Display Uniformity Improvement for Hole-in-Display LCD Module

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Abstract
This study addresses the challenges of light efficiency in LCD modules with hole-in-display designs, focusing on issues such as peripheral light emission, brightness inconsistencies, edge brightness lines, and shadows. Through optical simulations and physical verification, optimization strategies in design, process, and materials are proposed, enhancing the visual quality and aesthetics around the display holes

Author Keywords
Hole-in-display LCD module; light emission

1. Introduction
The reason for the poor backlight effect around the blind hole project is due to the extreme blind hole design, especially the border of the blind hole, as shown in size A in the following figure; At present, the limit design of blind hole border is 0.5mm, and with the improvement of technology, it may be further increased to 0.45mm in the future; The ultimate design of blind hole borders can reduce the hole area, thereby increasing the screen to body ratio; However, this further increases the risk of NG in the light efficiency around the hole. Currently, it is avoided through reasonable design of the hole area light guide plate and film section, with a gap of 0.15mm for size B film and an overlap of 0.25mm for size C film; Size D: Light guide plate gap 0.25mm; Size E: light guide plate overlap 0.15mm; This design is currently the optimal solution that balances light efficiency and reliability. Due to the tolerance fluctuation of ± 0.1mm during the assembly process of backlight film materials and light guide plates, a certain proportion of poor light efficiency around the holes may occur in the project process; At the same time, in environmental testing, the shrinkage and expansion of film materials and light guide plates in high and low temperature environments will exacerbate the degree of defects. This article proposes some new ideas to solve the pain point of circular hole light emission industry through in-depth research on the mechanism of poor light emission.

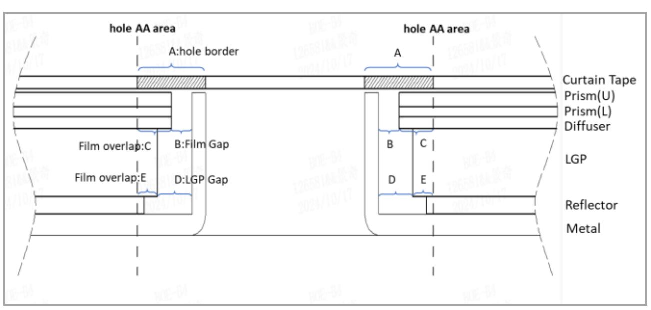

Figure 1. Hole section design

2. generation & disappearance mechanism
The emission of light from a circular hole, the illumination below the hole, and the illumination at the edge of the hole are all manifestations of the illumination around the circular hole. However, there are differences in the actual adverse phenomena and failure mechanisms. Firstly, we need to understand the differences between the three before further targeted research can be conducted.

The mechanism of light emission around the hole is that the light reflected by the iron frame enters through the side wall of the upper prism, refracts through the prism, and enters the AA area. Under a large viewing angle, poor light emission in the direction perpendicular to the prism can be observed; Regarding whether the light enters through the side wall of the upper prism or through the substrate, physical verification was conducted by blackening the lower side of the upper prism hole, and the emitted light still exists. However, blackening the side wall of the upper prism hole resulted in the disappearance of the emitted light, further confirming the accuracy of the side wall entry.

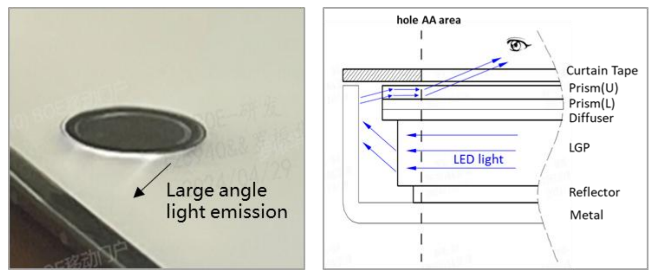

Figure 2. Hole light emission phenomenon&mechanism

The mechanism of bright lines around the hole is that the offset gap of the upper light enhancement film is too large, resulting in a narrow overlap width between the light shielding adhesive and the light enhancement, which cannot effectively block the edge light of the film material. Under a large viewing angle, different degrees of bright lines can be seen at the edge of the circular hole. Remove the upper prism that illuminates the hole, and the bright lines follow the upper prism. Confirm that the bright lines are the edge light of the upper prism.

