Flexible LCD with Colorless Polyimide

Kaijun Wang[1], Chunge Yuan[1], Zhuhui Li[1], Li Zhang[1], Qiao Huang[1], Linshuang Li[1], Shujhih Chen[1], Chia-Yu Lee[1], Xin Zhang[2]
[1]Shenzhen China Star Optoelectronics Semiconductor Display Technology Co., Ltd., Shenzhen, China
[2]Shenzhen China Star Optoelectronics Technology Co., Ltd., Shenzhen, China
Keywords: Flexible; Colorless Polyimide; LCD

ABSTRACT

We successfully realized 14-inch flexible LCD using colorless polyimide(cPI) as substrate. The LCD panel has the thickness less than 0.3 mm, which is IPS mode with some special materials and designs for avoiding predictable risks and solving issues during process.

1 INTRODUCTION

Undoubtedly, flexible displays are getting more and more attention from the public because of lightness, thinness, flexibility and unbreakable features.

Compared to flexible AMOLED, flexible LCD is currently not esay to be made into free foldaber display due to the limitations of related materials and backlight. Althought it is difficult to break those restrictions, it still has great advantages for small radius curved displays, because it is cheaper and longer life than flexible AMOLED [1]. On the other hand, compared to curved displays made of ultra-thin glass, flexible LCD can have a smaller radius of curvature or multiple radius of curvature [2].

Flexible LCD has many predictable risks, and numerous issues discovered during the process. We have avoided most of risks by selecting special materials and designs, at the same time, some process issues have also been solved by modifing designs and optimizing process conditions. We exhibited a 14 inch flexible LCD panel with colorless polyimide (cPI) in 2019 SID exhibition as shown in figure 1. This panel fixed on a backlight which have a curvature of 100mm. The conbination of indium gallium zinc oxide (IGZO) TFT, Color filter on Array substrate (COA) and Black Photo Spacer (BPS) shows the pentential to make a large size flexible LCD with plastic substrate.

Fig. 1 14-inch flexible LCD panel in 2019 SID exhibition

2 DISCUSSION

In order to get smaller curvature radius even free foldaber displays, we are constantly overcoming foreseeable difficuties and solving process issues.

2.1 Deal with liquid crystal leakage during bending

LCD panel involves two individual CF and TFT substrate, the two substrates are combined by frame sealant. When the flexible LCD panel is bending, the upper substrate is stretched, and the bottom substrate is compressed. Undoubtedly, this will lead to the haul of the sealant (figure 2), which will easily arouse the sealant to peel off from the substrate or crack itself, causing the liquid crystal (LC) to leak. It is possible to avoid the sealant to peel off from the substrate by selecting sealant with excellent adhesive feature, and to prevent the cracking of the sealant by picking the sealant with favourable tenacity. Considering comprehensively, we have already picked out a kind of sealant with excellent adhesion and toughness feature provided by KYORITSU CHEMICAL Co.Ltd. During the bending process, stripping or cracking of the sealant was not observed. However, figure 3 demonstrated that liquid crystal leakage still occured due to the separation among the layers in the area coated the sealant .

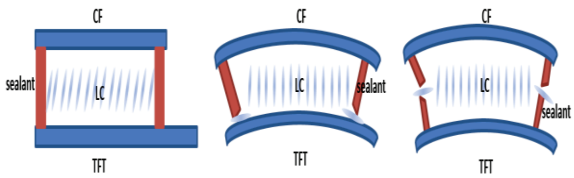


Fig. 2 (a) Before bending. (b) Sealant peeling off from substrate during bending. (c) Sealant cracking during bending

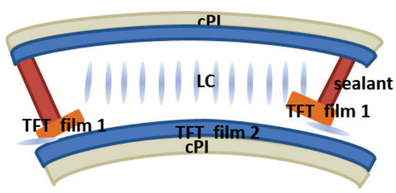
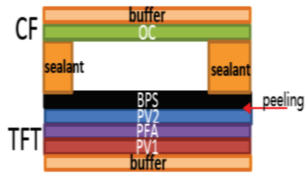
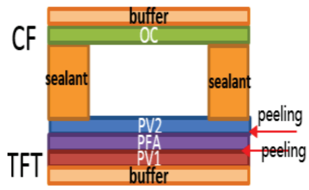
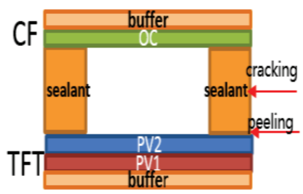


Fig. 3 Seperation among films causes LC leakage

We designed different film structures and tested the peeling force. It was found that the interface of the organic/inorganic stack on the TFT substrate was poorly adhered, as shown in Table 1. The BM on the CF is safe if it was protected by OC not patterned. Based on this result, we digged out the organic layers in the border area of the Array, and added BM layer to the corresponding area on the CF side for shading protection.

Table 1 Peeling force of different film structures

NO.	Structure	Peeling situation	Peeling force(N/mm)
1		BPS peeling to CF side	11.4
2		PV2 or PV2& PFA peeling to CF side	16.08
3		Sealant cracking or sealant and PV2 seperation	19.45

2.2 Deal with the bending shift and cell gap control

When the flexible LCD is bending, the dislocation of the upper and bottom substrate may cause light leakage and abnomal color performance. What's worse, it is also prone to uneven cell gap and leakage of corners caused by liquid crystal flow.

