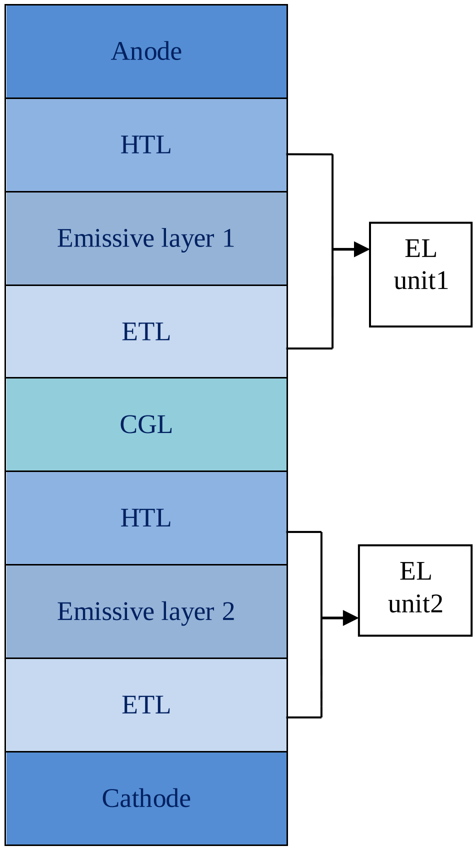

Fig.2: Basic structure of Tandem OLED

In this proposed work the Combination of CuPc (Copper phthalocyanine) and C60 (Buckminsterfullerene) is used as p-type and n-type layer of Charge generation layer which will support the movement of the charge carriers from CGL to the neighboring emissive layers.

IV. EXPERIMENTAL DESIGN

Three design structures of the OLED have been proposed in this paper. In these structures, ITO (Indium Tin Oxide) is used as anode, Al as cathode, spiroTad (2,2',7,7'-Tetrakis (diphenylamine)-9,9') is used as HTL, and BCP (1,3-Benzodioxol-5-yl(piperidin-1-yl)methanone) is used as ETL, MoO3 (Molybdenum Trioxide) and LiF (Lithium fluoride) are used as HIL and EIL, further to facilitate the injection of electrons and holes into the adjacent emissive units of the device, C60 (Buckminsterfullerene) and CuPc (Copper phthalocyanine) are used as p-type and n-type layers of the charge generation layers, PEDOT-PSS (Poly(3,4-ethylenedioxythiophene)) and CF2 (Difluoromethanethione) are interface layers or modification layers alongside CGL so as to improve the carriers injection and transport from CGL to the emissive units. The detailed design structure of the three devices is given in Table1.

Table1: Proposed layer structures of the devices

Proposed Layer Structures	
Device A	Conventional OLED ITO/MoO3/Spirotad/TCTA/BCP/LiF/Al
Device B	Tandem OLED without interface layers ITO/MoO3/Spirotad/TCTA/BCP/C60/CUPC/MoO3/ SpiroTad/ TCTA/BCP/LiF/Al
Device C	Tandem OLED with interface layers ITO/MoO3/Spirotad/TCTA/BCP/CSF2/C60/ CUPC/ PEDOT-PSS/ MoO3 /Spirotad/ TCTA/BCP/LiF/Al

V. EXPERIMENTAL RESULTS AND DISCUSSION

Simulation of the proposed structures of the OLED's has been carried out using the FLUXIM SETFOS version 4.6 software. The various results that are obtained from the simulation of different OLED structures are given in Table2.

Table2: Obtained Results

Device	Current efficiency(cd/A)	Luminance (lm/W)	EQE (%)
Device A	12.4422	37.2058	36%
Device B	19.1536	62.1511	34%
Device C	24.6356	116.3251	24%

As it is clear from the Table2, that lowest current efficiency is obtained from the simple OLED proposed structure that is 12.4422. Fig.3 shows the simple OLED structure.