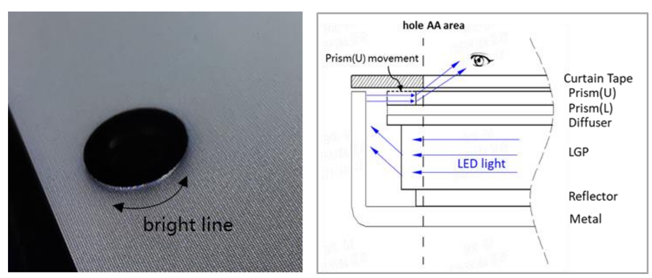

Figure 3. Hole Bright lines phenomenon&mechanism

The mechanism of under hole illumination is that the gap between the LGP at the bottom of the hole and the iron frame is relatively large. After reliability, the light guide plate shrinks towards the lamp mouth, and the gap between the LGP at the bottom of the hole and the iron frame is larger, resulting in light leakage and illumination in the display area.

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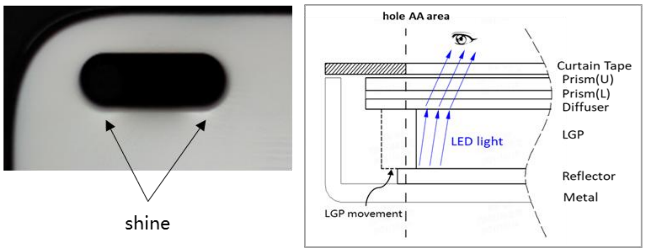


Figure 4. Hole shine phenomenon&mechanism

3. Experimental test and analysis

This article uses optical software simulation and physical verification. The optical simulation utilizes the command module provided by Light Tools to establish a solid geometry model, change material properties, and define the optical properties of the reflective sheet as a simple mirror; Add dots to define the optical properties of the light guide plate as a high reflectivity surface; Define diffuse optical properties as completely scattering surfaces; Use the Prism command module provided by the software to change the prism layout and shape; By changing the material properties, the optical properties of the iron frame are defined as diffuse reflection, simulating the uniformity of brightness at the backlight circular hole position and brightness at different viewing angles. Due to the brightness of the emitted light being close to that of the normal display area, it is difficult to find the emitted light under a large amount of light simulation; Therefore, it is necessary to simplify the model. Using a local model can provide a faster understanding of the mechanism of light emission.

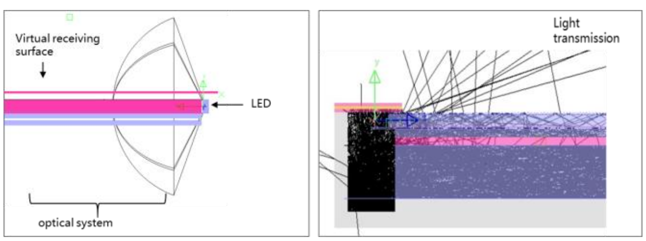


Figure 5. Optical Local Model

(a) The setting of prism angle has a certain relationship with the incident light. When the light reflected by the iron frame at the hole enters from the side wall of the prism, the schematic diagram of the light path in the non perpendicular prism angle direction is as follows. The closer the light is to the direction parallel to the prism, the larger the top angle η of the cross-section ; $sin\theta_2 = 1.61\sin(\theta_1 + \frac{\eta}{2} - 90^\circ)$, As η increases, The range of path light θ_2 increases, More light enters the next cycle; Compared to light rays perpendicular to the prism direction, incident light rays at an angle (not perpendicular) to the prism direction are more likely to enter the next cycle (or total reflection, or enter the next prism) in the light path, making it easier to observe the incident light at an angle perpendicular to the prism direction:

