OLEDs VS. LEDs - Organic LEDs and Their Feasibility in General-Lighting Applications

For many years, (light-emitting diodes) struggled to fulfill their promise as the dominant technology for the next generation of general-lighting. As the major LED manufacturers began to expand capacity (thereby driving down costs), many end users continued to complain about color quality, usable-life claims and the actual return on investment. Through this feedback, manufacturers realized that the requirements for the general-lighting market were not synonymous with those of the automotive, display or indicator markets. Over time, the major LED manufacturers made significant strides toward tuning their products specifically for the lighting market. As a result, today LEDs have reached a level of acceptance for use in most general-lighting applications. LED-based products provide a highly efficacious replacement for more traditional light sources, such as incandescent/halogen, fluorescent and high-intensity discharge. Although there is still much improvement to be realized, overall, LEDs are being successfully implemented in the general-lighting marketplace.

Organic LEDs (or OLEDs) are beginning to receive strong interest for use in general-lighting applications, similar to what we saw for LEDs around 10 years ago. They are being marketed as a uniform light source with the ability to reinvent how the world is lighted. In this document, we will provide a brief history, discuss their construction (and similarities to LEDs), examine their current applications, and then explore their potential in the general-lighting market.

History of OLED Research Leading to Commercialization

The first testament of organic electroluminescence (albeit not based on a diode) was recorded in the 1950s by researchers led by André Bernanose at the Nancy-Université in France. They found that by passing a high-voltage AC signal through thin film, they were able to observe electroluminescence.1 Further building on this research, a group of researchers out of New York University, headed by Martin Pope, found that through positive hold injections (i.e., doping), they were able to observe electroluminescence in a crystal exhibiting a linear ohmic relationship under a high-voltage DC input.2 Over the next 15 years, research continued on crystals.3

Then in the mid-1970s, the world finally saw electroluminescence on more practical substrates. Robert Partridge created a thin-film device between two injected electrodes that exhibited organic electroluminescence.4 The major breakthrough to creating a semiconductor device exhibiting light emission (later called an OLED) is credited to researchers at Eastman Kodak in 1987.5 In their research, they deposited organic material between an indium tin oxide (ITO) anode and a magnesium-silver (MgAg) cathode. Upon excitation of the resulting diode, they observed a stable, green electroluminescent diode with an efficacy of around 1.5 lumens per watt. The major limitation to this discovery is that it was done using monomers (small covalently bonded molecules), which are still relatively unstable. Richard Friend, of Cambridge University, published his results a few years later showing a similar device created using an organic polymer film called poly para-phenylene vinylene, or PPV, which is environmentally rugged and flexible.6

Diodes, OLED Construction and Similarities to LEDs

To explain the OLED function, we will begin by briefly introducing the function of a PN junction diode. Then we will discuss the general functioning mechanisms of an LED and OLED.

A PN junction diode is a combination of a p-type semiconductor and an n-type semiconductor material, creating a PN junction. The area in this junction, called a depletion layer, is created as a state of equilibrium between the two oppositely doped semiconductors is formed. In this state, no movement is exhibited between the electrons without a sufficient positively biased potential. Figure 1 (right) is a representation of this connection.

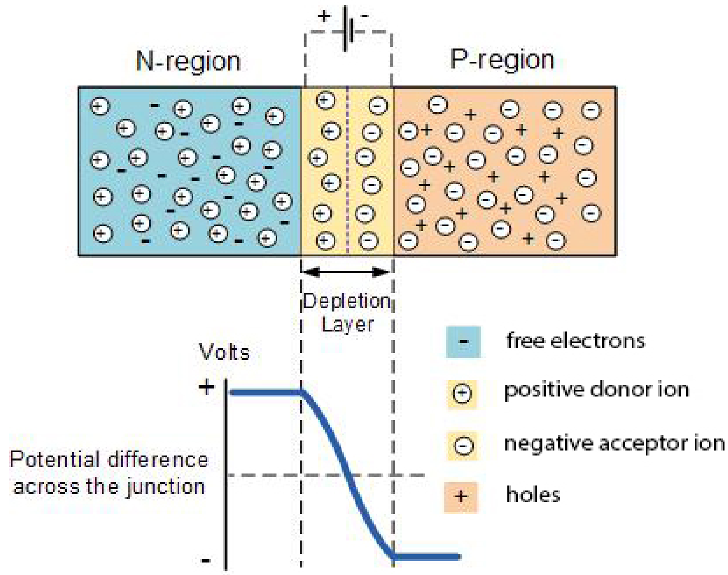

Figure 1: PN junction representation7

For current to flow (and for an LED/OLED to emit a photon of light), you must introduce a potential across this PN junction. This potential causes a reduction in the width of the depletion layer, allowing current to flow. It should be noted that the required forward bias potential for sufficient current flow is a characteristic of the materials utilized in the n-type and p-type semiconductors.

