High Impact Resistance Damping Structure and Thin-film Encapsulation Technologies for Flexible Display

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Keywords: Foldable, Impact Resistance, Solution-coated Gas barrier

ABSTRACT

A 3mm bending radius foldable AMOLED with high mechanical strength technology is demonstrated. This prototype can pass the ball drop impact test with 135g steel ball from 35cm height. And also, the advanced solution-coated gas barrier is proposed to OLED thin film encapsulation for new flexible AMOLED form factor applications.

1 INTRODUCTION

In the past, we showed a foldable display with the bending radius 7 to 3mm, and geared up for in-fold, 2-fold, Z-fold or 3-fold product applications [1-2]. Samsung unveiled its upcoming foldable smartphone, with a 7.3 inch in-fold AMOLED display in the end of 2018. The inner foldable display is around 7.3 inch AMOLED. The outer display is around 4.5 inch AMOLED. The whole device seems to be quite thick and about double the depth compared to a standard smartphone. This foldable smartphone seems to have two flexible AMOLED display inside one device.

Smart phone and tablet feature can be integrated by using one out-fold display. However, the out-fold touch AMOLED display exposed in the risk of the scratch and abrasion for user. Therefore, the foldable plastic window with abrasion and scratch resistance function is integrated on flexible AMOLED display to avoid the object like keys scratched. And also the out-fold display will directly face the impact for user behavior.

Second topic of foldable AMOLED developing is OLED TFE technology. In the conventional OLED TFE structure, ink-jet polymer layer plays the role to planar the particles and defects come from the OLED manufacturing process. And then, the SiNx or SiON film is deposited on ink-jet polymer layer by PECVD process. These particles and defects are well protected inside the ink-jet polymer and SiNx or SiON film structure after detach from glass and laminated on to the curve fixed rigid cover window. Nowadays, the flexible AMOLED form factor is changed from curve fixed product to dynamic folding smartphone devices. There are some technical issues are proposed to discuss for example like folding ridge, point defects, line defects causing from users folding behavior. Get into the detail of the flexible touch AMOLED structure, defects exist in OLED TFE is an issue for foldable AMOLED reliability, especially in the folding area. Compare to conventional rigid displays, it is easy to bend or deform for foldable displays comprising a plastic substrate like polyimide, PI. However, OLED material in plastic-based AMOLED display is significantly affected by moisture in ambient environment due to the property of poor gas barriers. In order to improve the performance of flexible OLED devices, gas barrier thin films are formed on OLED layer to avoid the moisture penetration [3-4]. The conventional gas barrier is conformal coating on the object surface by PECVD vacuum process. A new solution-coated gas barrier, SGB is proposed to OLED TFE for better defect coverage and filling property under the dynamic stress adding on flexible touch AMOLED panel. The SGB can be coated by slot die coating or ink-jet printing process. In the previous studies, the application of SGB on AMOLED has been discussed, including LTPS TFT backplane, OLED TFE and front plate [5]. In this paper, the SGB process will be studied by ink-jet printing method. It could be used for new form factor flexible touch AMOLED, like foldable, rollable and stretchable AMOLED displays.

2 EXPERIMENT

2.1 High Impact Resistance Damping Structure

The CPL, circular polarizer and plastic window were integrated on one colorless polyimide substrate to reduce the thickness of front plate. Low stress LTPS TFT process and OLED buffer layer was adopt in AMOLED structure. In order to prevent ball drop impact damage, the damping structure is designed under the flexible touch AMOLED display. The impact resistance flexible touch AMOLED structure illustrated in Figure 1. This display module is proposed to integrate in foldable device.

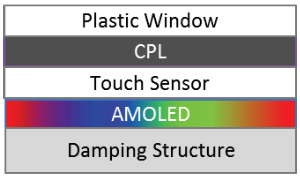


Figure 1. Impact resistance flexible touch AMOLED structure

Before the bending test, stress simulation was introduced to do some analysis of flexible AMOLED panel stress distribution. The flexure of the panel caused by external force, the two sides of the neutral axis are influenced by the tensile stress and compressive stress. The plastic window is most outside the flexible touch AMOLED display. The most stress and strain will occur on the hard coat layer of the plastic window.

