Research on the Design and Application of Integrated Cover

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Abstract

Aiming at the limited supportive function of traditional support metal mask strips, this paper proposes an Integrated Cover design that combines structural support and pixel shielding functions. Through optimization of structural parameters, the lateral bending performance is improved and the risk of false soldering is resolved. A tensioning model was established using finite element simulation software to compare the differences between the Integrated Cover and conventional metal mask strips during tensioning and attachment. Finally, Experimental validation demonstrated that the Integrated Cover achieved 0% defect rate caused by lateral bending and 0% false soldering rate, which is highly consistent with simulation predictions. These results confirm the technical feasibility of the design and provide a viable technical solution for the production of next-generation high-precision display panels.

Author Keywords

AMOLED; Integrated Cover; Structural Optimization; Lateral Bending and Toppling; False Soldering; Finite Element Analysis

1. Introduction

Organic light-emitting diode (OLED) display technology has emerged as a mainstream direction for next-generation displays, owing to its exceptional characteristics such as self-emission, high contrast ratio, wide viewing angle, fast response time, and flexible bendability, and is widely applied in smartphones, wearable devices, high-definition televisions, and automotive displays [1-2]. In current mass production of small- to medium-sized OLED panels, the approach combining vacuum evaporation with fine metal masks (FMM) remains the dominant technology for precise patterning of red, green, and blue (RGB) sub-pixels [3-4]. To maximize the utilization of expensive mother substrates and enhance production efficiency, OLED panel manufacturers adopt a "splicing" design and production approach. This approach integrates multiple pixel mask units (Sheet Mask) of different specifications on a single FMM master mask (Mask Frame) to simultaneously produce displays of varying models or sizes. Typically, the central area is used for manufacturing high-value, high-volume primary products (main screen), while the marginal spaces on both sides are utilized to incorporate smaller-sized or additional products (sub-screens), such as screens for smart watches and wristbands. The design outcome of a spliced FMM is illustrated in Figure 1.

This strategy significantly improves substrate utilization and production economy. However, this technical pathway still has certain limitations: when the main screen product is changed, even if the sub-screen product specifications and design remain entirely unchanged, the existing process requires the sub-screen mask design to be redesigned and adjusted according to the new main screen mask. This leads to extended design cycles, increased manufacturing costs, and considerable constraints on production flexibility.

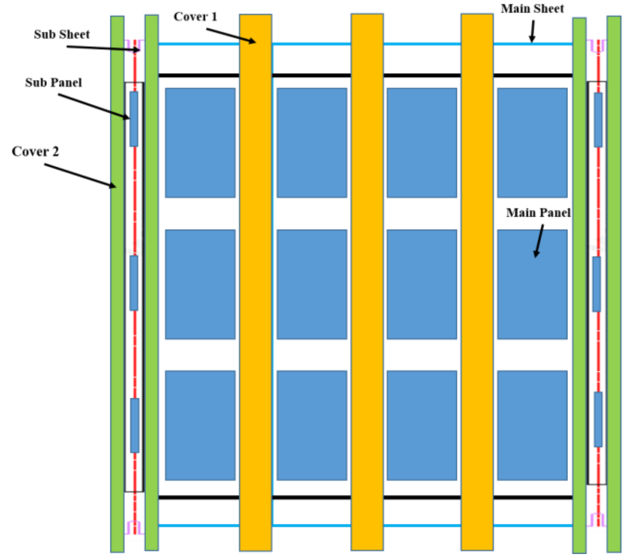

Figure 1. Traditional OLED FMM splicing design

To address the above challenges, this paper proposes a novel "Integrated Cover" structural solution. Its core concept integrates the mechanical support function of the mask strip and the pattern definition function of the evaporation area into a single component. Through a modular architecture, this design decouples the mask designs of the main and sub-screens: when the main screen product specifications change while the sub-screen remains unchanged, only targeted adjustments to the opening structure defining the evaporation area in the Integrated Cover are required, eliminating the need to redesign the sub-screen mask. This significantly Will simplify the splicing design process, reduces repetitive design and manufacturing costs, and greatly enhances production flexibility and response efficiency.

