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Organic Light Emitting Diodes: Innovative Lighting and Display Solution

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ABSTRACT

OLEDs (Organic Light Emitting Diodes) are a breakthrough innovation in lighting and display technology for a wide array of reasons. OLEDs can be implemented in various applications from home lighting, to TV screens or GPSs. OLEDs have a 30% higher efficiency than inorganic Light Emitting Diodes (LEDs) [1]. In this review, we will delve into the pros and cons of OLEDs, as compared to other current lighting/display technologies [2]. OLEDs utilize various combinations of organic substrates to suit many specific lighting applications. A wide array of applications will be brought up and analyzed in this review. For most OLEDs, the anode is transparent, while the cathode is made of metal. The organic layer in the OLED generally has a thickness between 100 and 150 nm [3]. The specific substrates used in these applications, and their benefits will be thoroughly investigated. OLEDs are a new-age solution to hazardous forms of lighting such as CFLs (Compact Fluorescent Lamps), which contain the pollutant, Mercury (Hg). [4] More information on their environmentally friendliness and social benefits will be explored in this review as well.

Keywords: Organic Light emitting diodes, efficiency, lighting applications

1. INTRODUCTION

Among one of mankind's greatest feats was the successful harness of light through the use of electricity in 1879 by Thomas Alva Edison through the invention of the incandescent light bulb. Releasing approximately 90 percent of the energy produced to heat rather than light, these bulbs are being phased out worldwide. [5]

Just 21 years later, American, Peter Cooper Hewitt invented the first mercury vapor lamp. Leading to the creation of the modern day CFL (compact florescent light), Hewitt's technology passes an electric current through argon and mercury vapor, which excites a phosphor coating that emits visible light. However, the toxicity of the mercury vapor and the lengthy warm up time for maximum luminance inhibited its growth at market. [6]

Then in 1962, Nick Holonyack, a consulting engineer for General Electric Company created the first visible light LED (light emitting diode). By providing voltage across to conjoined sections of semiconductor material, electrons are

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excited across the diode causing a photon emission- or light. [7] Although LEDs are remarkably efficient, they lack the luminance power needed in modern day applications.


Fig. 1. Effects of mercury poisoning on a foot. [2]

Today, engineers are racing to fabricate the next lighting solution that incorporates high luminance, efficiency, and longevity. As a result, companies such as Apple, Samsung, and Lg have invested both time and money into further research of OLEDs (Organic Light Emitting Diodes). [2] First developed by the Eastman Kodak Company in 1998, [9] OLED technology is largely researched and developed by many companies searching for an efficient alternative to current lighting and display technologies.

Since their first conceptualization, OLEDs have been seen as a promising future of display technology to overshadow liquid crystal display (LCD) displays currently in use through superior efficiency and durability.

Although most organic polymers in electronics have been traditionally associated with insulating properties, Shirakawa discovered an electrically conducting polymer, (doped polyacetylene) which was honorably awarded by the Nobel Prize in chemistry in 2000. [10] Since then, there has been a significant effort in industry and academia to further investigate π-conjugated molecules for their unique semi-conducting properties. π conjugated molecules are organic chains and rings which involve alternating saturated and unsaturated bonds. This π conjugation allows the carbons in these chains can easily share electron density from the P-orbitals of adjacent carbons. The discovery of electroluminescence in π-conjugated has led to the commercial applications of organic light-emitting diodes (OLEDs), photovoltaic cells (OPVs), and field-effect transistors (OFETs). [11]

The basic structure of an OLED consists of one or more thin films of organic electroluminescent (OEL) material sandwiched between a metallic cathode and a transparent anode, resulting in a 100 to 150 nm thick device. The OEL materials act as semi-conductors in the device, so when a voltage is applied between the cathode and the anode, electrons are injected into the organic material from the cathode, and holes are injected from the anode. [1] From the region where the injected holes and electrons recombine, reducing the energy level of the electron, a photon is emitted [12].

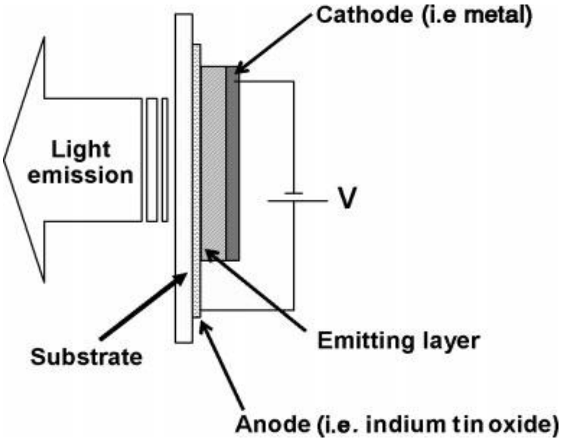


Fig. 2. Basic OLED device structure [12].

The color of the photon emitted is related to the energy difference between the highest occupied molecular orbital (HOMO) and the lowest unoccupied molecular orbital (LUMO) levels of the

OEL π-conjugated molecule used. This proves that the wavelength, and thus the color of the light emission can be controlled by the extent of the conjugation in the molecule or the polymer. [1] For efficient hole injection from the anode, a low HOMO barrier is required in the organic material (typically 5–6 eV). ITO is usually used for the anode because of its high work function, conductivity, and light permeability.

