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OLED (Organic Light Emitting Diode)

Tanu [1*], Bharti Diwakar [2]

[1] M.Sc. Student, Department of Physics, D.A.V. College, Muzaffarnagar, Uttar Pradesh, India

[2] Assistant Professor, Department of Physics, DAV (PG) College, Muzaffarnagar, Uttar Pradesh, India

Corresponding Author: * Tanu

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Abstract

Organic light-emitting diodes (OLEDs) are a promising organic electronics technology with many "self-emission attractive characteristics ", including flexibility, deep color, and high transparency. An OLED is an LED in which the emissive layer is an organic layer that electroluminesces when an electric current is applied. OLEDs have many features that make them the perfect candidate for the future of display technology. These features include high contrast display, rapid response time, and wide viewing angle displays. Because of this OLED technology is readily found in many of the display devices we use today including TVs, PC monitors, and even mobile devices and their portable gaming counterparts. Solid-state lighting is another area ripe with the potential for solid-state lighting with the development of white OLEDs. Like other OLED display technology, solid-state lighting will use carbon-based organic layers sandwiched between two charged electrodes. OLED display technology will utilize either PMOLED or AM OLED technologies. OLEDs do not require backlighting allowing displays to be thinner and lighter while providing a greater contrast and deeper blacks. The paper discusses the future of OLED technologies and the existing challenges of reliability and aging.

OLEDs blue light layers in particular have a short lifespan, and the technology is moisture sensitive and very expensive to manufacture. Both of these concerns are being targeted by researchers to find new organic materials or other methods of manufacturing.

For display technologies and solid-state lighting, OLEDs shows great promise. With the future development of displays consisting of flexible, transparent, and rollable screens, the possible applications of OLEDs can expand vastly.

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1. INTRODUCTION

OLEDs are composed of different organic layers. The layer responsible for emitting light is an organic layer of electroluminescent material, and in this layer, the light is generated as current passes through. OLEDs have emerged as one of the cutting-edge technologies in the display industry. Compared to conventional LEDs, OLEDs exhibit superior display performance, offer enhanced display quality, flexible displays, and greater color gamut, as well as wider viewing angles [1]. OLEDs are utilized in digital displays of various devices such as TV and computer displays, and portable displays such as mobile phones and portable game consoles. There is considerable research interest in the development of white OLEDs for applications in solid state illumination [2]. OLEDs can be of two types: small molecules based or polymer-based [3]. OLED displays can be either passive-matrix (PMOLED) or active-matrix (AMOLED). In an active-matrix (AMOLED) display, each pixel requires a thin film of a switching device, hence offers higher display resolution [4].

Organic light-emitting diodes (OLEDs) have great promise in flat panel display technologies, both for information display applications as well as in next generation solid state lighting applications [5, 6]. Tang et al.

In their study, source [7] shows the use of OLEDs for presenting full color display panels and as a sustainable source of light. Transparent conducting oxide (TCO) layers show greater opto-electrical characteristics, which is an excellent requirement for building high performance OLEDs [8]. Considerable improvements have been made in the past decades to OLEDs in terms of luminance efficiency and color gamut" and also in fabrication and device stability [9-11]. Currently, OLEDs serve different purposes from providing indoor illumination to being used in various display devices like televisions, pc displays, and even transparent displays in mobile phones, portable gaming consoles, digital still cameras, and super high-definition TVs [12-13].

Since the development of almost functional OLEDs in 1987, advantageous comparisons can be made between "OLEDs and standard LEDs. OLEDs, being the 'dream display,' serve as the latest mobile device display thanks to their high light efficiency, eco-friendliness, and ultra-low energy use [14]. Unlike traditional liquid crystal displays (LCDs), OLEDs do not require a backlight. Thin layers of organic materials coated on a flexible substrate emit light when energized [15]. Compared to LCDs, OLEDs become the better choice due to their greater freedom of design and display panel thickness, in addition to lower energy use, and viewing angles that are less restrictive. Thin LCDs typically result in display panels that are 3 mm or more compared in contrast to the 1 mm thick OLED displays.

