A 14-inch Foldable OLED Display with Excellent Optical and Mechanical Performances

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ABSTRACT

A 14-inch WQHD foldable AMOLED display was developed with superior optical and mechanical performances. High Adobe and DCI-P3 color space coverage indicates its excellent color expression capacity. No obvious optical and structural degradation could be detected after 240h static and 100,000 times dynamic bending tests.

1 INTRODUCTION

In the last few decade, active-matrix organic light emitting diodes (AMOLED) displays have gained unprecedented attention due to their obviously premium display quality, like ultrahigh contrast ratio and real-world colors [1-7]. Beyond that, further benefits have also been discovered. With rapid development of technology, consumers are not satisfied with traditional flat panel displays (FPD) as more and more creative and innovative applications need to be equipped with display panels which have flexible and light weight characteristics. AMOLED display, fabricated on flexible PI substrate, is considered as the most prospective candidate to realize the demands for future display.

Recently, cellphones with curved edge have largely appeared in the consumer goods market, and the more exciting news is that foldable mobiles are now reality and will gradually twist people's inherent perception of fixed shape of electronics. Apart from mobiles, other types of consumer electronics also require specific mechanical properties. Notebook, which needs to be carried around, is expected to be more freeform and lightweight. However, the market for foldable or even rollable notebook products is still blank. Although the concept of foldable notebook has emerged for quite a long time and kept showing up in science films, a real product is still out of reach for ordinary consumers.

In this study, we fabricated a 14-inch WQHD foldable OLED display and emphatically characterized its optical and mechanical properties. With nearly full coverage (>95%) of Adobe and DCI-P3 color spaces, this display can meet almost all the demanded colors for image processing and video watching. In addition, achieving 240h static bending and 100,000 times dynamic bending at a radius of 5mm without obvious brightness and color degrading also indicates its outstanding mechanical performance.

2 PANEL DESIGN AND PROCESS FLOW

This foldable OLED display was fabricated by depositing low temperature poly-silicon thin-film transistor (LTPS) on flexible PI substrate. After evaporating light emitting materials, a 3-layered encapsulation consisted of 2 inorganic layers and an inserted organic layer was then prepared. Afterwards, an ultra-thin circular-polarizer (C-POL) and a touch sensor layer were attached to the panel. To enhance surface hardness and protect the underlying layers from external corrosion, a plastic cover was finally affixed on the top.

Besides, another fabrication process was also adopted. We used a novel color filter on encapsulation (COE) method to replace C-POL and achieved excellent optical performance as well [8]. This color filter layer including black matrix, island shaped R/G/B and OC was fabricated on encapsulation and subsequently covered by touch sensor layer and plastic film. As color filter is much thinner than C-POL, this method is believed to promote mechanical reliability of the panel.

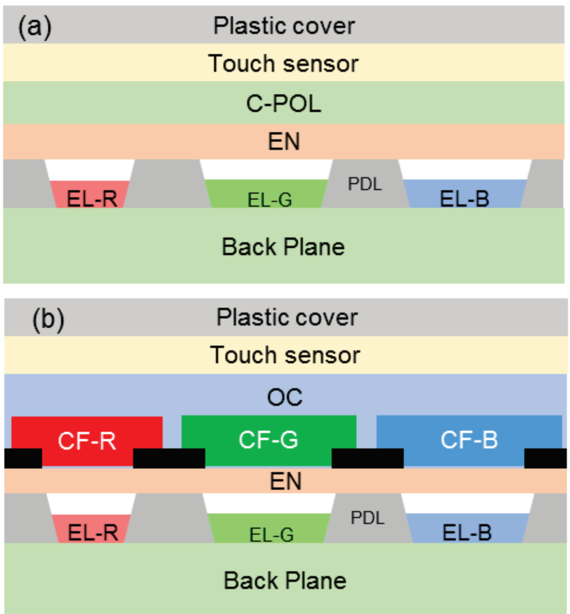

Fig. 1 Simplified module stack of adopting (a) C-

POL, (b) COE to prevent external light reflection

Simplified module stacks of these two processing methods were shown in Fig.1. It is noticeable that the dimensions of the layers in this figure are not applicable to the real situation.