2. Design and Optimization of the Integrated Cover

2.1 Structural Design

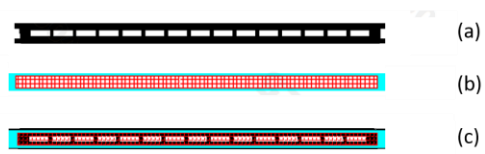

Figure 2. Mask Structure (a) Integrated Cover (b) Fully Etched Sheet (c) Composite Structure

For traditional spliced FMM designs, both the left and right sides of the spliced-in screen body's Sheet require the design of Covers to provide support. This study proposes an integrated shielding metal mask strip design scheme, as shown in Figure 2(a). Figure 2(b) shows the fully etched Sheet Mask, where the pixel openings of the sub-screen are etched across its entire surface. Figure 2(c) presents the combined diagram of the integrated shielding metal strip and the Sheet. This integrated shielding metal strip can achieve multiple core functions: Firstly, it provides overall support for the entire sub-screen Sheet, ensuring structural stability; secondly, the openings of the integrated shielding metal strip can precisely define the effective AA evaporation area of the sub-Sheet, guaranteeing evaporation accuracy; thirdly, it provides directional support for one side of the main Sheet. Particularly, when the main screen is a special-shaped screen, such as a water drop screen or a Notch screen, the protruding part on the right side of the integrated shielding metal strip can further provide auxiliary shielding for the irregular area of the main screen, expanding the range of adaptable scenarios. On one hand, this solution integrates the two Covers that would require independent tensioning in traditional designs into a single strip structure, significantly reducing the number of Masks and shortening tensioning time; on the other hand, when the main screen product is changed, there is no need to redesign the sub-screen Sheet—only targeted adjustments to the opening structure in the integrated shielding metal strip used to define the AA evaporation area are required, thereby greatly reducing resource waste caused by repetitive design.

2.2 Analysis of Lateral Bending Issues and Structural Optimization

Lateral bending is a typical structural instability phenomenon. During the tensioning process, the Mask is subjected to a tensile preload T along its axial direction. Its critical buckling load can be initially estimated using Euler's buckling theory. To more accurately analyze and optimize its stability, this study employs finite element analysis software to establish a numerical model.

Given that the plate thickness of the integrated shielding metal strip structure is much smaller than its dimensions in the width and length directions, it can be simplified and modeled using shell elements, with the material properties defined as Invar. The boundary conditions simulate the actual tensioning process: all degrees of freedom at the clamp positions are constrained except for the direction of tensioning, and a preload T is applied at both clamp locations.

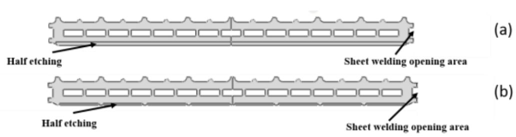

Figure 3. Optimization Plan

(a) Overall half-etching (b) Interrupted half-etching

In the initial design (structural schematic shown in Figure 2a), the main body of the Integrated Cover exhibited significant rightward deviation, with a lateral displacement difference of up to 72.31 μm (Figure 4a), which exceeds the tolerance range of high-precision manufacturing processes. Analysis revealed that this lateral bending phenomenon primarily stems from the structural asymmetry and uneven mass distribution of the Integrated Cover: the left side has significantly greater mass than the right side, leading to rightward bending deformation under preload.

To address this issue, this study employs a weight reduction strategy to balance the mass distribution between the left and right sides. Specific measures include localized semi-etching for weight reduction (as shown in Figure 3) and overall adjustments to key dimensions. Finite element simulations confirm that the optimized structure reduces the lateral bending displacement difference significantly to within the design tolerance (Figure 4 and Table 1). This displacement value is smaller than the designed clearance between the opening area of the Integrated Cover and the AA area of the sub-screen, thereby effectively avoiding the risk of the sub-screen AA area being obscured due to excessive lateral bending. Such methods, which use simulation to predict structural shrinkage, deformation, and internal stresses, have been widely validated as reliable analytical approaches in precision manufacturing fields such as additive manufacturing [5].

