Organic light emitting diode and liquid crystal display: structure, mechanism, preparation, and comparison

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Abstract. As technology is constantly evolving, and with the rapid development of mobile phones in recent years, OLED and LCD are widely used in the display of electronic devices such as mobile phone displays and TV displays. Both technologies have the characteristics of luminescence, but there are also great differences on their structure and mechanism behind. This review will introduce OLED and LCD in details, including the structure, mechanism, preparation, and comparison of those two technologies. This paper can give some ideas to consumers who are confused by OLED and LCD displays and help them better choose on mobile phone screens or TV screen that are suitable for them after understanding the differences.

Keywords: OLED and LCD, The display of electronic, Characteristics of luminescence.

1. Introduction

Organic light emitting diode (OLED) and liquid crystal display (LCD), two types of light-emitting displays, are well known in the field of mobile phone and TV screens. As both materials can emit light, the salesman will recommend more expensive products to customers, only saying that the more expensive products have better performance, without explaining the meaning of these functions and professional terms. And that behaviour of the salesman also causes consumers to feel cheated, but because they cannot distinguish the differences between LCD and OLED and which one is more suitable for them, they can only accept those recommendations.

On the whole, the application of OLED can be roughly divided into three stages. The first was the experimental phase of OLED from 1997 to 2001. In 1997, OLED was produced for the first time in the world for car audio and used in the market as a car display. Secondly, the growth stage of OLED from 2002 to 2005. During this period, people began to come into contact with more OLED-related products, such as electronic dictionaries, laptops, cameras, test instruments, etc. But most of them are based on small panels that are under 10 inches. Thirdly, after 2005, OLED began to move towards the mature stage. Manufacturers have launched mature products. Sony's first OLED TV was released in 2007 [1]. The Nokia N85 was the first to test the application of OLED on mobile phone screens, and the subsequent OLED mobile phones released by Apple and Samsung completely brought OLED to the market. It took only 16 years from the first commercial application of OLED to the successful launch of a 55-inch TV screen, while it took 32 years for LCD to go through this process. It can be seen that the global OLED industry is developing very rapidly [2].

The first LCDs originated in 1968 from dynamic scattering liquid crystal display, and in the late 1980s, LCDs began to be used in computer screens. After entering the 20th century, with the development of technology and customer demand, LCDs were used in more fields, such as ATM and POS machines, smart home appliances, navigation devices, blood glucose meters, blood pressure monitors, and other household medical equipment, etc. LCDs were used as displays [3].

OLED is a self-emitting material that achieves its luminescence through the process of energy level transition of electrons [4]. With the help of a backlight, LCDs emit light through twisted angles of crystals and coloured films [5]. For OLEDs, the main problems nowadays are the inability to achieve large screens and the damage caused by pulse width modulation to the human eye. Other disadvantages are the relatively high cost and short lifetime, but it has high energy efficiency, thinness and can be bent. For LCD, due to the complex structure, the screen is thicker, not bendable, and the colour display is poor. However, it has a longer life span, is cheaper, and causes less damage to the user's eyes.

Here in, the development of OLED and LCD will be introduced from three aspects. Part 2 demonstrates the basic structure and mechanism of OLED and LCD, and Part 3 describes the materials and technologies required in the preparation process. Finally, Part 4 compares the differences, advantages, and disadvantages between the two.

2. Structure and Mechanism of OLED and LCD

2.1. Structure and Mechanism of OLED

Organic light-emitting diodes, known as OLED, as shown in Figure 1, usually consist of a series of organic films sandwiched between a conductive cathode and anode. It has a substrate on the bottom, which can be glass or plastic. For the two electrodes, at least one of which should be transparent. In addition, there are five functional layers, the hole injection layer (HIL) and hole transport layer (HTL), which injects and transports holes, the electron injection layer (EIL) and electron transport layer (ETL), which injects and transports electrons, and the emission layer (EML), the core of the OLED, where electrons and holes meet and emit light [6].

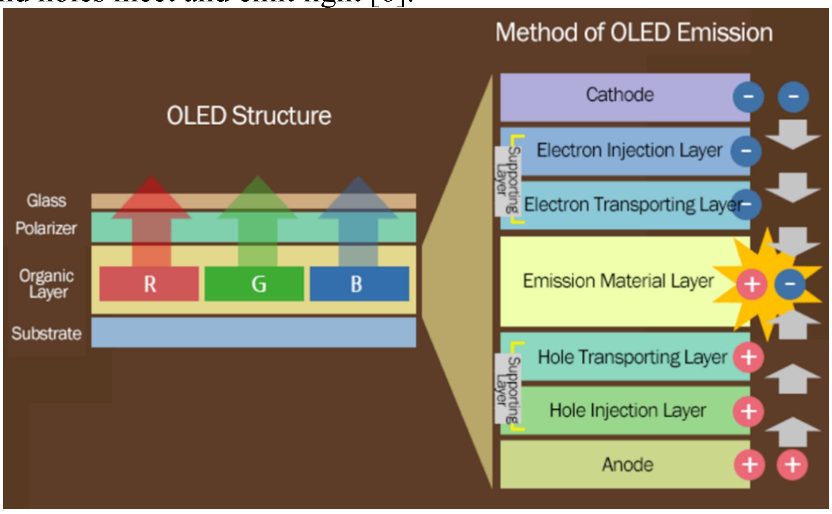

Figure 1. The structure and mechanism of organic light-emitting diodes [7].