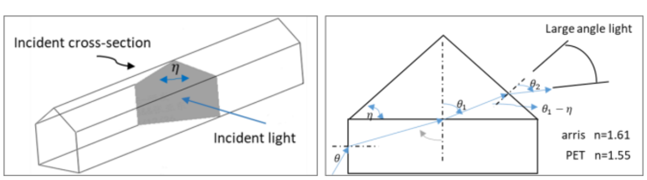


Figure 6. Light and Prism Angle

According to the principle, the stronger the incident light perpendicular to the angle of the upper prism, the heavier the incident light. Therefore, two light beams appear, which are defined as upper and lower respectively. By changing the angle of the prism, we can find the suitable angle for the weakest incident light perpendicular to the prism, in order to reduce the incidence of light. Based on the physical verification of the project and the organization of the column data table in the figure below, the following conclusion can be drawn: within the optional angle range, the angle of the upper prism (-45 ° -45 °) is better than (45 ° -135 °);

In addition, for single prism products, the absorption axis of the lower polarizer is perpendicular to the direction of the upper prism (consistent with the direction of light emission), and the light is absorbed and blocked through the absorption axis of the lower polarizer; The angle between the pol absorption axis and the direction of light emission below 20 ° can reduce hole light emission, and at 0 °, it can be maximally reduced. The following conclusion can be drawn: within the optional angle range, a 70 ° angle between the lower pol absorption axis and the upper prism is more optimal;

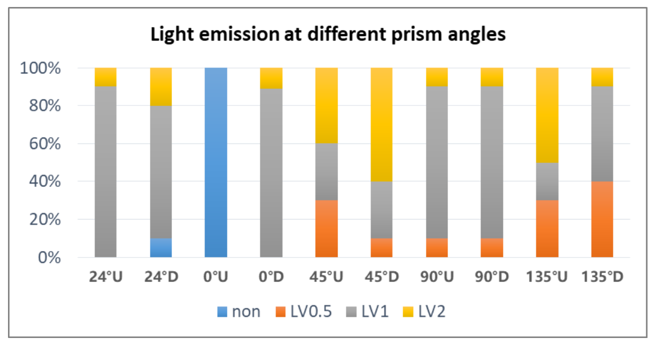


Figure 7. relationship between prism angle and Light emission

(b) At present, prism cutting is CNC punching, requiring a smooth and burr free cutting surface; This article breaks traditional thinking by roughening the sidewall of the upper prism hole. It is speculated that this can scatter the transmitted light, thereby reducing or solving the problem of light emission. Through software simulation, the roughness of the prism sidewall can significantly reduce the amount of light emitted; The actual implementation methods of hole wall roughening process include blade sandblasting treatment, laser burn treatment, etc.

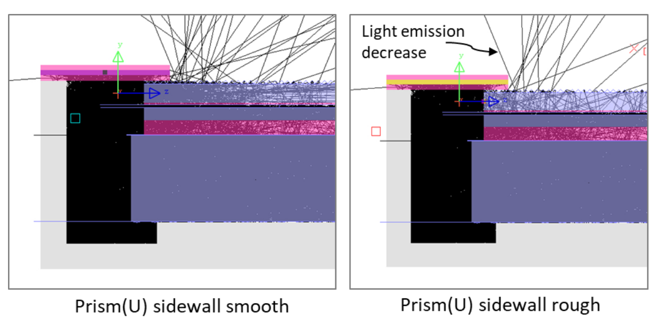
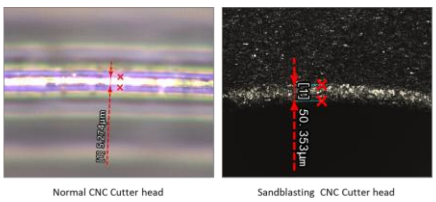


Figure 8. Relationship between Prism(U) sidewall roughness and Light transmission

