Flexible Ultra-high Gas Barrier Substrate for Organic Electronics

Min Yan, Ahmet Gün Erlat, Ri-an Zhao, Brian Scherer, Cheryl Jones,

David J. Smith, Paul A. McConnelee, Thomas Feist, Anil Duggal

General Electric Global Research Center, Schenectady, New York, USA
Phone; +81-3-3568-1519 E-mail; Michihiro.Ezawa@ge.com

Abstract
GE has developed a plastic substrate technology comprised of a superior high-heat polycarbonate substrate film and a unique transparent coating package that provides the ultrahigh barrier to moisture and oxygen, and chemical resistance to solvents used in device fabrication. This contribution will update recent progresses made at GEFlexible Ultra-high Gas Barrier Substrate for Organic Electronics on ultra-high barrier coated plastic substrate, both in batch mode and in roll-to-roll mode

1. Introduction
GE has developed and evaluated a plastic substrate technology comprised of a superior GE Advanced Materials high-heat (HH) polycarbonate substrate film and a unique transparent coating package that provides the ultra-high barrier (UHB) to moisture and oxygen, chemical resistance, and conductivity functionality required for successful flexible display manufacturing. This article provides an update of the UHB coating, presents a comprehensive evaluation of the fully integrated plastic substrate properties, and provides an update on its OLED fabrication compatibility.

2. High-Heat LEXAN Polycarbonate Film
Substrate Development efforts at GE have been based on a high temperature polycarbonate film provided by GE Plastics (GEP). During this time, GEP and others have developed new materials potentially suitable for display applications. Therefore, in this program, GE will develop the R2R UHB process on GEP high-temperature plastics (See "Table 1."). This will ensure the compatibility and flexibility of the R2R equipment and process that will be developed in this program.

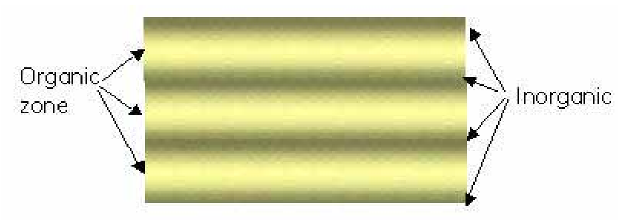
"Table 1. High-Temperature Plastics"

Transmittance	~90%
Glass Transition Temperature	~240C
Surface Roughness	Ra=0.5nm, Rp<10nm
Retardation	<5nm
Dimensional Stability	25 ppm/hr at 200C

3. Ultra-High Moisture Barrier (UHB)
GERC developed a novel graded UHB coating technology. The graded UHB consists of inorganic silicone oxynitride and organic silicone oxycarbide zones with non-discrete interfaces forming a highly robust structure (See "Figure 1"). The silicon oxynitride is one of the most commonly used inorganic barrier materials. The organic silicon oxycarbide zones are used primarily to decouple pinhole defects in individual inorganic zones to further reduce water

vapor transmission. This graded barrier structure has demonstrated a water vapor transmission rate (WVTR) in the mid 10-6 g/m2/day range, approaching the barrier performances requirement for OLED fabrication on plastic substrate.

"Figure 1. UHB Structure Cross Section"



The graded structure has unique advantages over multilayered barriers. First, continuous transition of the coating composition eliminates the possibility of delamination of the layers, since there is no discrete interface between different materials. Under the cross-sectional XPS analysis of the graded barrier coating, it clearly shows the transitional zones within the coating, where the composition of the coating changes monotonically from silicon oxynitride to silicon oxycarbide and vice versa. In contrast, for multilayered barrier structures, where the discrete interface exists between the layers, coefficient of thermal expansion (CTE) mismatch between two different materials can cause delamination of the layers, especially during the thermal cycles in display manufacturing processes.

4. UHB LEXAN® Film Performance

A comprehensive evaluation was carried out on the plastic OLED substrate. WVTR test was measured using improved Ca corrosion test, ITO sheet resistance was measured using 4-probe method, optical transparency was measured using UV-VIS spectrometer, adhesion was measured using ASTM3359 method, dimensional stability was measured using thermal mechanical analysis, and surface roughness was studied using optical profilometry. Chemical resistance, mechanical flexibility and thermo-mechanical stability were validated with both visual inspection and Ca corrosion test (See "Table 2.)

