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# An examination of improvements in OLED quality and fabrication

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## Abstract

This paper will discuss recent advancements in the fabrication and applications of OLED. As it stands now, OLED has revealed itself as having highly desirable qualities, applicable in a broad range of fields, from cutting edge computer technology, to improvements in medical diagnosis. Despite these advantages, OLED still lacks greatly in efficiency and reliability in comparison to other similar electro-optical materials systems such as LCD. This paper will cover the disadvantages of OLED as well as recent attempts and breakthroughs made in order to improve upon and negate these disadvantages. In particular, recent publications detailing methods to reduce the cost of fabrication of OLED through the novel use metal oxides, improvements in reliability through different surface treatments, and a new method of water protection are examined.

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## 1. Introduction

OLED stands for Organic Light Emitting Diode, and is a materials system similar to LED, except where LEDs emission layers made chiefly from non-organic compounds such as gallium phosphate, organic LED consist of an organic or polymer-based compound layered in between the two diodes of the LED (1). This results in a material that is thinner and more flexible than its inorganic counterpart. The OLED market is expected to grow six-fold over the next year, as improvements in fabrication and manufacturing allow it to be made more cheaply, making it an important material to be aware of over the coming years [2].

## 2. Background

In order to understand the drawbacks and issues with OLED, one must first understand their theory and functioning mechanism. The architecture of an OLED device is shown in **Figure 1** ~~below~~. All LED's consist of an anode, cathode, emitting layer, and two transporting layers. These transporting layers transport either electrons or holes to the emitting layer for hole recombination, which is the process that allows OLED to emit light. The main difference between OLED and LED is the material used for the emission and injection layer, and whether or not it is an organic layer [1]. In the example above, PEI is shown as the injection layer above ZnO, and the unmarked emission layer would also be an organic or polymer material. These two layers must also be conducting layers in order for holes and electrons to pass through and recombine. Since these layers are organic, however, major problems can arise from contact with water, including complete deterioration of the OLED device [6].

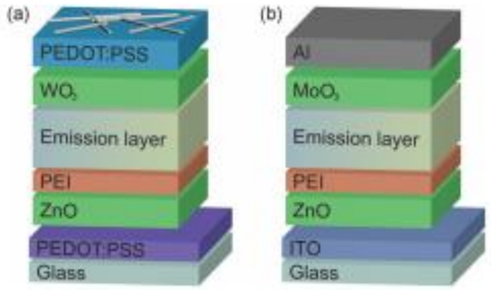

**Figure 1**: Architecture of OLED Materials System [1].

The mechanism for light emission of OLED is the same as for LED, and involves the use of holes and electrons in

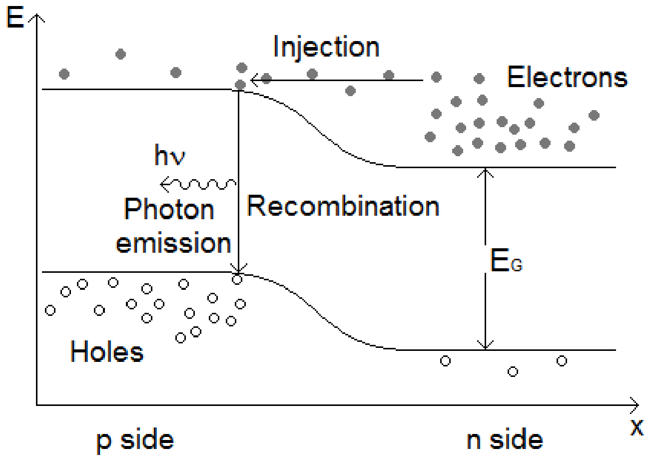

**Figure 2**: Electron-Hole Recombination Energy Graph [1]

order to produce light. **Figure 2** ~~below~~ shows how the energy transfer required for light emission [3]. In order to create holes and free electrons, energy must be added to the system, and this electron-hole disparity between the top layer and bottom layer of OLED leads to a potential difference [3]. The electrons and holes are thus pushed together following the potential difference, however holes do not flow through a conducting material the same way that electrons do, so an additional hole injection layer is needed [3]. Once the electrons and holes recombine in the emission layer, energy is released in the form of light. In order to reach as efficient a system as possible, the work function of the layers of the OLED should be as close as possible, so no additional energy is needed to overcome injection barriers. Increasing the efficiency of OLED in this manner is one of the major motivations of current materials scientists, as this efficiency has an impact on the lifetime of OLED devices [5].

## 3. Discussion

To improve the lifetime and efficiency of OLED devices, different surface treatments are used on the ITO layer[4]. Since OLED has comparatively low lifetime and reliability, there is great interest in new manufacturing methods to bring its dependability on par with other electro-optical materials. In the paper, two of the most common ITO pre-treatments were examined, being $O_2$ plasma and SAM absorption (self-assembled monolayer). In addition, PEDOT:PSS, which is a surface treatment method involving coating the surface of ITO in a polymer buffer layer, is examined as a reference.

