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Research Article

Flexible Organic Light Emitting Diodes-FOLED

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Abstract

Flexible Organic light emitting diodes are the electronic devices. These devices are made by placing a thin film of two different types of an electroluminescent organic material between two conductors of different work functions using flexible substrates. When an electrical voltage is applied, electrons and holes are injected into the electroluminescent material. When these electrons and holes recombine, energy is emitted in the form of light. One or more additional thin layers are generally added for different purposes such as electron and hole transport in device. OLEDs can be used for different purposes like large and small area flat panel flexible self-luminous displays in many consumer products. The performance achieved was 10,000 hours of lifetime at initial luminance of 1000cd/m^2. Some of the advantages of OLED technology work and focus on the easiness of chemically modifying the materials, either to tune the colors or to make them processable, through the control of solubility. This seminar paper presents a new application for large-area, high-resolution, flexible organic light-emitting diode (FOLED) display technology currently used to manufacture low-cost color flexible displays on thin metal foil or on plastic substrates.

Keywords: *OLED, FOLED, Electroluminance, polymide,* phenylene vinylene *,polyethylene terephthalate, substrate*

1. Introduction

Flexible Organic light-emitting diodes displays using plastic substrate have many attractive features. FOLEDs are thin and light weighted, in addition, it will be designed for the flexible display to utilize the flexibility of the substrate. Flexible Organic light-emitting diodes are one of the type of Organic Light emitting Diode (OLED). The main application of organic light emitting diode (OLED) is similar to light emitting diode (LED), but its emissive electroluminescent layer is composed of a film of organic compounds like phenylene vinylene. Size of single FOLED in a FOLED Display is 5.4 micro meter.
FOLEDs constitute a new and exciting emissive technology used in todays display. Any FOLED structure consists of a layers of fluorescent organic layers sandwitched and placed between a transparent conducting anode electrode and metallic cathode. When an appropriate bias voltage is applied to the device, holes are come out from the anode and electrons from the cathode; this recombination events between the holes and electrons result in electroluminescence (EL).

FOLED has much faster response time. It is Consume significantly less energy. It has wider viewing angle, thinner display and better contrast ratio. It is safer for the environment. It has potential to be mass produced inexpensively. Any OLEDs refresh almost 1,000 times faster than LCDs. The key issue in achieving such displays is how to protect FOLEDs from moisture and oxygen. Because of barrier film on a plastic substrate and a passivation film on the OLED device, the device showed good emission characteristics after storage, and its characteristics were generally equal to those of a device fabricated on a glass substrate.

1.1What is Flexible Electronics?

Flexible electronics is a technology where the electronic circuits are assembled on flexible substrates for use. These flexible electronics are very thin, light weight, portable and flexible and have many advantages over rigid electronic devices. Currently, researchers around the globe are trying to build flexible electronic devices in various fields of electronics.

The area of flexible electronics includes a wide range of applications such as flexible displays, flexible lighting devices, electrophoretic displays, packaging, textiles, medical devices, flexible sensors, etc.

1.2 Why We Need Flexible Electronics?

FOLED technology offers some benefits in comparison with the technologies already established in the display industry, like liquid crystals (LCs) because of which we can reduce the cost of damage and repairing of any

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solid device. They can also save the storage space of the machines and instruments. Some of the advantages of flexible technology have following benefits:

1. Thin and reduced size construction because a back light is no longer required like LCD.
2. High efficiency.
3. Higher contrast ratio.
4. No viewing angle dependency.
5. Flexible displays through the thin construction.
6. Full-color displays without the need for color-filter material.

2. History

The orign of organic light-emitting diodes (OLEDs) was in 1963, when Pope discovered the light-emission of Anthracen. Then Tang first time observed a blue glow of organic materials at comparably low voltages in 1987. And after his work OLEDs are an object of intensive world-wide research area. In 2005 the Institute for Large Area Microelectronics (IGM) installed inert gas filled glove boxes and thus created the possibility to conduct its own research in this field. In the year 2005, researchers have demonstrated a flexible OLED using cyclic olefin copolymer (COC) as the substrate. In the year of 2006, researchers have fabricated a FOLED in a vacuum-free lamination process by laminating an anode component and cathode component of an OLED using a roll laminator.