According to the simulation result of folding condition, the hard coat layer in plastic window and CPL are located far from the neutral axis that the flexure stress exceeds the limit of the yield strength. However, the flexure stress is much lower than the yield strength if well design of propriety flexible touch AMOLED module.

The integrated flexible touch AMOLED module was tested by dynamic bending tool as illustrated in Figure 2. The folding radius is 3mm at the central line on flexible touch AMOLED display.

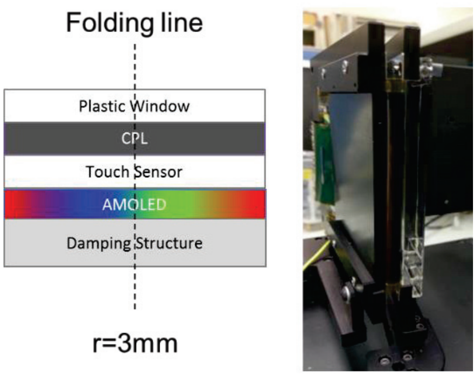


Figure 2. Dynamic folding test of flexible touch AMOLED module

The static folding test was also applied on this flexible touch AMOLED module as illustrated in Figure 3. Two plate, up plate and down plate, parallel fixed these testing samples.

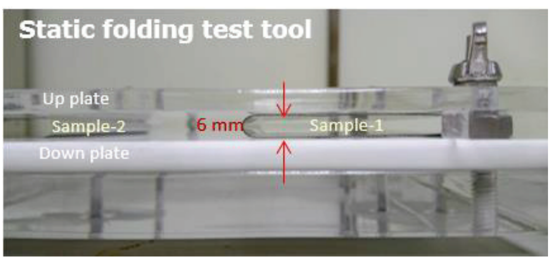


Figure 3. Static folding test of flexible touch AMOLED module

2.2 Thin-film Encapsulation Technologies

Two parts of experiments are investigated in this study, including SGB as OLED thin film encapsulation and the introduction of SGB printed by ink-jet printer. The main processes of SGB thin film are solution coating and plasma treatment, whose process flow shows as figure 4.

In the first part of the experiments, the precursor of SGB is coated on the OLED light source backplane by slit coater, and then it must be heated up at 100°C for 5 minutes to evaporate the solvent and form SGB thin film. Afterwards, the surface of SGB film is modified by Argon ion implantation apparatus to make it with gas barrier property.

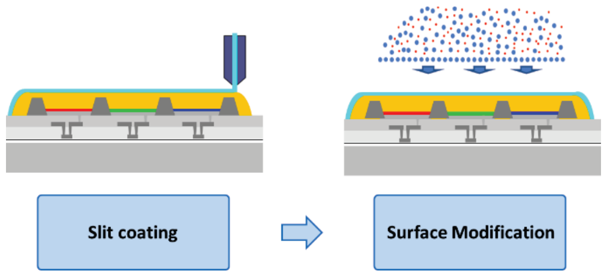


Figure 4. Process Flow of the SGB layers

In the other parts, the evaluation is the precursor of SGB jetted by an inkjet printer, Dimatix Materials Printer DMP2850, and the model of ink cartridges is DMC-11601. Jetting the SGB precursor is able to perform in the nitrogen environment, and jetting voltage is 8.8V as well as the drop space is 30μm.

2.3 Flexible Display Technology

In order to improve the flexibility of the display, we developed an islanding technology with ILD/Soft ILD/ILD multi-layer as lighting device carrier. The soft and organic material as Soft ILD with a small Young's coefficient is used to absorb stress. The rigidity and inorganic material as hard ILD with a higher Young's coefficient is used to disperse the stress. Figure 5 shows the results of the 2D simulation of the island structure of Micro LED display, in which we simulate the shear stress on the weakly bonding area (axis-1) and the weakly wiring area (axis-2). From the simulation results, the stress in the boding area was greatly reduced from 2,800 N/m^2 to 200 N/m^2 and in the wiring area was also reduced from 8,000 N/m^2 to 100 N/m^2, the result shows that islanding structure possess ability to reduced shear stress and will improve the flexibility on Flexible Display.

