Paper 54-1 has been designated as a Distinguished Paper at Display Week 2018. The full-length version of this paper appears in a Special Section of the *Journal of the Society for Information Display (JSID)* devoted to Display Week 2018 Distinguished Papers. This Special Section will be freely accessible until December 31, 2018 via:

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Authors that wish to refer to this work are advised to cite the full-length version by referring to its DOI:

https://doi.org/10.1002/jsid.663

World 1st Large Size 77-inch Transparent Flexible OLED Display

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Abstract
We successfully realized world first 77-inch transparent flexible OLED display with Ultra High Definition (UHD) resolution, which can be rolled up to a radius of 80 mm with a transmittance of 40%. The process flow and key technologies to fabricate a large size transparent flexible OLED panel will be discussed.

Author Keywords
Transparent Flexible Display; AMOLED; Multi Barrier; LASER Lift Off; Sacrificial Layer

1. Introduction
Information display has evolved into various aspects and new forms as technology advances. Especially, Flat Panel Display (FPD) is leading the technical maturity of information display, which is composed Plasma Display Panel, Liquid Crystal Display (LCD), and Organic Light Emitting Diodes (OLEDs). Above all, OLEDs are promising candidate to realize future display, which provide a number of major technical enhancements over conventional displays and TV such as high contras ratio, fast response time, and wide viewing angle. Furthermore, OLEDs could be used to produce paper-thin display, transparent display, and flexible display. Flexibility and transparency of OLEDs are particularly excellent when compared with other display types. In recent years, there are many studies in various types of flexible displays [1-4]. Large flexible OLED display provides various electronic applications such as curved, bendable, rollable, and commercial display, because of its thinness, light weight, and design freedom.

Recently, flexible OLED with Low Temperature Polycrystalline Silicon (LTPS) Thin Film Transistors (TFTs) backplane have been commercialized in small size mobile display. In contrary, although the stability of the metal oxide TFT is poorer than that of the LTPS TFT, continuous innovation in the metal oxide TFT in conjunction with other well-known advantages, such as low process temperature, low leakage current, high mobility, large area TFT uniformity and low equipment cost have endowed compelling reasons for the metal oxide TFT in the application of large size OLED displays [6-8]. Additionally, the production line compatibility between the metal oxide TFT and the conventional amorphous silicon (a-Si) TFT with minute modification further advocates the adaptation of the metal oxide TFT in large size OLED displays. Among various metal oxide semiconductors, amorphous Indium Gallium Zinc Oxide (a-IGZO) has a strong potential to be employed as the next-generation backplane technology for FPD, owing to its excellent mobility and stability. The maximum process temperature of a-IGZO TFT is below 350°C, even about 200°C or lower for low temperature process, which allows both Polyethylene terephthalate (PET) and Polyethylene naphthalate (PEN) films to be the proper candidates for flexible substrates. However, in the cases of processes that require temperatures above 300°C, PI coated and cured on glass substrate is the utmost material of choice to realize flexible display. PI has been the most widely utilized material for flexible display substrate due to its high glass transition temperature as well as the low thermal expansion coefficient [2]. However, typical plastic materials exhibit Water Vapor Transition Rate (WVTR) of $10^{1}\sim10^{-1}$ g/m^2 day at 25 °C, which is precariously high to degenerate the properties of OLED, and PI being a type of plastic material, is prone to the consistent challenge [9]. In order to overcome the shortcomings of the PI and to ensure the stability of the OLED displays with PI substrates, water vapor diffusion barriers composed of SiN_x and SiO_2 layers are essential [10,11].

In this work, the world first large size 77-inch transparent flexible display, fabricated on coated transparent PI substrate with specially developed multi-barrier employing a-IGZO TFT, is introduced by explaining key technologies and challenges to develop a large size transparent flexible OLED display.

2. Process Flow
"White OLED on TFT (as the bottom substrate) + color filter (as the top substrate)" method is used to fabricate the transparent flexible OLED display, which is similar with the conventional LCD process.

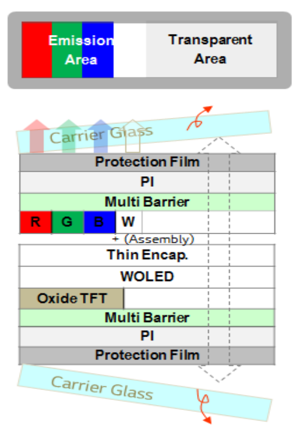

Figure 1. Schematic of 77-inch transparent flexible OLED panel structure.