On the cathode side, a low LUMO barrier is required in the organic material (typically 2–3 eV). Low work function metals such as Ca and Mg are ideal, but are very sensitive to moisture. More and more stable cathodes, such as Mg/Ag alloys are constantly being developed and introduced to overcome this issue. [1]

The complexity of layering in the structure of OLEDs can result in highly specialized functions. Multilayer devices are also greatly efficient, as they have more charge carrier/electron directing layers, resulting in more confinement of excitons and charge carriers, thus improving energy transfer from the cathode to the anode. This efficiency is even greater when transport layers are electrically doped to effectively increase charge promotion through the usage of heavy metal cations.

Most OLED devices employ a bottom emission, meaning light is emitted through the substrate side, although top emission is also possible given a transparent material acting as the cathode. Top emitting OLEDs (TOLED) were once considered not ideal due to the limited luminance output through the metallic cathode. However, engineers can now fit TOLEDs with silicon wafers in order to emit a higher resolution picture than that of bottom emitting OLEDs. [2] The main difference from this improvement in increased picture quality is that light emitted by TOLED organic substrates does not pass through the thin film transistor (TFT) on the bottom of the OLED. This also allows for a larger active area, resulting in lower power consumption for a fixed luminance output. However, TOLED technology currently suffers because the semi-transparent cathode layers used, such as silicon wafers, can only be applied to small OLEDs. [2]

Small Molecule-OLED (SM-OLED) Fabrication

Many of the low molecular weight materials (several hundred g mol $^{-1}$) are known to form amorphous, thin films when deposited onto a substrate by thermal evaporation in a high vacuum ($<10^{-6}$ mbar). [2] This deposition is popular because it allows a straightforward fabrication of multilayer OLEDs. Although these systems are straightforward, they are generally not suited for mass production due to insufficient material yield, low deposition rates, and unacceptable thickness homogeneity on large substrates. In addition, given the expenses involved in evaporation systems, they are unable to economically compete.

Polymer-OLED (P-OLED) Fabrication

Solution processing proves to be the way to true low-cost mass production of large-area OLED lighting devices. In small scale research applications, simple methods such as dip- and spin-coating can be used, but for larger areas, printing directly onto the surface may be more favorable. Although the fabrication of OLEDs with solution based deposition methods is substantially cheaper than vacuum deposition, the fabrication of multilayer devices is not as straightforward. This is because a previously deposited material could be dissolved by, or mixed with the next depositing layer, resulting in inhomogeneous films. [2]

The most prominent strategy to overcome this issue, is to render each layer insoluble after deposition. One approach to accomplish this is to use polymer precursors that can be made insoluble by a process of induced crosslinking (polymerization) after deposition, usually through thermal or photochemical steps. Among the polymerization reactions studied are polyadditions, [2 + 2] cycloadditions, and radical polymerizations. [2] However, this process is very difficult as many requirements must be met, otherwise the devices electrical and optical properties are harmed.

EFFICIENCY OF OLED TECHNOLOGY

The most prominent advantage of OLED technology is the high levels of efficiency demonstrated by all OLEDs. Efficiency is characterized by either its quantum efficiency, the current efficiency in cd A^{-1}, or the luminous efficiency in lmW^{-1}. [13] Although luminous efficiency is the most commonly known way to present efficiency, quantum efficiency and current efficiency are also equally valid methods.

Quantum Efficiency

Quantum efficiency takes into account two factors: the internal quantum efficiency (n_{int}) and the external quantum efficiency (n_{ext}). The external efficiency is defined as the number of emitted photons divided by the number of injected charges:

$$\eta_{ext} = (n_r)(\varphi_f)(x)(\eta_{out}) = n_{int} n_{out} \qquad (1)$$

where n_r is the probability that holes and electrons recombine to form excitons. [13] However, because charge carriers in organic materials are relatively immobile, this constant is nearly equal to 1. Nevertheless, n_r can be optimized through manipulation of the efficiency of electron and hole injection into the organic layers. This is accomplished by using an effective organic electron transfer material. [13]

Another contributing factor to the external quantum efficiency is the fraction of excitons that decays radioactively, or φ_f. However, in organic materials, and particularly in doped systems, the value of φ_f can approach 100%. Yet another major limiting factor for light sources is x; the probability for radiative decay which is also the fraction of singlet excitons emitted. Through research on spin statistics, the fraction of singlets is x=1/4. Additionally, through the process of doping, engineers can allow singlet to triplet energy transfer, allowing both (singlets and triplets) to emit excitons, thus producing light. [13] This is a major advantage over the rigid 25% of light emitting excitons of conventional fluorescent technologies.

η_{out} is the fraction of excitons that can escape the device. This is limited by the refractive index of the organic material used. The equation is as follows:

$$n_{out} \approx 1/(2n^2) \qquad (2)$$

With average refractive index values of between 1.7 and 2, typical fluorescent organic materials result in a n_{out} value between 12.5-17%. Therefore, if the organic substrate is not doped, the OLED is limited to a maximum external quantum efficiency of under 5%. [13] Through the understanding and experimentation with various substrates, engineers hope to devise new methods to lower the effects of the refractive attributes of the organic materials. As depicted in Figure 3, many waves of light are wasted due to refraction.

Quantum efficiency also most easily explains why Kodak's first OLED was substantially less efficient than modern day phosphorescent materials. Through doping, both singlet and triplet states are given enough energy to react with the electron "holes" and emit a photon in the process.