Compared to LCD displays, OLED displays have wider viewing angles and better screen anti-aging performance, due to their use of liquid structures. This allows people to view the same screen from various angles and locations, without distortion. For lighting applications, OLEDs not only allow for general, indoor, and outdoor lighting, backlighting, and decorative lighting, but also allow for the creation of innovative products, such as artistic, flexible, and illuminated wallpaper, as well as light-embedded windows and illuminated warning signs.

This research paper on the characteristics of OLEDs explores the optical, electrical, and structural properties of OLEDs. The study adopts a multidisciplinary approach that combines experimental techniques and theoretical methods. The aim of this study is to explain the mechanisms that are responsible for the operation and performance of OLEDs.

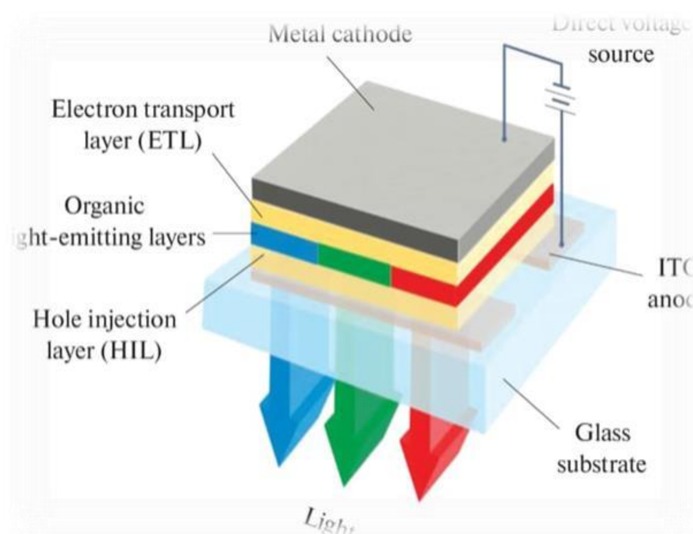
2. OBJECTIVES OF THE STUDY

1. To investigate the structure and design of an OLED device.
2. To examine the principles of physical mechanisms of electroluminescence in organic structures.
3. To investigate the materials of OLEDs.
4. To study the benefits and drawbacks of OLED s.
5. To study the prospects and applications of OLEDs.
6. Structure of OLED Devices

1. Structure of OLED Devices

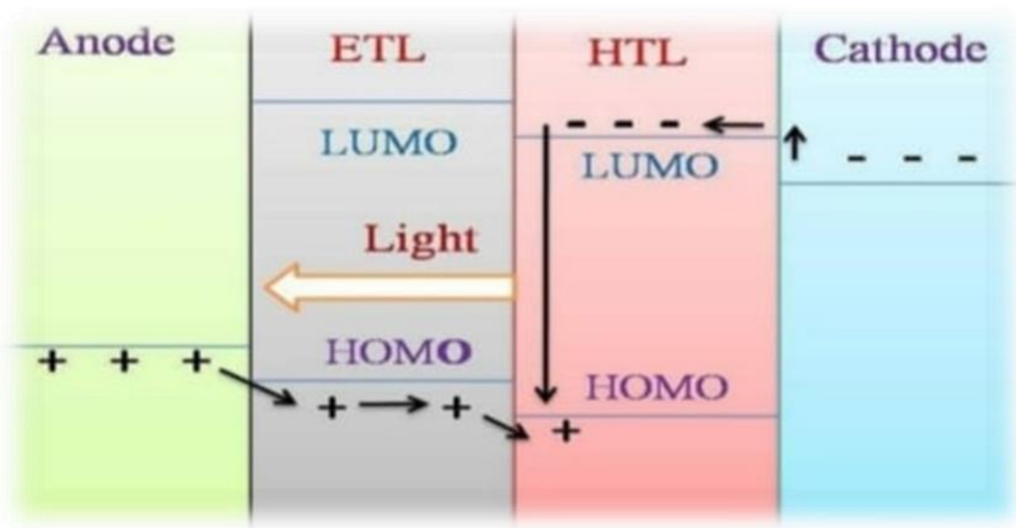
An OLED device has an emissive layer, a conductive layer, and an anode and a cathode. The emissive layer is made of a p-type polymer in the form of polyfluorene, which has the ability to transport plastic molecules and cathode polymers.

