International Journal of Science and Research (IJSR)
ISSN (Online): 2319-7064
Impact Factor (2012): 3.358

Organic Light Emitting Diodes: Materials, Fabrications and Applications

Anju Singh[1], H. L. Vishwakarma[2]

[1]Department of Applied Physics, Rungta Engg. College, Kohka Kurud Road, Bhilai (C.G), INDIA

[2]Department of Applied Physics, Rungta College of Engg.& Tech., Kohka Kurud Road, Bhilai (C.G),INDIA

Abstract: ***In this paper I have discussed many points like fabrication materials, methods and applications of OLEDs. OLEDs with its diverse properties like low cost, ease of fabrication, brightness, speed, wide viewing angle, low power consumption, and contrast, plays an important role in replacing Liquid Crystal Displays (LCDs) and other lighting devices. A number of materials have been generated and improved in order to satisfy the requirements of these applications. Optoelectronic devices using organic materials are becoming widely desirable for diverse reasons [1]-[4].Organic devices have the potential for cost advantages over inorganic devices. The inherent properties of organic materials such as their flexibility make them well suited for particular applications such as fabrication on a flexible substrate. The materials differ from one another not only by their structure but also by the mechanism involved in the electroluminescence produced (fluorescence versus phosphorescence). Owing to the advantages of solid-state, self-emission, full colour capability and flexibility, OLEDs have been recognized as one of the most promising flat panel display technology and has stepped into commercialization.***

Keywords: Electroluminescence, Optoelectronic devices, Liquid Crystal Displays (LCD), Self emission, Flat Panel Displays, OLED, Fluorescence, phosphorescence.

1. Introduction

Organic optoelectronic devices like organic resonant tunnelling diode[1],[2],organic light emitting diodes[3],[4],organic phototransistors[5],organic photovoltaic cells[6] and organic photo detectors[7] have played an important role in the domain of chemistry, physics and all other fields. The optoelectronic engineering is to recreate conventional lighting sources like incandescent and fluorescent lighting with much power efficient semiconducting light sources. Organic light emitting diodes have many advantages such as self renewability, less fire risk, ease of fabrication and low power consumption etc. OLEDs have become very promising of replacing liquid crystal diodes (LCDs) and other lighting devices due to their low cost, brightness, high speed and contrast. OLEDs have been divided into two parts where one is made of small organic molecules and the other is made of organic polymers.

Due to its remarkable properties like light weight, flexibility, transparent and colour tune ability, OLEDs becomes an ideal modern light source [3], [4]. It emits light when stimulated emission gets possible by electricity. OLED displays consists of organic electroluminescence (made by small molecules or polymers).The first electroluminescence was observed in 1950s when acridine orange and quinacrine were subjected to high voltage alternating current[8].This observation shows that electroluminescence devices which depend on organic materials are of great interest. It is 100 to 500 nm thick and a solid state semiconductor device which consists of a conducting layer and an emissive layer. These two layers are implanted between two electrodes and deposited on substrate. The conducting layer is made of organic plastic molecules which transport holes from the anode. The emissive layer is a film of organic compound which transport electrons from the cathode and emits light when electric current is applied. OLEDs are double charged injection devices which require the simultaneous supply of electrons and holes to the electroluminescent materials [Fig.1].

