Effect of OCA Properties on Foldable AMOLED Panel with a Module Structure

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ABSTRACT
The main design goal of the foldable OLED display is to avoid the film stack failure caused by bending stress during repeated folding and unfolding. This paper models and simulates the structure of the foldable OLED screen module, and explores the visco-hyperelastic mechanical characteristics for optical clear adhesive, such as the factors of influence of hyperelastic modulus, viscoelastic parameters $E_\infty$ and Poisson’s ratio.

1 INTRODUCTION
Recently, the importance of flexible display technology is increasing on a daily basis as a result of the sustainable development of personal intelligent device[1-3]. Several flexible AMOLED products are already on sale in the display market. But, these products have some defects, for instance, device peeling, visible wrinkles etc. In order to realize flexible display perfectly applied to therollable or foldable device of next generation, it is necessary to research the effective application of Optically clear adhesives (OCAs) in the flexible AMOLED module.

The structure of a module flexible AMOLED display can be divided into several parts: cover window, polarizer touchpad, panel film and backplane; Another important component Adhesives (OCAs) which can be used to bond cover windows, touch sensors and circular polarizers in a foldable OLED display (Figure 1). For a foldable display module, OCA changes the direction of film stress and minimizes strain on critical layers, which is defined a simplified 7-layer film stack structure. Finally, reasonable stack structures can be given to protect the available suggestions are given to optimize the flexible AMOLED display.

2 EXPERIMENT
A foldable display is laminated with numerous thin layers, which is defined a simplified 7-layer film stack (Table 1) without consideration of the detailed patterned layout and materials of the OLED devices. In the fully folded configuration, the space between the straight sections of the outer layer is 6 mm resulting in the bent section of the film stack forming an approximate semicircle of a radius of 3 mm as shown in Fig. 1. During the first second, the rigid body rotates counterclockwise around the reference point at 1.57 rad/s while moving leftwards at $(\pi/2-\pi)$ mm/s, and then stays for 300s. In-folding motion means that the front sides of the display are attached to each other, the observable face is the back of the display. Out-folding motion means that the back sides of the display are adhered to each other, and the outside can still visually see the imaging of the
The simulation was performed using the ABAQUS finite element analysis package. Due to the large ratio of film stack panel width to its thickness, a 2-dimensional plane strain model was used.

3 RESULTS

3.1 The affects of the OCA layer thickness

In this section, the first OCA layers is adjusted. The thickness of the original first OCA layer is 25 μm. When investigating the influence of the thickness of the first OCA layer, the thickness of 25 μm, 50 μm, 75 μm, 100 μm, 125 μm is selected for comparison. We discuss the strain distribution at the symmetry axis and the maximum strain of each OCA layer after the model bent, and the results are shown in Fig 3-1(a) and Figure 3-1(b).

With the increase of the thickness of OCA1 adhesive layer, the maximum strain of each film layer does not change; The maximum strain of OCA1 layer decreases significantly, and the strain of OCA2 layer also decreases significantly. The strain of other OCA layers tends to decreasing, but not obviously.

3.2 The effect of hyperelasticity of the OCA material

The hyperelasticity of the OCA material is mainly reflected in the change of the elastic modulus with time. In this section, the experimental data of the OCA material is modified in proportion to achieve the change of the elastic modulus. The fitting parameters are shown in Table 1.

After calculating, the strain distribution at the axis of symmetry and the maximum strain of each OCA layer after bending are shown in Fig 3-2(a) and Fig 3-2(b).

With the increase of the elastic modulus, the strain curve of the display area is obviously shifted to the right, and the tensile strain is significantly increased. When the elastic modulus is increased to 1400 times, the strain neutral layer phenomenon disappears. When it increases to 140,000 times, the strain distribution is linear, the strain of each film layer is greatly increased, and the risk of damage of the device is increased. At the same time, the strain of each OCA layer is also significantly decreased.

3.3 The effect of viscoelasticity of the OCA material

The Prony series used to describe the viscoelastic behavior can be represented by the formula, which is equivalent to:

\[ G(t) = G_0 \left( g_\infty + \sum_{i=1}^{N} g_i e^{-\frac{t}{\tau_i}} \right) \]  \hspace{1cm} (3.3.1)

In the formula, \( g_\infty \) is \( e_\infty \) and \( g_i \) is the curve coefficient, satisfying:

\[ g_\infty + \sum_{i=1}^{N} g_i = 1 \]  \hspace{1cm} (3.3.2)

When changing \( g_\infty \), other coefficients \( g_i \) can be obtained according to the ratio:

\[ g_i = g_\infty \frac{(1 - g_\infty)}{(1 - g_\infty)} \]  \hspace{1cm} (3.3.3)

In (1.3.3), \( g_0 \), \( g_1 \) are the Prony coefficients obtained by fitting the original data.