This means that rather than only emitting the singlet state excitons, these phosphorescent materials allow the remaining 75% of excitons in the triplet state to be emitted as light as well. [13] Further developments in OLED technology such as doping look to further maximize quantum efficiency.

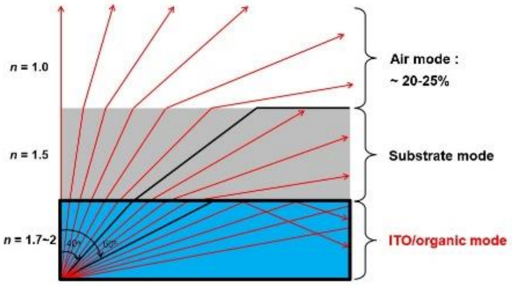


Fig. 3. Typical refraction levels for a simple OLED [13].

Current Efficiency

Another way of expressing efficiency is current efficiency (n_L). Also known as Faraday efficiency, current efficiency is expressed in candelas per meter squared (cd m^{-2}). This efficiency is proportional to the ratio of the luminance to the current density flowing into the diode. In order for a portable display to be competitive at market, it must at least match the typical device lifetime for portable electronics. Lifetime of a device is defined as the mean time it takes for the display to deteriorate to half brightness, and for portable electronics, the lifetime expectancy is over 20,000 hours with a brightness over 100 cd m^{-2}. [13]

The degradation of small-molecule-based devices such as OLEDs has been attributed to three main factors: dark-spot degradation, catastrophic failure, and intrinsic degradation. However, the first two of the three factors can be almost completely eradicated by controlling the device fabrication conditions. By creating these devices in a clean room and not allowing foreign particles to interfere with the internal components, the only factor that remains to limit the lifetime of an OLED is its intrinsic degradation. [2] Currently, limiting the intrinsic degradation of the blue component is the biggest challenge that engineers face in the application of OLEDs as a viable display solution.

In 2006, engineers' most efficient blue light emitting diode lasted between 6000 and 8000 hours of output at a minimum of 200 cd m^{-2}. However, today blue diodes can last over 14000 hours under the same conditions. Although blue diode efficiency is still not that of green or red diodes, significant progress has been made.

The diversity in efficiency of the various components also creates an additional problems for OLED functionality. As the blue component degrades faster than the other components, the display experiences a red shift. The severity of this shift toward the red color spectrum is related to the ratio of the degradation of the blue component to the other two. To combat these effects, blue substrates are often run at higher voltages to output higher brightness, or are even sometimes simply larger than other color substrates to allow for the same voltage to produce more light. However, both of these techniques simply create a blue shift in a new OLED which can be best described as a "washed out" picture. [13]

With an expected 40% smart phone market penetration by the year 2018 as predicted by Samsung, millions of dollars are being invested into the advancement of OLED technology. [15] Furthermore, with companies such as Apple, LG, and Samsung all with OLED smartphone patents, [1] OLED research funding is at an all-time high.

Luminous Efficiency

The final and most common method of describing efficiency is luminous efficiency. Given in lumens per watt (lm W^{-1}), luminous efficiency is the ratio of the optical flux to the power input and is given by:

$$n_P = (L\pi)/(JV)=n_L(\pi/V) \qquad (3)$$

where V is the voltage across the OLED, L is, and J is the current density. Because both n_L and n_P are measured with respect to eye sensitivity, different diodes with the same quantum efficiency (n_L) and working voltage can have varying luminous efficiencies. This is due to the fact that eye sensitivity is maximum in the green range, thus making blue and red diodes appear less luminously efficient. [7]

Fig. 4. New LG Flex (Released Jan 31st 2014) [8].

However, efficiency is not simply limited to the duration that a device can maintain a certain luminance. Upon the release of the Lg flex this past January 31st, [11] many users were skeptical of the average luminance value of 311 cd m^{-2} as the main competition, the iPhone 5, output 499 311 cd m^{-2}. Although these numbers may imply that OLED technology drains batteries at a faster rate than LCD technology, users experienced an unexpected effect. Due to the ability of the OLED in the Lg flex to absorb light rather than to reflect it, users found that to experience the same picture, OLEDs required substantially less luminance. This results in both increased battery life and picture quality in the presence of any glare. [8]

ORGANIC SUBSTRATES USED IN THE FABRICATION OF OLEDS

There are many different organic materials which can be used in between the anode and cathode in OLEDs. The anode, cathode, and mounting substrate can also be made of a wide array of inorganic or organic materials. Each OLED device which incorporates these possible materials will have different properties, including thickness, translucency, flexibility, and even possible implementation in fabrics.

The stack of organic and inorganic material which make up an OLED device are mounted onto a substrate which gives it stability and acts as the “backbone” of the device. Generally, OLEDs are mounted on thin glass sheets. Glass is an optimal material for OLEDs mainly for its complete impermeability to water and oxygen, two factors which OLEDs are found to rapidly degrade in the presence of. Glass is also has very high optical transparency, allowing for maximal photon recovery from the OLED device. Finally, glass is a cheap and easily available substrate to use in OLED research.