In the year 2008, researchers have fabricated FOLED using an UV-curable epoxy resin as an adhesive between the substrate and the anode. Later on the researchers have found a FOLED in which polymer layers were deposited by a polymer inking and stamping method that can be employed in a Roll to Roll (RTR) form of manufacturing. In the year 2009, researchers have shown a FOLED using flexible substrate made of polyamide/ organoclay nanocomposite. To date, flexible electronic devices such as OLED, polymer cells, etc., are manufactured by various companies like Samsung, Sony, Motorola, etc.

3. OLED

Organic Light Emitting Diodes (OLED) are a different type of solid-state lighting source. An OLED device is typically formed in a sheet with emissive organic layer(s) located between a cathode and anode and deposited on a substrate. The substrate can be rigid such as glass or metal or flexible using a polymer plastic. The number of emissive layers depends on the desired light output of the device. OLED technology has great potential for new uses such flexible paper-thin OLED panels, transparent OLED panels and white OLED.

OLED display devices use organic carbon-based films, sandwiched together between two charged electrodes. One is a metallic cathode and the other a transparent anode, which is usually glass. Organic compounds are any member of a large class of chemical compounds whose molecules contain carbon, with the exception of carbides, carbonates, carbon oxides and gases containing carbon.

The basic components of an OLED are:
• Substrate. This is support for the OLED. The examples of substrates used in OLEDs are plastic, glass, thin film of metal.
• Anode. The anode removes electrons when a current flows through the device.
• Organic layers. These layers are made of organic molecules or polymers.
-Conducting layer. This layer is made of organic plastic molecules that send electrons out from the anode.
- Emissive layer. This layer is made of organic plastic molecules (different ones from the conducting layer) that transport electrons from the cathode; this is where light is made.
• Cathode (may or may not be transparent depending on the type of OLED). The cathode injects electrons when a current flows through the device
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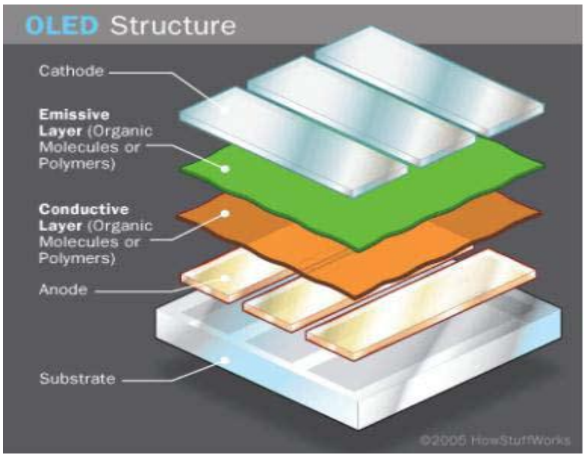

Fig 3.1: Basic structure of OLED

3.1 Types of OLED

Currently there are six types of OLED screens, each designed for a different type of use. The types are

3.1.1 Passive Matrix OLEDS (PMOLEDS)

PMOLEDS have strips of cathode, organic layers and strips of anode. The anode strips are arranged perpendicular to the cathode strips. The intersections of the cathode and anode make up the pixels where light is emitted. External circuitry applies current to selected strips of anode and cathode, determining which pixels get turned on and which pixels remain off. Again, the brightness of each pixel is proportional to the amount of applied current. PMOLEDs are easy to make, but they consume more power than other types of OLEDs, mainly due to the power needed for the external circuitry. PMOLEDs are most efficient for text and icons and are best suited for small screens (2- to 3-inch diagonal) such as those you find in cell phones, PDAs and MP3 players. Even with the external circuitry, PMOLEDs consume less battery power than the LCDs that are currently used in these devices.