Sandblasting process for blade: The CNC punching blade at the upper prism hole is subjected to sandblasting treatment (150 grit sandblasting), which damages the blade. As shown in the figure below, the measured width of the blade increases significantly by about 5um → 50um; Simultaneously test the surface roughness of the blade with Sa=2.084um and Sz=19.37um, as shown in Figure 9 below; The edges of the physical prism can be clearly roughened, as shown in Figure 10. The sandblasting treatment of the blade processing product can completely solve the problem of hole light emission and meet the current reliability testing requirements of various terminals, as shown in Figure 11. After sandblasting, due to the uneven cutting edge, the sampling error is large, and the cutting size tolerance has increased from ± 0.05 to ± 0.07mm. Currently, the size calculation of mobile phone products shows that each prism increases by about 0.01 yuan.



	Sa	Sz	Str
	μm	μm	
MAX	2. 084	19. 370	0. 102
MIN	2. 084	19. 370	0. 102
AVE	2. 084	19. 370	0. 102
RSD	0. 000	0. 000	0. 000
Area 1	2. 084	19. 370	0. 102

Roughness

Figure 9. sandblasting Cutter head shape

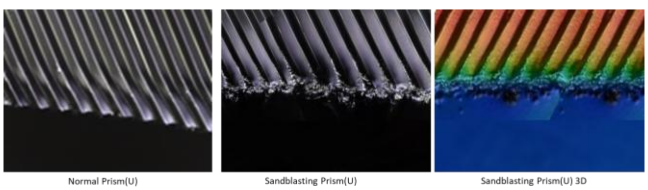
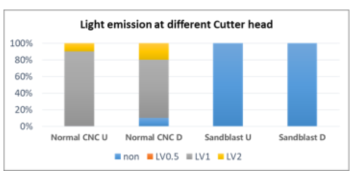


Figure 10. sandblasting Prism shape



Environmental testing		number	results
TST	TLCM	32	OK
THO	TLCM	32	OK
HTO	TLCM	10	OK
HTS	TLCM	8	OK
LTS	TLCM	8	OK

Figure 11. relationship between prism Sidewall roughness and Light emission

Laser cutting process: Due to the high energy, the cutting surface of the prism side wall in laser cutting will have a certain degree of coking, and the transmitted light at the coking point will be scattered, thereby reducing or solving the problem of light emission; As shown in the prism edge shape in the figure below, burn marks can be seen. From the proportion of light emission, the conventional laser cutting has slightly optimized the light emission compared to CNC cutting, and high-energy laser can completely solve the problem of hole light emission; However, the processing also burns the prism protective film, making it difficult to tear off the film, and further optimization of the subsequent process is needed.

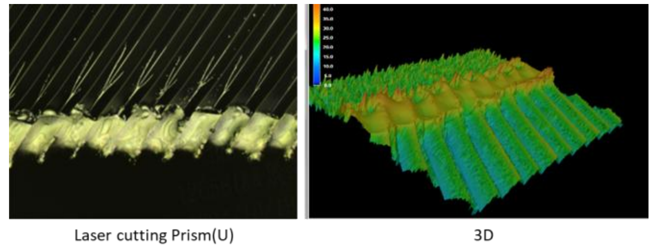


Figure 12. Laser cutting Prism shape

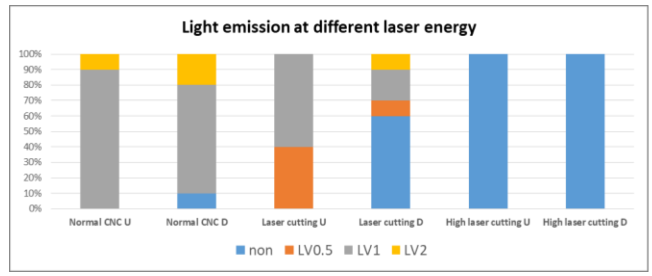


Figure 13. relationship between prism Laser cutting and Light emission

(c) The same prism material also has a significant impact on the emitted light. The refractive index of a single prism varies among different materials, with high brightness prisms having a higher refractive index. Light entering from the side wall can refract longer emitted light, while prisms with higher refractive index will have poorer performance; Compared to a single prism, a composite prism has a thinner upper prism, making it difficult for light to exit from the side wall. The emitted light mainly passes through the lower prism side wall, is dispersed by the adhesive layer between the lower and upper prisms, and then refracted and emitted by the upper prism. Therefore, the prism's light emission effect is better than that of a single-layer prism.

