Foldable OLED Display with 620 Degree Celsius LTPS TFT Manufactured by Weak Bonding Method

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ABSTRACT

By weak bonding method, the first OLED display with 620℃ LTPS TFT, without PI substrate, formed on a glass substrate is transferred to a non-PI flexible substrate. After transfer, the display image is free from defect and functions normally. The advantages of transferring are shown.

1 Introduction

Nowadays, for manufacturing of flexible display, coating-type polyimide (PI) on glass substrate as the array substrate is the dominating method, however the organic substrate limit the display performance. Flexible display with PI substrate, compared with glass substrate, usually suffers degraded performance issues such as image retention, burn-in, pattern distortion, low transparence and so on. [1-2] For Low Temperature Poly-silicon (LTPS), TFT mobility and stability are proportional to activation step temperature which is above 600℃ for glass substrate. On the contrary, because the temperature limit of PI is less than 500℃, the activation temperature must be lowered to around 450℃ and the TFT quality will be degraded, which brings image issues. [3] Besides, if the array process temperature rise from 450℃ to 600℃, the coefficient of thermal expansion of PI will make substrate bend so seriously that the pattern distortion will occur. Also, the high annealing temperature reduces the transparence of PI so transparent and flexile applications will be restricted.

In terms of manufacture cost, the usage of organic PI substrate brings extra cost. First, PI coating line is expensive, and the step is so time-consuming that it becomes the bottle neck of whole process. Second, in array process, thermal annealing must be replaced by oven, instead of rapid thermal process (RTP), so additional machine investment is required. Furthermore, in the latter laser lift-off (LLO) step, scratch or pollution on the back side of glass substrate lowers the yield at the early stage of Module.

In addition, to make thinner and transparent touch sensor on display, it is better to process touch sensor thin-film direct on display or combine with polarizer. However, processing touch sensor directly on display surface, such as OLED, may suffer more array yield loss. On the other hand, the process temperature of touch sensor is above the limit of OLED or polarizer. The better way is to make touch sensor thin-film alone and then transfer to OLED or polarizer.

In short, it is best to eliminate PI layer and put the electronics thin film to any flexible substrate as the application require. Figure 1 is the idea process flow of flexible OLED display. The touch sensor and OLED display are made on separate glass substrate so the electronic performance is as good as that on glass substrate. After combined with each other by vacuum assembly method, the glass substrates are removed and cover and flexible substrate are laminated. This method will open the largest window to choose stacking material and to optimize mechanical structure and electronic performance. In the following, OLED display on TFT thin film and touch sensor thin film are made on separate glass substrate and are transferred to flexible substrates with variable Young's modulus.

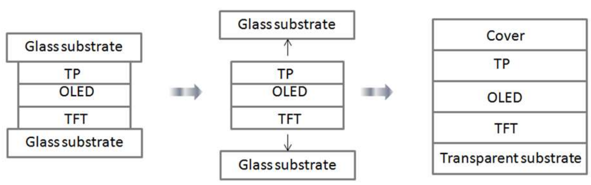


Fig. 1 Idea process flow of flexible OLED display with touch sensor function

2 OLED Display Transfer

Figure 2 is the process flow of OLED display thin-film transferred to a flexible substrate and the final light on image. First, the glass substrate is treated to be weak bonding with upper thin-film. [4] Following, LTPS TFT, activated at 620℃ by RTP method, is deposited. After array process, OLED layers are evaporated and patterned by fine metal mask. Finally, multi encapsulation layers, composed of inorganic and organic, are deposited to isolate OLED material from oxygen and moisture. To protect the top surface during transfer process, a carrier substrate is adhered onto the top. When applying a gentle mechanical stress to the weak bonding interface of thin-film and glass substrate, separation will proceed smoothly without crack. Next, a flexible substrate is laminated to the back surface of thin film by roller lamination method. After removing the carrier substrate, the panel is lighted on to check performance. As shown in the picture, the 1.85" panel has no visible defect which proves that the transfer process will not damage OLED and TFT.

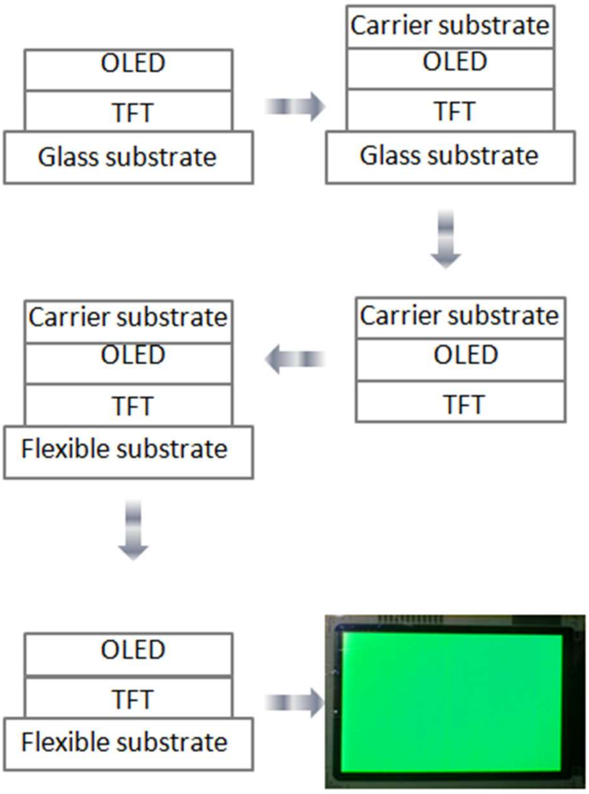


Fig. 2 Process flow of OLED display thin-film transferred to flexible substrate and the final light-on image