3 OPTICAL AND MECHANICAL PROPERTIES

For most liquid crystal display (LCD), color gamut larger than 100% NTSC is hard to be obtained. As LCD's color gamut is decided by color filter, for a certain color filter material, enhancement of color gamut will inevitably lead to a drop of panel transmittance. Therefore, achieving real world color display for LCD is truly a rough task. By contrast, it is much easier for OLED display to realize large color gamut as its radiation pattern is self-luminous. Generally, color gamut over 100% NTSC of OLED is very common.

A color space standard including all the nature colors is described as BT. 2020 [9]. However, it is not only for LCD, but extremely hard for OLED display to meet this strict specification. Apart from BT. 2020, there are some other color spaces with different significance. For example, Adobe RGB color space, introduced by Adobe in 1988, contains CMYK color space that standard RedGreenBlue (sRGB) color space does not cover and is widely used in many fields like image processing and printing. Another color space received much attention recently is DCI-P3 which is defined for digital movie projection. For most people, notebooks are mainly used for handling official business and entertainment like watching videos. Thus, achieving full coverage of Adobe and DCI-P3 color spaces is of great importance for notebooks.

We measured color coordinates of this 14-inch panel at luminance of 350nits and white balance of D65 (0.313, 0.329). Color performance and coverage of different color spaces were shown in Table 1 and Fig.2. In addition to 100% coverage of sRGB color space, full coverage of Adobe and 95% coverage of DCI-P3 were also realized. In other words, almost all colors that users need when editing photos or watching videos can be achieved on a notebook equipped with this panel. Color performances of samples equipped with COE structure were also measured. Color gamut was enhanced as expected, and full coverage of both Adobe and DCI-P3 color spaces were obtained. Besides, external reflection was decreased to about 7%. Although there is still a gap between COE and C-POL which has a lower reflection of 4.8%, it is actually not that obvious to human eyes.

Table 1. Summary of color performance and coverage of different color spaces

Color space	C-POL sample	COE sample
NTSC	107%	116%
sRGB coverage	100%	100%
Adobe coverage	100%	100%
DCI-P3 coverage	95%	100%

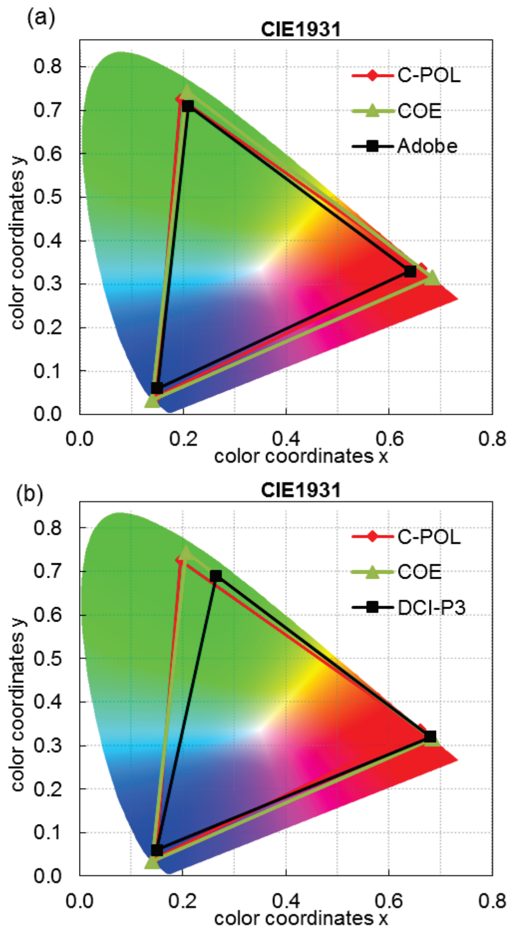

Fig. 2 Coverage of (a) Adobe and (b) DCI-P3 color spaces for C-POL and COE samples

In addition, bending performances at a radius of 5mm were also tested. We conducted a 240h static bending test and a 100,000 times dynamic bending test. Test conditions of dynamic bending were presented in Fig.3. After static bending, the panel gradually recovered from a certain angle to its initial flat state in several hours, revealing its superior structural stability. Slight marks at bending area could be seen after dynamic bending, but after standing for a while, they finally dissipated to an acceptable level. No obvious loss of image quality was detected after both static and dynamic bending tests.

