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Study of Effect of Environmental Factors on Organic Light Emitting Diode (OLED) Displays: A Review

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ABSTRACT: *Organic Light Emitting Diode Display is the most emerging technology in today's era for the flexible, lightweight, and thinner display systems. OLEDs are admirable as compared with other displays in number of attributes. It can be thought of to use OLED in many specialized applications such as mobile phones, cockpit instrumentation for surface transport and probably also for aviation because of its features such as low power required, better contrast ratio, wide viewing angle, high luminance, etc. However, there are many technical challenges faced by OLED display technology when applied for aerospace applications. These challenges include effect of environmental factors such as water vapor, oxygen i.e. humidity, harsh temperatures, solar radiation, vibration, etc. Luckily there are different technologies available to overcome these challenges such as use of desiccators and encapsulation methods. Different approaches to prevent OLED from degradation have different effects and requirements. The paper reviewed such different approaches and methods in respect of humidity and water vapour.*

Keywords - *OLED, Desiccants, Encapsulation, Water, Oxygen, Humidity.*

I. INTRODUCTION

The cockpit displays used in aircraft applications requires considerable amount of human machine interface (HMI) to demonstrate important messages to the pilot flying the aircraft [1]. HMI provides number of benefits in relation to pilot safety as the presentation of data within visual accommodation of the pilot enables better and quick recognition and action on the information. There are a number of displays inside aircraft cockpit such as head-up displays, head down display, multi-functional displays, head mounted displays, standby display units, etc. These displays not only provide vital information to the pilot in most efficient manner but also enhance the HMI efficacy thus enhancing pilot's efficiency as well. HUD is basically a monitor that presents messages on the front windshield of a vehicle or aircraft. Each of these display has its own purpose and utility. These displays allow pilot to a comfort that he/she doesn't need to look around to read messages from number of instrumental panels while flying and thus they are able to read messages directly.They have been traditionally designed over various available display technologies such as active matrix liquid crystal display (AMLCD), cathode ray tube (CRT), etc [2]. These displays have to perform their role efficiently in different environments to ensure mission's success. Each operational environment has different level of humidity that can affect the electronic device very badly and result in degradation in performance of the device. Typical humidity level required by different electronic devices must be in the range of 2500- 5000 ppm to prevent the device from premature degradation within operating or storage life of the device [3].OLED is one of best candidate for its use as a display device for cockpit displays. Basic structure of an OLED consists of a substrate, an anode, a hole-transporting layer(HTL) which is made up of an organic compound, an organic luminescent layer having suitable dopants, after that an electron-transporting layer and at last a cathode. In this review paper, different desiccants and encapsulation methods are studied that can help in decreasing the degradation in OLEDs.

OLED Review:

There are number of reasons why an OLED display form such an exciting options especially for cockpit displays for aerospace display applications. It has a number of attractive features, for example, high efficiency, high luminance, wide range of viewing angle, fast response time, high resolution versus area and many more. Moreover, OLED has the capability of high visibility using self-light emission; therefore, backlighting is not required. One of the most important features of OLED is that it is very lightweight and flexible display having a thin structure. Thus, OLEDs are having the potential to replace AMLCD and CRT for aircraft cockpit display usage, which are the right now the preferable options for applications like head-up displays, head down display, multi-functional displays, head mounted displays, standby display units, and so on.

Any aviation based instrument has to work in harsh environmental conditions. Humidity forms one of the major factors in affecting system's performance. The display technologies have undergone great revolution – from conventional Cathode ray tubes to liquid crystal displays, plasma displays, electroluminescent display, field emission displays, OLED displays, etc. The display screen of the display device needs to be covered from front and back as well to protect them from harsh environmental conditions. While covering them, we also compromise with the light transmitted outside, distortions, etc. When compared to other electronic display devices, OLED forms a very promising prospect in using them as display source for cockpit displays in aerospace application owing to number of advantages they offer in term of OLED display's superlative performance. However, OLED displays are much more delicate and must have humidity to be less than 1000 ppm and sometimes even less than 100 ppm for proper operation. Not only this, humidity levels also affect the OLEDs life as well as consistent performance over a period of time.

As humidly forms one of the major factor in affecting OLED's performance, we have studied various methods namely desiccators and encapsulation techniques, which could be used to minimize the effect of humidity on OLED's performance, which are discussed in the next section.

