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Flexible OLED on a Polyimide Substrate

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Abstract

Organic light emitting diodes (OLED) are new generation display technologies replacing heavy and bulky CRTs and unidirectional LCDs. OLED is more thinner, more compact and has a wide viewing angle (up to 160 degrees). OLEDs are self luminous and do not require any kind of backlighting like LCD. Regular OLEDs are usually fabricated on a glass substrate, but by replacing glass with a flexible plastic such as polyethylene terephthalate (PET), OLEDs can be made both bendable and lightweight. This paper deals with the various polymers used to act as a plastic substrate. Among many polymers PEN, polyamide and polyimide are found to have more better qualities to serve as a plastic substrate which provides better flexibility and more resistant to moisture and oxygen permeation.

Keywords: *PEN, ALD, Silicon-dioxide, tunneling current, hafnia, zirconia..*

1. Introduction

A new ultralow-cost, lightweight and flexible display technology, based on organic light emitting diodes (OLEDs) is emerging. OLEDs are thin film devices which use electroluminescent organic materials. Organic light emitting diodes (OLEDs) are electronic devices made by placing a thin film of an electroluminescent organic material between two conductors of different work functions. When an electrical voltage is applied, electrons and holes are injected into the electroluminescent material. When these recombine, light is emitted. Additional thin film layers are usually added for different purposes such as electron and hole transport. OLEDs can be used for large and small area flat panel flexible self-luminous displays in many consumer products.

Recently, the number of publications on OLEDs has increased because of their potential applications in flexible displays and cheap electronic circuits such as radio-frequency identification tags. OLEDs fabricated on plastic substrates, such as polyethylene naphthalate (PEN), polyester, PET, PI, and polycarbonate are the best flexible displays because they can be very thin and consist entirely of solid-state materials. However, thin-film encapsulation is required in manufacturing to prevent degradation of the OLEDs, which are very sensitive to water vapor and oxygen absorption. Some of the advantages of OLED technology relay on the easiness of chemically modifying the materials, either to tune the colors or to make them processable, through the control of solubility. New materials have been developed with controlled color emission (for multicolor displays), controlled charge injection, controlled solubility, and controlled interchain interactions for optimization of luminescence efficiency.

2. MANUFACTURING ISSUES

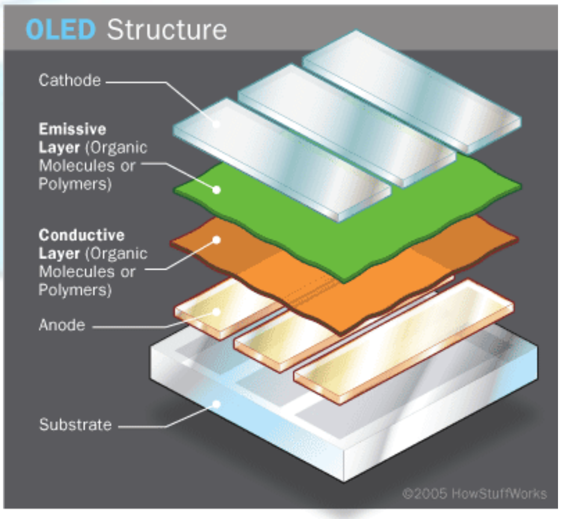

Fig Caption 1: OLED Structure

Table 1: Goals and Milestones

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Issues	**Impact , Focus**	**Now**	**5 Years**	**10Years**
Plastic substrate: replacement of polyester	Better, defect-free, high temperature plastic substrates	No replacement available	Polysulfon-es	Polya-mides, polyimide.
Large area coating of OLED panels	Cost competitive large scale manufacturing	Single layer, roll-to-roll coating	Multiple layers, different solvents, drying conditions determined	Roll-to-roll coating combined with vacuum deposition.
Packing/ encapsulation	Protection of OLEDs against ambient	Methods proposed and evaluated	Manufacturability assessed	Optimum techniques identifi-ed and tested.
Infrastructure / device powering	New paradigm in powering light fixtures.	Dialog with architects, utilities, etc. initiated.	Feedback provided to OLED manufactures.	Standard set, manufacturing ready.

