Journal of Graphic Era University
Vol. 4, Issue 1, 32-40, 2016
ISSN: 0975-1416 (Print)

Performance Comparison of Bilayer and Multilayer OLED

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Abstract
Active Matrix organic light emitting displays are emerging as the display of the future due to their active contribution towards the flat panel display technology. Organic light emitting displays have all the features due to which it dominates the flat panel display technology. The AMOLED displays have various features like low cost, low power consumption, high brightness, wide view angle, good color contrast and its ability to be fabricated on a flexible substrate. The display is basically an array of independently controllable pixels. Therefore, the number of pixel depends on the dimension as well as on the resolution for the required application. This paper defines the types of OLED on the basis of its mode of operation (Active matrix and Passive matrix). Different characteristics and parameters of individual OLED structure are extracted and compared to show their structure dependent behavior. Undoubtedly a higher performance is achieved for multilayer OLED structure with respect to the bilayer due to a significant increase in the carrier recombination rate.

Keywords- Active Matrix Light Emitting Display (AMOLED), Organic Light Emitting Diode (OLED), Hole Transport Layer (HTL), Electron Transport Layer (ETL), Emissive Layer (EML).

1. Introduction

Over the past few years organic light emitting diodes (OLEDs) have emerged as an important area of research due to their increased use in flat panel display and lighting devices (Pope, 1963). Flat panel displays are preferred over conventional cathode ray tubes (CRTs) because of their smaller size, lighter weight and lower power consumption. OLED based display technology has various advantages like flexibility, fast response time, high efficiency and wide viewing angle (Lin, 2008). OLEDs are electroluminescence devices that consist of one or more organic semiconductor layers sandwitched in between anode and cathode. First OLED exhibiting electroluminiscence in green spectral region was demonstrated by Tang *et al.* in 1987 (Park, 2010; Lin, 2010; Cho, 2010; Lee, 2011; Chiu, 2013). Organic electronics has proved to be the most interesting field for academics as well as industries over the past two decades. Commercial electronic devices with organic materials are entering into the market. With the improvement in the electrical properties and stability of organic semiconductors a broad area for organic electronics has opened. Among these upcoming areas one such field is Organic Light Emitting Diodes (OLEDs). The OLED is the advantage for the large area, low cost display technology due to which it is also called the screen of the future. It was first developed in 1950s in France (Pope, 1963). The OLED devices are made up of organic materials which emit light with the application of external bias. In OLED, an

Journal of Graphic Era University
Vol. 4, Issue 1, 32-40, 2016
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organic semiconductor layer is sandwiched between the two conductors which form a junction where light is emitted (ATLAS User's Manual Device Simulation Software, 2014). OLED has good color contrast because it only expresses pure colors when an electric current stimulates the relevant pixels.

2. Simulation Setup

For in-depth understanding of the simulation of the semiconductor devices we need numerical simulation. Since, it is highly expensive and time consuming to fabricate a device, so, we go for the simulation first to test whether the device meet our requirements or not and then for the fabrication. The tool used for the simulation is Atlas Silvaco, which helps us to understand the internal physics of the device properly. One of the best qualities of this software is, it can support 2-D as well as 3-D structures. We can also define user-defined material through this tool. The flow chart of the function of ATLAS-Silvaco is shown in Figure 1 (ATLAS User's Manual Device Simulation Software, 2014).

3. Bilayer OLED

The first device simulated is a bilayer OLED device. The structure of the device is shown below in Figure 2. This structure has four layers, the bottom most layer is of ITO (Indium Tin Oxide), acting as anode from where the light emits, the most important reason of taking this layer is its transparency. Further, the second layer is of NPB (N, N'-Di(1-napthyl)- N,N'-diphenyl-(1-1'-biphenyl)-4,4'-diamine), acting as the hole transport layer. The third layer is of the Alq_3 (tris(8- Hydroxyquinolinate) aluminium) acting as electron transport layer.

The topmost layer is made up of the Aluminium which is acting as the cathode. The dimensions taken for the simulation of the device are shown in Table 1. The OLED structures are simulated using industrial numerical 2-D simulator ATLAS by Silvaco. To investigate the impact of the introduction of different layers in OLED structure they are analyzed using the benchmarked industry standard organic module of the Silvaco Atlas 2-D numerical device simulator. This simulator helps in accepting the Device physics in a well explained way. In this simulator user defined materials can also be used.

