International Journal of Computer Networks and Communications Security

VOL. 8, NO. 9, September 2020, 80–83
Available online at: www.ijcncs.org
E-ISSN 2308-9830 (Online) / ISSN 2410-0595 (Print)

Structural Analysis of Enhanced Performance Organic Light Emitting Diodes (OLEDs)

REHAN YOUNAS[1] and AMMAR YOUNAS[2]

[1] PhD Candidate, University of Notre Dame, USA

[2] PhD Candidate, School of Humanities, University of Chinese Academy of Sciences, China

[1]reh.younas@gmail.com, [2]doctorammaryounas@gmail.com

ABSTRACT

We present a detailed study on structure of Organic LEDs (OLEDs) that promise flexibility and enhanced performance. Ordinary LEDs fail when it comes to need of ultra-smart size, thin, flexible smart screens and high efficiency light sources. With electroluminescent layer made of organic compounds, OLEDs promise all such features. We did a comprehensive analysis to find what structural features distinguish OLEDs from semiconductor LEDs. We found that it is the special six layered structure with organic emissive layer and delocalized charges due to weak pi bonds that enable OLEDs to perform better. We dis-cuss a few limitations related to production and life of these LEDs and suggest possible solutions to overcome these challenges. A rigorous, in-depth analysis of this structure is imperative to further comprehend the working of this device in order to make future devices cheaper and more efficient.

Keywords: *(160-4890) Organic Materials; (230-3670) Light-emitting-diodes; (310-4165) Multilayer Design.*

1 INTRODUCTION

This paper discusses the structural features that enable OLEDs to perform better than conventional semiconductor LEDs. We discuss how inherent nature of organic materials enable us to fabricate them on flexible substrates making bendable screens possible [1-4].

With the invention of first visible LED in 1962- “The Magic One” – LED found its use in communication and electronics. At the same time, large size and very low efficiency limitations restricted its use to only a limited set of applications. As the technology evolved and progressed to be more sophisticated, a need of more compact and efficient LED arose. This is when Organic LEDs came into existence. Finding its use in more sophisticated applications, such LEDs are lightweight, portable and ensure promising future [1]. Major contribution of this technology is towards OLED based television screens. Though quest for OLEDs begun in late 1960s where scientist strived to utilize organic materials to produce light, real work begun in early 1990s when the idea of such bendable screens stroked [2]. OLED technology, though much efficient than conventional LED, is still very expensive for commercial applications. The reason being availability of a limited set organic materials that can serve to make LEDs. Researchers have long been utilizing a number of organic materials to make light generation possible [2][5], what is still unknown to us is how we can make these LEDs cheaper and long lasting. The question of choice of other organic materials and efficiency improvement is still unanswered. If, somehow, we could be successful in overcoming these barriers, entire scientific community in general and electronic industry in particular would revolution-ize [1-4].

This letter explores the structure of organic light emitting diodes to enhance our understanding of how this structure works in order to enable us to further explore this domain for future improvements. We explore the inner structure of OLED [5], [7] and investigate how different organ-ic layers work for light generation. We found that the inherent structure of organic materials used make efficient charge recombination right at the interface region resulting in higher efficiency at lower power consumption. High mobility of holes

in the hole transport layer (HTL) was one of the major contributor towards excellent charge transport and high efficiency [1], [4].
We now discuss rest of the paper. In section I we discuss the working principal behind an LED. In section II we discuss the structure of OLED followed by detailing out the composition of organic layers used in these LEDs. In section III we discuss the characteristics comparison of OLEDs with normal LEDs. We conclude our paper in section IV with outlining our findings.

2 WORKING PRINCIPAL

The working principal behind an LED is simple- electron and hole recombine to emit light. Voltage is applied across a p-n junction, formed by joining two layers of semiconductors one rich with electrons (n-type) and other with holes (p-type), causing electrons and holes to flow in opposite direction [4-6]. These electrons and holes recombine to emit photons (figure.1). Depending upon the wavelength of emitted photon, we see different colors of light. The emitted wavelength is a materials property which can be controlled by using different type of materials depending upon our requirement [4].

$$\lambda = \frac{Eg}{h\nu} \qquad (1)$$

Here, Eg is the bandgap of the material and λ is the wavelength of the emitted light. By controlling the bandgap of the material we see different colors of emitted light.

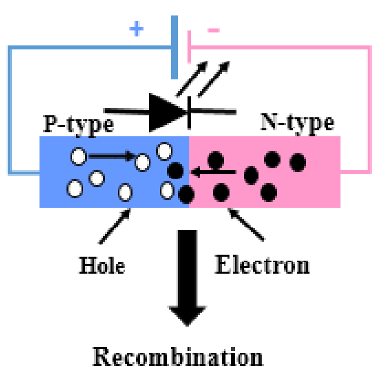

Fig. 1. Working principal of an LED. Under the influence of applied potential (forward biasing) electrons from N-type material and holes from P-type material move to recombine across the interface region to emit light.