2.1 MAJOR ISSUE

OLED has been developed since decades based on many upcoming issues. OLED consist of an arrangement of anode and cathode in between is the layers of organic polymers. This whole set-up is embedded on a glass substrate. OLEDs manufactured using glass substrate suffers from a major disadvantage, i.e. it doesn't offer a flexible top barrier. One such main issue is the replacement of this glass substrate by the plastic substrate on which the OLED is embedded. The presently used plastic substrate is a PET. A research paper suggests that this polyester can be replaced by polysulfone in next 5 years and polyamides and polyimide in next 10years. There is a need for a new OLED substrate polymer with

- High thermal resistance to at least 200 degree Celsius - shrinkage or expansion free (see above).
- Optical transmittance of 90% from 400 nm to 700 nm and 85% with ITO coating.
- Minimum surface roughness.
- Low oxygen permeability (<10^{-5} cc.m^2 per day)
- Low water permeability (<1 mg/m^2 a day)
- Virtual absence of defects (crystals, bubbles, filaments etc).

No commercial material meets all these requirements. Methods will have to be found to mitigate the deficiencies of present materials.

2.2 REPLACEMENTS

2.2.1 PEN

A literature survey on Polysulfone and PET confirms that they are the next generation plastic substrates which will replace polyester in another five years. PET has high refractory index, exhibits optical anisotropy, and it is a very good oxygen barrier. The analysis of certain polyesters has proved that PEN has a better property which makes it suitable to be used as a plastic substrate for OLEDs. The main disadvantage still prevailing in the manufacture of OLEDs is the permeation of oxygen and water molecules into the OLED through the plastic substrates. Many materials used as plastic substrate for restricting the entry of oxygen and water molecules proves to be not much worthy. This problem is best solved by a polyester PEN. It can be used at both substrate and flexible top barrier unlike glass substrate in emitting OLED displays. In addition to the above advantages, PEN has excellent transparency and optical purity which is in excess of 95 %.

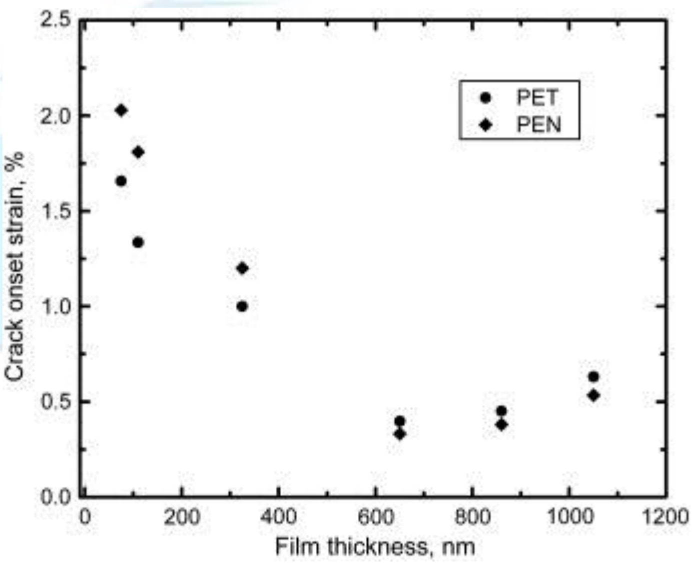

Fig Caption 2: Film thickness and crack onset strain of PEN and PET.

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2.2.2 POLYAMIDES

Another survey says that polyamide and polyimide are the next generation plastic substrates which will replace all polymers in another ten years. It has a high refractive index (1.691-1.696) and optical transmittance which is higher than 80%. There are 5 types of polyamides; they are PA6, PA6G, PA66, PA12, and PA46.

Among these, PA12 is the best suggested polymer that can be used as plastic substrate for OLEDs. All polyamides have the important property in common which is high moisture absorption capacity with dimensional stability. But PA12 is an exceptional polymer in polyamides. It has the LOWEST WATER ABSORPTION capacity among all the polyamides and it also has good impact resistance, good sliding properties and very good stress and cracking resistance.

2.2.3 POLYIMIDES

It has the highest refractive index (1.70), also the polyimide molecules are highly ordered along the chain axes as well as in the lateral direction and furthermore are highly oriented in the film plane. It has low friction behavior, its thermal conductivity is 0.12 W/m/k, and dielectric constant its 3.4 at 25 micrometer. It satisfies all the necessary conditions which makes it suitable to be used as plastic substrate for OLEDs.

2.2.4 KEY CHALLENGES FOR ENGINEERED SUBSTRATES INTO FLEXIBLE DISPLAY APPLICATIONS

Refractory index

(1) Anisotropy.
(2) Thermal conductivity.
(3) Polarizing clarity.
(4) Thermo optical purity.
(5) Sliding property.