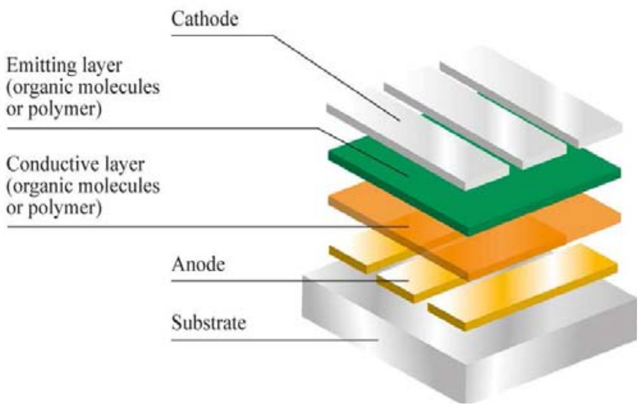

Figure 1: Fundamental structure of OLED

In two layers based OLED, at the electrode-organic layer interface, electrons are injected from the cathode in the conduction band (LUMO) of the organic compound and, holes are injected from the anode in the valance band (HOMO) of the organic compound. In three layers based OLED, the conductive layer is replaced by an electron transport layer (ETL) and a hole transport layer (HTL).When a very high positive electrical potential is applied to the anode with respect to cathode, injection of holes is possible from the anode into the HOMO of HTL, while electrons are injected from the cathode into LUMO of ETL. In the organic emissive layer (EML) when electrons and holes are spatially close on the same molecules, a percent of them recombine and form an exciton (a bound state of the electron and hole), which is a localized electron-hole pair having an excited energy state. In some cases, the exciton may be seen on exciplex (excited complex) .Non radiative mechanisms, like thermal relaxation, may also be possible, but are generally considered undesirable. In the case of recombination energy is emitted as light and at least one electrode must be semi transparent to enable a light emission perpendicular to the substrate which gives very bright and less power consumption than the usual LCD and LED.Fig.2 shows basic mechanism in OLED.

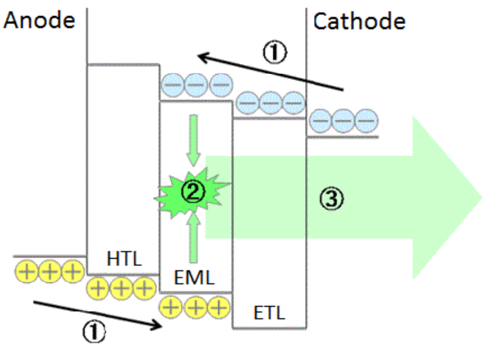

Figure 2: Scheme of the electroluminescence mechanism in an OLED

1) Electrons (blue) and holes (yellow) are injected from the electrodes to the organic emissive layer (EML).
2) Formation of an electron-hole pair or exciton (green).
3) The radiative recombination of this exciton leads to a photon emission.

In 1990, many researchers invented the first polymer light emitting diode using a conjugated polymer, poly-para-phenylene vinylene (PPV) Fig.3(a)[11].A further boost for polymer based devices came when emission was obtained from polyfluorenes [12] Fig.3(b).The configuration of a single layer OLED which is sandwiched between a transparent anode and metallic cathode is very difficult to achieve and gives poor efficiency (~0.05%) for anthracene [13] and brightness or high driving voltage(larger than 100 V[14]).The use of two layers of different organic materials substantially improved the external quantum efficiency(~1%) and decreased the driving voltage(~10 V)[10].Adding hole and electron blocking layers to force the charge carriers to recombine within the bulk have helped to achieve 8% efficiency for fluorescent OLEDs[15] and 19% for phosphorescent OLEDs[16] where the triplet excitons are also converted into light. Most highly fluorescent or phosphorescent organic materials of interest in OLEDs tend to have either n-type (electron transport) or p-type (hole transport) charge transport characteristics [17]-[21].

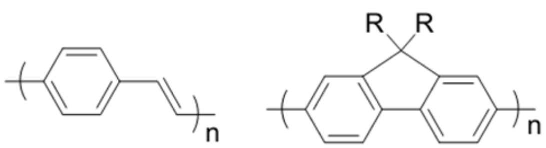

Figure 3: Mostly used polymers to produce electroluminescence in OLEDs

2. Materials

The materials are main factor for efficiency and longivility of OLED. The utilization of new materials has allowed revolutionary improvements in efficiency of OLED. High luminescence quantum yield in the solid state, good carrier mobility (both n and p type), good film forming properties, good thermal and oxidative stability and good colour are the basic requirements for OLED materials.