Figure 1 illustrates the detailed structure to fabricate 77-inch transparent flexible OLED display on a plastic substrate. On both top and bottom substrates, transparent PI was coated on a glass substrate by slot-die coater to produce approximately 10~20 μm thick transparent plastic substrates upon curing. To prevent moisture and gas permeation through the plastic substrate, multi-barrier layer was deposited on the transparent PI and subsequently oxide-TFTs with top-gate coplanar structure were fabricated on the multi-barrier of the bottom substrate.

 ISSN 0097-996X/18/4702-0710-$1.00 © 2018 SID

white top emission OLED layer was deposited on the oxide-TFTs using evaporation process and subsequently thin encapsulation process was performed over the deposited white OLED layer. Meanwhile, the conventional color filter process with black matrix was prepared on the multi-barrier of the top substrate and subsequently the top and bottom substrates were assembled. After scribing the assembled structure, Chip On Film (COF) and Printed Circuit Board (PCB) were bonded on PI/Glass substrate. Finally, LASER Lift-Off (LLO) process, which detaches PI from a carrier glass, was carefully performed using UV LASER and subsequently a protection film was laminated on both PI sides.

3. Results and Discussion

3.1 Multi Barrier for transparent flexible display

In order to reduce the permeation rate of moisture through the PI substrate, inorganic barrier layer is usually prepared [12]. The extremely low level of the WVTR required by an OLED layer through a single inorganic barrier layer is unattainable due to potential defects from pinholes and particles during deposition. As previously reported, the multi-barrier, which usually consists of the combination of SiO_2 and SiN_x, reduces the number of defects and prevents the penetration of the moisture and gas from environment more effectively [2]. The consistent scheme of SiN_x and SiO_2 stacks was deposited at elevated temperature on transparent PI substrates as a multi-barrier layer to effectively reduce the WVTR properties (~10^{-6} g/m^2 day) [4]. In case of a transparent flexible display, the multi-barrier is required the additional consideration to overcome the decrease of transmittance due to the difference in refractive index of the conventional multi-barrier. We developed the special multi-barrier to increase transparency with superior WVTR characteristic as shown in Figure 2 and Figure 3.

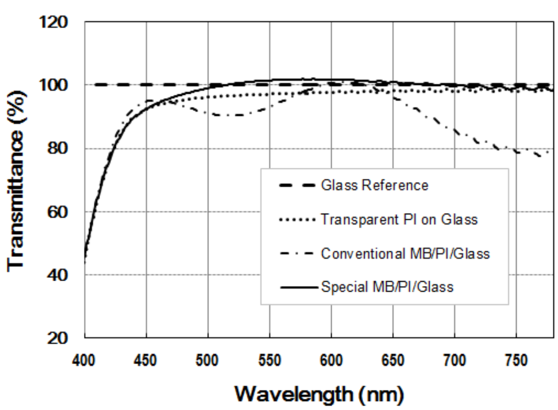

Figure 2. Relative transmittance characteristics of various structures with glass reference.

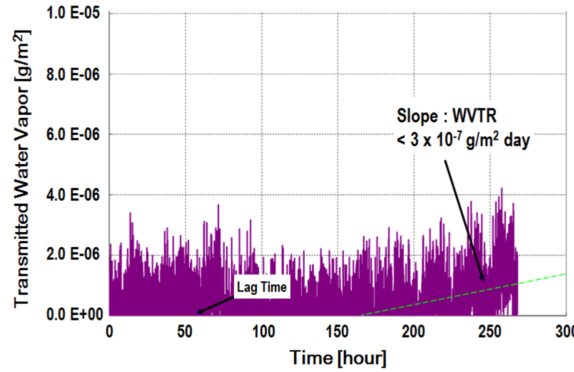

Figure 3. WVTR characteristic of specially developed multi-barrier.