The performance of these samples was determined by collecting surface work function data via XPS. This data provides a reference for the stability of the fabricated surface, which is related to the device's reliability. In order to determine the lifetime of the devices, an OLED Lifetime Test System 58131 was used. In order to increase the reliability of the results, devices were grouped by type and compared against each other. ~~The results of the experiment are shown in **Figure 3** below.~~

~~From these graphs, it's shown that overall~~ Overall, SAM treatment was most effective in extending the lifetime of the OLED devices, which also relates to its high work function stability compared to the other treatments. However, it must also be acknowledged that the type of device has a significant effect on its lifetime and the effectiveness of each of these treatments. For example, in device (a), $O_2$-Plasma was far more effective in maintaining reliability of the device than PEDOT:PSS, but in device (b) this was not the case. With that in mind, it's also important to remember that while SAM treatment may have greatly increased lifetime, these graphs are normalized with respect to brightness, so it's possible that the SAM treated devices had poor efficiency and transmittance in regards to the other two treatments.

In order to improve the cost of OLED fabrication, the use of different silver compositions in the anode layers of devices [5]. Replacing the original anode material ITO, which is very expensive and has significant power loss, silver grid layers are exposed to different durations of UV light, in the hopes that different levels of exposure would affect the work function of the silver grids to reduce the mismatch with the transport layer and improve efficiency.

The length of time that these films were exposed to UV affected the composition of the silver layers, and subsequently affected the properties of the film. For reference, the untreated silver grid had a surface potential, or work function of 4.7 eV. The injection layer, $MoO_3$ has a work function of 5.3 eV, resulting in a barrier of .6 eV. It was found that UV exposure of 15s resulted in a low quality $Ag_2O$ layer, which has a work function of 5.0 eV. However, this layer was highly inconsistent and unreliable. At 30s, a good quality $Ag_2O$ layer was fabricated, reliably decreasing the injection barrier by .3 eV. At 60s of exposure, an $AgO_x$ layer is produced, which has a 5.3 eV work function, however this layer exhibits higher resistivity, so reduces its electrical efficiency.

The performance of the devices created was determined through transmittance and electrical efficiency. The electrical efficiency was measured by generating a current vs voltage plot, and transmittance was measured across various wavelengths. ~~The data from these measurements is shown in **Figure 4** below. From these graphs it's seen that silver~~ Silver grids exposed to 30s of UV were the most electrically efficient, however this came at the cost of transmittance. The 15s samples were greatly hindered by their defects, and it was found that overexposure of 60s led to significantly reduced performance across the board compared to the 30s samples. Overall, this experiment revealed a novel way to replace the expensive ITO layers used in modern OLED using far cheaper silver oxide anodes, which retain the work function properties of ITO.

While reliability and cost are the most pressing disadvantages to OLED use, the vulnerability to water and reactive gas exposure prevents OLED from widespread use in handheld electronics. Different methods of improving the resilience of OLED against reactive gases such as oxygen in the environment are examined in order to negate this drawback [6]. Current solutions to this vulnerability involve the use of rigid layers to encapsulate the OLED functional layers. This defeats a primary advantage of using OLED, being ~~it's~~its flexibility. This paper proposes the use of thin film silane based encapsulants in order to retain the unique mechanical properties of OLED.

In order to compare the viability of TFE (thin film encapsulation) to glass encapsulation, OLED devices were fabricated and encapsulated in glass, and additional OLED devices were fabricated using thermal deposition. These films were then encapsulated in an $Al_2O_3$/silamer multilayer, and their performance was measured over time both in air and immersed in water~~, shown in **Figure 5** below~~. It was found in this experiment that $Al_2O_3$/silamer encapsulated OLED had a considerably longer lifetime than the untreated OLED, and that the TFE resulted in an OLED that was essentially impervious to the effects of water. While reactive atmospheric gases still affected the lifetime of the devices, the TFE were shown as a viable replacement to the rigid glass encapsulation that is commonly used in commercial OLED.

## 4. Conclusions

From the experiments described in this paper, the driving force behind improvements in OLED is the discovery of new applications for existing materials for use in its architecture. New methods of fabrication and surface treatment create an avenue for a wide array of materials to replace the expensive and unreliable materials composing modern OLED. The mechanism of OLED from a nanoscale relies on principles of the electrical properties of semiconducting materials, and the unique abilities of OLED stem from the mechanical properties of the organic materials they are composed of. The three major issues of OLED, being cost, lifetime, and vulnerability to water, are being addressed in innovative ways through novel materials processing methods and new hybrid materials systems. As time goes on, it becomes clearer that OLED is at the forefront of cutting edge commercial technology, improving the mechanical properties and quality of products in the rapidly growing market of electro-optical devices.

## Conflict of Interest

The author declares no conflict of interest.

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