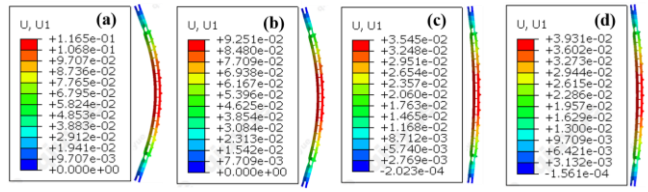

Figure 4. lateral bending(100 times deformation ratio)

(a) Base (b) Size reduction(c) 3mm half etching

(d) 3mm broken half etching

Table 1. lateral bending

Plan	Lateral bending
Base	72.31 μm
Size reduction	71.91 μm
3mm half etching	24.90 μm
3mm broken half etching	27.17 μm

2.3 Optimization of Cold Solder Joint Risk

Cold solder joints typically result from excessive wrinkling of the mesh during the tensioning process, leading to gaps between the welding area and Frame. To simulate this process, an additional analysis step was added to the tensioning model of the Integrated Cover. A rigid body was positioned below the welding area of the Integrated Cover, with dimensions matching the contact area between the strip and the Frame. After completing the tensioning process simulation, the Integrated Cover was lowered to observe the gap between the strip and the rigid body.

Figure 5 shows the simulation results. The gap for the original 3 μm semi-etching design was approximately 6 μm (Figure 5a), while the gap in a conventional FMM design was about 2 μm. An excessively large gap could lead to cold solder joint defects. To prevent this issue, the welding opening dimensions in Figure 3 were increased, redirecting the wrinkling during tensioning to the outside of the welding area of the Integrated Cover. After optimization, the gap with the Frame was further reduced to 1.7 μm (Figure 5b), with no significant changes in lateral bending or tilting values, effectively mitigating the cold solder joint problem.

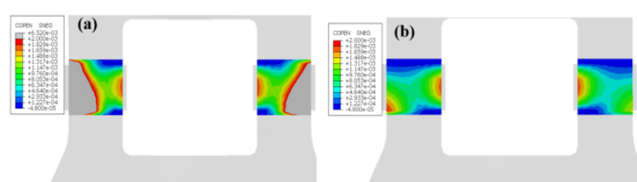

Figure 5. Welding gap

(a) Base (b) Increase welding opening

2.4 Stability Analysis

To ensure that the Integrated Cover does not undergo deformation affecting production requirements during long-term use, we conducted a simulation analysis of its structural stability. The simulation employed the displacement method by adding an analysis step to the tensioning model of the Integrated Cover. A concentrated force was applied along the X-direction at the center of the metal strip, and its displacement response in the X-direction was observed.

The simulation results are shown in Figure 6. Figure 6(a) displays the displacement contour of the Integrated Cover, with a maximum displacement of 109.9 µm; Figure 6(b) shows the response of a conventional metal strip under the same load, with a maximum displacement of 918.1 µm.

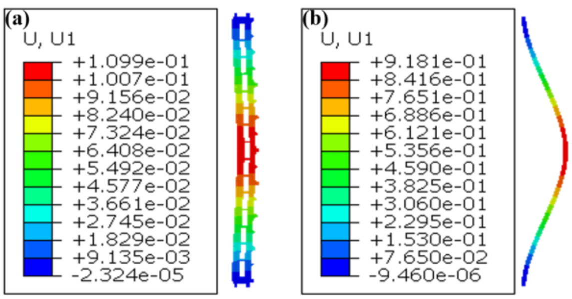

Figure 6. Deformation displacement (100 times deformation ratio)

(a) Integrated Cover (b) Basic mask

The comparison indicates that the deformation of the Integrated Cover under external loads is significantly smaller than that of the conventional structure. This demonstrates that the Integrated Cover possesses excellent anti-deformation capability within the existing evaporation process cycle, effectively avoiding deformation accumulation due to long-term use and thereby ensuring product yield.