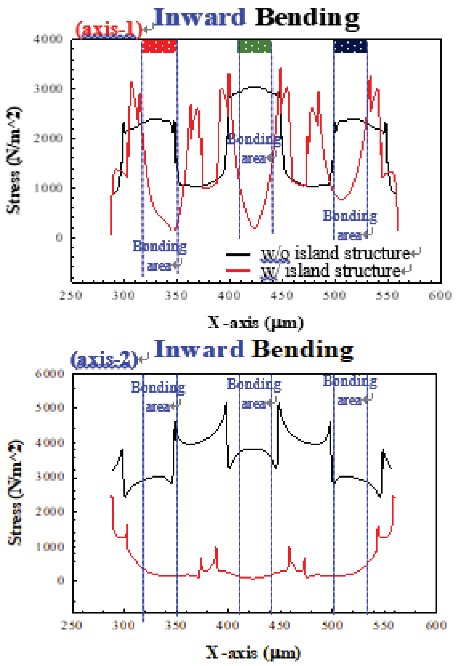


Figure 5. The shear stress distribution of islanding structure in bonding area (axis-1) and wiring area (axis-2).

3 RESULTS

This section describes the detailed guidance for preparing figures and tables in the manuscript.

A 7.1 inch out-fold touch AMOLED display is demonstrated with stylus test and abrasion test. The stylus with 200g loading is put on the surface of display. The # 0000 steel wool with 500g loading is moving by robot as illustrated in Figure 6.

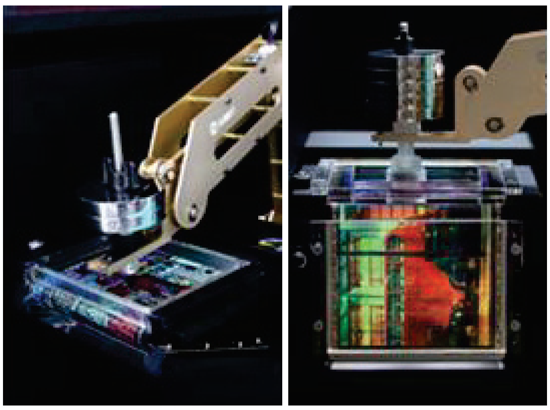


Figure 6. Out-fold touch AMOLED display with scratch and abrasion demonstration

The out-fold touch AMOLED display module was integrated inside foldable device. The 135g steel ball drop from 35cm height is demonstrated as shown in figure 7.

Figure 7. Out-fold device with steel ball drop demonstration

The high impact resistance 7.1 inch out-fold AMOLED display module can reach the dynamic out-fold at radius 3mm with 200k times, static folding at radius 3mm with 240hrs, pencil hardness 7H, abrasion with #0000 steel wool 500g loading 2,000 times and 135g steel ball with 35cm height impact test without any dimple on the display surface as shown in table 1.

Table 1. 7.1 inch out-fold AMOLED display module performance

Items		Foldable AMOLED
Display size		7.1 inch
Form Factor		Out-fold
Dynamic Folding Ability	Radius	r=3 mm
	Folding Times	200K
Static Folding Ability	Duration	240hrs
Protection Ability	Pencil Hardness	7H (at 500g loading)
	Anti-Abrasion	500g/2000 times #0000 steel wool
	Impact Resistant	135g/35cm steel-ball drop (no dimple)

To evaluate the reliability of OLED device whose thin-film encapsulation layer is SGB, devices were executed temperature humidity storage test in 85℃/85% R.H. environment. As figure 8 shows no dark spot or edge shrinkage exists in the array.