The principle of Bilayer OLED is similar to that of an inorganic LED. Electrons and holes are injected from the electrodes cathode and anode respectively (Park, 2010; Klauk, 2007). Thereafter, they move towards each other and recombine to form exciton, it on decaying releases energy in the form of light. The simulated structure of the bilayer OLED and The Langevine recombination is shown in Figure 3. Conventional OLEDs used to have a basic structure in which the electrons and holes are correspondingly injected from the cathode and anode and then these charge carriers recombine to produce electroluminescence, the recombination occurs at the organic layer placed between the electrodes.

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ISSN: 0975-1416 (Print)

For proper transportation of the charge carriers we need to have layers which will facilitate the migration of the charge carriers from their respective electrodes. The results obtained after simulation of the bilayer OLED are shown below in Figures 4 and 5 in terms of the Anode current and Luminescent power respectively. The hole transport layer (HTL) and the electron transport layer (ETL) provides ease in the movement of the carriers from their respective electrodes to the recombination region.

The results extracted after the simulation of the Bilayer OLED are shown above in the Table 2. the Turn-ON voltage achieved for the Bilayer OLED is 9.5 V, the anode current and luminescent power achieved for the OLED are 3.92 μA and 2.05×10^{-8} W/μm, respectively. The above results are showing that the recombination will start at 9.5 V.

4. Multilayer OLED

To enhance the performance of the conventional OLED we have introduced additional layers to our conventional structure. The structure consists of ten layers. Besides this, the results in terms of the anode current, luminescent power and turn-ON voltage are compared in order to show how the introduction of the specific layer can improve the performance of the OLED. Further, we have simulated multilayer OLED and its performance is compared with the Bilayer OLED.

The structure of the multilayer device is shown above in Figure 6. This structure has ten layers and the bottom most layer is of ITO (Indium Tin Oxide), acting as anode from where the light emits, the most important reason of taking this layer is its transparency. The Anode is at the bottom hence, the Device is a bottom emitting OLED. The second layer is of NPB, acting as the whole transport layer. The third layer is of the MEH-PPV acting as the emissive layer. The third layer is of Alq_3 acting as electron transport layer. Finally, the topmost layer is of Aluminium, which is acting as the cathode.

The dimensions taken for the simulation of the multilayer OLED are shown in Table 3 shown below. The multilayer OLED simulated is a bottom emitting OLED. In this the bottom most layer is of anode of the thickness 150 nm, thereafter the hole transport layer is taken of 10 nm, after that come the EML of 10 nm, further layers are the repetition of the HTL and EML, thereby, again we have HTL of 6nm, again we have EML of 10 nm. Furthermore, we have HTL of 10 nm and EML of 50 nm, thereafter, comes the HBL of 20 nm. Whereas, the thickness if the electron transport layer of 30 nm. Finally, the topmost cathode layer is of 150 nm. The principle of multilayer OLED is similar to that of conventional OLED. Electrons and holes are injected from the electrodes cathode and anode, respectively. Thereafter, they move towards each other and recombine to form exciton, it on decaying releases energy in the form of light. The multilayer structure consists of various layers stacked one above the other. First of all comes the HTL, The purpose of this layer is to transport holes from the emissive layer to the anode which, it must be a p-type semiconductor whereas, the ETL is attached to the

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metal cathode and is responsible for transporting electrons from the cathode to the emissive layer (Kumar, 2014).

The third layer used is an EML (emissive layer), in this layer the electron-hole pair recombines to produce photons. By using better material for the emissive layer the band gap energy requirement can be reduced and the rate of recombination can increase (Mittal, 2016). In organic materials the mobility of the injected holes is more than the mobility of the injected electrons. Hence, for proper recombination an additional Hole Blocking Layer (HBL) is introduced. It improves the performance of OLED by providing proper injection and transportation of the charge carriers. The HBL lies after the EML layer closer to the cathode.

The results obtained after simulation of the multilayer OLED are shown below in Figures 8 and 9 in terms of the anode current and luminescent power, respectively. Figure 8 is showing the variation in the anode current with the change in anode voltage and Figure 9 is showing the variation in the luminescent power with the change in anode voltage. The results extracted after the simulation of the multilayer OLED are better than the results extracted in case of the bilayer OLED. The results extracted are shown below in the Table 4. The results extracted after the simulation multilayer have shown enhancement of the performance in terms of the anode current and luminescent power of **9 times** and **10 times** with respect to the bilayer OLED.

The multilayer structure is a very efficient structure in terms of power consumption and in terms of luminance generation (Klauk, 2007). The anode current and luminescent power achieved at the same voltage of 10 V is 560 µA and 2.85 W/µm. In comparison to the bilayer OLED the performance of the multilayer OLED has been improved by 9 and 10 times in terms of the anode current and luminescent power, respectively.