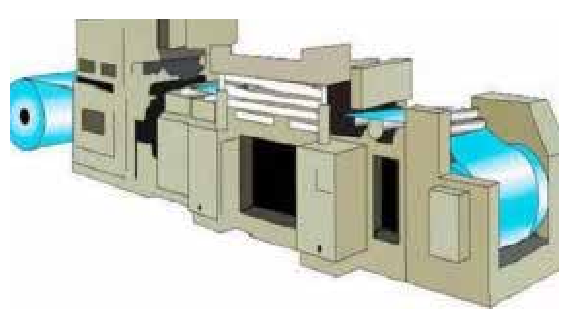
"Table 2. GE UHB Performance"

	USDC Specifications	GEGR Performance
WVTR	10-6g/m2/day	low 10-5~mid 10-6
Chemical Resistance	acid, solvent, alkali	Pass
Electrical Conductivity	<40 ohmn/sq	40.3 ohmn/sq
Optical Transparency	>80%	82%
Mechanical Flexiblity	bend around 1" radius	Pass
Thermo-Mechanical Stability	200C for 1 hour	Pass
Adhesion	>4B	4B
Dimension Stability	<20ppm/hr at 150C	4ppm/hr
Average Surface Roughness	<5nm	0.6nm

5. Roll-to-Roll Process

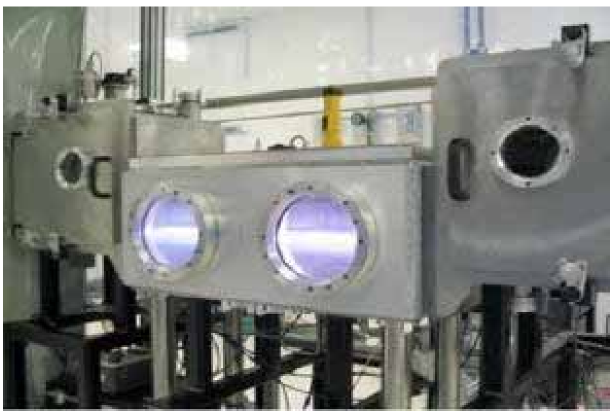
GERC has focused on developing Roll-to-Roll (R2R) process for this UHB coating process(See "Figure 2). During the GE UHB LEXAN Film process, we could utilize the present process technology of Wet coating, however GE needed to develop the continuous PECVD process for our optimized UHB coating system. Based on the technology and process expertise, which we have developed through the batch reactor mode for UHB coating, we started developing R2R reactor mode. We already achieved graded structure of UHB layers by R2R PECVD process.

"Figure 2. Roll-to-Roll Process Model"



Our next target is to optimize this R2R PECVD process for our Graded Ultra-high barrier process under commercial acceptable tact time. Also, we try to verify this R2R compatibility with future OLED device fabrication process. We built our pilot process of R2R PECVD for UHB coating (See "Figure 3.), and have

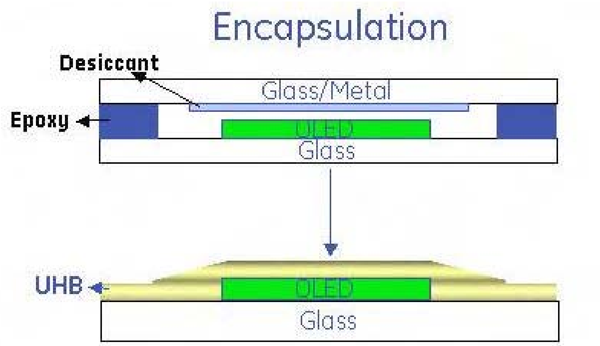
"Figure 3. R2R PECVD Pilot"



6. Film Encapsulation

OLED Industry has been requiring Direct Film Encapsulation technology, which is enable to coat directly to OLED device and eliminate Desiccant and Adhesion of Glass/Metal Encapsulation process. However, any encapsulation technology could not assure, or be satisfied by customer with regard to both Gas barrier capability for OLED device and commercial acceptable tact time for process at same time. GE UHB process has capability to reach the requirements for both its barrier and tact time from OLED industry (See "Figure 4"). Right now, GE internally has been doing kinds of tests for direct film encapsulation, and figured out the new method that Industry be able to utilize GE UHB technology for Direct Encapsulation. GE will demonstrate this new concept to OLED display industry.

"Figure 4. Direct Film Encapsulation Concept"



7. Next Step

OLED display technology offers the potential to enable low cost, highly functional electronic devices that are area-scalable and mechanically flexible (See "Figure 5."). To achieve this potential, it is crucial to develop viable R2R process methods and equipment that are capable of manufacturing coated plastic substrates in mass quantity. To be successful, the R2R plastic substrate must ultimately enable a lower OLED system cost than achievable with display quality glass. Through a detailed understanding of the materials, process, and infrastructure needed to create a R2R plastic substrate, GE will demonstrate compatibility of its R2R substrate with the economic needs of the OLED display industry.

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"Figure 5. Flexible OLED Device Sample"