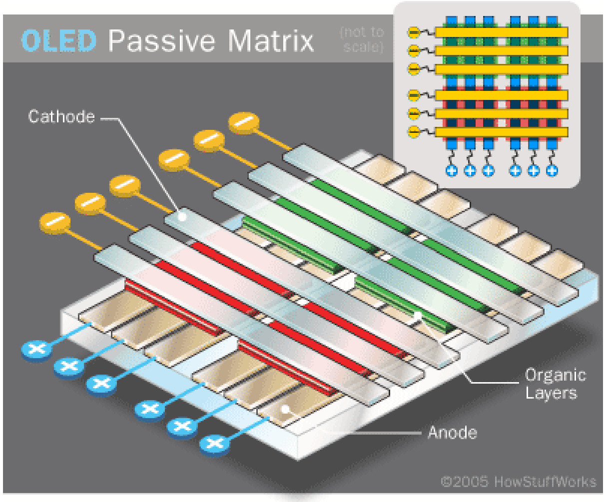

Fig. 3.1.1 Basic structure of PMOLED

3.1.2 Active-Matrix OLEDS (AMOLEDS)

AMOLED have full layers of cathode, organic molecules and anode, but the anode layer overlays a thin film transistor (TFT) array that forms a matrix. The TFT array itself is the circuitry that determines which pixels get turned on to AMOLEDs consume less power than PMOLEDs because the TFT array requires less power than external circuitry, so they are efficient for large displays. AMOLEDs also have faster refresh rates suitable for video. The best uses for AMOLEDs are computer monitors, large-screen TVs and electronic signs or billboards. The life span of AMOLED is 30,000 hrs.

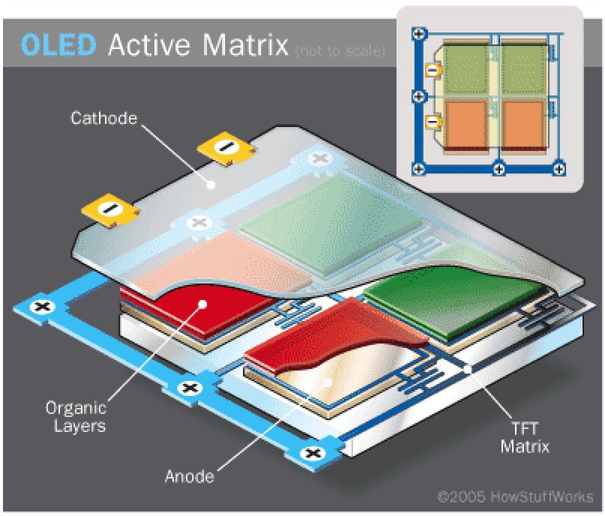

Fig. 3.1.2 Basic structure of AMOLED

3.1.3 Transparent OLEDS

Transparent OLEDs have only transparent components (substrate, cathode and anode) and, when turned off, are up to 85% as transparent as their substrate. When a transparent OLED display is turned on, it allows light to pass in both directions. A transparent OLED display can be either active or passive-matrix. This technology can be used for heads-up displays.

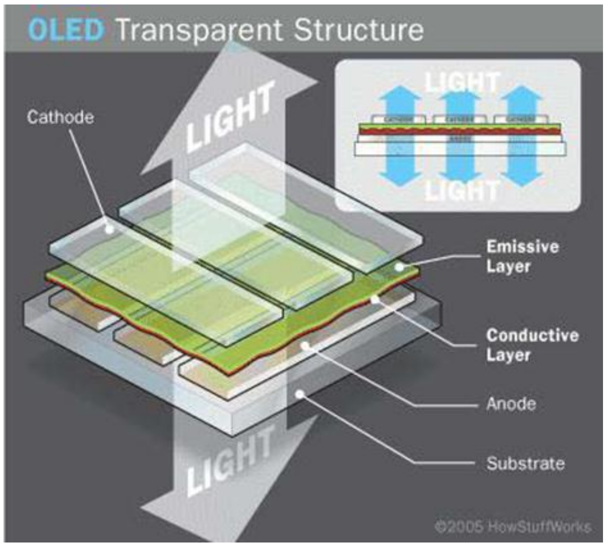

Fig. 3.1.3 Basic structure of Transparent OLED

3.1.4 Top-Emitting OLEDS

Top-emitting OLEDs have a substrate that is either opaque or reflective. They are best suited to active-matrix design. Manufacturers may use top-emitting OLED displays in smart cards. Its efficiency is 500cd/m2 and life span is1700 hrs.

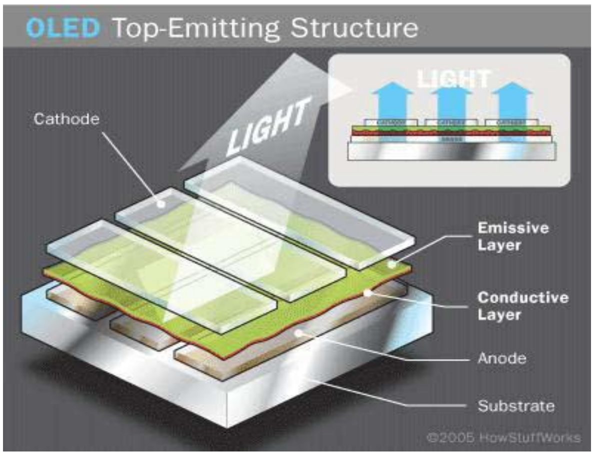

Fig. 3.1.4 Basic structure of Top emitting OLED

3.1.5 White OLEDS

White OLEDs emit white light that is brighter, more uniform and more energy efficient than that emitted by fluorescent lights. White OLEDs also have the true-color qualities of incandescent lighting. Because OLEDs can be made in large sheets, they can replace fluorescent lights that are currently used in homes and buildings. Their use could potentially reduce energy costs for lighting. Luminance is 1000cd/m2.