An LED and an OLED function in the same manner, just with different materials utilized in their structures. The major difference is that OLEDs consist of organic layers (meaning carbon-based) sandwiched between an anode and a cathode. The anode is typically ITO, due to its clear properties. A sufficient potential applied across these terminals creates excitation within the organic recombination region. For these bounded pairs to return to their initial states, a photon (and also heat) must be released. Figure 2 (below) is a reference to this general structure.

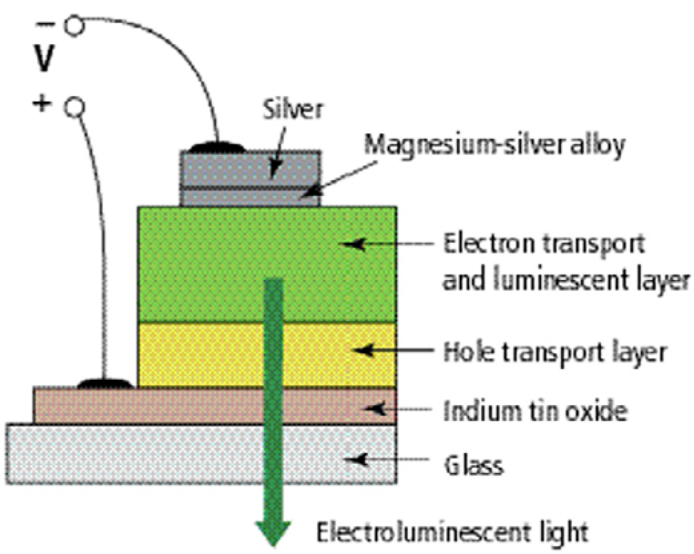

Figure 2: General diagram of an OLED8

Since white is not a single wavelength (or color), but rather a collection of wavelengths, there are two popular ways to achieve a “white” output from LEDs. The first is called phosphor converted, or PC. This method relies on the use of a shorter-wavelength (InGaN) LED coated with a scintillator (type of phosphor), which mixes with the shorter-wavelength-LED output to create a white output to the human eye. This method is identical for OLEDs.

The other method for achieving white light with LEDs is called color mixing. This method relies on the mixing of multiple individual LEDs (sometimes within the same package) to achieve an overall white output in appearance. A major advantage for OLEDs is that they can achieve this same color-mixing technique using a stacked architecture (thus the name SOLEDs). In this format, the SOLED utilizes three different PN junctions (red, green and blue), all stacked on top of one another as you can see in Figure 3 (below). Each junction is separated by an insulator and can be individually controlled. Upon excitation these three junctions emit photons of their respective properties, which mix to create a white output.

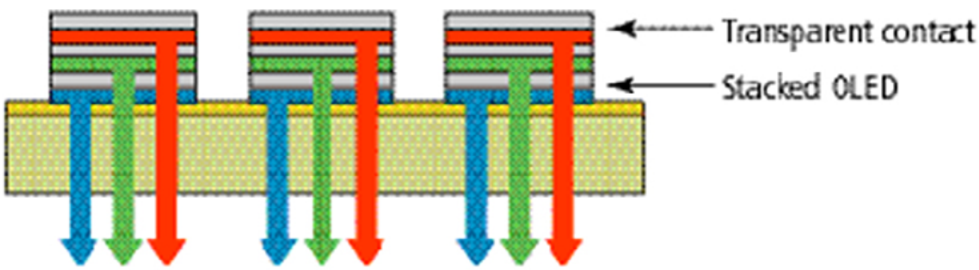

Figure 3: SOLED structure8

Current OLED Applications

The most successful application of OLED panels to date has been the small-panel-display market. This consists mainly of cell phones, tablets, wearables, and other small electronics. Traditionally, these displays were LCD panels, which utilized white side-firing LEDs to illuminate the screens' pixels. The software determined which of these pixels to open or close, resulting in the screens' image.