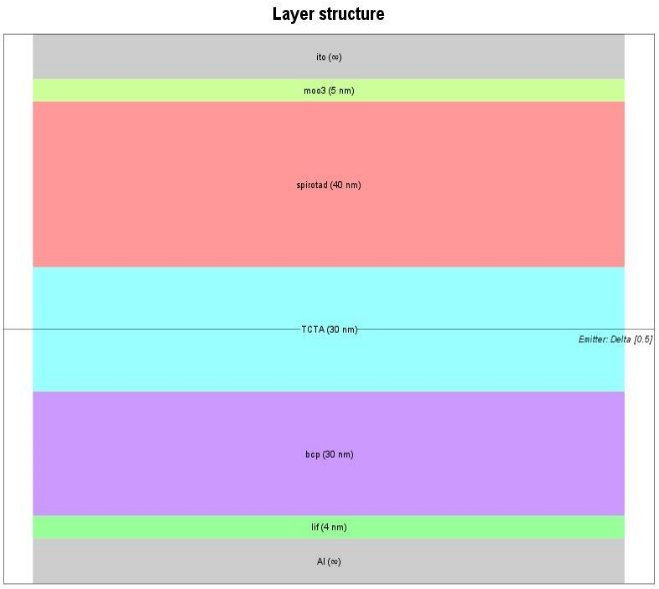

Fig.3: Simple OLED structure

In the Fig. 3 MoO3 and LiF is used as HIL and EIL. The EIL and HIL layers are usually called as the buffer layers, these layers are usually proposed in the OLED structure to enhance the performance of the device and increase the current efficiency of the device. The HIL allows the efficient injection and transport of the holes from anode to the emissive layer through HTL, by lowering the energy gap between the two layers, it helps the carriers to be more concentrated in the emissive layer, which adds up to the higher carrier recombination at low power input. It is generally used for increasing the stability and efficiency of the OLED. Fig.4 and Fig.5 shows the graphical results of the current efficiency and luminance of the simple OLED.

