Organic Light Emitting Diodes (OLED)

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Abstract:
Organic light emitting diodes (OLEDs) have been receiving a lot of attention over the world as a new type of display technology. OLEDs have many advantages over conventional display technologies. First, the fabrication process is easy, and devices are thinner and lighter than those fabricated by cathode ray tube (CRT) display technology. Second, there are also some advantages over liquid crystal (LC) displays: OLEDS can be viewed from different angles and don't need a backlight. Finally, the drive voltage and power consumption are low. 1 The first commercial OLED display was introduced by Pioneer Electronics as the front panel of a car stereo in 1997. After that, some other applications are in the market, such as cell phones, digit cameras, GPS, radios etc.

Keywords: ETL, HTL, EML, OLED, HOMO, LUMO, Ef, ITO.

1. INTRODUCTION

Background:

In OLED devices, organic materials are incorporated between two electrodes. When electrical current is applied, the organic layers give off light (electroluminescence). Organic electroluminescence was first discovered by Pope et al. in 1963.[2] they observed luminescence when a voltage of about 400 V was applied to an anthracene crystal. However the development of devices based on organic electroluminescence was very slow, because of the high voltage required and the low efficiency. In 1987, Ching W. Tang and Steve Van Slyke developed a novel electroluminescent device at Eastman Kodak Company: this is considered the first organic light-emitting diode.[3] The device was fabricated by vapor deposition using Alq3 (Fig.1-1) and diamine (Fig.1-2) in a double layer structure. This structure makes the electron and hole recombination effective: the - 2 - device has a 1% external quantum efficiency, 1.5 lm/W luminous efficiency, and a brightness of more than 1000 cd/m2 at a driving voltage of about 10 V. In 1990 another type of OLED emerged from Richard Friend's group at Cambridge University: they developed a PPV (Fig.1-3) -based LED, which is called polymer-LED or PLED.[4] The light emission is in the green-yellow part in the spectrum, and the efficiency is about 0.05%. Since then, OLEDs have attracted a lot of attention from universities and industries and made much progress over the past twenty years. Table 1 summarizes the performance of present OLEDs
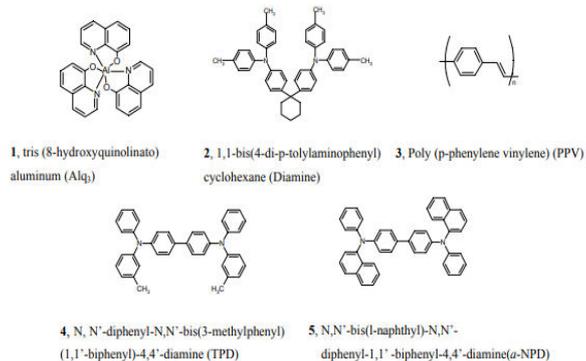

Figure 1 Chemical structures of organic molecules

1.1 Basics of light emission

Light is one type of energy. So in order to emit light, the molecules must absorb energy from other sources. Once a molecule has absorbed enough energy, it can go to the excited electronic state. When the molecule relaxes to the ground singlet state, it can use - 3 - different processes, one of which is to emit light. Fluorescence occurs when it returns from an excited singlet state to the ground singlet states. Because the two states have same multiplicity, it is spin-allowed and is very fast (10^{-5} to 10^{-8} seconds). Phosphorescence occurs when it returns from an excited triplet state: this is spin forbidden and is often slow (10^{-4} seconds to minutes).

