Roll-to-Roll OLED for Lighting

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Organic electronics could revolutionize the electronics industry by providing highly functional devices at low cost and high volume. To eliminate the manufacturing hurdles that are impeding this revolution, GE Global Research (GEGR) has built a complete roll-to-roll (R2R) research line for organic light emitting diode (OLED) device fabrication and has developed processes that successfully demonstrated the feasibility of fabricating OLED lighting devices in a continuous R2R manner. Accomplishing this paves the pathway to manufacture OLED device at high throughput low cost for general lighting application.

OLEDs consist of a set of thin organic layers positioned between two electrodes, at least one of which is transparent or semi-transparent. There are two basic types of OLEDs—those where the organic layers are deposited by vacuum thermal evaporation, and those where the organic layers are solution processible. Typically, the vacuum deposited variants are based on small-molecule materials and the solution processible variants are based on polymer materials. In both cases the underlying physics of device operation is the same. In a manner similar to LEDs, charge carriers are injected from the electrodes into the organic layers where they recombine and emit light that escapes the device through a transparent electrode. Since the active layers of the device are very thin, ~100 nm, OLED devices are generally not freestanding, but are fabricated on a glass or polymer substrate. Figure 1 (a) shows a schematic OLED device structure and Figure 1 (b) shows flexible OLED devices fabricated on polymer substrates. Since OLED devices are very thin, they can be formed directly into any desirable shape, avoiding luminaire losses. Materials used in OLED devices have broad emission spectra. This gives OLEDs an advantage over LEDs in that minor changes in the chemical composition of the emissive structure can tune the emission peak of the device. Therefore, getting good-quality white light from OLEDs is easier and it is anticipated that the quality of the white light will improve with the science. Unlike traditional lighting technologies, OLEDs naturally emit their own diffuse light and do not require reflectors or diffusers. In addition to displacing existing lower-efficiency light sources, the new form factors enabled by a thin, mechanically-flexible OLED light source will lead to new lighting and architectural applications such as "wrap-around lighting," "lighting wallpaper", "lighting curtains," etc.

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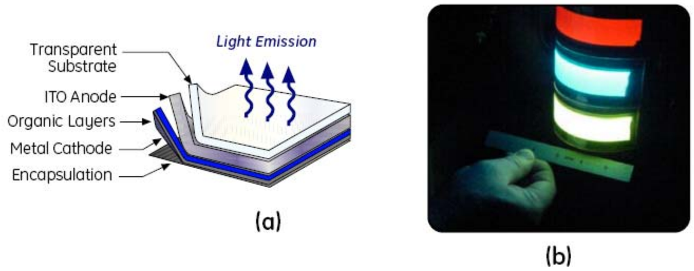

Figure 1 (a) Schematic of an OLED device. (b) Flexible red, blue, and green OLEDs.

GE has demonstrated the fundamental promise of OLED lighting first by demonstrating that illumination-quality white light was possible and then by developing large-area, scalable, fault-tolerant architectures (Figure 2) [1]. GE has also developed a plastic film substrate with ultra-high water and oxygen barrier properties appropriate for OLEDs [2] and proved that such a novel plastic barrier substrate could be fabricated in continuous R2R manner. The key requirements for a R2R compatible plastic OLED substrate are optical transparency, mechanical flexibility, chemical resistance, thermal stability, and impermeability to OLED degradation accelerants such as water and oxygen. Impermeability to water and oxygen represents the most demanding technical requirement for a roll-to-roll compatible OLED substrate because the active organic materials and electrodes of an OLED degrade in the presence of water and oxygen [3]. Simple calculations suggest that in order to achieve a device lifetime of tens of thousand hours, the substrate must provide a barrier that limits diffusion to less than 10^{-6} g/m^2/day and 10^{-5} cc/m^2/day for water and oxygen respectively [4]. In order to meet this stringent gas barrier requirement, GE developed a graded ultra-high barrier (UHB) coating that can effectively stop defects from propagating through the coating thickness. The coating is fabricated using plasma enhanced chemical vapor deposition (PECVD) with a parallel plate capacitively coupled plasma reactor. It consists of a novel, graded single layer made up of inorganic and organic materials as schematically shown in Figure 3. In this barrier structure, the organic materials effectively decouple defects growing in the thickness direction but, instead of having a sharp interface between inorganic and organic materials, there are “transitional” zones where the coating composition varies continuously from inorganic to organic and vice versa. These “transitional” zones bridge inorganic and organic materials that result in a single layer structure with improved mechanical stability and stress relaxation. GE’s graded ultra-high barrier plastic substrate has proven to be compatible with GE’s batch-solution OLED device fabrication processes and can effectively protect OLEDs from being attacked by moisture and oxygen.

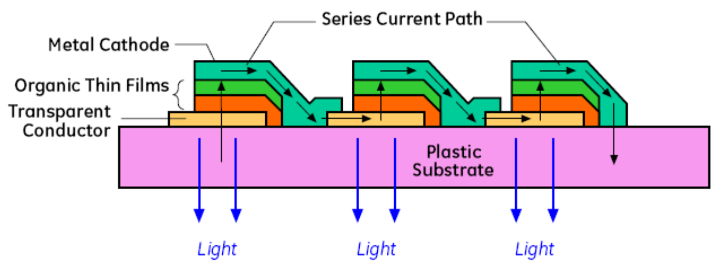

Figure 2 Fault tolerant monolithic series device architecture for large area OLEDs.