In the Multilayer OLED the current is either trap charge limited or space charge limited. The recombination in organic materials is based on the diffusive motion of the electrons and holes. Thereby, it is described by the Langevine theory. Furthermore, this theory exhibits the relation between the current and voltage and also with the thickness of OSC. Further, it shows that thinner devices always have better output.

In Multilayer OLED we have various layers to improve its performance, the ETL is attached to the metal cathode and is responsible for transporting electrons from the cathode to the emissive layer. Whereas, the purpose of HTL is to transport holes from the emissive layer to the anode. This must be a P-type semiconductor. Thereafter, comes the EML, it lies in the middle of the OLED. In this layer the electron and hole pairs recombine to produce photons. This is the layer where the dye molecules can be introduced. Besides this, through

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Vol. 4, Issue 1, 32-40, 2016
ISSN: 0975-1416 (Print)

introduction of various florescent and phosphorescent small molecules, the band gap energy between the HOMO and LUMO levels can be controlled.

5. Conclusion

In this paper, focus has been laid in understanding the working of OLEDs by taking into account different OLEDs. The OLEDs have different organic semiconductor layers. Besides various merits, OLED has the problem of improper recombination thereby leading to a low anode current for use in advance electronic devices. Hence, in this paper, analysis of different OLED structures has been done to enhance its performance in terms of anode current and luminescent power. The performance of multilayer OLED has been improved by 9 and 10 times in terms of the anode current and luminescent power, respectively than that of bilayer OLED.

S. No.	Material	Usage	Thickness (nm)
1.	Indium Tin Oxide (ITO)	Anode	150
2.	N, N’-Di(1-napthyl)- N,N’-diphenyl-(1-1’-biphenyl)-4,4’-diamine (NPB)	Hole Transport Layer	200
3.	tris(8- Hydroxyquinolinate) aluminum (Alq3)	Electron Transport Layer	100
4.	Aluminum	Cathode	100

Table 1. Materials and dimensions used for the simulation of bilayer OLED [Uttwani, P. K., 2009]

Device	Turn-On Voltage (V)	Luminescent Power (W/μm)	Anode Current (μA)
Bilayer OLED	9.5	2.05×10^{-8}	3.92

Table 2. Extracted performance parameters for the bilayer OLED

S. No.	Material	Usage	Thickness (nm)
1.	Indium Tin Oxide (ITO)	Anode	150
2.	NPB	Hole Transport Layer	10
3.	MEH-PPV (Poly [2-methoxy-5-(2-ethylhexyloxy)-1,4-phenylenevinylene])	Emissive Layer	10
4.	NPB	Hole Transport Layer	6
5.	MEH-PPV (Poly [2-methoxy-5-(2-ethylhexyloxy)-1,4-phenylenevinylene])	Emissive Layer	10
6.	NPB	Hole Transport Layer	10
7.	MEH-PPV (Poly [2-methoxy-5-(2-ethylhexyloxy)-1,4-phenylenevinylene])	Emissive Layer	50
8.	Alq3	Electron Transport Layer	20
9.	Alq3	Electron Transport Layer	30
10.	Aluminum	Cathode	150

Table 3. Materials and dimensions used for the simulation of multilayer OLED

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Name of the Device	Turn-on Voltage (V)	Luminescent Power (W/µm)	Anode Current (µA)
Multilayer OLED	2.1	2.85	560