3. THIN FILM ENCAPSULATION FOR FLEXIBLE AM-OLED

"ALD has been developed and introduced worldwide with the name atomic layer epitaxy (ALE) in the late 1970s. The first application of ALE was thin-film electroluminescent displays, requiring high quality dielectric and luminescent films on large area substrates. And then, interest in ALD has increased with focusing on silicon-based microelectronics."

We use silicon dioxide as a gate oxide material for decades. If we consider any electronic device, they have all decreased in size, the thickness of the silicon dioxide gate dielectric has steadily decreased to decrease the gate capacitance and thereby drive current, raising device performance. As the thickness scales below 2nm, leakage currents due to tunneling increase drastically, leading to high power consumption and reduced device reliability. As silicon has a gate capacitance, it will act as a barrier for oxygen and water. But OLEDs are a very small device, if the thickness of this barrier (silicon dioxide) reduces, as mentioned above, there may be leakage of currents. So there is an alternative i.e, replacing the silicon dioxide gate dielectric with high k materials allows increased gate capacitance without the associated leakage effects. Capacitance of SiO_2 is 1x and leakage current is 1x Capacitance of high k dielectric is 1.6x and leakage of current is 0.01x.

The motivation for high k oxides comes from the problem of high tunneling currents through the currently used SiO_2 MOSFET gate dielectric when it is a downscale to a thickness of 1.0nm and below. This is what we need in a OLED, so this may me considered to reduce the leakage current. Some more words from the above mentioned research paper "Among emerging applications, the low temperature ALD enables us to create unique inorganic / organic polymer composites and to deposit thin and conformal diffusion barrier films on thermally sensitive materials auch as organic polymers. In particular, Al_2O_3 ALD has been employed to passivate or encapsulate OLED to prevent water permission."

Al_2O_3 has applications as high k dielectric in gate stacks and high density capacitors but also as a moisture diffusion barrier for OLED displays. If Al_2O_3 is used as a barrier in OLED it has to be deposited by a method called ALD. ALD introduces two complementary precursors alternatively into the reaction chamber. Typically, one of the precursors will adsorb onto the substrate surface until it saturates the surface and further growth cannot occur until the second precursor is introduced. Thus the film thickness is controlled. But in the above mentioned research paper , the scalability of ALD is considered as a drawback , this can be overcome by the use of high k dielectric.

3.1 DISADVANTAGES OF SILICON-DIOXIDE

In the evolving trends, huge electronic devices are reduced to micro and mini devices. To make these devices small, we need to manufacture small components. SiO_2 has been used as a gate dielectrics in many electronic devices. But if the size of SiO_2 is reduced it leads to

*Direct tunneling dominates leakage current.

*Tunneling current exponentially increases with decrease in oxide thickness.

*If the oxide thickness reduces, the barrier property reduces.

Thus the ultimate use of SiO_2 gets vanished.

So in this case, it is advisable to use high-k dielectrics. There are many substituent for silicon dioxide. They are ZrO_2, HfO_2, TiO_2, Ta_2O_5, Y_2O_3, Al_2O_3, Gd_2O_3, La_2O_3 .

3.2 REQUIREMENTS TO DEVELOP 1nm OLED

- I should find an element which is in amorphous form that should be in high temperature.
- I have to select an element among Al_2O_3, TiO_2, Ta_2O_5, La_2O_3 , Y_2O_3. Each of the above element mentioned has more than 1 disadvantage. What I should do now is I have to select an element among this and should try to overcome their disadvantage so that the element can be used as an alternative for SiO_2.
- Concentrate on hafnia and zirconia and try to overcome their difficulities in practical use.
- Hafnia has trace amount crystallized phases, high degree of phase inhomogeniety between the surface and the bulk region.
- There is a need to find out another deposition method since SiO_2 is superior in its unique deposition methods.
- We can use some element or compound in combination with HfO_2 to avoid the formation of SiO_2 layer at the interface.
- Oxygen in HfO_2 can be combined with some element or removed and can add either molecules like N or S.

4. CONCLUSION

To overcome the issues related to plastic substrates, PEN (polyester) can be used as a plastic substrate to OLEDs. Nest comes polyamides (PA12) which replaces all the other polymers because of its lowest water absorption capacity. Finally it can be concluded that the plastic substrate for future generations is Polyimide which is analyzed to be the best polymer to replace all the existing plastic substrates for OLED meeting all commercial and technical requirements.

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