Upon measuring the relative transmittance characteristics with glass substrate as a reference, the average values of the transmittance in visible range were as follows; transparent PI on glass 91.4%, conventional multi-barrier on transparent PI on glass 86.5%, and special multi-barrier on transparent PI on glass 93.5%. In case of the conventional multi-barrier, the transmittance characteristics were decreased at specific wavelength due to the internal reflection caused by the difference in refractive index between SiN_x and SiO_2. In case of the special multi-barrier, the transmittance characteristics could be improved through appropriate adjustment of the refractive index and film thickness. The WVTR through transparent PI substrate with the special multi-barrier was analyzed by a radioactive tracer method with tritium. The radioactive tracer method, which is very sensitive for measuring moisture permeation, inserts a radioactive tracer material, such as tritiated water (HTO), to the permeating H_2O and subsequently uses a sensitive scintillation counter to determine the amount of accumulated HTO that permeates the barrier. Applying the ratio of HTO/H_2O allows calculation of WVTR and the detection limit is 3.0×10^{-7} g/m^2 day. The special multi-barrier shows superior WVTR characteristic which is below the detection limit, $<3.0\times10^{-7}$ g/m^2 day.

3.2 TFT characteristics on transparent PI

a-IGZO TFTs with self-aligned top-gate coplanar structure have been employed on plastic substrate as active layer to improve an electrical uniformity and lower RC delay due to reducing parasitic capacitance [7,8].

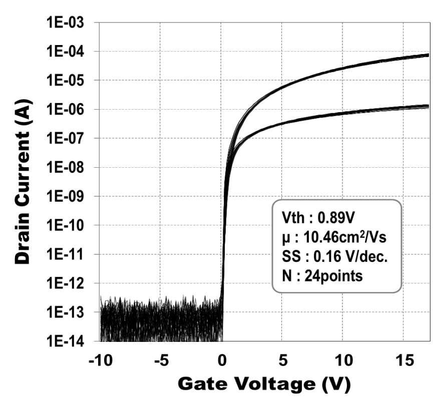

Figure 4. Transfer characteristics of a-IGZO TFT measured at 24 points on 8th generation substrate.

Figure 4 shows excellent electrical characteristics of a-IGZO TFTs on specially developed multi-barrier when measured at 24 points on 8th generation substrate. The threshold voltage (Vth) value was 0.89V with the global Vth range of 0.37V, as well as the field effect mobility (μ) and the sub-threshold swing (SS) values of 10.46 cm2/Vs and 0.16 V/decade respectively. Based on a-IGZO TFT process optimization work, the highly uniform electrical performance was achieved for large size OLED display on plastic substrate.

3.3 Laser Lift-Off for transparent flexible display

One of the challenging technologies to realize large size transparent flexible OLED display on plastic substrate is in the LLO process. In order to successfully perform the LLO process in large size panel, optimization of the key parameters such as LASER beam size and shape, energy density, overlap ratio, and stage control accuracy is decisive.

Figure 5. Photography of panel failure after LLO process.

Figure 5 shows the typical failure of a transparent flexible panel after LLO process. The whole panel area had wrinkles, which were caused by a point defect in the marked black circle at the red box in the image. The panel failure mechanism during LLO process caused by a particle in PI is illustrated in Figure 6.

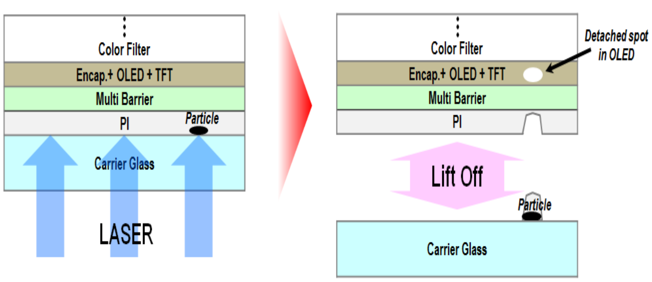

Figure 6. Panel failure mechanism during LLO process caused by a particle at the interface of PI/glass

As shown in the image, a particle near the interface of PI/glass blocked an irradiating beam and generated an unreleased spot area which caused an "internal detachment spot" in OLED induced by physical pulling force during lifting off of the PI. Once the detached spot is created in OLED, it propagated into the whole panel area as time lapse. Finally, the propagated detachment in OLED forms wrinkles on the whole panel area and causes a fatal panel failure that cannot be turned on when the transparent flexible panel is driven. In order to prevent the panel failure of the internal detachment, a sacrificial layer (SCL) was applied between PI and a carrier glass. A SCL layer plays the role as a catalyst to react the specific wavelength of LASER. When LASER irradiate the SCL layer, hydrogen jet out from the SCL layer and subsequently separate the PI and a carrier glass [3,5]. The SCL layer successfully worked to reduce the panel failure due to the aforementioned particle as described in Figure 7. Only the particle near the interface of PI/glass caused the serious panel defect.