Table 4. Extracted performance parameters for multilayer OLED

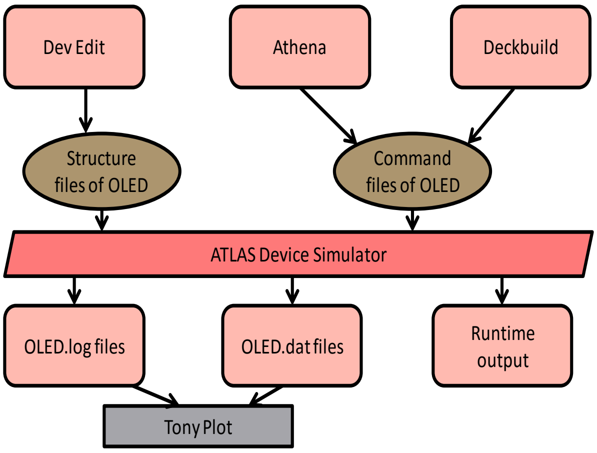


Figure 1. Flowchart of ATLAS Silvaco

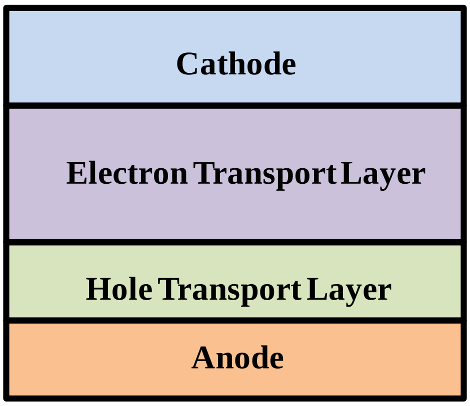
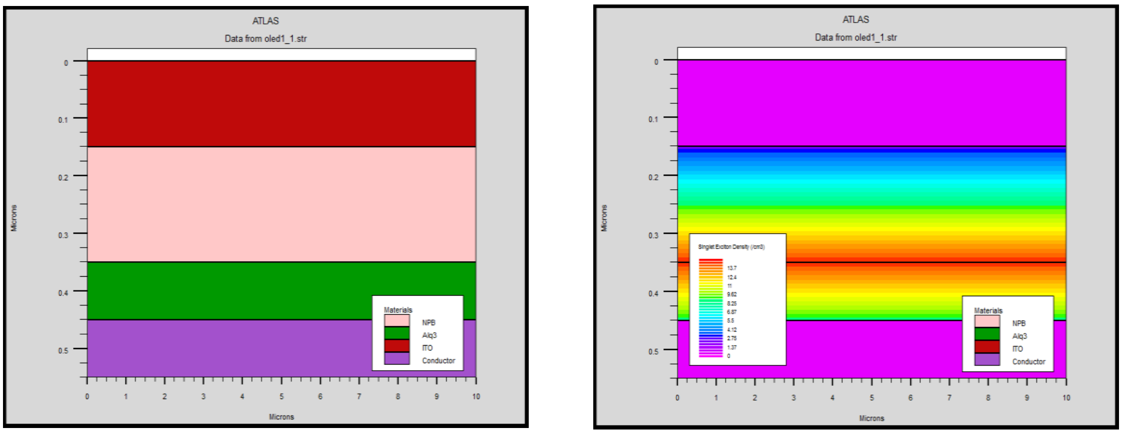


