Fundamentals of Organic Light Emitting Diode

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Organic light emitting diode (OLED) has drawn tremendous attention in optoelectronic industry over the last few years. Their properties such as low cost, light weight, flexibility, and transparency have raised enormous interest for their potential applications in displays and lightings. In this article a brief review is presented on basics of OLED, including its operating principles and device structure. Selection of appropriate organic materials and their design in electron transport layer (ETL) and hole transport layer (HTL) are discussed. In addition, chemical properties of electrode/organic junction are reported. The article also describes recent progress and key challenges to be overcome for their potential applications.

Key words: OLED, Organic Semiconductor, Hole Transport Layer.

1. Introduction

Organic materials have emerged as potential materials for various optoelectronic applications such as solar cells (Li et al 2005); light emitting diodes (Hung & Chen 2002, Kulkarni et al. 2004), photochromic devices, and phototransistors (Karzazi 2014). These materials are being considered promising because of low processing cost, environment friendliness, and flexibility. Organic light emitting diode (OLED) is an electroluminescent device which emits current when an external voltage is applied. There are mainly two kinds of OLED based on small organic molecules and conducting polymers. It was first introduced by a team in Kodak in 1987 (Tang 1982, Tang & Vanslyke 1987), and after few years the Cambridge group of scientists declared a polymer based LED in 1990 (Friend et al. 1990, Friend et al. 1993). Since then, extensive research is being carried out in this technology considering its potential application in flat panels.

It is thinner and lighter than liquid crystal display (LCD). OLED has exclusive properties such as light weight, transparency, flexibility, and color tune ability (Hung & Chen 2002). In addition, properties like wide view angle, improved brightness, faster response time, low operating voltage (less than 5V), and wide range of color have grown interest both in academia and industry (Karzazi 2014). However, there are few breakthroughs still to be achieved for this technology to make it commercially viable. The life time of organic materials is still a critical issue. The luminance of OLED degrades due to chemical breakdown of organic molecules. Efficiency is also another important issue (Hung & Chen 2002).

Design of electroluminescent materials is a critical parameter for device performance. Scientists are performing intensive research to get over the critical challenges they are dealing with this technology. This article reports basics of OLED which includes its working principle, materials, device architecture, fabrication methods, applications, and challenges. Furthermore, the current research and achievements in this technology are discussed in this report.

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2. Working principle

A typical OLED consists of two organic layers (electron and hole transport layers), embedded between two electrodes. The top electrode is usually a metallic mirror with high reflectivity and the bottom electrode a transparent ITO layer on top of the glass substrate. An external voltage is applied between the electrodes (anode and cathode). Higher potential is applied at anode and consequently it injects holes into the hole-transport layer (HTL). On the contrary, cathode injects electrons into the electron-transport layer (ETL). The injected holes and electrons move toward cathode and anode respectively, and recombine near the junction in the luminescent ETL. As a result, emission of light occurs (Hung & Chen 2002).

![Figure 1. Electroluminescence principle in OLED.](image)

The OLED materials are known as organic semiconductors because of their conductivity value and this conductivity arises from delocalized pi electrons in the molecules. The highest occupied molecular orbital (HOMO) and lowest unoccupied molecular orbital (LUMO) are known as valence and conduction band respectively. The heterojunction is designed in order to assist hole injection from HTL to ETL and to hinder electron injection from the reverse direction for increasing number of excitons and their recombination at the interface (Fig. 1.). Consequently, electrons are confined in ETL. Moreover, hole has low mobility which increases hole density in ETL, and results enhancement of collision capture process (Hung & Chen 2002).

Quantum efficiency of the OLED has been increased up to 19% by employing graded heterojunction. A dopant emitter inside the graded heterostructure continuously alters the composition of hole and electron transport materials, which increases charge injection and at the same time balances charge transport in the emissive region.

3. Materials

3.1 Substrate and electrodes

Plastic or glass materials are generally used as substrate in OLED. Anode material should have high work function in order to facilitate hole injection in HTL. Indium tin oxide (ITO), which has high work function, is the most common anode material. It is also transparent. Another anode based on graphene demonstrates similar behavior like ITO transparent
anode (Wu et al. 2010). For cathode low work function is needed to facilitate electron injection in ETL. Generally, magnesium silver alloy, barium, aluminum are used as cathode material.

### 3.2 HTL and ETL

For HTL materials, properties such as efficient hole injection and sufficient hole mobility are important as the total current of OLED is governed by hole current. N,N'-diphenyl-N,N'-bis(3-methylphenyl)(1,1'-biphenyl)-4,4'-diamine (TPD) and N,N'-bis(1-naphthyl)-N,N'-diphenyl-1,1'-biphenyl-4,4'-diamine (NPB) are the most common hole transport material. They have a glass transition temperature ($T_g$) below 100°C and a hole mobility in the range of $10^{-3}$-$10^{-4}$ cm$^2$/ (V s).