3.1.6 Foldable OLEDS

Foldable OLEDs have substrates made of very flexible metallic foils or plastics. Foldable OLEDs are very lightweight and durable. Their use in devices such as cell phones and PDAs can reduce breakage, a major cause for return or repair. Potentially, foldable OLED displays can be sewn into fabrics for "smart" clothing, such as outdoor survival clothing with an integrated computer chip, cell phone, GPS receiver and OLED display sewn into it.

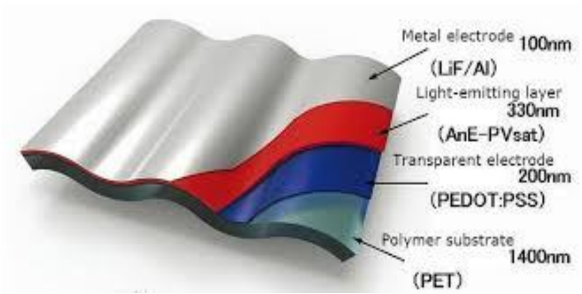

Fig. 3.1.5 Basic structure of Flexible OLED

4. Working of OLED

A typical OLED is composed of a layer of organic materials situated between two electrodes, the anode and cathode, all deposited on a substrate. The organic molecules are electrically conductive as a result of delocalization of pi electrons caused by conjugation over part of the molecule. These materials have conductivity levels ranging from insulators to conductors, and are therefore considered organic semiconductors.
Following are the working principle steps behind the OLED:

1. Power supply of the device containing OLED applies a voltage across electrodes of OLED.
2. An electrical current flows from the cathode to the anode through organic layer of OLED.
3. The cathode gives electrons to the emissive laver of organic molecule.
4. Anode removes electrons from the conductive layer of organic molecules.
5. At the boundary between the emissive and the conductive layers, electrons and holes meet.
6. When an electron finds a hole, the electron fills the hole.
7. When this happens, the electrons give up energy in the form of photon of light.
8. The OLED emits light. The color of the light depends on the types of organic molecules in the emissive layer. Manufacturers plays several types of organic films on the same OLED to make color display.
9. The intensity or brightness of the light depends on the amount of electrical applied.

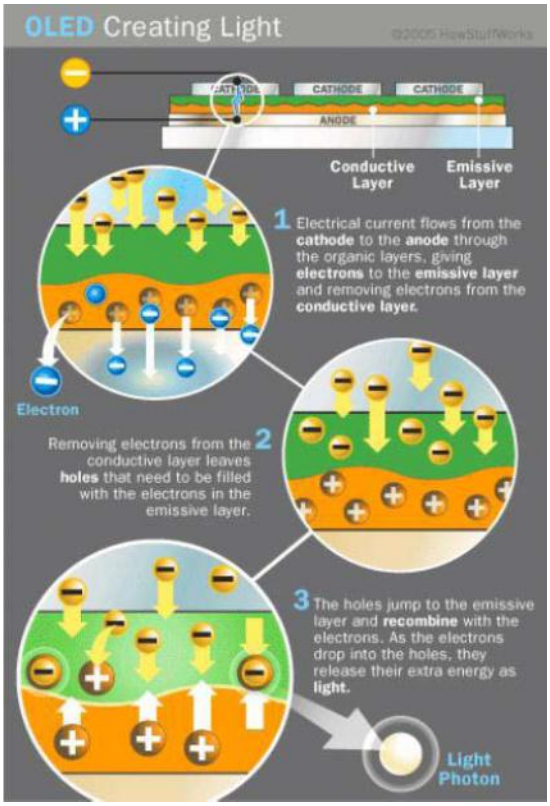

Fig.4.1 Graphic explanation of how the technology works

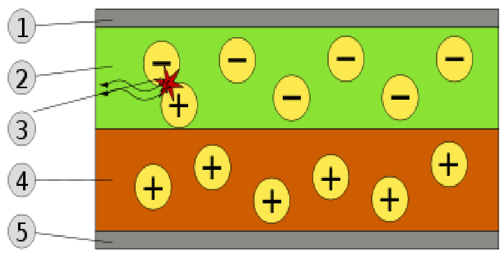

Fig.4.2 Schematic of a bilayer OLED: 1. Cathode (−), 2. Emissive Layer, 3. Emission of radiation, 4. Conductive Layer, 5. Anode (+)