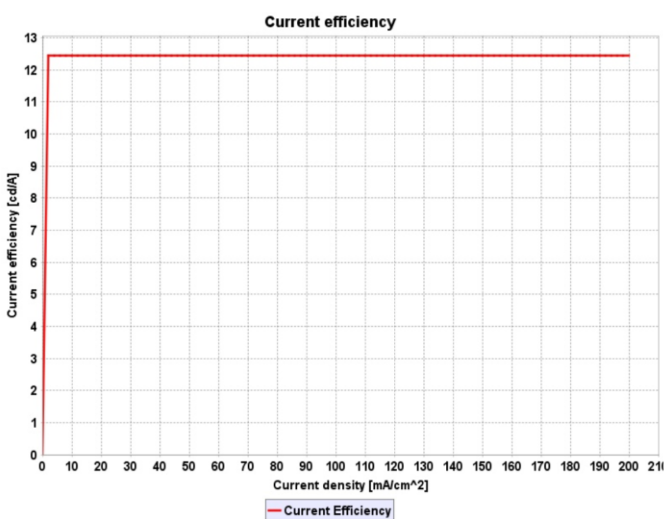

Fig.4: Current efficiency of Device A

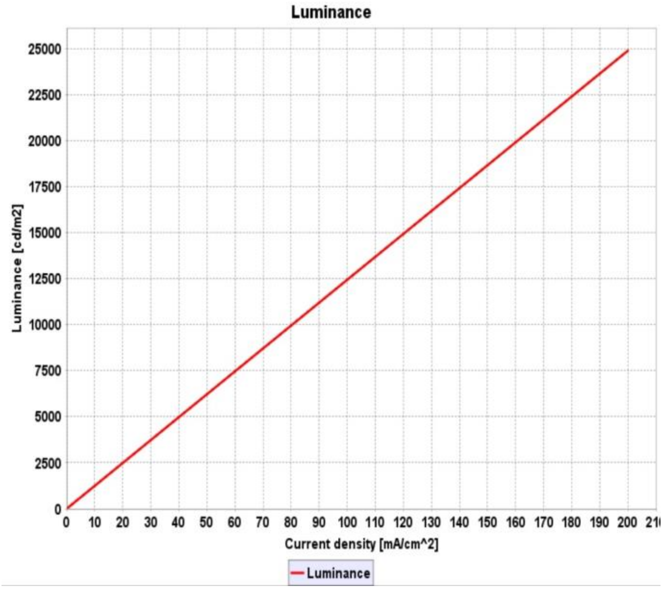

Fig.5: Luminance efficiency of Device A

For further increasing the current efficiency of the device A, a few of the changes are made. A charge generation unit is added in between the same simple structures, thus the tandem device is proposed with the same layers as used in the simple OLED structure. Thus the Device B proposed is basically a tandem OLED having two emissive units separated by CGL layer. Fig.6 shows the proposed design of the tandem OLED

Fig.6: Layered structure of the tandem OLED

The CGL layer used in the proposed design is a combination of C60 and CUPC. Charge generation layer plays an important role in the enhancement of the current efficiency in the tandem OLED and is basically composed of p-doped layer and n-doped layer for the injection of the electron and holes. For the different EL units or emissive units in the tandem OLED to start the electroluminescence, at initial stage the CGL supplies the electron and holes to the adjacent emissive units. Then these electrons and holes recombine with the charges supplied by electrodes to form photons. It is also clear from the Table1 that the current efficiency and luminance efficiency of the tandem OLED has increased as compared to the basic OLED design, the graphical results of current efficiency and luminance efficiency obtained is shown in Fig.7 and Fig.8.

