Viewing Angle Improvement of Reflective Liquid-Crystal Display by Optimizing the MRS Structure

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Abstract

Reflective LCDs often use an uneven reflective layer (micro-reflective structure, MRS) to enhance diffuse reflection and thus improve the viewing angle. In order to design the MRS structure of the reflective layer more effectively, we have developed an optical simulation method that can be used to simulate the viewing angle and reflectivity of reflective LCDs. Through this simulation method, the MRS design can be optimized more easily and the best design parameters can be obtained. The optimized design of MRS can effectively improve the viewing angle of the reflective LCD, and the distribution of left and right brightness viewing angles becomes more symmetrical.

Author Keywords

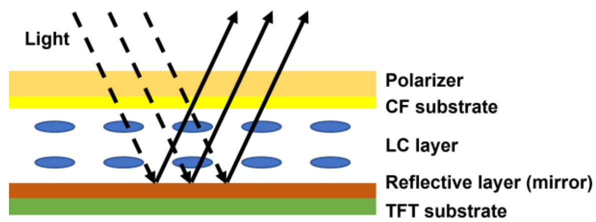
Reflective LCD; MRS structure; Viewing angle.

1. Introduction

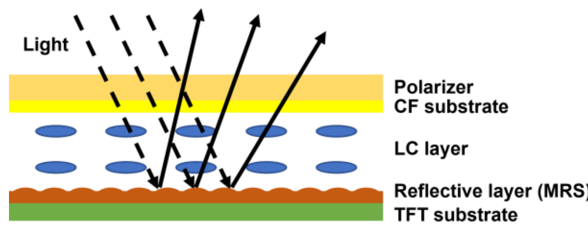
People use electronic devices more and more in their daily lives. This means there is a growing need for eye protection and low-power products. Eye protection must address two primary concerns: first, it must block blue light, which has been linked to eye fatigue and discomfort; second, it must prevent screen flicker, which can also contribute to visual strain. To address these needs, electronic paper (E-paper) and reflective LCD (RLCD) products are being developed. While E-paper exhibits a superior paper-like effect, it possesses a comparatively slower response time, a more constrained color range, and a lower refresh rate compared to LCD [1]. This limitation restricts its efficacy in displaying vibrant images and videos. Reflective LCD, while still categorically belonging to the LCD family, avoids the disadvantages mentioned above [2, 3]. Additionally, RLCD utilizes ambient light for display, emitting low-hazard blue light devoid of strobe [3, 4]. The application of reflective LCD is versatile, including use in readers, flat panels, outdoor signage, and other scenarios.

Compared to a normal LCDs, which employ a backlight to facilitate display, reflective LCDs have the capacity to utilize ambient light for display purposes. This functionality is primarily attributable to the fact that reflective LCDs are coated with a reflective layer on the TFT side. This reflective layer is often made of highly reflective metal, such as silver and aluminum. As a result, the viewing angle of reflective LCDs is limited by the ambient light source and the design of the reflective layer. Therefore, the reflective layer is one of the most important parts in the design of reflective LCDs, which can affect the screen brightness, viewing angle, and more.

In reflective LCDs, the reflective layer can be smooth or rough, as shown in Figure 1 (a) and (b). The rough reflective layer, also known as micro reflective structure (MRS), can improve the utilization of ambient light and the diffuse reflection ratio, thereby optimizing the brightness and viewing angle of the reflective LCD [5]. Therefore, it is important to design the MRS structure for reflective LCDs. In order to better design the MRS structure and achieve better display, we established a simulation model using Light Tools software. The optimal value of the MRS structure is determined through simulation, and the diffuse reflectance of this optimized MRS structure is significantly enhanced. This improvement leads to a substantial increase in the viewing angle of the reflective LCD, accompanied by a more symmetrical distribution of the left and right viewing angles of luminance.



(a) Mirror reflective layer



(b) Uneven reflective layer (MRS)

Figure 1. Reflective LCD structure. (a) Mirror reflective layer; (b) Uneven reflective layer (MRS).

2. Simulation model and method

The structure of a reflective LCD is shown in Figure 1, with TFT substrate, reflective layer, liquid crystal layer (LC layer), CF substrate, and polarizer from bottom to top. All of these materials have an impact on the display effect of the product, such as viewing angle and paper-like effect. Among these factors, the reflective layer and liquid crystal are of significance. The reflective layer is typically deposited by vapor deposition.