The first generation of efficient devices invented by Tang and Van [22] from Eastman Kodak was based on fluorescent materials [9, 10].In this case, the releasing of light is due to recombination of singlet excitons, but the internal quantum efficiency is limited to 25%.The second generation uses phosphorescent materials where all excitons can be converted into emissive triplet states by efficient inter system crossing. These materials are four times efficient than fluorescent materials. In an OLED the components differ according to the number of layers of the organic material. The efficiency of the device increases due to increase in the number of layers. Increase in a layer helps in injecting charges at electrodes and also helps in blocking a charge from being dumped after reaching the opposite electrode. Amorphous or semi-crystalline films as materials are used for OLED.

The substrate made of plastic, foil or glass is used for support of OLED. The anode component for OLED is ITO (Indium Tin Oxide)..This material helps injection of holes into the HOMO level of organic layer. It is transparent to visible light and a great conductor has a high work function. A conductive layer behaves as a transparent electrode. It changes the transitionally used ITO. It consist of PEDOT:PSS polymer or poly (3,4-ethylenedioxythiophene) poly(styrenesulfonate) [24] as HOMO levels of this materials. It lies between the work function of ITO and the HOMO of other commonly used polymers, reducing the energy barriers for hole injection. Another anode based on grapheme yields to performance comparable to ITO transparent anodes [25].The component of cathode is depending on the type of OLED. The cathode materials are Barium, Calcium and Aluminium which have lesser work function than anodes. These materials help in injecting electrons into the LUMO level of the different layers [23]. For SM-OLED, typical p-type materials are derivatives of triarylamines, and n-type materials consist of derivatives of metal chelates such as tris (8-hydroxyquinolato)aluminium (III) (Alq3), triazoles or ox diazoles. The components of Electron Transport Layer (ETL) are PBD, Alq3, TPBI and BCP which shows in Fig.4.P-type materials such as TPD and NPB are used for Holes Transport Layer (HTL)[26]. The components of emissive layer are organic plastic molecules like polyfluorene. A number of organic layers are used for colour displays. The colour of the produced light can be increased due to type of organic molecules.

3. Fabrication of OLEDs

Due to the excellent film forming properties and ease of application over large surfaces through simple, economically viable coating techniques of polymer based OLEDs are made attractive. Small molecules emissive materials are coated as thin films via vacuum-deposition which is difficult over large areas and is not cost effective. The main feature of manufacturing OLEDs is its application of applying the organic layers to the substrate. This process can be done in the following different ways:-

3.1 Vacuum Deposition (VD)

This method is used for deposition of small molecules. In this method organic molecules are heated in a vacuum chamber (10^{-5} to 10^{-7}torr) and allowed to condense as thin films on the cooled substrates. The heating method is so complicated and have the strictness of parameters should be highly accurate. This method is more costly and of limited use for large-area devices than other processing techniques. Vacuum deposition method is not suitable for forming thin films of polymers. This method is capable of formation of well controlled, homogeneous films and construction of very complex multilayer structures. This high flexibility in layer designing, enabling distinct charge transport and charge blocking layers to be formed, is the main reason for the high efficiencies of the small molecule OLEDs.

3.2 Organic Vapour Phase Deposition (OVPD)

This method is very efficient at very low cost. In this technique at low pressure, hot walled reactor chamber is used. In this method a carrier gas transports evaporated organic molecules on the cooled substrates, where they condense into thin films. By using carrier gas, the efficiency of OLEDs increases whereas the cost decreases.

3.3 Inkjet Printing

This technique is reasonable and most commonly used method. This technology is highly economical and greatly reduces the cost of OLED manufacturing and allows OLED to be printed on the very large films for large displays like big TV screens and electronic billboards. This technique is same as the paper printing mechanism where the organic layers are sprayed on the substrates.

3.4 Transfers-Printing

This is a growing technology. This technique is capable to assemble a large number of parallel OLED and active matrix OLED (AMOLED) devices under adequate conditions. This technique also takes advantage of standard metal deposition, photolithography and etching to create alignment marks on device substrates, mostly glass. For enhancement of resistance to particles and surface defects, thin polymers adhesive layers are applied. This technique is efficient of printing on the target substrates up to 500nm x 400nm.Increase in the size limit is required for transfer-printing to become a common process for the fabrication of large OLED/AMOLED display [27].