The conductive layer consists of organic plastic molding hills that transport holes from the anode and the conducting polymer of polyaniline. The substrate supporting the OLED consists of flexible plastic, cheap glass or metal foil. The anode that removes electrons when current flows through the device is normally made of Indium Tin Oxide and is transparent while the cathode that injects electrons and, in some cases, when the device is made of metals, aluminium and calcium.



2. Physical Principles Responsible for Electroluminescence

It is founded on the principle of Radiative Recombination of charge carriers that are injected and leave behind holes. The process of excitation and emission of light is dependent on the application of a voltage. In this process, electrons travel from the cathode to the Lowest Occupied Molecular Orbital (LUMO) whilst holes travel from the anode to the Highest Occupied Molecular Orbital (HOMO) of the organic material. The charge carriers travel through an organic layer and meet. The charge carriers are transported through two types of layers, the Hole Transport Layer (HTL) and the Electron Transport Layer (ETL). The light emitted is dependent on the energy difference between the HOMO and LUMO of the molecules that meet and recombine to form an exciton state. This process of recombination of Electron and Hole is known as Electroluminescence.



3. Material used in OLED Fabrication

The fabrication of OLEDs involves both dry and wet processes and the organic materials used may vary. In the dry process, vacuum evaporation is the most commonly used technique to fabricate OLEDs. However, fabrication of OLEDs can also be done by vacuum deposition, vacuum thermal evaporation, organic vapor phase deposition, inkjet printing, transfer printing, laminating, spray coating and spin coating.

In the emissive layer, the PPV and Ir(ppy)3 and in the conductive layer, the PEDOT: PSS, and in the cathode layer, materials like Al, Ca, and Ba are used, and in the anode layer, Indium Tin Oxide (ITO) is used. With the help of these materials the different layers of OLED are constructed.

4. Advantages and limitations of OLED displays

Advantages

1. Manufacturing of OLED is less expensive than that of TFT, LCD, and Plasma Displays.
2. OLEDs can be fabricated on flexible and light plastic substrates.
3. Compared to other display technologies, OLEDs are more power efficient.
4. Compared to LCD, OLEDs have better response times.

Limitations

1. Compared to LCD, OLED manufacturing is more expensive.
2. OLEDs can be damaged in the presence of moisture.
3. The image on an OLED display can persist due to the organic dyes having a shorter lifespan and this can cause an inconsistency.
4. OLEDs can be damaged by exposure to ultraviolet light.
5. Having a static element on the screen can cause permanent burn.

5. Future Developments and Applications of OLED technology

Future Developments

With future developments, OLED technology may be able to achieve data transfer rates of 10-15 Mbits/s and thereby be able to fully adopt and integrate with the standard 10BASE-T Ethernet technology.

Collaboration is ongoing with manufacturers to improve device response times. The newer displays demonstrate faster response times and show greater dynamic contrast. Rather than being a prototype, the newspaper of the future may consist of OLED based displays in automotive dashboards, billboards, home and office lighting.

Application of OLED Technology

OLED displays are being used in small screen devices such as mobile phones, PDAs, and digital cameras and DVD players. As a flexible display technology, it saves weight and space. Some of the applications are shown in Figure 18. In March 2003, Kodak created the first digital camera with an OLED display.

Several companies have prototypes of built-in displays and TVs with OLED technology. The concept of a scroll laptop from Nokia is an example of this technology. The Fraunhofer Institute has made an OLED display with SVGA (600x800) resolution that fits in a 0.6-inch display with a pixel density of 1,667 ppi. The range of applications for OLED is rapidly increasing.

3. MATERIAL AND METHOD

The operational lifetime and efficiency of OLED displays rely heavily on the materials used. In this regard, OLED technologies have shown great improvements. These improvements have also made OLED technologies competitive to LED technologies within the 550 nm spectrum. It is also possible, with continued improvements and advancements in OLED technologies, to reach lifetimes of several hundred thousand hours.