3. Experimental Validation

To validate the performance of the optimized Integrated Cover in real production environments, we conducted a series of mesh stretching and vapor deposition tests.

3.1 Tensioning Results

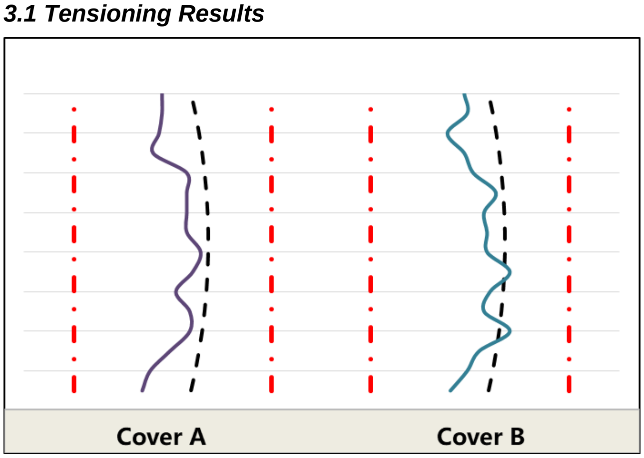

Figure 7. Integrated Cover tensioning

Figure 7 shows the tensioning deviation results of the Integrated Cover (the red dashed line represents the Pixel Pitch Accuracy(PPA) control limit, and the black dashed line represents the deviation curve after scaling the simulation results). As shown in the figure, the lateral deviation of the Integrated Cover remains within the limited, and the scaled simulation results align closely with the actual tensioning results, with a deviation within 9%. During the tensioning process, no defects caused by lateral bending, tilting, or cold soldering were observed. The lateral deviation of the Sheet Mask supported by the Integrated Cover maintain consistency with conventional projects.

In summary, the overall tensioning results of the Integrated Cover solution are consistent with those of conventional designs, demonstrating its feasibility for tensioning applications and compatibility with the design and process requirements of standard products.

3.2 Evaporation Results

To validate the production feasibility of the Integrated Cover solution, this study measured the evaporation shadow in the AA area and the evaporation PPA in different evaporation chambers.

The evaporation shadow test results indicate that the sub-screen evaporation shadow value is approximately 4~6µm, which falls within the target design limit of 6µm. This suggests that the Sheet lamination process of the Integrated Cover solution did not exhibit significant abnormalities. The main screen evaporation shadow value ranges from 3~5µm, indicating minimal impact on the main screen's evaporation morphology.

Regarding evaporation deviation (PPA), data show that under the Integrated Cover solution, 94% of data points for the sub-screen non-stretching direction meet the specification requirement of control limited, while the stretching direction fully complies with this standard. The main screen achieves 100% compliance with the control limited of deviation requirement in both stretching and non-stretching directions, with overall data distribution remaining consistent with individual production.

In summary, both evaporation shadow and PPA results demonstrate that the Integrated Cover solution has minimal impact on main screen product quality, but may slightly affect pixel alignment accuracy on the sub-screen. Therefore, it is recommended to appropriately increase the pixel design margin for the sub-screen in practical applications of this solution to mitigate potential color spot defects caused by deviations exceeding tolerance limits.

4. Conclusion

This study proposes an integrated support and shielding metal strip design for structural optimization and process validation of mask metal strips in tiling design. Through structural optimization, finite element simulation, potential issues such as lateral bending and cold soldering of the integrated shielding metal strip were resolved, theoretically enabling its technical feasibility. Experimental Validation results demonstrate that the integrated shielding metal strip solution performs comparably to conventional designs in key metrics such as tensioning deviation, evaporation shadow and PPA, validating its feasibility and engineering value in high-precision display manufacturing. This research provides an innovative solution for the manufacturing of tiling schemes, with significant prospects for engineering applications.

5. References

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