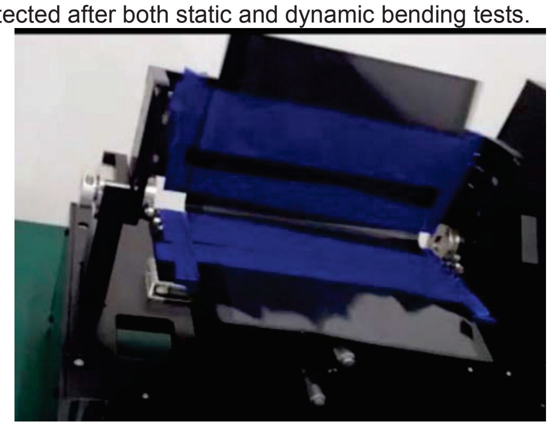

Fig. 3 Dynamic bending test conditions

4 PROTOTYPE EXHIBITION

We realized a 14-inch WQHD foldable display and demonstrated our prototype under flat and bending conditions in Fig.4. Ultrahigh contrast ratio and powerful color expression were clearly delivered through these pictures. Color coordinates were tuned to obtain almost full coverage of Adobe and DCI-P3 color spaces, aiming to meet consumers' requirements for notebook. Considerable foldable performances were also achieved. Besides, by incorporating a flexible cover film, 4H hardness was implemented to enhance surface strength of the panel. Summary of panel specification were listed in Table 2.

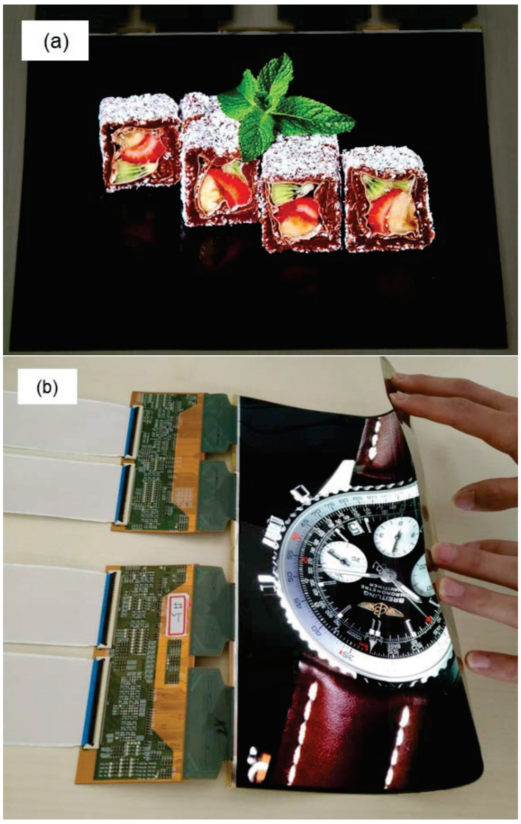

Fig. 4 Prototype demonstration under (a) flat and (b) bending conditions

Table 2. Summary of panel specifications

Size	14 inch
Resolution	WQHD
Panel Luminance	350 nits
Contrast ratio	>50,000
Color gamut	107% NTSC
Bending radius	5mm
Bending times (inward)	100,000
Surface hardness	4H

5 CONCLUSIONS

We have successfully developed a 14-inch foldable display and characterized its optical and mechanical properties. With high saturated color coordinates, this panel could achieve almost full coverage of Adobe and DCI-P3 color spaces, revealing high color expression capacity. After 240h static and 100,000 times dynamic bending tests at a radius of 5mm, no obvious optical and structural degradation could be detected. Development of this innovative panel will hopefully bring flexible AMOLED display technology to a bigger and higher platform and make freeform electronics more reachable for ordinary consumers in the future.

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