Recently, flexible panel OLEDs have been a major topic of international research. The major inherent problem is the rapid degradation of OLED materials due to the sensitivity to vapor and chemically reactive oxygen. For OLEDs to have reliable performance lifetime, oxygen and moisture transmission rates must be below 10^{-6} g/m^2 day. [15]With the utilization of Thin Film Encapsulation (TFE) technology, OLED displays can be fabricated as thin as the organic material used in the device. These TFEs have good diffusion barriers to water and oxygen penetration, high optical transparency, high flexibility to avoid cracking during bending, and also allow good heat diffusion. Polyethylene (PE), polypropylene (PP), and polyethylene terephthalate (PET) are of a special interest due to their compatibility with flexible technology. According to Table 1, all these plastics have water and oxygen transmission rates which are much higher than the maximum tolerable 10^{-6} g/m^2 for the industrialization of long-time driving OLED display, meaning a barrier film must be added on the substrate. [8]

Table 1. Transmission rates of the different types of plastic films

Material (μ m)	density ($g.cm^{-3}$)	melting point (℃)	O_2 ($cm^3m^{-2}d^{-1}$)	H_2O ($gm^{-2}d^{-1}$)
PE(30)	0.91-0.94	104-120	4800	15
PP(19)	0.84-0.91	130-170	1700	5
PET(12)	1.38-1.42	256-260	140	46

It has been found that the most highly desirable polymer, PET has a relatively rough surface as compared to glass, which can be very detrimental to the optical efficiency of the OLED. To combat the issues of surface roughness, and water/oxygen permeability, Plasma Enhanced Chemical Vapor Deposition (PECVD) is used to add a passivation film of SiOx, followed by a SiNx film. As illustrated in Figure 5, this order of layering is used because the particle diameter of SiOx is bigger than that of SiNx, leading to a smooth composite passivation film. [8]

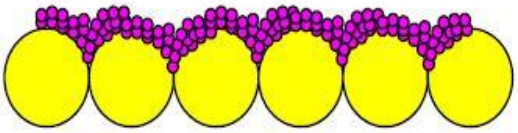


Fig. 5. SiOx/ SiNx film deposition [8].

The PECVD process is used because of its use of cold plasma, thus keeping PET substrates at safe, low temperatures. [16] In order for an OLED device to be functional and flexible, these layers must be implemented onto the PET substrate in very thin layers, and reliably. Figure 6 depicts the entire flexible OLED device including all necessary layers for functionality.

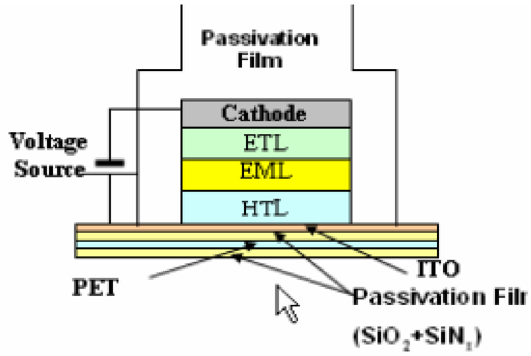


Fig. 6. Cross-sectional view of a typical OLED on a layered PET substrate. [8].

According to Figure 7, PET based, and glass based substrates have relatively competitive light outputs. This proves that the extra layers implemented to allow for flexible devices, do not have a detrimental effect on light output compared to a single layer of glass.

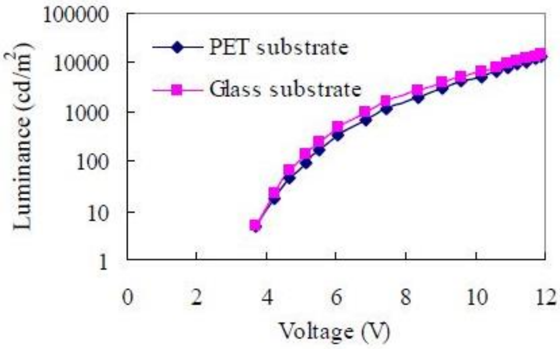


Fig. 7. Luminance as a function of voltage for OLEDs with PET, and glass substrates Transparent Cathode Materials [12].

The cathode of the OLED can also be manipulated by using various materials, so alter its properties, and thus the properties of the OLED device. Low work function metals such as Ca and Mg are ideal for use in the cathode of an OLED, but they are very sensitive to moisture. Currently, a thin

LiF layer (~1 nm) capped with a thicker Al layer is used as the cathode, and is completely opaque. [16]

To allow for the OLED device to be transparent, for future "see-through" electronics, a transparent cathode is essential. Thin films of Ag doped Mg (Mg:Ag) are often looked to for transparent cathodes, however, Mg:Ag suffers from high chemical reactivity and poor electrical conductivity. Utilizing MoO_3/Ag/MoO_3 (MAM) stacks as transparent cathodes in OLEDs is one solution to this problem. In this specialized material, a 14-20 nm film of Ag is sandwiched between two thicker, 40 nm MoO_3 films. [17] The Ag film is very thin, because, according to Figure 8a, as the thickness of this metallic film increases, optical transmittance decreases. Conversely, the Ag film cannot be too thin, because as thickness of the film increases, Figure 8b depicts that its resistance also decreases, which is desirable for the cathode. Furthermore, due to the smoothness of MoO_3, the negative effects of the rough Ag are suppressed. [17]