3 OLED STRUCTURE

OLED comes to our rescue offering lower power consumption, smaller size and better efficiency. The key feature that distinguishes OLEDs from conventional ones is the structure which is the key parameter we are interested exploring. OLEDs are different on the fact that here instead of using p-type and n-type semiconductor layers to form a junction diode [1], [6], [7], we use organic materials to achieve the same goal of electron-hole recombination. The most common OLED structure comprises six layers as shown in figure 2.
Top and bottom layer is made of glass, plastic or any other coating that serves as protective layer. In many designs, this bottom layer serves as substrate as well and the entire structure of LED is fabricated on it using bottom up approach [1]. The layer below the top layer is of cathode contact serving as electron contact. The layer above the bottom layer is anode commonly known as hole contact. In between these contacts are two layers made of organic material [5]. The layer right under cathode is called emissive layer where light is produced under which is the other layer called conduction layer. The biggest advantage of OLEDs comes from the fact that these organic layers can be manipulated chemically, providing us bandgap control and enabling us with huge coloring options. In addition to that, fabrication process, for example, inkjet printing on a simple plastic substrate is extremely simple [2].
For light generation, a potential is applied across cathode and anode. Source adds electrons to the cathode and similar positive charge appears across anode. Cathode being negatively charged terminal pumps electrons to emissive layer. Opposite happens at anode end where holes are added to conductive layer. Now holes being more mobile than electrons move to the emissive layer where they recombine with electrons. This recombination results in photon emission that generates light [4-6].

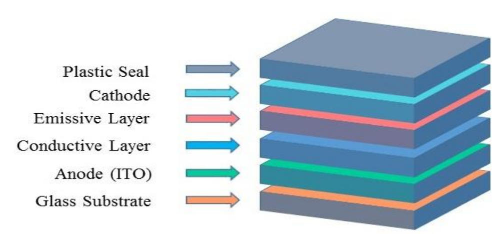

Fig. 2. Six layered structure of organic LED. Glass layer serves as substrate as well as a window for generated light. Anode is made of transparent material like Indium Tin Oxide for efficient light emission.

4 ORGANIC COMPOSITION

In OLED, electrons are pumped to the conduction band while holes to the valence band of some organic material- for this case it's the emissive layer as shown in figure 3. An unequal distribution of electrons and holes result in recombination of particles to produce excitons. These excitons decay to result in photon emission. Since the whole process results due to induction of current through metal electrodes, this process is called as electroluminescence. Depending upon types of organic layers used, OLEDs fall in two major categories.

1. Small molecular structure (SMOLED)
2. Large polymer structure (PLED).

Our general understanding suggests, since polymers are plastics they should not conduct. A polymer is a long chain of carbon atoms with occasional boding of oxygen, hydrogen and nitrogen where electrons occupy the lowest energy states [1], [5].

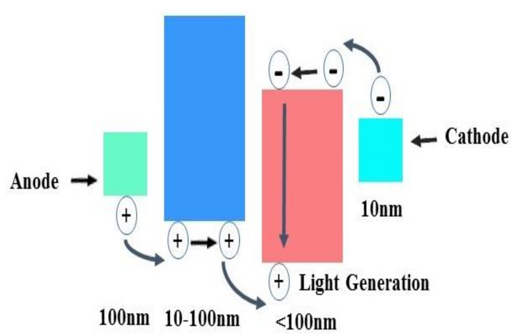

Fig. 3. Charge movement inside an OLED. Cathode pumps electrons to emissive layer (pink) and anode pumps holes to the conductive layer (blue). Holes from conductive layer moves to the emissive layer due to their higher mobility and recombine at interface to emit light.

Under such conditions, polymers do not conduct electricity and are often find use for insulation purposes. At the same time, in a polymer, a carbon carbon double bond encompasses a weakly localized pi (π) bond. This pi bond results in delocalization of electrons that can contribute to conduct electricity under the influence of potential. Here, 2Pz orbitals have same probability of being closer to either carbon atom resulting in electron delocalization. This results in splitting of pi bond in π and π^* band. This delocalization distributes in two bands similar to the conduction and valence band of a semiconductor. Here π corresponds to the bonding orbital or conduction band while π^* corresponds to antibonding orbital or valence band of the semiconductor [1-3]. These bands are also known as Lowest Unoccupied Molecular Orbital or LUMO and Highest Occupied Molecular Orbital or HOMO [1]. Depending upon symmetry of such polymer structures, these polymers can exhibit semiconducting or even metallic characteristics.