SOLEDs are direct-view, meaning each pixel contains its own red, green and blue OLED. This architecture provides numerous advantages. First, the individual colors provide a wider color gamut, resulting in the ability to provide more saturated colors and deeper blacks. Second, the removal of the thin-film transistor (TFT) panel used in LCD means these devices are thinning and have a faster response time, which allows for smoother image motion. Finally, the viewing angle of the OLED is typically wider, which helps to improve the overall experience. The major disadvantage of OLEDs continues to be cost, so most manufacturers use them only in high-end applications with smaller panels (due to low manufacturing yield).

Interest is growing for the use of OLEDs in general-lighting. Today, these fixtures are offered by a small quantity of manufacturers. Their target markets currently are specialty and decorative, because OLEDs do not match the performance, life or lower cost of LEDs. In most (if not all) current designs, fixture manufacturers are using multiple small-panel OLEDs (blue OLED plus phosphor) to achieve the desired output. This approach is similar to that of LEDs. However, this also means there are similar challenges in regard to panel consistency (mainly color, output and life). The main driving factor for these applications seems to be the ability to reshape the form of lighting beyond the traditional sense. While novel fixtures are important as technology evolves, they do not fully satisfy the current state. For the mass market, the major focus should be to provide an efficient, high-quality, cost-effective product.

Challenges Facing OLED Adoption

Although much progress has been made with OLEDs, there remains significant hindrances to their widespread adoption in the general-lighting market. Here we will address each of these challenges:

1. Cost

The most important factor comes down to cost. According to the U.S. Department of Energy, in 2015 the expected cost of OLEDs remains at $25/kilolumen. By comparison, commercially available LEDs are surpassing the $1/kilolumen threshold. The high of OLEDs cost is associated with a number of factors including poor yield ratios, expensive topological structures for white-light generation (i.e., SOLED), and general low capacity due to low demand.

2. Life

Current technology in general-lighting applications (fluorescent and, newly, LEDs) meets or exceeds 50,000 hours of “usable” life. (The usable life of an LED is determined by the time taken for the light output of the LED to drop to 70% of its initial output.) By comparison, commercially available OLEDs currently sit around 15,000 to 25,000 hours of usable life. For applications with SOLEDs, the degradations of the red, green and blue PN junctions are all different, causing color shift in the white panel if no special electronic controls are involved to correct the moving color point.

3. Utilization efficacy

The current efficiency of OLEDs is significantly less than is found in commercially available LEDs today (80lm/W vs. 180lm/W). In addition, one of the major advantages of LEDs is they can be easily lensed for precise control as directional light sources¬-which was previously unheard of in general-lighting. OLEDs by comparison are a uniform, omnidirectional source, similar to that of fluorescent.

4. Advances in LED light guides

One of the major benefits often cited in support of OLEDs is their uniform diffuse-surface capabilities due to their omnidirectional nature. However, in the past few years, optics and plastic manufacturers have found ways to use light guides in conjunction with LEDs to mimic this effect, effectively mitigating this advantage. These LED fixtures are available purchased today, are cheaper and are more efficient than OLED panels of much smaller output and size.

Conclusions on the State of OLEDs

OLEDs are a very exciting technology. Over the next 10 years, it is expected they will dominate the display market (cell phones, billboards, monitors, etc.). In the meantime, the LED lighting market continues to improve in terms of cost-effectiveness, color quality, life expectancy, and efficacy. A recent discussion at the Lighting Research Center, at Rensselaer Polytechnic Institute in Troy, N.Y. brought together chief technology officers from major lighting manufacturers in North America to discuss lighting in general. One of the major conclusions that were drawn from this meeting was that although OLEDs are an exciting technology, they will not replace LEDs for most general-lighting applications. Instead, they will be used “where the diffuse surface is an advantage in the application at hand.”9 In addition, a recent research paper provided a follow-up to 1999 research, comprehensively outlining the promise and potential of LEDs for general illumination. 10 The findings reported in that paper were that after LEDs fully realize their potential in the general-lighting market, there will be no justifiable room left for further technological advancement, due to the high investment costs required. In essence, LEDs will be the last technological shift for general illumination. 11 Hence, for lighting purposes, OLEDs will fail to provide a pleasant, well-lighted environment that is energy-efficient and cost-effective.

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