**Table.1. Present OLEDs efficiency and lifetime**

Colors	Red	Green	Blue
Efficiency(cd/A)	5.5	19	5.9
Lifetime(h)	80,000	40,000	7,000

Figure 2 shows the basic principle of an OLED. By applying a bias voltage, holes are injected into highest occupied molecular orbital (HOMO) from the anode, to form radical cations, while electrons, injected into lowest occupied molecular orbital (LUMO) from the cathode, form radical anions. The anions and cations will move under the influence of the electrical field. When some of radical anions and cations meet somewhere in the electroluminescent layer, this will form singlet and triplet excited states, but light can only be emitted when singlet excitons form in the emissive layers. This is because the materials currently employed are typically fluorophores, and have a low probability to emit light from a triplet state.
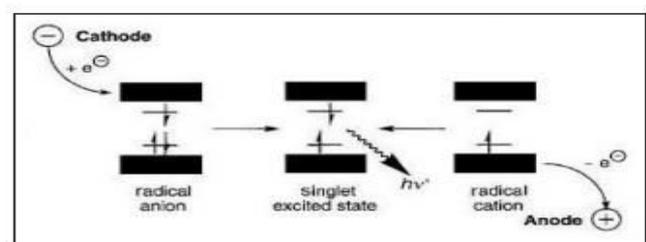
**Figure .2. The Process of Light Emission from OLEDs**

1.2 OLED structure

The basic OLED structure is shown in Figure 3. The hole transporting layer (HTL) can transport holes from the anode to the emitting layer (EML). The electron transporting layer (ETL) is used to transport electrons from the metal cathode to the EML. 8 The mobility of electrons and holes is different in organic compounds. The key point to operate OLEDs is to control the exactions (electron and hole pairs), so that holes and electrons meet in the emissive layer in equal quantities.
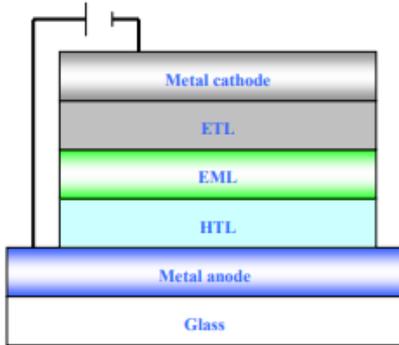

Figure .3. The Structure of OLEDs

In Figure 4, the HOMO level of the molecules in the HTL is below the Fermi energy of the anode. The HOMO of HTL is also slightly above that of the ETL; so that holes can - 5 - readily enter into the ETL. The ETL has a LUMO level, so that the energy barrier of electron injection from cathode is minimized. The LUMO of the ETL is significantly below that of the HTL, so that the electrons are confined in the ETL, increasing the possibility of exaction formation.10 Figure 5 shows the emission spectrum of first two layer OLED. The peak intensity is at 550nm, and color is green.
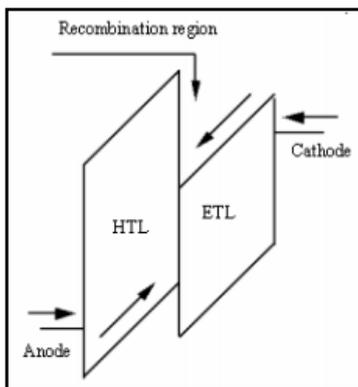
Figure .4. Energy Level Diagrams of Two Layer OLEDs
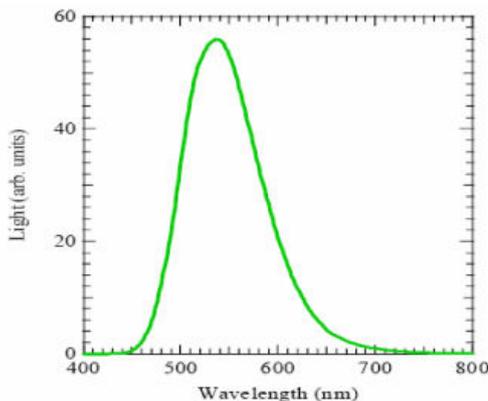
Figure.5. Electroluminescent Spectrum of ITO/ Damien /Alq/ Mg:Ag