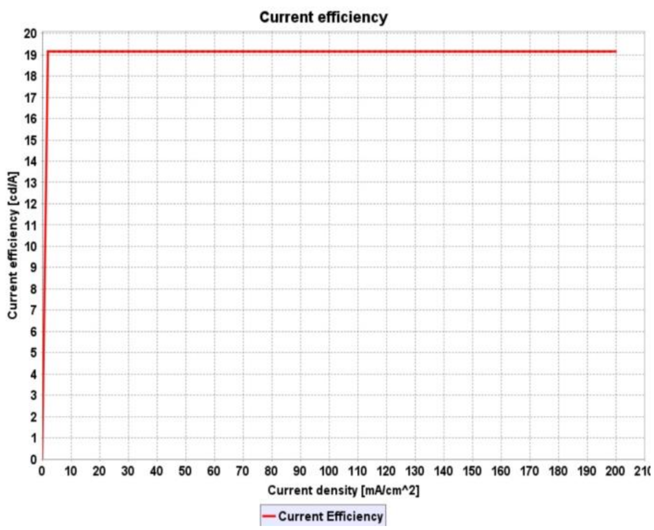

Fig.7: Current Efficiency of Device B

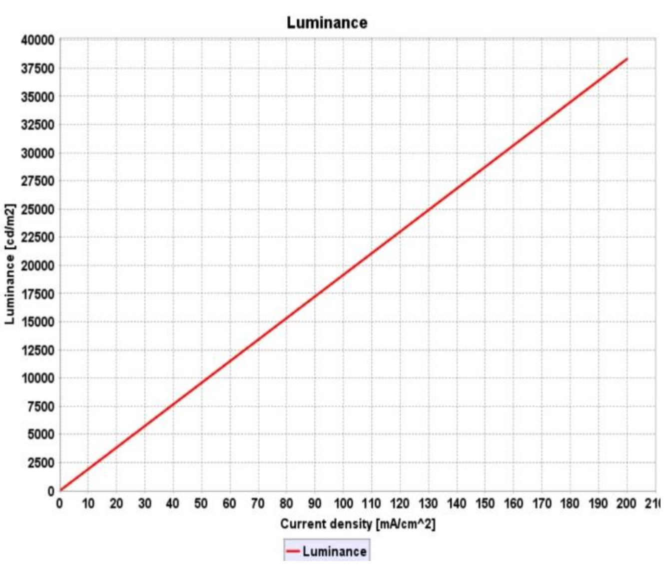

Fig.8: Luminance Efficiency of Device B

To further enhance the current efficiency of the device the Device B is further optimized with the addition of the supporting layer with the CGL, these layers are called as the modification layers or the interfacing layers. The interfacing layer to be used with the CGL must be of the compatible material i.e. should have matched HOMO (highest occupied molecular orbit) and LUMO (lowest unoccupied molecular orbit) levels with the CGL that would add up to the enhancement of the current efficiency of the tandem OLED further more. The interfacing layers that are used are CSF2 (Difluoromethanethione) and PEDOT-PSS (Poly (3, 4-ethylenedioxythiophene)). The HOMO level of the PEDOT-PSS is 5.1eV and that of CuPc is 5.2eV the difference between the homo levels of the two is very small 0.1eV. Fig.9 shows the structure of the tandem OLED with modification layers.

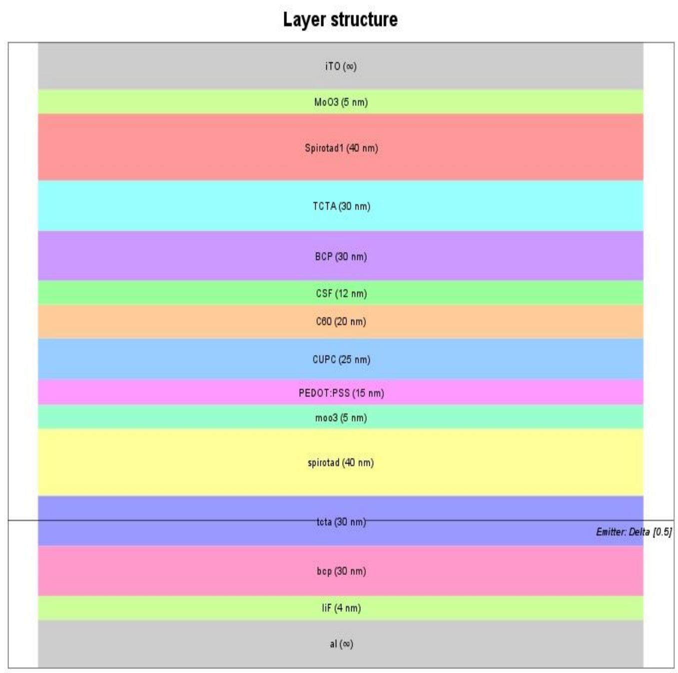

Fig.9: Layered Structure of Device C

When modification layers are used along with the CGL in the tandem OLED structure, then the highest current and luminance efficiency is obtained after simulations, as depicted in Table1. The increment in current efficiency shows that the materials selected for the modification layers are compatible with the proposed CGL. This is due to the fact that the HOMO-LUMO levels of the two materials chosen are aligned slightly to the HOMO-LUMO levels of the CGL and the emissive units (EL), this increases the carrier recombination and hence there is an increment in the current efficiency of the device. Fig.10 and Fig.11 shows the results of the current efficiency and the luminance efficiency of the device C.