The basic operation steps of OLED are shown in Figure 1, which is divided into the following four parts with five layers and two electrodes. First, holes and electrons are injected into the hole injection layer (HIL) and electron injection layer (EIL) from the anode and cathode, respectively. Second, the holes and electrons enter the hole transport layer (HTL) and electron transport layer (ETL) and are transported to the emission layer (EML). Third, electrons meet holes in the EML. In the last step, the electrons fall to a lower energy level to fill the holes that emit photons in the process. As a result, light is emitted due to photon production.

2.2. Structure and Mechanism of LCD

Liquid crystal displays, also known as LCD, are another type of light-emitting device. Unlike OLED, LCD cannot emit light by themselves, but require a backlight as the light source. In general, LCD are composed of two parallel glass plates with transparent electrodes in the middle, the liquid crystal layer sandwiched between the two electrodes, and a colour filter attached to the outside of the electrodes. In addition, there are display glass, reflective mirror, and polarizing layer.

The principle of LCD is that when an electric current is applied to a liquid crystal molecule, the molecule tends to untwist. This causes the angle of light which is passing through the molecule of the polarized glass and also causes a change in the angle of the top polarizing filter. As a result, a small amount of light is allowed to pass through the polarizing glass to a specific area of the LCD. In other words, that particular area will become darker than other areas and the LCD will work according to the principle of light blocking. When an LCD is manufactured, a reflective mirror is placed on the back side of the LCD. A polarizing glass with a polarizing film is placed on the bottom of the device along with an electrode plane consisting of indium tin oxide. The whole area of the LCD must be surrounded by a common electrode with liquid crystal substance above it [8].

3. Preparation of OLED and LCD

3.1. Preparation of OLED

The common materials use for the manufacturing of different layer of OLED are shown in **Table 1**.

Table 1. Materials for each OLED layer [9].

Anode	HIL	HEL	EM	ETL	EIL	Cathode
ITO IZO Au Pt Si	Cu Pc (polycarbonate) TiOPc m- MTDATA(Shirota) 2-TNATA(Shirota)	TPD NPD(Kodak) PVK Spiro- TPD(Covion) Spiro- NPB(Cpvion)	Alq_3(Kodak) $Almq_3$ Blue (Ricoh) TBADN(Kodak)	Alq_3(Kodak) $Almq_3$ DVPBi(Idemitsu) TAZ(Sumitomo) OXD(Saito) PBD (Idemitsu0 BND PV	LiF MgP MgF_2 Al_2O_3	Mg/Ag Al Li Ca In ITO IZO

Currently, in the manufacturing of all commercial OLED products, in addition to ITO electrodes, other functional layers and metal cathodes usually use thermal evaporation plating technology so called vacuum deposition which is shown in Figure 2. It is a method of coating thin layers in which under high temperature and vacuum conditions, the material is evaporated into vapor particles and move to the substrate and then condense into a thin film on the cooled substrate [10]. However, this process is inefficient and the requirements for vacuum conditions lead to the high cost of it. Besides, it can only be used for molecules rather than polymers, and it is also difficult for the manufacturing of large-area OLEDs.

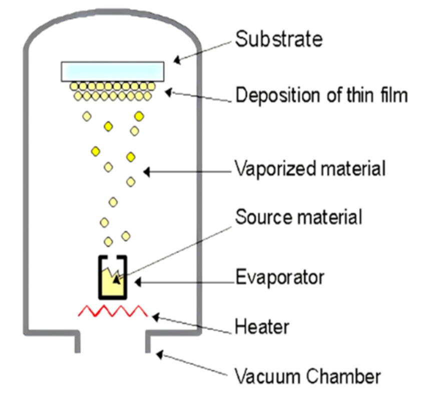

Figure 2. The vacuum deposition [11].