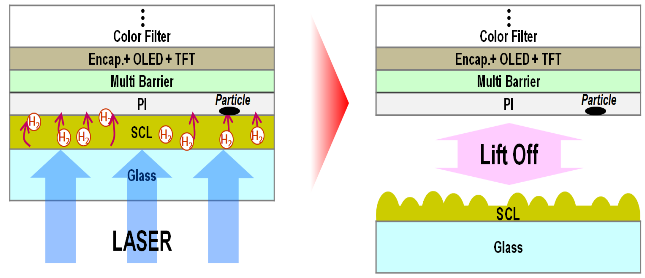

Figure 7. LLO process with SCL to prevent panel failure caused by a particle.

3.4 Transparent flexible OLED display

Figure 8 shows the photograph of the 77-inch UHD transparent flexible OLED display with 80 mm rolling radius and 40% transparency as shown in Figure 9, which is the world first large size transparent flexible panel. In order to maximize the brightness and color reproducibility, RGBW pixel structures are employed. Table 1 shows the panel specifications and it will be exhibited during SID 2018 display week.

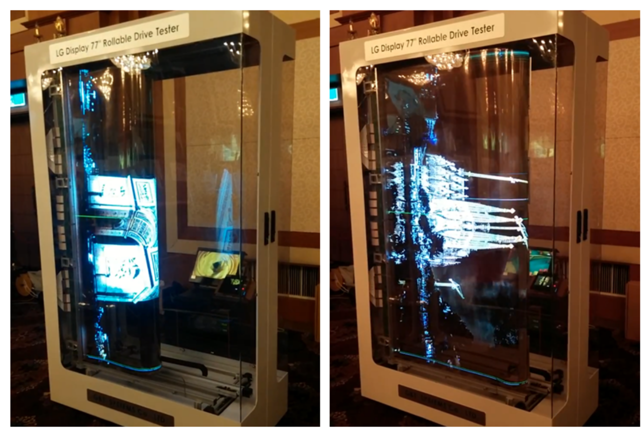

Figure 8. Photography of 77-inch transparent flexible OLED display during cyclic rolling with a radius of 80 mm.

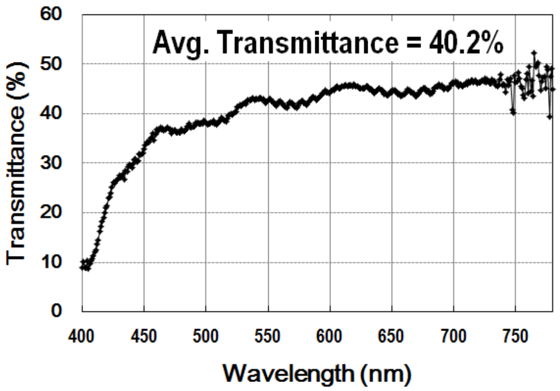

Figure 9. Transmittance characteristic of 77-inch transparent flexible OLED panel.

Table 1. Specification of 77- inch Flexible OLED Panel.

Item	Content
Panel size	77 inch
Resolution	UHD (3840 × RGBW ×2160)
Emission Type	Top Emission
Transparency	40%
Rollable Radius	≤ 80mm
Back-plane	Oxide TFT
Substrate	Transparent PI

4. Conclusion

LG display's world first 77-inch transparent flexible display is a milestone that demonstrates the application of large flexible display in the field of rollable TV and commercial display. This work provides technical challenges to realize a large flexible display and the measures to overcome the difficulties. In order to fabricate large size transparent flexible display, the special multi-barrier with superior WVTR characteristic was developed, a-IGZO TFTs with highly uniform electrical characteristics were employed, and the optimized LLO process with SCL was suggested. We are confident that the possibility of 77-inch transparent flexible OLED panel will be a catalyst to boom up information display in various application and new market with design free shaped.

5. Acknowledgements

This work was supported by the IT R&D program of MOTIE/KEIT. [10042412, More than 60" transparent flexible display with UD resolution, transparency 40% for Transparent Flexible Display in Large Area]

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