![Figure 2. HTL and ETL materials (Hung & Chen, 2002).](image)

Tris (8-hydroxyquinolinato) aluminum (Alq$_3$) is the most common material for electron transport layer (ETL) and its electron mobility has a value of approximately $10^{-6}$ cm$^2$/ (V s) at $4\times10^5$ V/cm. In addition, Alq$_3$ emits in the green with a broad emission peaking at 530 nm, used as emissive material. Other colors can be generated by adding suitable dopant (Hung & Chen 2002).

### 4. Fabrication

Small organic molecules and polymers are the main active semiconductor materials in OLED. These organic materials are deposited on the substrate by several methods like thermal evaporation, inkjet printing. Thermal evaporation, commonly used for depositing small molecules, is based on evaporation of molecules by heating in a vacuum chamber ($10^{-5}$-$10^{-7}$ torr). Homogeneous and complex multilayer structure can be obtained by this method. However, this deposition method is not suitable for large area applications due to high cost. Besides, this technique is limited to small organic molecules, not favorable for polymers (Karzazi 2014).

Inkjet printing is an efficient and most widely used technique. Organic layers are sprayed on substrate and it is as simple as paper printing. It is the cheapest method among all available techniques.
Another technology called transfer printing is becoming popular day by day. It exploits advantage of standard metal deposition, photolithography, and etching to align the substrate as required. Further improvement is needed in order to overcome its size limitation for its use in large OLED display (Karzazi 2014).

5. Applications

OLED has its main applications in various optoelectronic devices like TV screen, computer monitor, mobile phone, digital camera, car lighting etc. It is very popular among the portable devices because they are used intermittently and low life span of organic semiconductor does not make big issue. Recently, flexible and transparent OLED has been developed such as flexible signing, lighting, and display applications (Kanellos 2007). In transparent OLED, also known as TOLED, substrate, anode, cathode all are transparent. The device can be used both as top and bottom emitting. Visual aid glasses which enhance vision of visually impaired people are being developed by a research group in Oxford University. Furthermore, flexible OLED display can be used with fabrics to develop smart clothing.
Figure 3. OLED devices (a) curved OLED TV, (b) OLED smart phone, (c) flexible laptop monitor, and (d) transparent OLED mobile handset.

Universal Display Corporation, a pioneer company in display and lighting industries, is developing phosphorescent OLED technologies by collaboration with several renowned research groups including Princeton University, the University of Southern California, and the Michigan University. They are also sharing their technologies with the giant companies in optoelectronics device field like Samsung, LG, Sony, and AU Optronics CMEL. Different top brand mobile handset manufacturing industries have used OLED technologies in their recent handsets including Samsung, HTC, Sony Ericson, LG, Nokia, and Motorola.

Automotive industries are also planning to use OLED technology. BMW plans to manufacture tail lights and interior lights by employing OLED (Fingas 2014). By improving brightness they can be used in brake lights, headlights, and indicators.

![Figure 4. OLED car light developed by BMW (Fingas 2014).](image)

6. Challenges

OLED technology has to get over several challenges in order to dominate optoelectronic device applications especially in display and lighting industry. The two main issues are life time of the organic semiconductors and efficiency. Life time of organic materials is the most critical issue for devices which are operated continuously for longer time such as TV, computer monitor. Due to chemical breakdown of organic semiconductors, their luminance degrades (Kondakov et al. 2007). However, different manufacturers and research groups are performing rigorous research aiming to enhance the lifespan of these molecules.

Efficiency is also a key factor for commercialization of OLED displays in large scale. So far red (625nm) and green (530nm) diodes have achieved external quantum efficiency values of 20% and 19%, respectively, while blue diode has only achieved in the range of 4%-6% (Mikami 2006). Color balance is also an important issue other than the two issues mentioned above. In OLED luminance of blue light degrades rapidly compared to other colors. This variation causes color imbalance which is easily detectable.

Conclusions

In depth research is being carried out in this technology and so far, a substantial amount of improvement has been achieved. Charge injection, charge transport, and emission are the three vital parameters for OLED. Operating voltage and luminance efficiency depend on them. Various cathode materials and ITO as an anode material have been developed for
increasing charge injection. For higher brightness and low power consumption, materials with higher electron mobility are needed in ETL. Designing suitable materials for this purpose is a critical task in terms of constraints present such as appropriate energy level alignment with other materials.

Recently, flexible and transparent OLEDs have brought a new dimension in optoelectronic device industry and they are becoming popular day by day for their light weight, low power consumption, and flexibility. However, for commercialization of this technology in display and lighting applications in a large scale its life span and brightness should be enhanced. Designing and developing new materials are still the biggest task to be accomplished to bring this technology viable.

References


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