There are also variations in the layers of organic materials and the number of components included in an OLED display.

OLEDs have been divided into three categories based on how many layers they have: single-layer, double-layer and triple-layer. Generally speaking, the more layers of an OLED, the better its performance will be. Increasing the number of layers of an OLED enhances the flow of charge carriers across the electrodes and assists in the prevention of charge carriers being quenched (absorbed) before reaching" the opposite electrode. Even with design variations, the bulk of any OLED is the same.

Substrate

All OLEDs need a supporting structure known as a substrate. Substrates can be made of different materials including plastic and glass, and can be flexible or rigid. If the light emitted by an OLED panel passes through the substrate, then the OLED panel is considered to be a bottom-emission device.

Anode

Indium tin oxide (ITO) is commonly the material of choice of anodes. It is transparent to visible light, highly conductive and has a high work function to assist in the hole injection to the HOMO level of the organic layer. Conductive layers can take the place of ITO as a transparent electrode, such as the "PEDOT: PSS polymer or poly(3,4-ethylenedioxythiophene) poly(styrenesulfonate) [23], since the HOMO level of this polymer is usually between the work function of ITO and the HOMO levels of the other polymers, therefore, it effectively eliminates the hole injection barrier. Gr/Epoxy composite based anode also exhibits performance similar to transparent ITO anode [24].

Hole Transport Layer (HTL)

The two p-type materials commonly used as HTL are TPD and NPB.

TPD = N, N-diphenyl-N, N-bis(3-methylphenyl)-1,1 biphenyl-4,4-diamine;

NPB = 1,4-bis(1-naphthylphenylamino) biphenyl

Emissive Layer (EML)

The EML is mainly composed of organic luminescent materials and the material that is most commonly used is polyfluorene. Combination of phosphorescent and fluorescent dyes are used in these emitters. In organic semiconductors holes are mostly more mobile than electrons. Excitation state decay causes an electron transition and relaxation to a lower energy state resulting in emission of radiation at visible spectrum. This emitted radiation is a function of the material's band-gap which is the difference in energy between the Highest Occupied Molecular Orbital (HOMO) and Lowest Unoccupied Molecular Orbital (LUMO). The emitted light depends on the organic molecule used. To make a full colour display, many layers of organic sheets are used. Current also affects emitted light. The more current that flows through the OLED, the more intense the light.

Electron Transport Layer (ETL)

PBD, Alq3, TPBI and BCP are the most widely used materials. PBD is 2-(4-biphenyl)-5-(4-t-butylphenyl)-1,3,4-oxadiazole, Alq3 is tris(8-hydroxyquinoline) aluminum, TPBI is 1,3,5-tris(N-phenylbenzimidizol-2-yl) benzene, and BCP is bathocuprene.

Cathode

The type of OLED determines the type of cathode used. In some cases, a transparent cathode is used. Generally, barium, calcium and aluminum are used as they are low work function metals. They are more favorable than anodes which aids in the electron injection into the LUMO of the OLED layers [25].

Fabrication of OLEDs

Polymer-based OLEDs have excellent film forming capabilities. It can be easily deposited onto large surfaces with cost-effective techniques like spin coating or inkjet printing. It can be difficult to cost effectively deposit small-molecule emissive materials as thin films over large areas, as vacuum deposition (the most common method) is both expensive and difficult to deploy over large areas. The primary part of OLED construction is depositing organic layers on a substrate, which can be achieved by one of three techniques.

Vacuum Deposition or Vacuum Thermal Evaporation (VTE)

This technique is exclusively used to deposit small molecules. The process occurs in a vacuum chamber at 10^{-10} torr, where organic molecules are heated until they evaporate and subsequently condense on the surface of the chamber as thin films. Because the heating process is intricate and requires precise control of numerous parameters, this method is more expensive than most and is largely impractical for the construction of large area devices. While vacuum deposition is not appropriate for the construction of thin films of polymers, it can be used to create homogeneous films and construct complex multi-layered structures. The flexibility of this method to create numerous transport and charge blocking layers is what primarily contributes to the high efficiency of small-molecule OLEDs.