1.3 Common materials for OLEDs

Using proper materials can also optimize device performance. Organic materials offer two key advantages over inorganic materials: they are made into films more easily, and have high fluorescence efficiency. The common hole transport material TPD (Fig.1-4). The most important electron-transport material is Alq3, which is also used as an emissive material. For polymer based-OLEDs, PPV is widely used as the active material. Because PPV itself is insoluble and difficult to process, the synthesis of PPV is typically performed via a solution-process able precursor, which is spin-coated on the proper substrate and converted to PPV by thermal treatment.4 Indium tin oxide (ITO) is often used as the anode material for hole injection: it has a high work function, to match the HOMO of the organic material. ITO is also transparent, so that the light can leave the device. The work function of ITO can be controlled by surface treatment. The most common method is UV ozone treatment, to increase the ITO work function, which increases hole-injection efficiency into HTL from the ITO anode.11 the cathode is a low-work function metal, which is useful for electron injecting: Mg0.9Ag0.1, Ca and Al are commonly used as cathodes. 3,4,12 For the Mg0.9Ag0.1, Ag is deposited with the Mg, for the purpose of providing nucleation sites, to enable the deposition of the Mg, because Mg has a low sticking coefficient on the surfaces of organic molecules, and Ag protects the Mg from oxygen and water.

1.4 Fabrication methods for OLEDs

There are two methods to fabricate OLEDs: thermal evaporation of the organic small molecules and spin-coating polymer layers. Thermal evaporation is often performed in a vacuum. The vacuum pressure is usually about 10-6 torr or better. In addition to depositing molecules, it can also be used to deposit cathode materials. There are some advantages to using thermal evaporation. During the fabrication the thickness of each layer can be monitored easily, compared to spin-coating. The vacuum equipment is already in the semiconductor industry, and it is easy to achieve the multi-color displays by using shadow masks for depositing organic materials. Spin-coating is widely used in the polymer-based LEDs. The polymer layers can be deposited from solution directly, but the thickness can't be monitored during the deposition.

1.5 Interface in OLEDs

The effective injection of charges from metal contacts to the organic molecules is important for OLED. For example, it was found that charge injection is the most important issue to increase the device efficiency, and its lifetime is dependent on interface between the organic layers and the metal contacts.
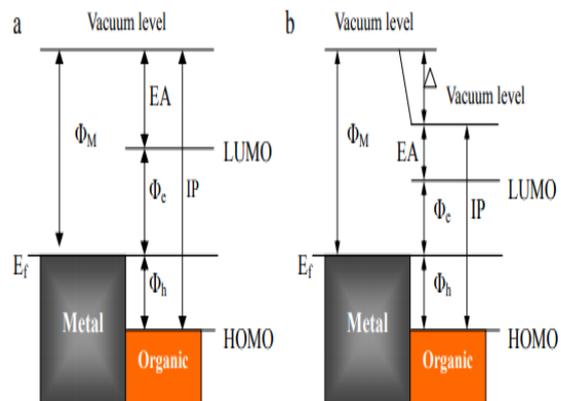
Figure.6. Schematic of Organic metal Interface Energy Diagram (a) without and (b) with an interface Dipole

The Schottky-Mott model is the simplest model to describe the interface of a metal with an organic semiconductor. The Schottky-Mott assumes there is no interaction between interfaces, so the metal and the organic have a common vacuum level at the interface. In Figure 6, Φ_M is the work

function of the metal, EA represents the electron affinity of the organic molecules, IP is the ionization potential of the organic layer. The hole barriers (Φh) and electron barriers (Φe) are dependent on the energy difference of HOMO and LUMO of the molecules, with respect to the metal Fermi level (Ef). If the Scottky-Mott rule is valid, the hole barriers (Φh) and the electron barriers (Φe) should be linear functions of the metal work functions, $\Phi h = IP - \Phi M$ and $\Phi e = \Phi M - EA$, respectively. However, sometimes this is not true. It was argued that there is an interfacial dipole (Δ) between the vacuum level of metal and organic layers. The origin for this dipole barrier has different explanations. It is thought that when the molecules are adsorbed on the metal surface, the surface electrons are compressed back into the sample surface. The work function is considered to be composed of two
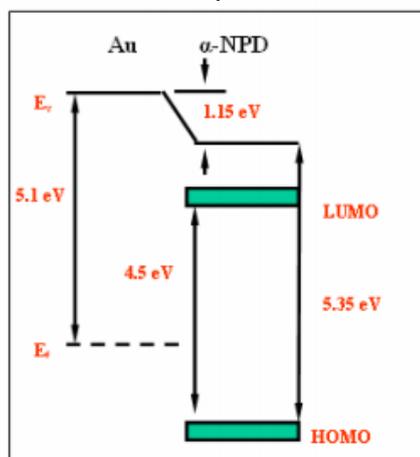
**Figure.7. Schematic Energy level diagram of the interface between α-NPD and Au**