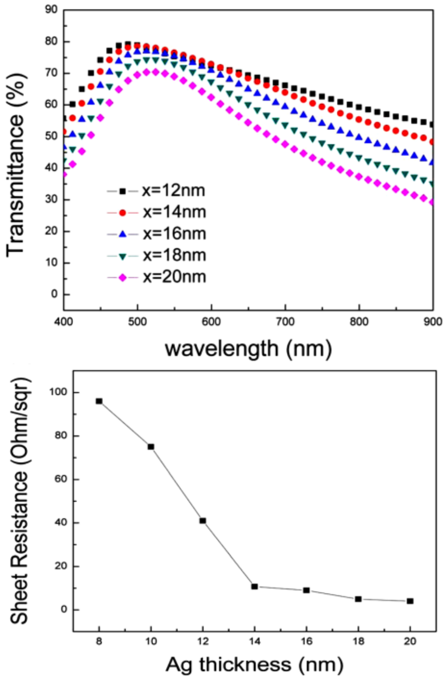
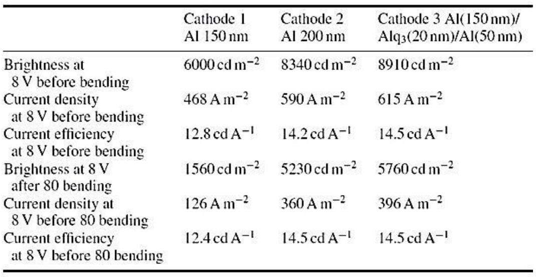


Fig. 8. Optical transmittance (a), and sheet resistance (b) of MoO3 (40 nm)/Ag (x nm)/MoO3 (40 nm) MAM stack on glass, with x varying from 12 nm to 20 nm. [12].

Flexible Cathode Material

For an OLED device to be flexible, the cathode must resist degradation after multiple bend tests. Flexible organic light-emitting devices (FOLEDs) are fabricated on a polymer substrate with metal/organic multilayers of Al/Alq3/Al as the cathode. Compared with the control device with the Al cathode, the decrease in the current density and the luminance after repetitive bending is reduced. This is due in part to a few reasons. The surface of pure Al cathodes tend to bunch up, and become wavy after multiple bend tests. This results in delamination from the device, promoting degradation. The device with the Al/Alq3/Al cathode however, showed no black cracks in the resulting image area after the bending test. Along with physical damage to the Al cathodes, brightness, current density, and current efficiency were drastically reduced after 80 bend tests, while the Al/Alq_3/Al cathode stayed relatively constant as depicted in Table 2. [17]

Table 2: The brightness, current density and current efficiency at 8V of the devices with cathodes 1, 2 and 3 before and after 80 bending cycles [11]



	Cathode 1 Al 150 nm	Cathode 2 Al 200 nm	Cathode 3 Al(150 nm)/ Alq_3(20 nm)/Al(50 nm)
Brightness at 8 V before bending	6000 cd m^{-2}	8340 cd m^{-2}	8910 cd m^{-2}
Current density at 8 V before bending	468 A m^{-2}	590 A m^{-2}	615 A m^{-2}
Current efficiency at 8 V before bending	12.8 cd A^{-1}	14.2 cd A^{-1}	14.5 cd A^{-1}
Brightness at 8 V after 80 bending	1560 cd m^{-2}	5230 cd m^{-2}	5760 cd m^{-2}
Current density at 8 V before 80 bending	126 A m^{-2}	360 A m^{-2}	396 A m^{-2}
Current efficiency at 8 V before 80 bending	12.4 cd A^{-1}	14.5 cd A^{-1}	14.5 cd A^{-1}

A key issue of flexible OLEDs is the short lifetime. By increasing the cathode's mechanical stability, the lifetime of the flexible OLEDs was greatly improved, as seen in Figure 9.

This evidence proves that the Al/Alq$_3$/Al cathode is more efficient than its Al cathode counterpart, making it a very desirable cathode material in flexible OLEDs.

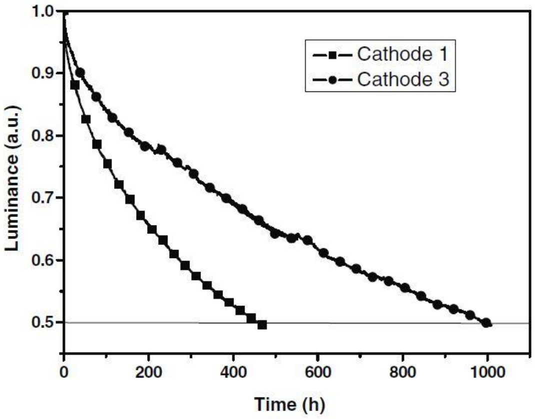


Fig. 9. The luminance decay curves of the devices with cathodes 1 and 3 (Al cathode, and Al/Alq$_3$/Al cathode, respectively) under constant current driving. [12]

Anode Materials

Indium doped Tin Oxide, (ITO) In$_2$O$_3$, is the most commonly used organic material in anodes of OLEDs. ITO has a favorably high work function, allowing relatively good injection of holes to the organic electroluminescent (OEL) material. ITO also has a fairly low sheet resistance, which is directly proportional to power efficiency in the OLED device. The major downfall of ITO, is the fact that is brittle, and not able to be utilized for large scale OLEDs, such as large TV screens. [18]