4. Applications

The enormous covers have been made in the science and technology of organic electroluminescence (EL).This kind of progress has been applied in the development of flat panel displays. OLEDs are used to generate digital displays in devices like television screens, computer monitors and portable systems like mobile phones, digital media players, car lighting, handheld games consoles etc. If this rate of development can be upheld in the next decade, organic EL technology has the potential to apply an effect not only on the displays, but also on the general lighting applications. For intelligibility in sun light and their low power drain, these kinds of portable applications support the large light output of OLEDs .Organic electroluminescence displayed on rigorous and soft substrates are recreated to play a significant if not major role in the field of flat panel displays. In a significant way the small, passive and active matrix organic light displays which are inexpensive have also entered the commercial market. Organic electroluminescence displays are small, easy to handle on large flat screens which can be rolled up or hung flat on wall.

OLEDs can be divided into several types on the basis of their manufacturing and nature of use:-

4.1 Passive Matrix OLED (PMOLED)

PMOLEDs have organic layers and strip of anode arranged perpendicular to the cathode strips. The light released from the pixel is made from the intersection of cathode and anode. The brightness of every pixel is proportional to the quantity of supplied current. PMOLEDs are easy and inexpensive to fabricate, but they consume more power than other OLED. It is used to display character data or small icons and they are also used in MP3 players, mobile phone sub displays etc.

4.2 Active Matrix OLED (AMOLED)

AMOLEDs have full layers of cathode, organic molecules and anode. The anode layers have a thin film transistor (TFT) plane in parallel to it so as to produce a matrix. This helps in switching each pixel to its on or off state as required, thus forming an image. This is a less power consuming device. It helps in increasing the life of a battery and is also used in computer monitors, large screen TVs and electronic signs or billboards.Fig.4 shows Full HD AMOLED TV.

Figure 4: Full HD AMOLED TV

4.3 Transparent OLED

In this type of OLED, it consists of only transparent components like substrate, cathode and anode. When this display is turned on, it allows light to pass in both directions. This OLED can exist in both the active and passive matrix. This device has a great contrast even in bright sunlight [28]. It is used in head up displays, laptop, mobile phones and smart windows.Fig.5 shows transparent OLED.

Figure 5: Transparent OLED laptop

4.4 Top-emitting OLED

Top emitting OLEDs have a substrate that is either opaque or reflective. It is more suitable for active –matrix applications as they can be more easily integrated with a non transparent transistor backplane. It may also be used in smart cards.

4.5 Foldable OLED

Foldable OLED have substrate made of very flexible metallic foils or plastic. This material is strong, reduces breakage and therefore it is used in cell phones and large curved screen TVs.Fig.6 shows foldable OLED.

Figure 6: Foldable OLED smart phone (Samsung galaxy S4)

5. Conclusion

It is concluded that OLEDs are more effective when they passes through the three important processes like charge injection, charge transport and emission. Various layers in the organic stack are dedicated to one of the three processes above, such as surface modification in Hole Injection Layer and Electron Injection Layer, high mobility materials for transport with Hole and Transport Layer and Electron Transport Layer as well as Emission Layers with high efficiency emitter dopants. Various cathode materials and different surface treatments of ITO have been generated, leading to substantial enhancement of charge injection. For low power consumption, it is highly required to design EL materials with superior electron mobility. In order to achieve high device efficiency, the amount of electrons and holes arriving at the recombination and emission zone must be balanced. The performance of OLEDs meets many of the targets necessary for applications in display. Passive-matrix addressed displays are attractive, as the device construction is relatively simple. The trend towards low power, light weight and rugged displays led to the development of flexible OLEDs offering many advantages over both LCDs and LEDs. The substrate and organic layers of OLEDs are thinner, lighter, more flexible and brighter than the crystalline layers in an LED or LCD.OLEDs are easier to produce and because they are essential plastics, they can be made into large, thin sheets.