For flexible display, dimension change is critical for both manufacture process and final product design. Flexible display often encounters obvious dimension change due to the thermal stress from plastic material layer in the stacking, such as PI substrate. To confirm the deformation in the transfer process, pitch variation is recorded. Figure 3 shows the pitch measuring directions, parallel and vertical to the separation direction before and after transferring to a non-PI substrate. Table 1 list the measured pitch values and calculated total pitch variations. The pitch variations in both directions are less than 3 um which falls within the measuring tolerance. The calculated total pitch variations are both less than 1E-4, while that of coating-type PI substrate panel is around 1~6E-4. Owing to the low separation force between thin-film and glass by weak bonding method, the pitch variation can be very low even for debonding a Gen 1 size thin-film at one time.

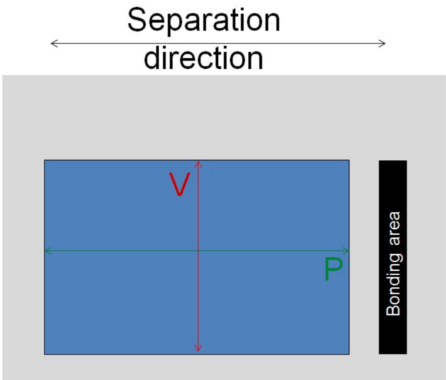
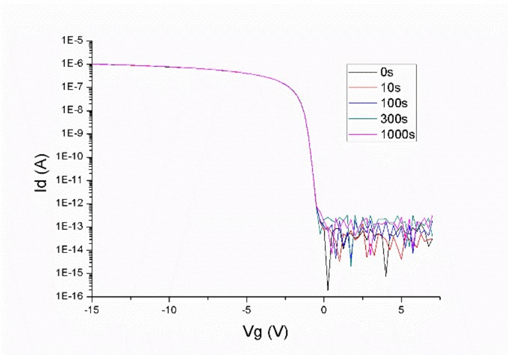


Fig. 3 Pitch measure directions, parallel and vertical to the separation direction in relationship with panel

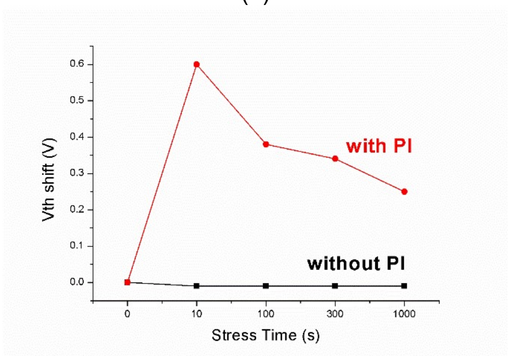
Table 1 The measured pitch variations and calculated total pitch variations

Direction	Parallel	Vertical
On glass (mm)	39.9225	24.9855
Transferred (mm)	39.9223	24.9870
ΔTTP	-5*E-6	+6*E-5

For OLED display, TFT operates in saturation region where current is sensitive to threshold voltage (Vth). Therefore, once Vth change is above the compensation limit, OLED will be driven by wrong voltage so display luminance will be different. Consequently, image retention or even burn-in image will appear. Figure 4(a) shows the Id-Vg curves of a transferred test-key on a thin-film transfer sample (without PI) during the TFT stress process. The TFT channel length is around 17 micrometer, and width is around 5 micrometer. After stress, the off current remains around 10E-13 ampere, and the Vth is around -0.91 volts. Figure 4(b) plots the Vth variation curves, with and without PI substrate, by the same stress method as Figure 4(a). The Vth of thin-film TFT transferred to no-PI substrate has only about 0.01 volts change. On the contrary, when using coating-type PI substrate (with PI), the Vth vibrates violently as the red line shows and the maximum variation is around 0.6 volts which maybe beyond the compensation capability of circuit. For coating-type PI substrate, the CTE mismatch of PI and inorganic thin-film brings in thermal stress in anneal process. Therefore, by laminating flexible substrate to the back side of thin-film TFT after array and OLED process, no thermal stress is applied so Vth shift degree is as low as that on glass substrate.