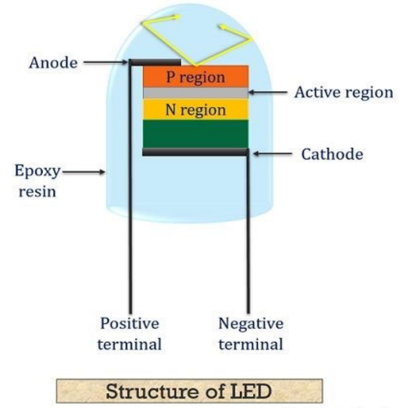

Figure 3. The structure and mechanism of light emitting diode [12].

The inkjet printing is another major manufacturing technique that is used to produce films by spraying OLED material onto a substrate. This inkjet technology reduces the cost and increases the efficiency of film production, allowing the material to be printed onto large films, such as TV screens. However, vacuum deposition is still the most common production method for OLED due to the scalability and stability of the products manufactured by inkjet printing.

3.2.Preparation of LCD

As the light of LCD comes from its backlight, there are different types of backlights used, separately the cold cathode fluorescent lamp (CCFL) and Light emitting diode (LED).

The CCFL is made using a mixture of inert gases Ne and Ar encapsulated in a glass tube containing trace amounts of mercury vapor and a phosphor coated on the inner glass wall. Then the UV light excited by gaseous mercury collides with fluorescent powder on the wall of the tube to produce a luminescence effect that releases energy and emits light [13]. The mainstream phosphors currently on the market are cerium ion activated yttrium aluminium pomegranate series materials (YAG: Ce^{3+}) and $CaAlSiN_3$: Eu^{2+} (CASN: Eu^{2+}) [14]. The backlight CCFL has relatively high requirements on AC voltage, but in terms of its light-emitting principle and physical structure, it is similar with commonly used fluorescent tubes. CCFL is considered as an ideal backlight source for LCD due to its simple structure, small lamp size, easy processing and melding, low surface temperature, good colour rendering, and uniform luminescence. Therefore, the most common backlight source for LCD in the market is still CCFL, but this technique also suffers from some shortcomings such as insufficient brightness uniformity, insufficient colour expression, high power consumption, short life span, and may cause environmental pollution.

LED is another type of backlight, as shown in Figure 3, and is a semiconductor device that converts electrical energy into visible light. It consists of a semiconductor chip encapsulated in epoxy resin, with positive and negative terminals connected at each end. The luminescence principle is that the P-type semiconductor in the chip contains holes, and the N-type semiconductor contains electrons. When the two semiconductors are connected with electric current, the electrons are pushed into the P region, where they combine with the holes and emit energy in the form of photons. Currently, LED backlights are mainly divided into two types, white LED (WLED) and RGB-LED, depending on the colour of the light emitted. Since white is a mixed colour with no identifiable wavelength value, WLEDs suffer from colour deviation. While RGB-LEDs are composed of red, green, and blue LED that modulate the light-emitting units into light. The common pattern of the LED backlight consists of 1 red, 1 blue and 2 green LED, which can independently control the light source to achieve full colour effect, thus achieving more accurate colour reproduction and better image quality. Compared with CCFL backlight, LED backlight has the advantages of wider colour gamut, better colour reproduction, better brightness uniformity, energy saving and eco-friendly, ultra-thin appearance, and clear and stable images. However, the brightness is low, and the cost is high. Besides, the use of the RGB-LED backlight for a long time will affect the quality of the display screen.

4. Features and Difference comparisons

4.1.Thickness

OLED displays are typically 10 to 40 nm thick, while LCD are usually 5 to 25 micrometres thick. Because OLED is a self-emitting material, it can emit light without a backlight, but LCD requires a backlight, and the liquid crystal layer and more other components make its LCD much thicker than an OLED device, as shown in Figure 4.

OLED displays are typically 10 to 40 nanometres thick, while LCDs are typically 5 to 25 micrometres thick. Because OLED is a self-luminous material, it does not require a backlight to emit light. However, LCD does require a backlight, and the liquid crystal layer and other components also make its much thicker than an OLED device, as shown in Figure 4.

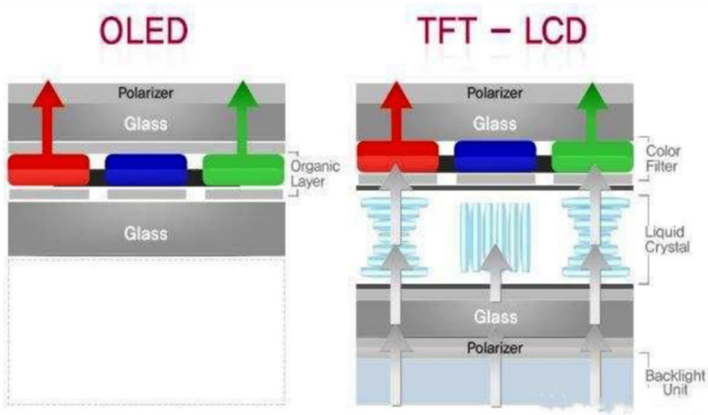

Figure 4. The comparison of thickness and components between OLED and TFT-LCD [15]

4.2.Bend ability & Flexibility

The liquid crystal layer and glass plate in LCD cause the display of LCD cannot be bent, while OLED has no strict restrictions on that. From the past few years, the foldable mobile phones produced by Huawei, Samsung and other mobile phone manufacturers have successfully reflected the bendable property of OLED.