References

[1] Karzazi Y., Cornil J., Bredas J. L., J. Am. Chem. Soc., 123,10076,2001.
[2] Karzazi Y., Cornil J., Bredas J. L., Nanotechnology, 14,165,2003.
[3] Kulkarni A. P., Tonzola C. J., Babel A., Jenekhe S. A., Chem. Mater., 16, 4556,2004.
[4] Hung L. S., Chen C. H., Mater; Sc. Eng., R 39, 143,2002.
[5] Hamilton M. C., Martin S., Kanicki J. IEEE Trans. Electron Devices, 51,877,2004.
[6] Li G., Shrotriya V., Huang J. S., Yao Y., Moriarty T., Emery K., Yang Y., Nature Mater., 4, 864,2005.
[7] Peumans P., Yakimov A., Forrest S. R., J. Appl. Phys., 93,3693,2003.
[8] Bernanose, M. Comte, P. Vouaux, J. Chim. Phys. 50, 64,1953.
[9] Tang C. W., US Patent, 4356429,1982.
[10] Tang C. W., VanSlyke, S. A., Appl. Phys. Lett., 51,913,1987.
[11] Burroughes J. H., Bradley D. D. C., Brown A. R., Marks R. N., Mackay K., Friend R.H., Burns P. L.,Holmes A. B., *Nature*, 347,539,1990.
[12] Fukuda M., Sawada K., Morita S., Yoshino K., Synthetic Metals, 41,855,1991.
[13] Vincent P. S., Barlow W. A., Hann, R. A., Roberts G. G., Thin Solid Films, 94, 171,1982.
[14] Helfrich H., Schneider W. G., J. Chem. Phys., 14, 2902,1965.
[15] Baldo M. A., Thompson M. E., Forrest S. R., Nature, 403,750,2000.
[16] Adachi C., Baldo M. A., Thompson M. E., Forrest. S. R., J. Appl. Phys., 90,5048,2001.
[17] Tang C. W., VanSlyke S. A.; Chen C. H., J. Appl. Phys., 65,3610,1989.
[18] Braun D., Heeger A., J. Appl. Phys. Lett., 58, 1982,1991.
[19] Kraft, A., Grimsdale A. C., Holmes A. B., Angew. Chem. Int. Ed., 37 ,402,1998.
[20] Friend R. H., Gymer R. W., Holmes A. B., Burroughes J. H., Marks R. N., Taliani C., Bradley D. D. C.,Dos Santos D. A., Brédas J. L., Lögdlund M., Salaneck W. R., Nature, 397 121,1999.
[21] Sheats J. R., Antoniadis H., Hueschen M., Leonard W., Miller J., Moon R., Roitman D., Stocking A.,Science, 273, 884,1996.
[22] Tang CW and Van Slyke SA, Appl Phys Lett 51:913,1987.
[23] Carter S. A., Angelopoulos M., Karg S., Brock P. J., Scott J. C., 70 ,2067,1997.
[24] Wu J., Agrawal M., Becerril H. A., Bao Z., Liu Z., Chen Y., Peumans P., Acs Nano, 4,43,2010.

[25] Bellmann E., Shaheen S. E., Thayumanavan S., Barlow S., Grubbs R. H., Marder S. R., Kippelen B.,Peyghambarian N. Chem. Mater., 10 1668,1998.
[26] Bower C. A., Menard E., Bonafede S., Hamer J. W., Cok R. S., IEEE Transactions on Components packaging and manufacturing Technology, 1 ,1916,2011.
[27] Thompson M. E., Forrest S. R., Burrows P., US Patent, 598640, 1999.

Author Profile

Dr. H. L. Vishwakarma did PhD from Rani Durgavati University, Jabalpur (M.P.), at present he is professor and head of department of Applied Physics and P.G coordinator in Rungta College of Engineering and Technology, Bhilai (C.G). He is a Chairmen of Board of Studies in Applied Physics in CSVTU, Bhilai (C.G). He has published more than 70 papers in national and International Journals.

Anju Singh did M.Phil from C.V Raman University and pursuing PhD in CSVTU, Bhilai (C.G.).She is working as a Assistant Professor in Rungta Engineering College, Bhilai (C.G.)