Graphene is a flexible monolayer film of sp^2-hybridized carbon atoms, and has potential to be used as an anode material in OLED devices. Large-scale graphene films can easily be made using chemical vapor deposition (CVD) onto flexible substrates similar to the PET based substrate previously covered. Despite its strong potential as a transparent anode, the utilization of graphene alone as a flexible anode of an OLED is less than ideal because of its relatively low work function (~4.4 eV) and high sheet resistance (>300 Ω) compared with ITO, which has a work function and resistance of 4.9 eV and 10 Ω respectively. Also, the low conductivity of pure graphene limits the luminous efficiencies. [18]

To achieve a high CE in OLEDs that have graphene anodes, a hole injection layer (HIL) composed of poly-(3,4-ethylenedioxythiophene) doped with poly-styrenesulphonate (PEDOT:PSS) and a perfluorinated ionomer (PFI) copolymer is used. This PFI provides a higher work function through the layer (5.95 eV), and thus enables holes to be injected efficiently to the organic electroluminescent layer. [18]

Devices with anodes containing four layers of graphene doped with HNO$_3$ displayed higher current efficiencies, and comparable luminance to the industry standard ITO material according to Figures 10a and 10b, respectively. [18]

AuCl$_3$ also proved to be a superior doping agent over HNO$_3$, decreasing graphene's sheet resistance to ~30 Ω, nearly identical to that of ITO. Devices with four layers of graphene anodes doped with AuCl3 showed a high maximum current efficiency (CE) of 27.4 cd/A, and luminance efficiency (LE) of ~28.1 lm/W. [18]

With a bending radius of 0.75 cm, it was found that the graphene device maintained its current density after 1,000 bending events, while the ITO device failed after 800 events. [18] This proves that this doped graphene anode has excellent bending stability, and is practical for implementation to flexible OLED devices.

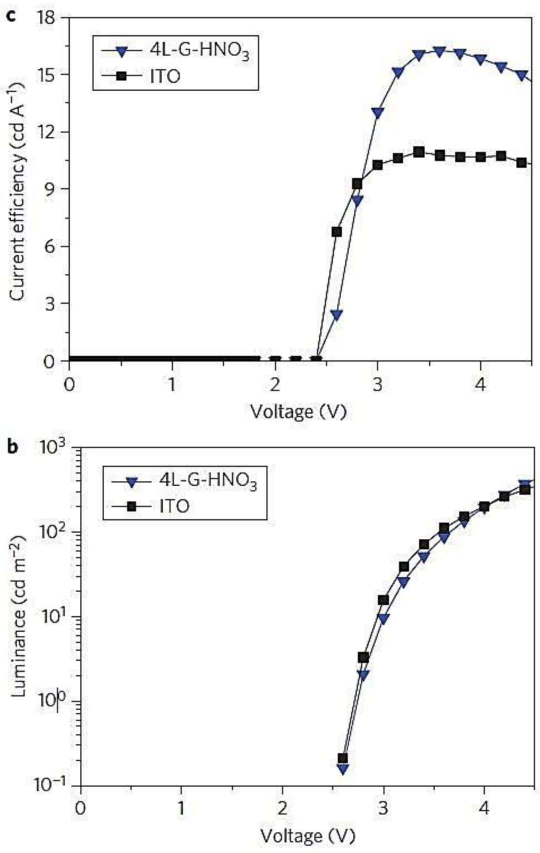


Fig10: Luminance (a), and current efficiency (b) as a function of voltage for flexible white OLED devices with 4 layer graphene anode (doped with HNO3), vs ITO anodes. [10]

MAXIMIZING OLEDS PERFORMANCE, AND WOLEDS

Increasing Efficiency of ITO Based Anode

Although the organic material which is generally used in OLED devices is Indium Tin Oxide (ITO), a layer can be added between the ITO and the hole transport layer (HTL) to greatly improve efficiency. Through the self-assembled monolayer technique (SAM), which will not be covered in this review, 4-[(3-methylphenyl) (phenyl) amino] benzoic acid (MPPBA), can be coated on the ITO surface to act as a hole injection layer (HIL). MPPBA’s structure, as seen in Figure 11, involves a carboxylic acid functional group, which allows monolayer chemical anchoring to the ITO surface.

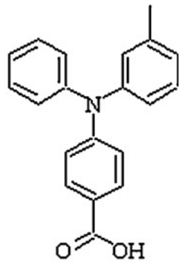


Fig. 11. Molecular structure of the MPPBA molecule [6].

As you can see in Figure 12a, luminance, measured in cd/m^2, increased when the ITO anode was enhanced by adding MPPBA. Figure 12b shows an OLED device’s luminance efficiency with and without a MPPBA layer on the anode. [19]