Dessicants:

Desiccant is a drying agent used to absorb water. It controls humidity that can degrade the performance of a device. Desiccantcan also be defined as "A substance, such as calcium oxide or silica gel, which has a high affinity for water and is used as a drying agent [4]". There are number of desiccants available to control the humidity to a specified level, for example silica gels material, molecular sieve material, and other materials commonly known to as drierite materials [3]. Silica gel material and drierite material are not suitable for OLED because they cannot achieve humidity level below 1000 ppm. But, the molecular sieve materials can be used to obtain such a low moisture level. However, in this case, encapsulation would require large quantity of drying agent; therefore, there can be a problem if the space between the encapsulation is limited.

Various methods have been proposed over the years by researcher, which have been used to control the humidity level within a specified range or below a particular level within an encapsulation of device. Kawami*et al.* presented a method in which a desiccant layer was grown over the organic layer of OLED by using method of vacuum vapour deposition, spin coating and sputtering between the top seals and the substrate[5]. The desiccant used was required to be coated on the interior wall of the encapsulation. The encapsulation using this technique of applying desiccant required very wide walls to hold enough amount of the agent for the complete lifespan of device. Kawami et al. in their patent presented the use of electro luminous element along with a drying agent to obtain a restrained crosstalk and leakage current i.e. a stable light emission for a long time.

Grover *et al.* employed a thin organic encapsulating layer that consisted of four alternate stacks of two different organic materials namely Tetra-phenyl-di-amino-phenyl (TPD) and XP using different morphologies placed by vacuum thermal evaporation technique[6]. The inorganic films had the restriction in their performance due to the defect in the film that provided paths for water vapour and oxygen to permeate through the barrier layers. XP was reported to be very amorphous having a roughness value of 2.235 mm even after 960 hours of working at ambient temperature. On the other hand TPD was known to be crystallize easily as its glass transition temperature is low i.e. 64ºC. Therefore, the alternate arrangement of TPD and XP could be an efficient encapsulating layer which resulted in increasing the effective diffusion length for water vapour or oxygen molecules. Fig. 1 shows effect on luminance with the use of TFE(Thin-Film-Encapsulation) and without TFE.

The TFE employed by Rakhi Grover *et al.* slowed down the penetration of oxygen and moisture into device that increased the operational lifetime of OLED[6].

Different transparent drying agents were proposed by Yoshihisa *et. al.*[7] that were based on chemisorption and could be used in OLED display. The author disclosed an organic electro-luminance device that consisted of a transparent water capturing film that incorporated an organometallic compound demonstrated by chemical formula (Fig. 2). Here R was representing an aryl group, alkyl group, hetero-cyclic group, cyclo-alkyl group and acyl group each having one or more carbon atom and the M is a trivalent metallic atom.

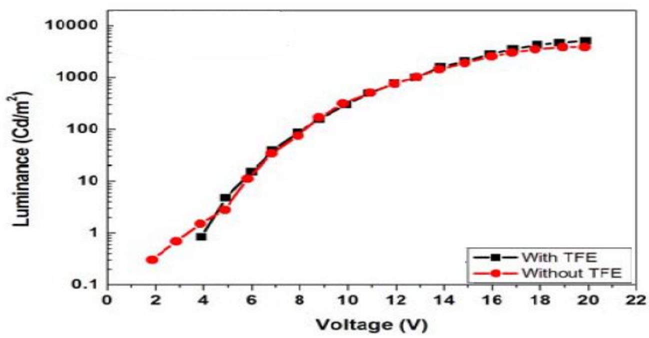

Fig.1:Luminancevs voltage characteristics of OLED fabricated without and with TFE [6].

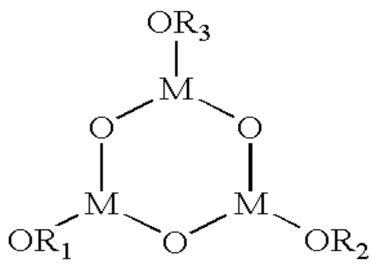

Fig.2:Chemical structure for organometallic compound [7].

The film formed was transparent and it was possible to see through the drying agent. But this method had a drawback, as a chemisorption desiccant changed its properties in the presence of moisture (humidity). Hence, it might be possible that the optical path properties of device might change during the device lifetime, resulting in dominant changes in vision of display[7].