Figure 2. Structure of bilayer OLED



(a) **(b)**

Figure 3. Bilayer OLED (a) Simulated structure and (b) Langvine recombination

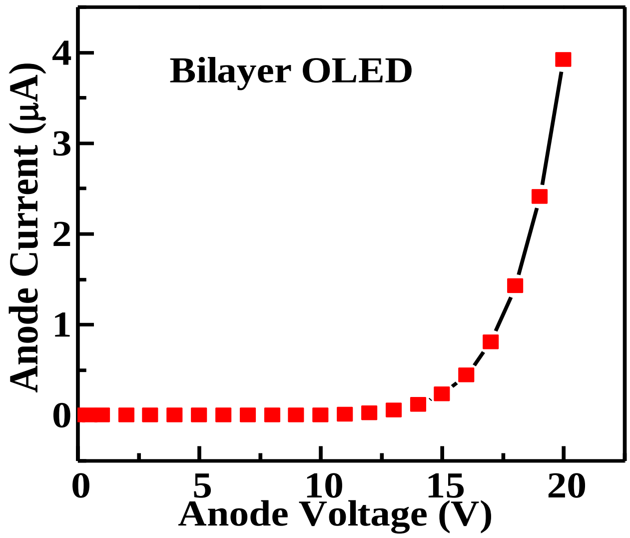


Figure 4. Anode voltage vs. anode current of the bilayer OLED

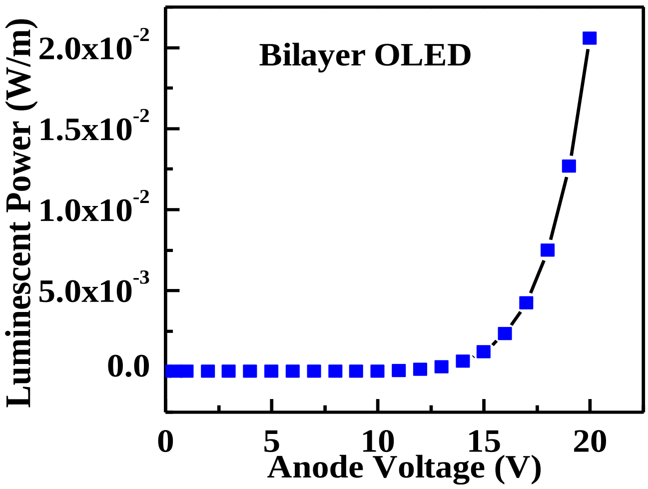


Figure 5. Anode voltage vs. luminescent power of bilayer OLED

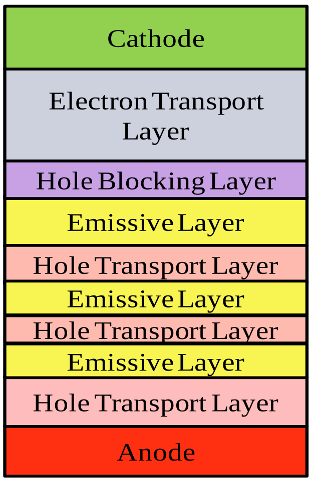


Figure 6. Structure of multilayer OLED

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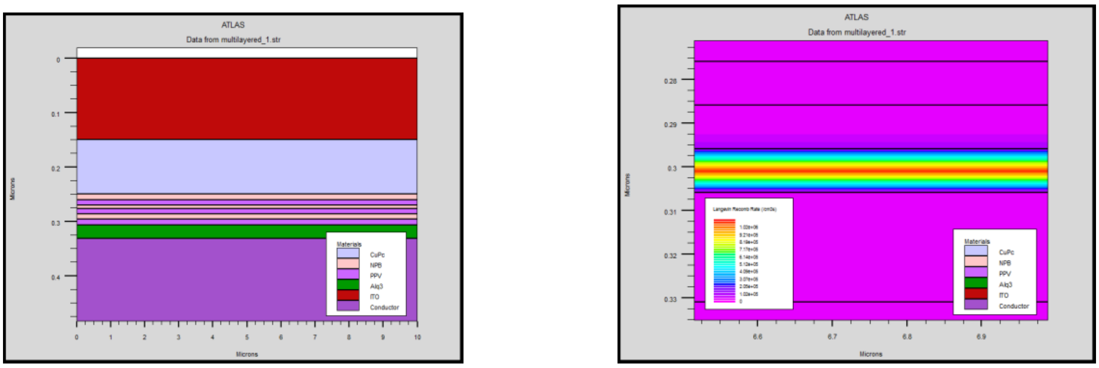

(a) (b)

Figure 7. Multilayer OLED (a) Simulated structure and (b) Langevine recombination

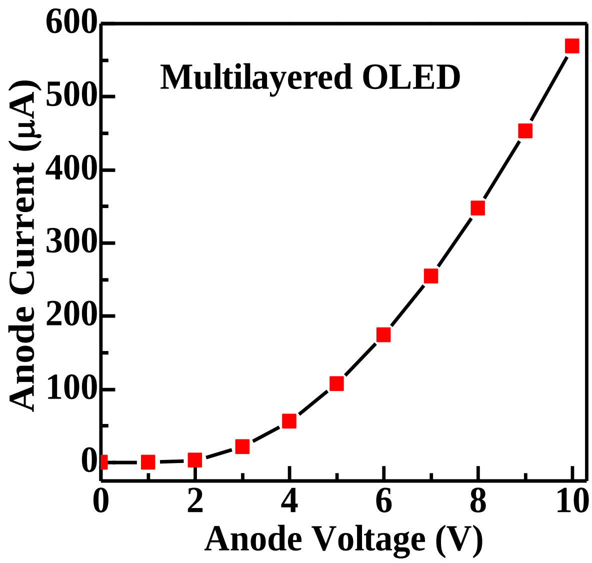

Figure 8. Anode voltage vs. anode current of the multilayer OLED

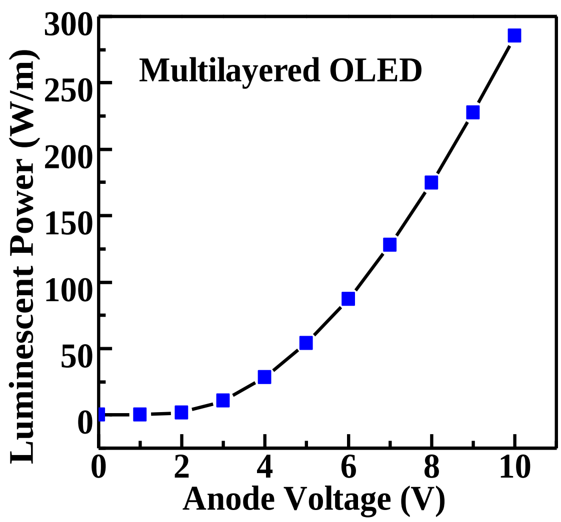

Figure 9. Anode voltage vs. luminescent power of multilayer OLED.

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