4.3.Colour gamut and contrast ratio

The colour gamut is related to the wavelengths in the visible spectrum and is measured based on the human perception of colour. OLED has a wide display colour gamut that covers more than 110% of the NTSC colour gamut, allowing nearly 100% colour reproduction and making the image colours more saturated and realistic [16].

OLED displays can control the opening of individual pixels, and when a black screen is displayed, the pixels in some areas are turned off, i.e., all black. Pure black gives it higher contrast and better colour rendering. LCD, on the other hand, is provided with light by a backlight source and cannot control the switching on and off of individual areas, so the backlight panel cannot go all pure black, so the contrast and colour rendering are not as good as OLED.

4.4.Energy Efficiency

OLED can control the switching of individual pixels, reducing the power consumption of unnecessary areas and achieving higher energy efficiency. LCDs need to rely on a backlight to emit light and adjust the brightness of the screen by increasing or decreasing the voltage. The inability to control the switching of areas on or off in this way leads to unnecessary power consumption and low energy efficiency [17].

4.5.Life expectancy

As mentioned in 4.4 Energy Efficiency, the ability of OLEDs to control the switching of individual pixels is one of their strengths, providing greater energy efficiency. However, at the same time, this feature has an impact on the screen. A pixel used for a long time or not used for a long time will make it lose its function and reduce its life. LCD has a longer life because it controls the entire backlight on and off and does not cause individual pixels to be scrapped like OLED does.

4.6.Responding speed

The OLED display is through the organic light-emitting layer to excite photons to light, while the LCD is by changing the voltage to adjust the twist angle of the liquid crystal and the brightness of the light, the speed of the liquid crystal twist limits the response speed of LCD, making it slower than the response of OLED.

4.7.Cost

As shown in Figure 5, based on a comparison of OLED and LCD display costs, the manufacturing cost of a 55-inch TV in 2017, OLED cost was significantly higher than the manufacturing cost of LCD displays. Based on that phenomenon, the reason for the lower cost of LCD is that it is a relatively mature technology with decades of development history and a mature industry chain, making its price relatively low. Although OLED has also been developed for several years, but its price is higher due to the materials and methods involved in the production process.

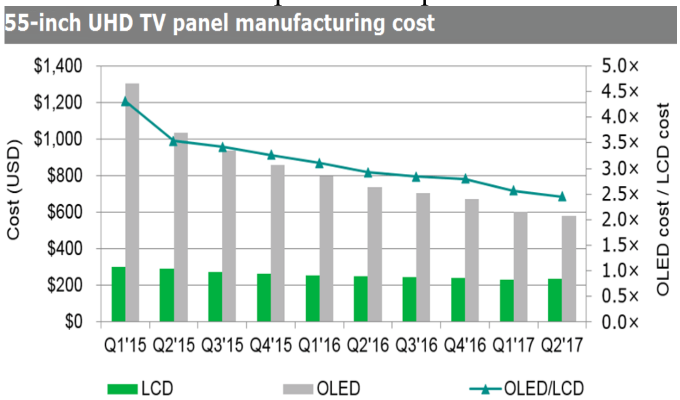

Figure 5. The cost between OLED and LCD displays [18]

4.8.Impact on users

The brightness of OLED screens is achieved through pulse width modulation (PWM) dimming. The effect of continuous luminescence is achieved by using the rapid alternating flicker of the screen and the visual residual effect of the human eye, also known as the stroboscopic effect. Even though this stroboscopic flicker is invisible or not obvious, it can still cause discomfort to the user and lead to visual fatigue or vision loss. However, the dimming of the LCD through the backlight panel is not out of such problems.

5. Conclusion

In this research, structures, mechanisms, and preparation of LCD and OLED have been summarized. In general, although OLEDs and LCDs are both light-emitting devices, there are significant differences. OLED is self-luminescence by the energy level transition of electrons, while LCD require the help of a backlight to emit light. In addition, those different structures and mechanisms lead to different applications and performance. LCDs are cheaper, last longer, and cause less damage to the user's eyes. OLED can be bent, better colour display, higher energy efficiency, and faster response speed.

Based on the advantages and disadvantages of both techniques and the current development trend, OLED is the dominant, but LCD is not going to disappear in the market. The discussion of various aspects of OLED and LCD in this paper can help people better choose their mobile phones, TVs or other devices that use LCD and OLED according to their needs.

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