5. Flexible OLEDs

OLEDs that can be manufactured in rollable form are termed as flexible OLEDs. A crucial requirement for these kinds of OLEDs is that the substrate must be flexible which means that it must be bendable, flexed and also rollable any number of times without degrading its performance. All the materials that are laid on top of the substrate must also be flexible. For transmissive displays, opaque materials for substrate cannot be used as they should be able to transmit light through them.

5.1 Flexible Substrate Materials

Research is currently active in the testing of suitable materials for substrates that will be flexible, economical and compatible with the other layer materials of OLEDS. The most common materials that have been used as of now are polymeric films, stainless steel foils and ultra-thin flexible glass. Each of them has unique properties which are suitable for certain applications. The ultra-thin flexible glasses cannot be processed in RTR form while stainless steel cannot be used for transparent OLEDs. Metal foils are very expensive and hence cannot be used for large size displays. Polymeric films are best suited to be manufactured in rollable form but they have the disadvantage of not being resistant to oxygen and moisture. Thus, proper encapsulation is required with flexible barrier materials when polymeric materials are being used for the substrate.

The polymeric materials chosen for substrate must have very high mechanical, thermal and dimensional stability, high resistance to chemical materials, low coefficient of thermal expansion, high optical transparency, very smooth surface along with being impermeable to oxygen and moisture. The most common materials used for flexible substrates are polyethylene terephthalate (PET), polyethylene naphthalate (PEN), polyamide, polycarbonate (PC), cyclic olefin copolymer (COC), polyamide/ organoclay nanocomposite (PI/OMMT), poly ethersulphone (PES), poly dimenthyl siloxane (PDMS), polyvinylidene difluoride (PVDF), polyetheretherketone (PEEK), etc.

6. Substrate Preparation Methods

Applying the organic layers to the substrate can be accomplished in three ways:

1. Vacuum Deposition or Vacuum Thermal Evaporation (VTE): In a vacuum chamber, the organic molecules are evaporated through a slow heat process and then allowed to condense as thin films onto a cooled substrate. This is a very inefficient and expensive process.
2. Organic Vapor Phase Deposition (OVPD): This process employs an inert carrier gas (such as nitrogen) to precisely transfer films of organic material onto a cooled substrate in a hot-walled, low pressure chamber. The precise transfer and ability to better control film thickness translates to lower material cost and higher production throughput.
3. Inkjet Printing. OLEDs are sprayed onto the substrate the same way our desktop inkjet printer sprays ink onto paper. This greatly reduces the cost of manufacturing of OLEDs and allows for printing on very large films. This allows for a much lower cost and larger home display products.