Organic Vapour Phase Deposition (OVPD)

This is one of the most efficient techniques, and is cost effective as well. This method employs a low-pressure, hot-walled reactor chamber in which a carrier gas is used to transport organic molecules which then condense as thin films on a cold substrate. The use of a carrier gas makes the process more efficient and less expensive.

Inkjet Printing

The method currently dominating the market for costs and manufacturing efficiency of OLED technology is inkjet printing. Inkjet printing like other printing technologies, removes the layers of an OLED stack by spraying organic materials on a substrate, similar to how paper is printed. Inkjet printing enables large area OLED fabrication for large displays such as TVs or electronic billboards.

Transfer-Printing

This technology is under development and is able to manufacture parallel OLED and Active Matrix OLED (AMOLED) devices under relatively favorable conditions. Transfer-printing utilizes conventional techniques.

To create alignment marks on device substrates (usually glass), metal deposition, photolithography, and etching are utilized. Thin layers of polymeric adhesive are implemented to improve the coating's resistance to particles and surface defects. A layer of anode is formed on the device backplane to constitute the bottom electrode. In conventional vapor deposition processes, the OLED layer is deposited on the anode layer and is sealed with a conductive metal electrode layer. Currently, Transfer-printing technology is able to print on substrates of the dimension 500 mm x 400 mm. In order to make Transfer-printing a mainstream technology for the manufacture of large OLED/AMOLED displays, a larger size range is necessary [26].

4. CONCLUSION

The advancement of OLED performance resulting from improvements in the synthesis, development, and use of electron transport materials has led to a better understanding of the construction of organic electroluminescent devices and materials. The performance of an OLED device is determined by three major operations: charge injection, charge transport, and charge emission. Various layers in an organic stack are focused on charge transport and emission. This is seen through the use of surface modification in the charge injection layers as well as the use of materials with high transport mobility in the charge transport layers and high emissive dopant layers in emission layers.

The charge injection and transport characteristics are crucial to the operating voltage and luminous efficiency of an OLED. High electron mobility in ETMs is desirable, particularly in OLEDs designed for use in high brightness displays and lighting applications. There has been a marked improvement in charge injection due to the development of a variety of cathode materials and ITO surface treatments. The design of electroluminescent materials with high mobility and electron dopants is therefore desirable to minimize power consumption. Although doping reduces the operating voltage, rapid diffusing dopants create quenching centers in the emission layer, which are a large concern. The efficiency of an OLED device is limited by internal optical losses and non-radiative decay of excited states.

To maximize the efficiency of each device, the ratio of electrons to holes in the recombination and emission zone must be maintained. Mobility control in the transport layers is key to balancing electrons and holes. Non-radiative recombination predominates in fluorescent OLEDs due to the spin conservation selection rule. Some progress in the field of OLEDs has been made by using different phosphorescent dyes to promote the radiative recombination and achieve light emission. OLEDs have achieved operational stability and have advanced their performance. Many requirements for display applications and for passive-matrix displays in particular, which are easier to manufacture, have been satisfied by OLEDs. As they tend toward being lightweight, low power and flexible, OLEDs outmatch both LCDs and LEDs. The layers in LEDs and LCDs are not as thin, flexible, and light as OLEDs which also have the advantage of being low power. This is extremely useful for applications in portable devices which have a limited capacity for power, such as cellular phones. The manufacturing of OLEDs is low cost due to the plastic nature of their components and they can be made in large sheets. Compared to LCDs, the refresh rate of OLEDs is in the range of thousands of times faster. This allows video displays to be more fluid.

The newspaper of the future will be an OLED display that refreshes with breaking news. OLED technology is close to being perfect for all display types and has many advantages. However, there are still some issues to resolve. Some OLED displays struggle with low blue dye longevity, and internal blue dye stability is currently low [54]. Also, water intrusion damages OLED displays and requires sealing which affects the overall display lifespan [55].

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