We used the Color filter on Array substrate (COA) and Black Photo Spacer (BPS) structure, as shown in figure 4, to avoid light leakage and abnomal color performance. In addition, this structure can maintain the uniformity of the cell gap to a certain extent[3].

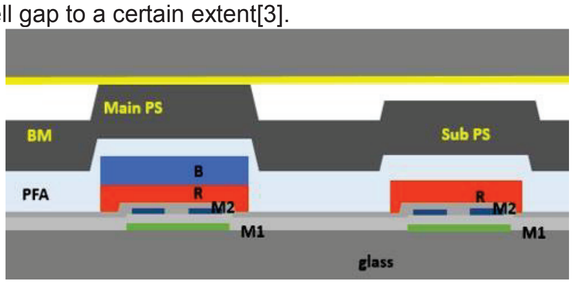


Fig. 4 COA and BPS structure

At the same time, we are also developping polymer wall liquid crystal (PWLC, supplied by Merck) and found the best process conditions. Moreover, we fabricated some small LC cell sheets using PWLC and normal LC, proving that the polymer walls formed in the cell can maintain the uniformity of cell gap and prevent corner leakage[4].

Furthermore, we plan to apply PWLC to the 14-inch flexible LCD, expecting to get a flexible LCD with a smaller radius and better display effect.

2.3 Deal with the curling of cPI film

For cPI, compared to yellow PI, one of the biggest problem is the crimp of cPI film after laser lift off (LLO) process. Rolling up of the cPI film, coupled with its poor toughness, is easy to cause the fracture of the substrate. We reported how to improve the process flow after cell to decrease the difficulty of lamilating polarizers and bonding caused by curing of cPI film[3]. However, this method is cumbersome and cannot greatly cut down the propotion of the crack of cPI after LLO.

In order to solve the easy curling of cPI in essence and enhance the yield of process after cell, we studied and analyzed the reasons of cPI curling. Generally speaking, the stress of the film is divided into compressive and tensile stress. The compressive stress is positive and the tensile stress is negative. According to our reseach, the degree of cPI curling after LLO process is strongly correlated with the magnitude of the stress of cPI, whatever it is positive or negative. Table 2 shows the stress test results of different cPI samples, and Figure 5 shows the situation of different cPI samples after LLO process.

Table 2 Stress of different cPI samples

Sample	1	2	3
Stress(Mpa)	22.36	12.36	20.7
Phenomenon	Serious curling	No curling	Serious curling

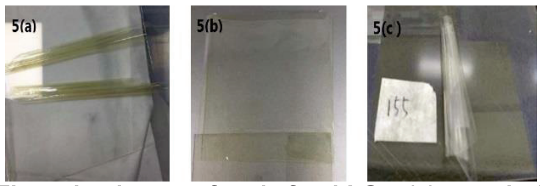


Fig. 5 the degree of curl after LLO. 5(a) sample 1, 5(b) sample 2, 5(c) sample 3

Meanwhile, there are many other layers that need to be deposited on the cPI, such as silicon nitride and silicon oxide, and most of them have stress. We hope that the total stress of those stacked layers including cPI and films on cPI the smaller,the better. Therefore, we will spend a lot of energy to arrange layer stacking and select the suitable materials of cPI and the membrane layer.

2.4 Deal with the bow of substrate

Many layer stacking with different Young' s module and different coefficient of thermal expansion (CTE) may cause problems, not only in the reliability of bending and process after laser lift off, but also in TFT/CF/Cell process. Commonly, the substrate will become warped after the heating and cooling process, due to the big difference of CTE among those layers, especially between cPI and glass. Many equipment, especially the exposure and the vaccum assembly equipment, have high requirement for the flatness of substrate. Therefore, the flexible substrate with excessive bow is difficult to pass through the exposure and cell processes.

To solve this matter, it can be improved from materials, process and equipment. In terms of materials, in order to decrease the warpage of the flexible substrate after the heating and cooling procedure, we can reduce the difference of CTE between cPI and glass by lowering the CTE of cPI or increasing the CTE of glass. In additon, increasing the thickness and hardness of glass or reducing the thickness of cPI is also an effective method. In terms of process, the substrate warpage can be generally cutted down by reducing the process temperature. On the device side, if the adsorption stable, including the centre and the corners, is desighed with suction holes densely, the warped substrate can be well adsorbed. Alternatively, some auxiliary adsorption tools can be added around the stable which can press the warped substrate to the platform to solve the difficulty. Without a doubt, there are many other ways, and we are looking forward to the achievement of equipment and materials suppliers.

3 CONCLUSIONS

Even if the probability of making a flexible display that can be repeatedly bent is relatively low, the flexible LCD still has an unshakable advantage in applications with small or multiple curvature radius. We have demonstrated the way to make a flexible LCD, and have been working hard to reduce the radius of curvature, improve the display effect, and raise the yield of qualified panel. We believe that our technology about flexible LCD is not far from being applied in mass production .

REFERENCES

[1] Wen-Yuan Li et al, "The First Flexible Liquid Crystal Display Applied for Wearable Smart Device," SID Digest,pp 98-101 (2015).

[2] Wei Ming Huang et al, "Curved LCD and Future Application," IDW, pp 1494-1496 (2017).

[3] Yu Shi et al, "14 Inch Flexible LCD Panel with Colorless Polyimide," SID Digest,PP 597-599 (2019).

[4] Kaijun Wang et al, "Research and Analysis of Polymer Walls Technologies for Flexible Display," ICDT(2019).