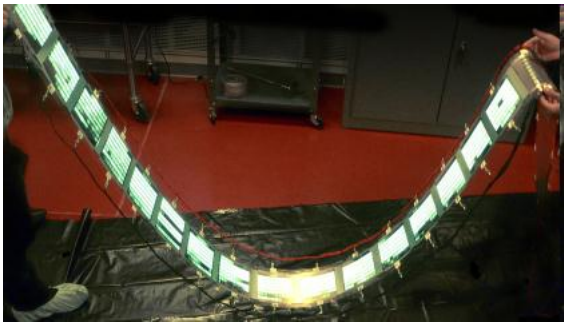

Fig. 6.1 Roll to Roll Printing

7. Advantages

1. In FOLEDs, the organic layers are plastic and hence are lighter, thinner and flexible compared to the crystalline layers of LED or LCD.
2. FOLEDs are brighter than LEDs. The substrate used to support FOLEDs can be made of plastic rather than the glass substrates used for LEDs. The glass substrate absorbs light, but that problem does not exist in OLED.
3. FOLEDs consume less power than LCDs since there is no back lighting in OLEDs. This is one of the major advantages of any OLED over LCD.
4. OLEDs have a wider viewing angle of up to 170 degrees and can operate at very low voltage ranges (2−10 volts). Thus the image can be seen from any angle clearly without having problems of blurring or color contrast.
5. OLEDs have a better contrast and faster refresh rate i.e. 1000 times better than LCD, as a result motion blur is minimized.
6. Flexible OLED displays can be rolled, bent, conformed to any shape. Such properties can be used to produce portable rollable displays, irregular shaped displays, wristband displays, etc.
7. It has ability to emit light from the surface, low heat generated and environmentally safe as compared to fluorescent lamp.
8. The plastic and organic layer of FOLED id much thinner so the size of FOLED is between 100 to 500 nm.
9. They are brighter than LED because organic layer is much thinner than inorganic crystal layer of LED. Also they do not require any glass support which absorbs some light.

8. Disadvantages

1. It is currently expensive to manufacture. Limited lifetime of the organic material OLEDs. But many companies are trying to develop Roll to Roll (RTR) technologies to manufacture OLEDs in web form which would reduce the cost of manufacturing to a great extent.
2. OLEDS have a problem of operating in direct sunlight because of their emissive nature. Since they are emissive, when they are viewed under direct

sunlight, they face readability problems. Research is being actively pursued to resolve this problem.

3. Indium is a rare earth element and thus expensive to mine and difficult to recycle. Low temperature conditions must be accommodated when using ITO with glass substrate in order to obtain low sheet resistance and high optical properties.

4. Water can damage organic layer of the FOLED and reduce the longitivity of flexible display. Therefore proper encapsulation processes are required for practical manufacturing.

5. Limited lifetime of the organic materials Lifespan- While red and green OLED films have long lifetimes(10,000 to 40,000 hours), blue organics currently have much shorter lifetimes(only about 13,000 hours).

6. Fabrication of substrate is complex and expensive progress in the production of TFT LCD, so flexible substrate such as ROLL-UP displays are used.

9. Applications

1. Kodak has launched its first digital camera using OLED in the market followed by Pioneer which introduced it in car radio and cellular phones.

2. Samsung has designed a prototype for televisions, computers that has 15.5 inches monitor followed by 17 inch space PLED by Toshiba and 24 inch multi panel screen.

3. In October 2013, following many years of development and prototype demonstrations, both Samsung and LG Display finally started producing flexible AMOLED displays on plastic (polyimide) substrates. Both Korean companies are now mass producing such displays, which are being used in mobile phones and wearable devices - such as the Galaxy S6 Edge (shown below), the LG G Flex 2 and even Apple's Watch.

Fig. 9.1 Galaxy S6 Edge

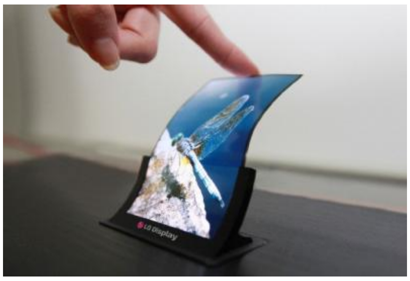

Fig. 9.1 LG 5'' Flexible OLED prototype photo

10. Future Scope

After years of research, in October 2013, following many years of development and prototype demonstrations, both Samsung and LG Display finally started producing flexible AMOLED displays on plastic (polyimide) substrates. Both Korean companies are now mass producing such displays, which are being used in mobile phones and wearable devices- such as the Galaxy S6 Edge, the LG G Flex 2 and even Apple's Watch. Samsung Display is currently producing flexible OLEDs in a 5.5-Gen line with a capacity of only 8,000 substrates per month - which is about 1 million 5" panels at 100% yields. Samsung aims to start production in its new 6.5-Gen flexible OLED fab in early 2015. LG Display currently produces plastic-based OLEDs in its Gen-4.5 fab, with a monthly capacity of 14,000 substrates. Reportedly, LGD is also planning to increase its production capacity with a new Gen-6 line.

Conclusion

OLED is an emerging display technology that enables beautiful and efficient displays and lighting panels. Thin OLEDs are already being used in many mobile devices and TVs, and the next generation of these panels will be flexible and bendable. When we talk about flexible OLEDs, it's important to understand what that means exactly. A flexible OLED is based on a flexible substrate which can be plastic, metal or flexible glass. The plastic and metal panels will be light, thin and very durable - in fact they will be virtually shatter-proof. Flexible Organic Light Emitting Diodes are evolving as the next generation displays. As FOLED display technology matures, it will be better able to improve upon certain existing limitations of LCD.

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