The Prony parameter \( \tau_i \) remains unchanged when \( E_\infty \) changes. The Prony parameter corresponding to different \( E_\infty \) is shown in Table 2. Using parameters to fit, the viscoelastic curve is obtained as shown in Figure 1-3. The larger the value of \( E_\infty \), the closer the material is to elasticity. When \( E_\infty = 1 \), the material loses viscoelasticity and only has hyperelasticity.

It can be seen that the change of the viscoelastic parameters \( E_\infty \) does not cause a apparent change in the strain of the film. The strain of each layer is basically the same at 0 s after bending. However, the maximum strain of the layer at 300 s after bending, there have been changes, The fourth layer of OCA maximum strain grows 28.6%.

It indicates that the parameter \( E_\infty \) affects the material relaxation and creep properties, which affects the deformation of the material. When the \( E_\infty \) is larger, the viscoelastic property is less obvious. When the same time is left, the degree of deformation of the OCA material is more small.

4 DISCUSSION

A constitutive model was presented to describe the nonlinear viscohyperelastic behaviors for OCA. Based on the mechanical model, the stress and strain distribution of the flexible AMOLED touch panel in the folding state were analyzed by the finite element method. The folding symmetry, which is matched to the smallest curvature radius, bears the maximum stress. The curvature radius gets larger as the position is further away from the symmetry center. The stress can be decreased to nearly zero in the unbending area.

5 CONCLUSIONS

As the thickness of the first OCA layer from 25μm to 50μm, the relative difference in OCA maximum strain of down to 37.5%. With the increase of the elastic modulus, the strain curve of the display area is obviously shifted to the right, and the tensile strain is significantly increased. When the \( E_\infty \) is larger, the viscoelastic property is less obvious. When the same time is left, the degree of deformation of the OCA material is more small.

REFERENCES


Table 1. The simplified 7-layer display film stack layup and the properties used in the simulation. The thickness shown in the table are the values used for stack layup 2

<table>
<thead>
<tr>
<th>Panel Component</th>
<th>Thickness (μm)</th>
<th>Elasticity Modulus (GPa)</th>
<th>Poisson ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cover Window</td>
<td>90</td>
<td>5.6</td>
<td>0.29</td>
</tr>
<tr>
<td>OCA1</td>
<td>50</td>
<td>/</td>
<td>0.48</td>
</tr>
<tr>
<td>Polarizer</td>
<td>47</td>
<td>3.769</td>
<td>0.33</td>
</tr>
<tr>
<td>OCA2</td>
<td>20</td>
<td>/</td>
<td>0.5</td>
</tr>
<tr>
<td>Touch</td>
<td>25</td>
<td>2.3</td>
<td>0.31</td>
</tr>
<tr>
<td>OCA3</td>
<td>25</td>
<td>/</td>
<td>0.49</td>
</tr>
<tr>
<td>TFE</td>
<td>9</td>
<td>76.9</td>
<td>0.22</td>
</tr>
<tr>
<td>Array</td>
<td>7.5</td>
<td>49</td>
<td>0.30</td>
</tr>
<tr>
<td>PI Substrate</td>
<td>15</td>
<td>9.1</td>
<td>0.33</td>
</tr>
<tr>
<td>OCA4</td>
<td>25</td>
<td>/</td>
<td>0.5</td>
</tr>
<tr>
<td>PET Backplane</td>
<td>75</td>
<td>4.076</td>
<td>0.32</td>
</tr>
</tbody>
</table>
Fig 3-2(a) The strain at the symmetry axis

Fig 3-2(b) The maximum strain of each OCA layer axis

Fig 3-3 Comparison of different elastic modulus after bending

(a) The strain at the symmetry axis

(b) The maximum strain of each OCA layer axis

(c) Maximum strain of each rubber layer at 0 s

(d) Maximum strain of each rubber layer at 300 s

Fig 3-3 Comparison of different viscoelastic $E^\infty$ after bending