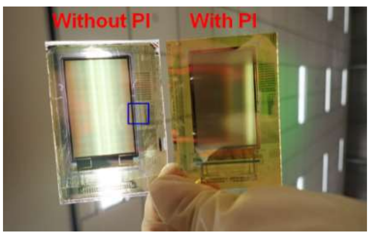
(a)



(b)

Fig. 4 (a) Id-Vg curves of a transferred test-key on a thin-film transfer sample (without PI) during the TFT stress process. (b) Comparison of Vth variation, with and without PI substrate, during TFT stress process

Transparence is important for many applications, such as augmented reality and window. Figure 5(a) shows transparence difference of flexible panels with and without PI substrate. With PI substrate, the yellow color of high temperature PI is inevitable. Without PI substrate, the color of laminated flexible substrate is not annealed in high temperature so its transparence is high. Figure 5(b) is the enlarged picture of the blue marked area from 5(a). The white and transparent area is made by removing organic planarization layer. The inorganic layers, such as silicon nitride and silicon oxide, can be further reduced to increase transparence. Ideally, the transparence of flexible substrate can be higher than 99% which is higher than normal display glass substrate.

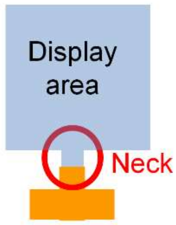


(a)

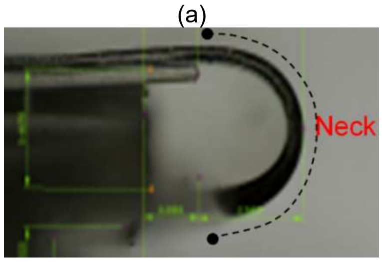
(b)

Fig. 5 (a) Image shows transparence difference of flexible panels with (right) and without PI (Left) substrate. (b) The enlarged picture from the blue marked area from 5(a)

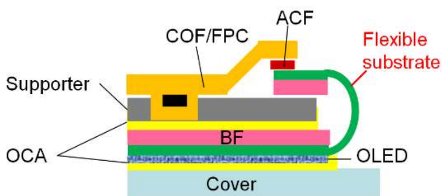
Since high screen to body ratio provides user more information and more fashion design, small bezel width has become more and more popular. To hide the bonding area, for flexible display, bonding area is folded to the back side of display by folding the neck area as shown in Figure 6(a). Figure 6(b) is the cross-sectional OM image showing that the folding radius is around hundreds micrometer. Figure 6(c) is the cross section view of folding structure near neck area. The bonding area and COF are both hid to the back side so that the bezel width is reduced to the radius of folding.



(a)



(b)



(c)

Fig. 6 (a) Display area connected with bonding area by neck design before folding. (b) Cross-sectional OM image of neck area. (c) Cross- section view of flexible OLED display near neck area

In order to further reduce bezel width, the folding radius is getting smaller. Under such small folding radius, the strain at the neck area is dominated by substrate rigidity and increases proportionally with substrate rigidity. With PI substrate, the strain mainly comes from PI layer whose Young's modulus is around 8 GPa. By replace of PI by softer substrate, the strain will be lower and can be balanced by coating organic layer on metal signal line. Figure 7 shows the simulated strain with varied Young's modulus of flexible substrates after folding neck where the radius is 300 micrometer. In the case, the optimized Young's modulus of substrate is around 2.5 GPa, close to Young's modulus of PET. The strain and array stacking can be further optimized by using softer organic planarization layer and substrate. [5]

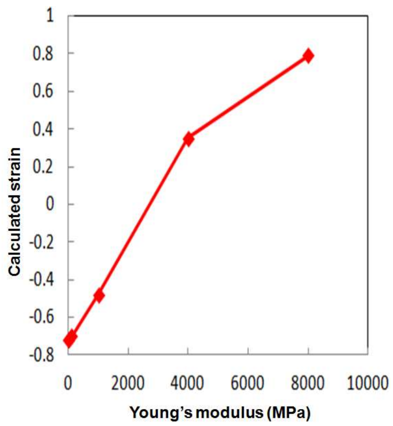


Fig. 7 The simulated strain with varied Young's modulus of flexible substrates

By reducing the Young's modulus of substrate, the OLED panel is tested by folding machine. In Figure 8, after folded 10 thousand times at folding radius of 4 mm, the panel maintains crack-free. The red dash line represents the folding axis, and the panel still has no visible bending trace, which can be explained by low rigidity of substrate and therefore low folding stress.

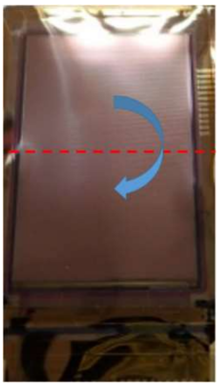


Fig. 8 Image of OLED panel after folding along the red dash line at folding radius of 4 mm for 10 thousand times

3 Conclusions

In sum, by weak bonding method, a 1.85" OLED display with 620℃ LTPS TFT is transferred to a non-PI substrate and light-on without any damage. The transferred TFT quality is as good as on glass substrate and the transparence is even higher. Also, the transferred 7.8" touch sensor shows normal function and has pitch variation under measuring tolerance. In the future, since flexible display will be more popular, not only display quality must meet the highest quality, but also the price must be lower. By the process in Figure 1, electrical device thin film, for both OLED and micro LED, can be made on any substrate with high quality and low cost, no matter for flexible or even stretchable.

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