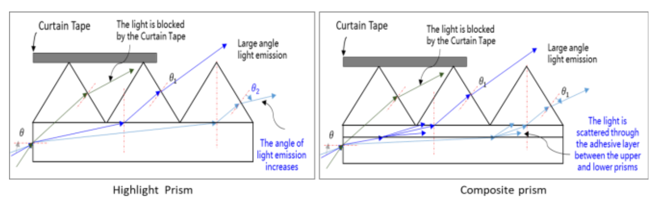


Figure 14. The influence of different prism materials on Light emission

(d) The different roughness of the iron frame will result in different light emission effects. Due to the greater roughness of SF10 and SF30 compared to SUS304, the light reflected by the iron frame to the prism is scattered, reducing the direct light entering the prism and thus reducing the light emission; SF10 and SF30 cannot completely solve the problem of light emission compared to the original scheme SUS304, but they can reduce the degree and proportion of light emission to a certain extent. Overall, the comparison is SF30>SF10>SUS304.

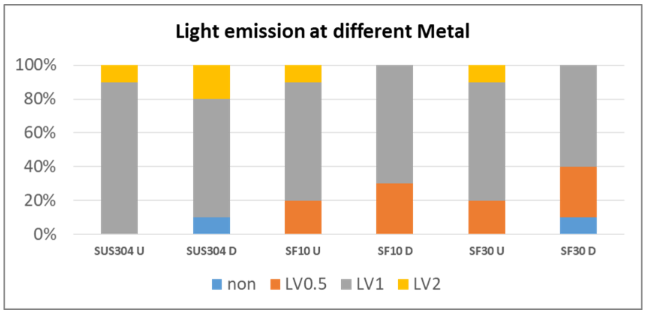


Figure 15. relationship between Metal and Light emission

(e) Using pure black adhesive to block light, some of the light on the refractive amplification path of the prism is blocked, thereby reducing the amount of incident light; Compared to traditional transparent adhesive, pure black adhesive can reduce hole light emission.

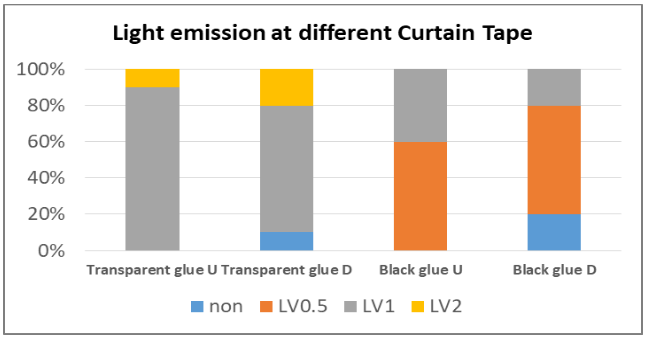


Figure 16. relationship between Curtain Tape glue and Light emission

4. Conclusion

By using light tools to build a light efficiency model around the hole, simulating the mechanism of poor performance and proposing theoretical improvement directions, and synchronously verifying the matching of the mechanism through physical verification, four measures for improving the mass production of hole light emission are output: ① the lower pol absorption axis and upper prism angle are above 70 °; ② Upper prism angle (45 ° -135 °) ->(-45 ° -45 °) ③ Upper prism hole sidewall roughening: using US imported sand 150 grit sandblasting, spraying the blade at the prism hole; ④ Light shielding adhesive material: transparent adhesive ->black adhesive.

5. References Acknowledgements

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