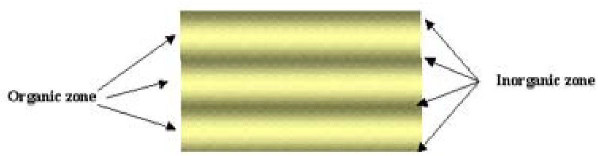

Figure 3 Schematic of graded inorganic-organic ultra-high barrier coating.

Through a NIST-ATP program, GE collaborated with Energy Conversion Devices (ECD) and successfully built a prototype manufacturing research infrastructure for low-cost OLED lighting device fabrication. The goal of this program was to build a R2R printing line that can continuously make solution-processible OLEDs at a substantially lower cost than that is possible with today's glass-based, batch processed technology. This four-year effort was successfully completed in 2007 and demonstrated world's first R2R manufactured OLED lighting devices. Over the past 2 years, GE has been continuously upgrading R2R line and optimizing R2R process. GE has used this line to prove that high-quality OLEDs can be made in a continuous roll-to-roll fabrication process (Figure 4). The key equipment innovation in GE's R2R research line is a novel gas gate design [5] that enables continuous transfer of web from atmospheric pressure to high vacuum over a range of wide-web speeds without the need for intermediate roll or unroll steps. This novel gas gate design integrates solution process steps with high-vacuum deposition steps into a continuous-web, single-line system. The key process innovation in GE's R2R research line is a low-cost organic layer patterning technique called solvent assisted wipe (SAW) (Figure 5) [6]. SAW is used to selectively remove organic materials in the area where series electrical connections need to be formed for fault-tolerant device architectures. The SAW process first applies a specific solvent (that can effectively dissolve organic material that requires patterning) to the organic thin film in the area to be patterned. Next, a polymeric wiping-head is used to physically remove the already softened/dissolved organic coating material. This innovative high-throughput low-cost patterning technique enables OLED to be both R2R solution coated and R2R patterned while maintaining high device performance and high web speed.

To summarize, GE has made significant contributions in developing all aspects needed to enable R2R solution processible OLED a viable lighting technology.

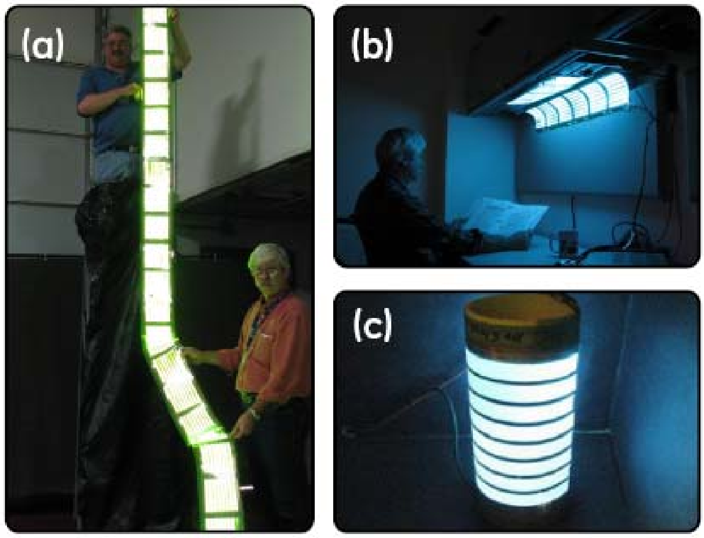

Figure 4 (a) 15 feet long green R2R OLEDs. (b) Under cabinet light made from blue R2R OLEDs. (c) Blue R2R OLED wrapped around a three-inch-diameter plastic core.

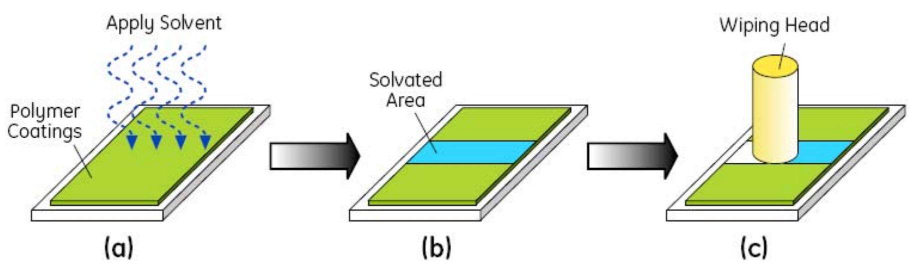

Figure 5 Low cost R2R compatible solvent-assist-wipe patterning technique for organic thin film. (a) Apply solvent to the to-be-patterned area. (b) Solvent dissolves the organic coating material in applied area. (c) Use a polymeric wiping-head to physically remove organic material.

Reference

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