Figure 8. Results of OLED light source storage in 85℃ /85% R.H. environment.

After OLED light source folds 1.5mm radius with 200,000 times test, no delamination or crack are observed in folding area and luminance keeps higher than 99% as shown in figure 9.

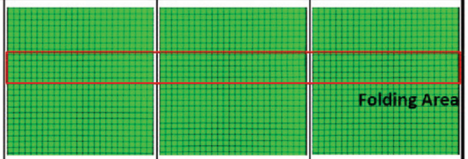
Folding Times	0	50,000	100,000
Image			
Luminance (nits)	215 (100%)	214 (99.5%)	218 (101%)

Figure 9. Folding torture test with 1.5mm radium of OLED light source

While SGB thin film of the inkjet printing process is performed, figure 10 illustrates that gas barrier property reaches lower than 5×10-4 g/m2·day, the limitation of the MOCON instrument, and is the same as a slit coating process. On the other hand, transmittance of TFE structure Polymer/SGB/SGB film is around 96% shown as figure 11.

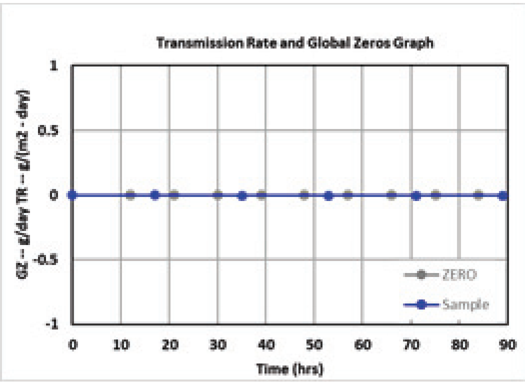


Figure 10. WVTR of SGB structure fabricated by ink-jet printer

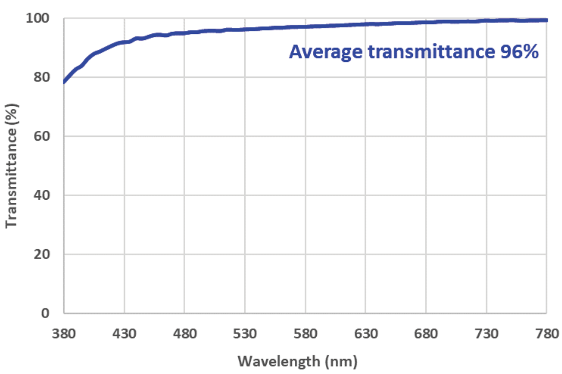


Figure 11. Optical property of SGB structure fabricated by ink-jet printer

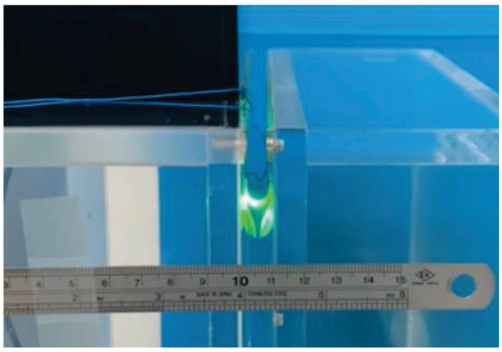


Figure 12. The 2 inch Micro LED TEG with 100 x 100 Micro LED chip array under r = 5 mm bending test.

Finally, to evaluate the bending reliability of display, we fabricated the Micro LED TEG (Test element group) with islanding structure and examined by bending instrument. In figure 12. The 100 x 100 Micro LED chip array on islanding structure of display with brightness 1,000 nit will pass through r=5 mm bending test.

4 CONCLUSIONS

The high impact resistance out-fold AMOLED display module has been proposed to future outward folding device application.

Solution-coated gas barrier (SGB) successfully applied to Flexible AMOLED as thin film encapsulation. Advantages of this technology includes an effective cost and yield improvement .Finally, our islanding technology on flexible display possess ability to reduced shear stress and will pass through r = 5 mm bending test.

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