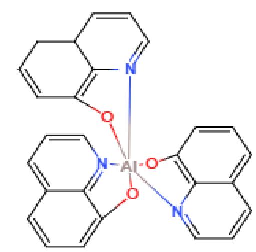

Fig. 4. Bond model of commonly used organic material Alq3 with small molecular structure (SMOLED).

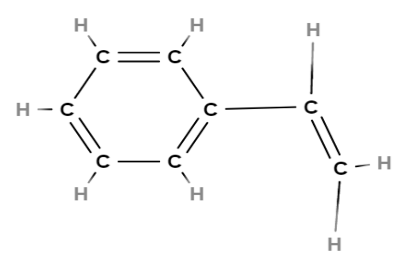

Fig. 5. A single monomer of organic polymer PPV (PLED). Such monomers repeat to form a long chain of polymer.

The OLED structure comprises two such organic layers. One working as hole transport layer (usually naphthyl substituted benzidine derivative) and Alq3 as electron transport layer. Both these organic layers are sandwiched between metal electrodes. Thickness of these layers is about 10-100nm. When a potential is applied, electrons from the cathode are transported to the LUMO of the elctron transport layer and holes are transported to the HOMO of the holes transport layer. Here, holes due to their higher mobility drift towards emissive layer ETL where they recombine with electrons to emit light. Generated light passes through anode which is made of transparent material ITO (indium Tin Oxide) that further adds to the output optical power [3][5]. The reason behind high efficiency and superior functionality of OLEDs is this two layer design that provides sufficient energy barriers to localize recombination of charges right at the interface. Since OLEDs utilize organic materials, they suffer severe degradation of material. A major setback for initial models of OLEDs was this short lifetime problem. However with recent technological advancement, choice of organic material and fabrication refinement, 10,000 hours lifetime of OLED has been achieved[1][3].

5 CHARACTERISTIC COMPARISON

OLED find its most use in making television screens. Conventional LED displays utilize the fact that pixels are illuminated by LEDs to produce image on screen. In case of OLED based displays, each OLED works as a pixel itself and provides self-illumination. Comparison of OLED displays with simple semiconductor LED displays reveals striking differences with OLED beating semiconductor LED in efficiency, power consumption and compatibility while semiconductor LED beating OLED in terms of cost, lifetime and manufacture ease[4][7]. Table 1 summarizes comparison of OLED based television screens with semiconductor LED displays.

6 CONCLUSION

Structural analysis of organic light emitting diodes reveals that organic layers with high interface recombination- due to delocalization of charge in carbon chains- and high mobility of charge carriers result in enhanced performance OLEDs. This in-depth structural analysis helps us comprehend basic device working and enables us to experiment in order to improve its performance. The possibility to manufacture organic materials on large scale ensures a bright future for this technology. High fabrication cost of OLED narrows down its use to only limited applications. In addition to that, degradation of organic materials with time restricts OLEDs lifetime to be nearly five times less than semiconducting LEDs which is the biggest drawback of this technology to this date. With introduction of less expensive fabrication technologies and choice of better organic materials which do not degrade that fast, OLED technology can be cheap and long lasting.

Table 1: Characteristic comparison of semiconductor based LED displays with organic LED displays.

Technology	LED	OLED
Power Consumption(W)	60-300	24–150
Resolutions (pixels)	1920x1080	1920x1080
Colors	16.7 million	16.7 million
Brightness (cd/m2)	350-500	1000
Contrast	350:1-1.000:1	1.000.000:1
Response Time	8-12ms	0,05ms
Viewing Angle	170/170	178/178
Lifetime (hrs)	50.000-60.000	10.000

7 REFERENCES

[1] Y.D Kim, K.H Han, S.J Park, J.B Kim, J.H Shin, J.J Kim, and H. Lee, Opt. Lett. 39, 5901 (2014).
[2] S. Kunic, Z. Sego, Proc. IEEE 1334-2630, 31(2012)
[3] 3. H. Gu and C. Warde, Opt. Lett, 30, 8576(2016)
[4] T. Bocksrocker, J.B Preinfalk, J.A Tauscher, A. Pargner, C. Eschenbaum, F.M Flaig, and U. Lemme, Opt. Express, 56, A932(2012)
[5] S. Reineke, Nat. Photonics, 8, 269(2014)
[6] Q. Zhang, B. Li, S. Huang, H. Nomura, H. Tanaka and C. Adachi, Nat. Photonics, 8, 326(2013)
[7] N.N Bakin, V.I Tuyev and E.F Yauk, Proc. IEEE, 1815-3712, 346(2011)
[8] D. Ammermann, A. Bohler, J. Schobel and W. Kowalsky, Proc. IEEE, 31(1995).