Parts: bulk electronic structure & surface dipole contributions. With a compression of the surface electrons, the metal work function will decrease. In Figure 7, when the α-NPD (Fig.1-5) is adsorbed on the Au surface, the vacuum level shifts downward. The interface dipole barrier is about 1.15 eV, which increases the energy difference between the Ef and the HOMO of the molecules. Another explanation about the formation of interface dipole is charge transfer. 21, 22 In Figure 8, the interface between Alq3 and Ca exhibits a dipole, and the vacuum level moves upward by about 1.2 eV. It was argued that the metal has a low work function, and the organic molecule has a high electron affinity, so an electron can transfer from Ca to Alq3: this forms an interface dipole. This interface dipole will increase the energy level between the organic molecules and metal Fermi level, in order to stop the charge transfer. So the vacuum level shifts to a higher level.
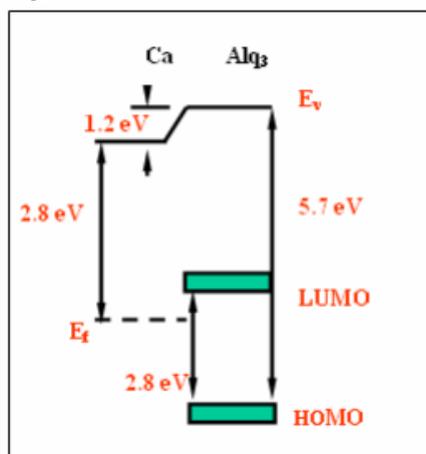
Figure.7. Molecular Energy level alignment diagram for the Ca/Alq3 interfaces.

1.6 Degradation in OLEDs

The stability of device is an importance aspect in the OLEDs. The degradation of devices can occur both during operation of devices and during storage. The mechanisms of the degradation have been investigated: one of the most important aspects of degradation is the formation of non-emissive dark spots in the metal/organic interface.23 It is proposed that a majority of dark spots are caused by the formation of metal oxides or hydroxides at the metal/organic interface. Moisture is thought to come through pinholes in the cathode surface. If the device is in ambient air, increasing the moisture will accelerate the formation of dark spots. In Figure 9, when the device is put in the ambient conditions for 12 hours, the non-emissive spots grow to larger size, which will reduce the device lifetime. In order to improve the device stability, cathodes are often made of a metal alloy where a low work function metal alloyed with a stable or inactive metal. Good encapsulation is also helpful for increasing the device lifetime.
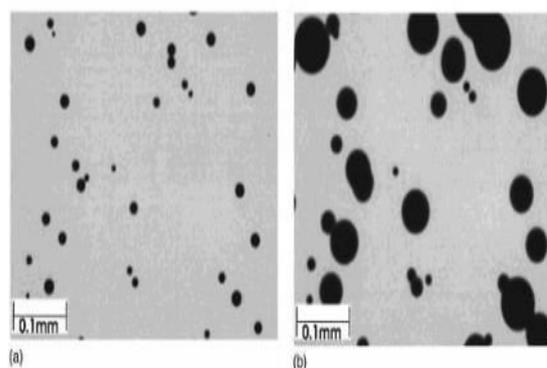
Figure.9. Optical micrograph of OLED viewed under the device own EL only right after the device is made (a), and after storing for 24 h in ambient conditions (b)

2. CONCLUSION

OLEDs offer low device operating voltage and high luminescence efficiency, which means they are likely to be useful in future display applications. However, there are still many problems that must be addressed. Novel electron and hole transport materials are needed, and longer device lifetimes are required. When all this is achieved, it will have an important impact on flat panel display technology in the future.

3. REFERENCES

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