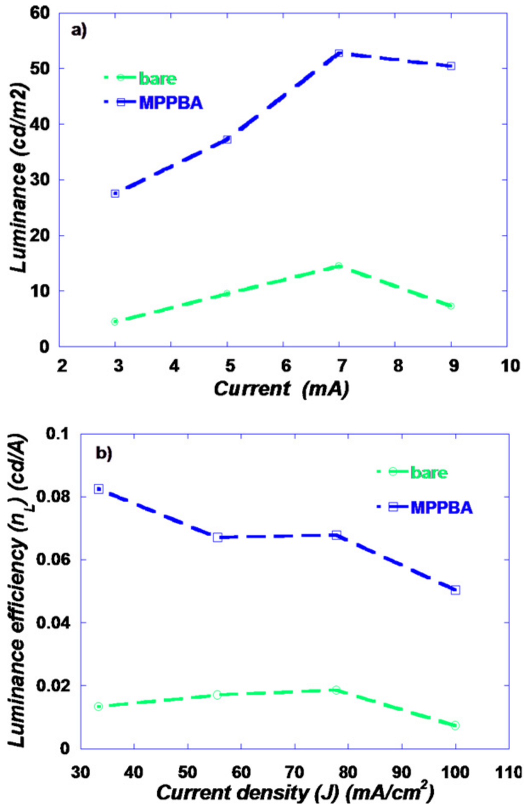


Fig. 12. Luminance (a) and luminance efficiency (b) characteristics of an OLED device consisting of the following layers: SAM-modified ITO/TPD (50 nm) /Alq_3(60 nm)/Al (120 nm). [19]

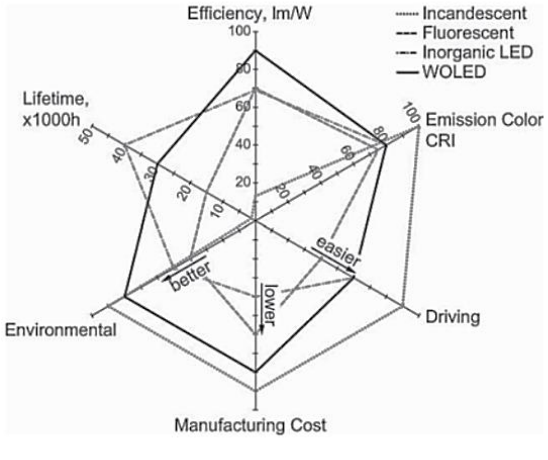
The increase in the luminance intensity of MPPBA modified OLED devices can be explained by the increased number of tunneling channels over its π -conjugated structure improving hole injection by modifying work function of the ITO anode. [19]. A variety of HILs can be employed to increase the anode’s work function, and thus drastically improve overall efficiency.

Increasing Efficiency of Cathode

The efficiency of the cathode in an OLED device can be greatly improved through the implementation of a doped electron injection layer (EIL), and electron transport layer (ETL).

Photon formation is limited by the number of injected electrons because most organic semiconductors mobility of electrons are in general lower than that of holes. Therefore, the effective doping of the EIL and ETL can make a huge difference in the efficiency of the OLED device. Lithium nitride, which is stable in air, (Li_3N) was found to be an efficient n-type doping material in tris-(8-hydroxyquinoline) aluminum (Alq3), which is both an ETL, and an EIL material. [20]

This n-type doped device (donor) exhibits higher luminance, and current efficiency than that of the non-doped device, with the highest values for the device with thickness of 10 nm, as shown in Figure 14a and 14b respectively.



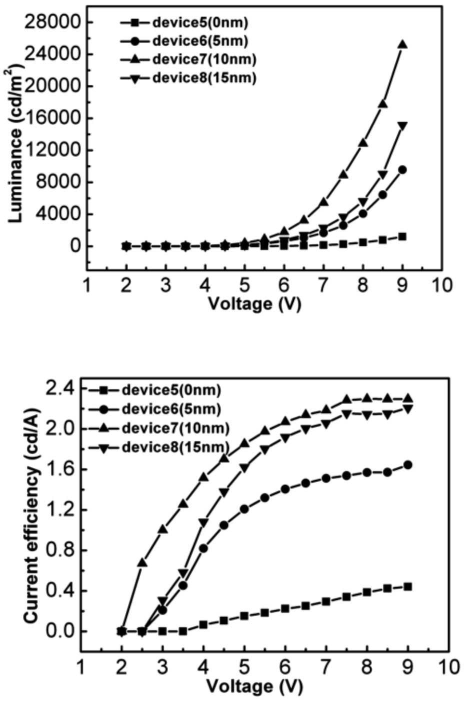


Fig. 13. Luminance vs voltage curve for 4 devices of differing doping layer thicknesses ,Current efficiency vs voltage curve for 4 devices of differing doping layer thicknesses[18].

The device with a 10 nm doping agent produces the highest current efficiency, 2.30cd/A at 8V, which is 5.2 times higher than that of the non-doped device. [20] This proves that doping the EIL and ETL can have very considerable effects on the OLED device’s current efficiency.

White Organic Light Emitting Diode (WOLED)

WOLED technology, the most efficient application of OLED devices, incorporates many of these efficiency improving techniques along with specialized functionality. Emitting wavelengths across the entire visible spectrum, WOLEDs emit white light with greater efficiency than any other current available manufactured light source. By blending the light emitted from various substrates, engineers have optimized the color-rendering index (CRI) to a value of over 80. As shown in Figure 14, the only light source with a better CRI are incandescent which are being phased out of the U.S. market due to their inefficiency and containment of Mercury.