Michael Boroson[8] brought to light the method to reduce moisture contamination in top-emitting OLED display. Two different chambers for desiccants agent above the top and bottom surfaces were defined in which moisture absorbing materials absorbed the moisture. Since the light did not passed through the chamber at the bottom surface, thus did not changed optical properties of the drying agent (DA). Method employed in patent [5] might require placing an opaque layer over the topmost organic layer of the device, including the emitting layer as well. Benefit of using this technique was that the desiccant agent was used without increasing the non-emitting area of the device and the top emitting OLED display could be constructed without the use of complete hermetic seals. Another Patent gave the method to reduce moisture permeability of an OLED with minimum non-emitting area and protected the device from the moisture from entering the sealed region of OLED[3]. The device could be designed without the requirement of complete hermetic seal.

Using a proper desiccant in the packaging of an electronic device could extend the lifetime of device, but it didn't made that device immune to less or failure due to the moisture permeation from the outer environment. Completely hermetically sealed devices provide a controlled environment for functioning, but it was difficult to achieve. For OLED hermetic sealing was difficult to obtain because OLED is temperature restrained because over 100ºC OLED tend to deteriorate[9].

II. ENCAPSULTION TECHNIQUES

OLED packaging or encapsulation plays a very important role in preventing OLED from moisture and oxygen. Syamal Ghosh *et. al.* provided a hermitically sealed encapsulation method for moisture sensitive electronic device. It was a method of sealing using a cover plate that provided encapsulation using a low temperature metal-alloy. This encapsulation method was suitable for OLED display and other highly moisture sensitive device [9].

Table I[10] shows the objectives of encapsulation methods. There are various encapsulation methods presented in table II[11]. Each method has its own merits and demerits of physical, chemical and hybrid encapsulation.

Table I Objective of Encapsulation[10]

S.No.	**Parameter**	**Details**
1	Permeability	1. < 1 x 10-6 g_{water}/m^2/day 2. < 1 x 10-5 g_{oxygen}/m^2/day
2	Cost	$ 10-20 per square meter
3	Reliability	1. 40,000 hours active/20 years lifetime 2. Prevent from damp heat degradation 3. Mechanical stress 4. Thermal stress

Table II Different Characteristics Of Species Used As Substrate[11]

Substrate	**Glass**	**Metal thin film**	**Plastic**		
			PET	***PP***	***PE***
O_2	●	▲	✚	✚	✚
Water	●	▲	✚	✚	✚
Flexibility	✚	▲	●	●	●
● Excellent		▲ Good		✚ Poor	

The species chosen for the encapsulationmethod must be considered according to their characteristics. Table II lists the characteristics of the different species of substrate. There are large numbers of materials available that can be used in encapsulation technology. These materials along with theiradvantages and disadvantages are listed below in table III.

TABLE II Different Choices for Material Used in Encapsulation[10]

S. No.	**Materials Used**	**Merits**	**Demerits**
1	Metal can	Low cost; Easy to pocket for desiccants	Poor CTE match; Stamping cost; Edge sealing required
2	Thick Glass(>2mm)	Excellent moisture, oxygen and thermal resistance; Low cost; Expansion match to substrate; Transparent	Rigid; Pocket required for desiccants if frit seal is not used; Edge seal required
3	Polymer film	Flexible	High cost; Edge seal required; Damage sensitivity
4	Deposited coating	No edge seal	High cost; Additional and complex deposition step required; Backup glasses may be required; Damage sensitivity
5	Thinglass(<0.2 mm)	Flexible andcomfortable; All other glass advantages	Fragile and may require polymer backup; Flexible edge seal required with flexible substrate

Physical Encapsulation Technology

Fig. 3 shows one of the most widely used encapsulation technique for OLED devices. In this method Ultra-Violet curing epoxy adhesive(3) was used to seal the sheet-shape glass(1) along with desiccators (2) onto the substrate(4). The frame used had total thickness of about 1.4mm that depended on the selected glass cover. Ultra-thin glass was proposed as the substrate and encapsulation cover for flexible OLED. But such glass had difference in toughness and was brittle[12]. Presently used ultra-thin glass cutting technology could easily cause the edge micro fissure flaw. Therefore, using such encapsulation method display device was sealed in the dry inert gas environments[11].

Chemical Vapor Deposition

Different approaches were studied such as poly (p-xylylene) film obtained by method of vapor-deposition polymerization [13]. This polymer thin film was proved to have outstanding obstruction to oxygen and water, and its light transmittance-rate could be up to 95% in visible light region and near infrared region.