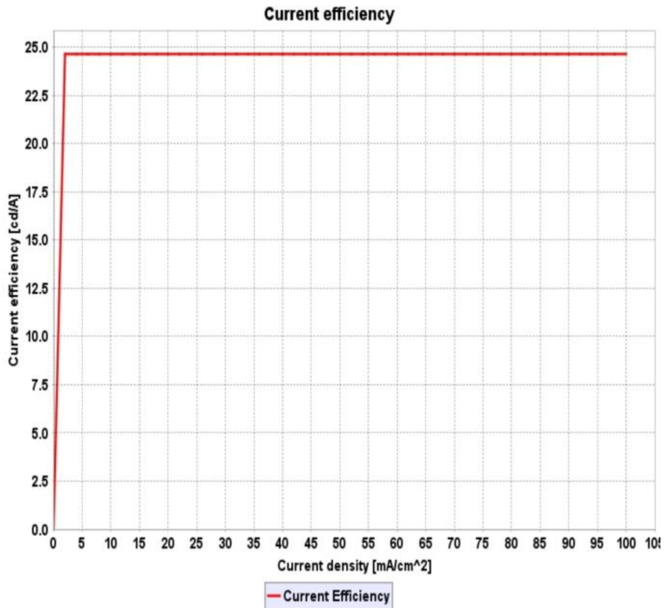

Fig.10: Current Efficiency of Device C

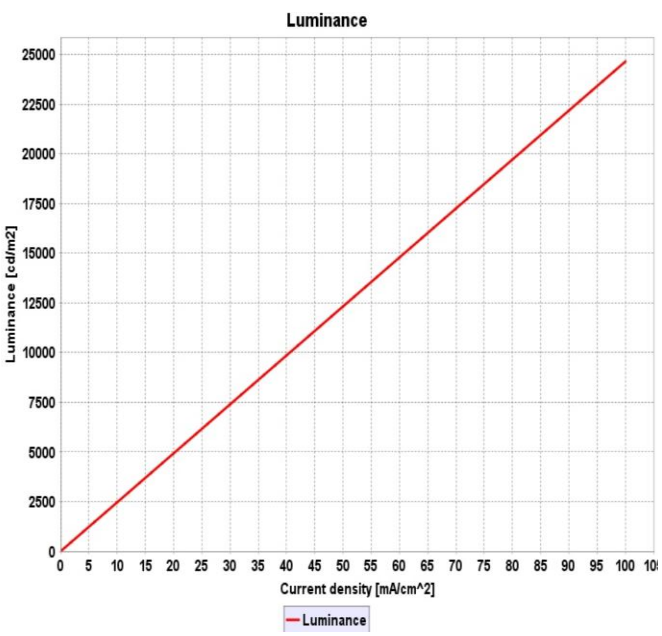

Fig.11: Luminance Efficiency of Device C

Fig.12 shows the comparison of current efficiency and luminance of the three proposed device structures in the form of the bar graph. It can be seen in the graph that the maximum current efficiency and luminance is obtained by the Device C, than for Device B and the minimum current and luminance efficiency is obtained by the Device A.

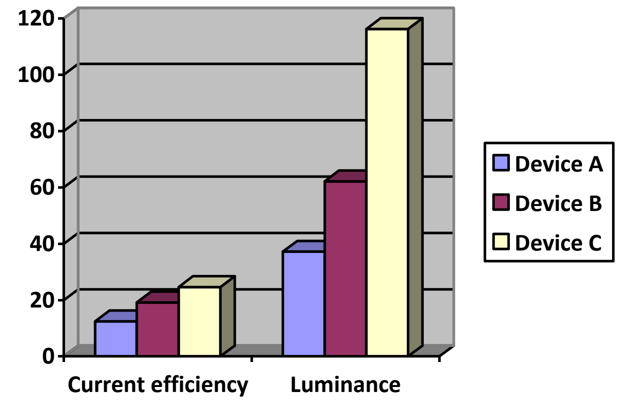

Fig.12: Comparison graph between the three device structures

VI. CONCLUSION

In this paper we have proposed a Tandem OLED with CsF2/C60/CuPc/PEDOT-PSS as the charge generation layer in which C60 and CuPc combination behaves as PN junction and CSF2 and PEDOT-PSS as the interface layers of CGL that favors the injection of the carriers and their recombination (as their HOMO and LUMO levels matches with that of CGL) from CGL to the adjacent emissive unit there is an enhancement in the overall performance of the Tandem Device as compared to the conventional device. The current efficiency is increased to 24.6356 from 12.4422 which is approximately twice the current efficiency obtained from the simple OLED structure at 10 mA/cm^2. Moreover the luminance efficiency is increased to 116.3251 from 37.2058 when compared with simple OLED which is enhanced by approximately thrice the luminance as compared to the single emissive unit device at 100 mA/cm^2. Thus with the proposed CGL there is a remarkable enhancement in the overall performance of the device. Thus we have proposed Tandem OLED with efficient charge generation layer.

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