Although inorganic LEDs have a similar CRI, their lack of efficiency and containment of the harmful chemical arsenic makes them a less viable option for a steady and sustainable light source for the future. All other light sources currently on the market have a CRI less than 80, meaning that the light emitted is non-continuous and can result in irritating color tint. [2]

ADDITIONAL APPLICATIONS OF OLED DISPLAYS

In addition to the possible implementation of WOLEDs into modern lighting applications, OLED technology has also penetrated the market in many other forms. Flexible OLEDs have been incorporated into televisions, phones, and fabrics to provide a vast array of specialized products. Curved televisions fitted with OLEDs combine the wide viewing angle of OLEDs, the Imax effect of a curved display, and a thickness of 4.3 mm. Cellphones can now also bend, allowing for higher resolution and durability. In addition, the incorporation of flexible OLEDs into fabrics allows for displays that can be draped, folded, and stored like a cloth. Even the automotive industry has shown interest into OLED application. Touch screen windows, heads up windshield displays, and various other efficiency oriented applications are being researched for more luxurious and safer driving conditions through the use of transparent OLED displays. [1] With such practical and desirable applications possible, OLED technology shows promise as a display solution to reduce both wasted energy and environmental devastation.

Practicality of OLED Technology

Determining whether or not a new technology will survive in the market relies on a few aspects. Cost is a big boundary which years of international research have been able to start to break down. As covered in the applications section of this report, specialized OLEDs can greatly outperform current technologies in place.

Samsung has predicted that OLED technology in smart phones will have a 40% flexible market penetration by 2018, a 200 fold increase from the .2% market penetration in 2013. Also, according to Samsung’s CAPEX financial plan, (depicted in Figure 15) they will slowly reduce its funds in LCD research, and greatly increase its funds to active matrix OLEDs (AMOLEDs) in the next 3 years. [15]

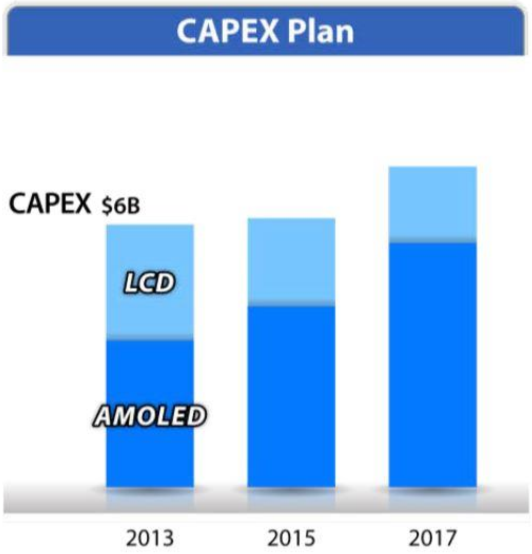


Fig. 14. Financial budgeting plan for Samsung in upcoming years[10].

Apple has also shown great interest in OLED technology in the past years. March 27, 2013, US Patent & Trademark Office published a patent application from Apple that reveals a stunning future iPhone with a wraparound display so that both sides of this iPhone will be able to display content either individually or as one continuous display. This patent is outlines in Figure 16 using relatively vague pictorials.

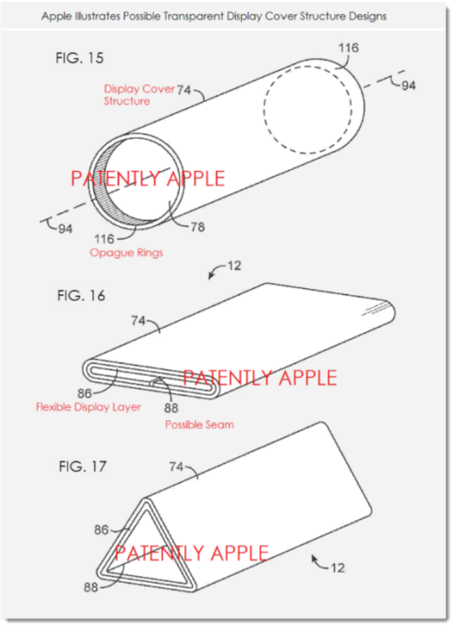


Fig. 15. An outline of possible future technology to be used by computing giant, Apple. [7]

Competition such as this will most certainly result in a race for a better OLED display and application. As a result, it can be safely assumed that OLED technology will become a household name in the coming years.

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دیودهای نور گسیل آلی: نمایشگر و راه حل نوآورانه نورپردازی

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چکیده

دیودهای نور گسیل آلی تکنولوژی با اهمیت و نوآوری در صنعت نمایشگر ها ایجاد کرده است. تکنولوژی نورپردازی و نمایشگری توسط دیودهای نورگسیل آلی نسبت به تکنولوژی های مشابه دیگر، به مقدار ۳۰ درصد بازدهی بالاتری ایجاد کرده است. مزایای زیاد این تکنولوژی در صفحه نمایش تلویزیون و صنعت نورپردازی باعث شده است که جایگزین تکنولوژی‌های دیگر شده است. در این مقاله مزایا و معایب تکنولوژی دیودهای نورگسیل آلی نسبت دیودهای نورگسیل دیگر بررسی شده است. در دیودهای نورگسیل آلی آند شفاف است، در حالی که کاتد از فلز که عموما ضخامتی بین ۱۰۰ تا ۱۵۰ نانومتر دارد، ساخته می شود. همچنین در این مقاله طیف وسیعی از کاربردهای دیودهای نور گسیل آلی بررسی شده ومورد تجزیه و تحلیل قرار گرفته است.

کلید واژه‌ها: دیودهای نور گسیل آلی، بازده، کاربردهای روشنایی

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