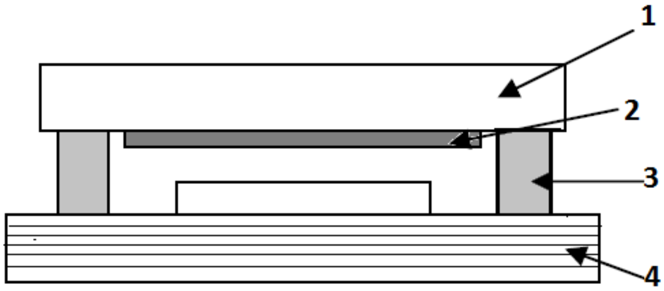

Fig.3.SealedOLED schematics (1 sheet-shape, 2 desiccators, 3 adhesive, 4glasssubstrate[11]

PECVD (plasma enhanced chemical vapor-deposition) proposed by Huang et al.[14], was used toprepare SiNx (silicon nitride) thin film, which was used for straightly sealed OLED. PECVD has excellent properties against ion corrode and humidity. In 1970s SiNx was developed by PECVD. But it had the disadvantage that SiNx prepared by PECVD needed temp of 180ºC, thatwas very high as compared to bearing temperature of organic material used in OLEDs. But, the SiNx films deposited at comparatively low temperature could be used in OLED packaging effectively.

Hybrid Encapsulation Technology

Hybrid encapsulation technology also called as multi-layer barrier film was also considered as one of the important potential method. This technology removed the disadvantage arising due to single organic compound or in organic package. Two different approaches were often used for flexible OLED for TFE. They were: single layers and multi layer thin films[11]. In single layer, thin film passivation PECVD and thermal evaporation deposition method were employed, for fabrication of one buffer layer in the substrate to prevent it from permeability of water and oxygen. Multi-layer structure consisted of alternating oxide and polyacrylates layer as proposed by different researchers[15][16][17]. Barix technology developed by American Vitex Corporation incorporated polymer layer and inorganic layer[18]. This technology realized the OLED encapsulation effectively. As compared to traditional packaging, this method had the advantages such as low cost, thinner and long life.

In addition, a novel multilayer stack was proposed by Lifka*et al.* that consisted of alternate layers of silicon nitride and silicon oxide employing TFE by PECVD[19].

III. CONCLUSION

There will be a large market for OLED Displays in future especially for cockpit displays for aircraft and helicopter applications. For cockpit displays in aircraft application, OLEDs could prove to be of immense use owing to its number of advantages. We have discussed in detail various methods which could be employed to minimise the effect of moisture and humidity on OLED display performances. Desiccators and encapsulation techniques have different applications in order to provide immunity to OLED display w.r.t humidity and water vapour.Desiccant areused for OLED display packaging to absorb moisture and water and thus control humidity. The desiccator materials which could be used for preventing moisture entering OLED include calcium oxide or silica gel. They both have affinity for moisture and thus could be utilized as a drying agent. Silica gel and drierite material are found unsuitable for OLED display owing to their inability in achieving humidity below level of 1000 ppm. The molecular sieve materials have been found suitable as they are able to achieve very low moisture levels even under harsh moisture conditions required for OLED display working.

Hermitical sealing encapsulation method has been found to very effective for minimizing moisture effect in OLED displays. Various materials could be used for encapsulation such as metal can, polymer film, deposited coating, thin and thick glasses, etc. They have own merits and demerits in terms of their usage in OLED display applications. While thick glass s encapsulation provides excellent moisture protection, but is rigid and requires edge sealant, the polymer film is flexible but it also requires edge sealing and is damage sensitive. The deposited coating requires no sealing but coating process is complex and is also damage sensitive. Three types of encapsulation technology were discussed. In physical encapsulation technology, the OLED display is sealed in ultra thin glass under dry inert gas environment. In chemical vapor disposition, polymer thin film or other types of similar property films could be used to block oxygen and moisture. In addition, it results in high light transmission in visible range. In hybrid encapsulation technology, multiple layered barrier film could be used to achieve flexible OLED structure for display.Different applications using OLED display require use of these technologies according to their requirement. These technologies of shielding OLED displays have to be used judiciously to prevent effect of factors affecting the device's lifetime and the performance. The advancement and development in technology with time is the only key to avoid the disadvantages of OLED.

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