When the reflective layer is required to produce an uneven shape, it can be realized using processes such as photomask exposure, nanoimprinting, etching, and others. The structure of MRS varies depending on the process. This paper mainly simulates the MRS structures generated by three processes, as shown in Figure 2 (a) ~ (c). The first method is making a micro-bump on the TFT substrate's uppermost surface (PFA), and then coating an Ag layer on this micro-structure to achieve the MRS. The second method is to use nanoimprinting, imprinting optical adhesive on top of the mirror Ag layer, which produces micro-convex structures. The third method is to roughen the silver layer by etching, which produces nanoscale Ag particles on the silver surface to achieve surface roughness.

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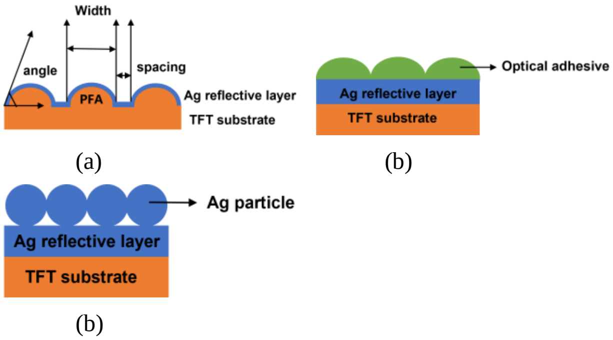


Figure 2. MRS structural model (a) with PFA micro bump structure on TFT substrate; (b) nanoimprinting with optical adhesive; (c) roughen the Ag layer.

Simulation model: In order to evaluate how the reflective layer structure affects viewing angle, we built a simplified reflective LCD model by Light Tools software, as shown in Figure 3. The model consists of a TFT substrate, a reflective layer (Ag), a light source, and a light receiver. The reflective layer is used to reflect incident light, which made of silver with a reflectivity set to 98%. The MRS structure of the reflective layer is shown in Figure 2. The MRS structures are arranged in a mosaic pattern. The light source is a D65 point light source with a Lambertian distribution of light intensity. The light source enters at an angle of 30° to the normal. The light receiver is located above the reflective layer and receives the reflected light. The simulation results show how the reflected light intensity is distributed, that can be evaluated the viewing angle of the reflective LCD model.

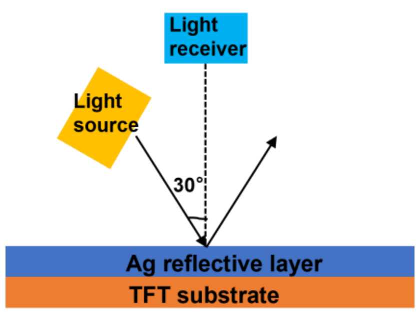


Figure 3. Reflective LCD structure model.

3. Analysis and Discussion of Simulation Results

Mirror reflection layer: When the reflection layer is a specular surface and the light source is positioned at an angle of 30° relative to the normal, the maximum brightness angle of view in the horizontal direction is at -30°, and the distribution of the left and right brightness angle is asymmetric, as shown in Figure 4. The subjective perception of the human eye is based on an angle of view of 0°, whereas the ideal angle of view for brightness is symmetrical. When the brightness viewing angle center deviates from 0°, the visual perception will be distorted. In the simulation results, the maximum brightness viewing angle differs from 0°, leading to a biased brightness perception when viewed from the side. Furthermore, the maximum brightness value diminishes at a 0° viewing angle, which is due to the reduced utilization of ambient light by the reflection layer. Therefore, the viewing angle of RLCD using a mirror reflection layer is greatly limited by the angle of the incident light.

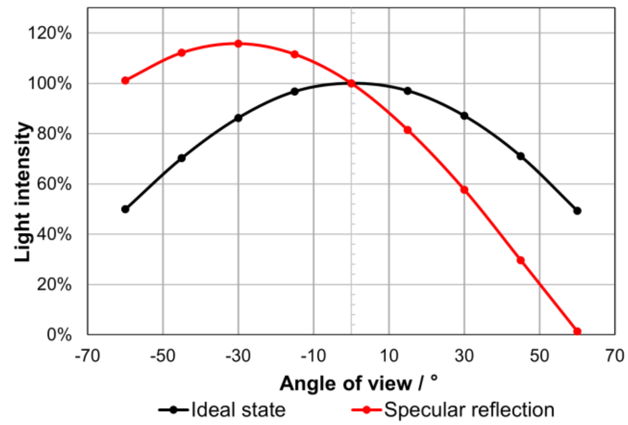


Figure 4. Distribution of light intensity with mirror reflection layer.

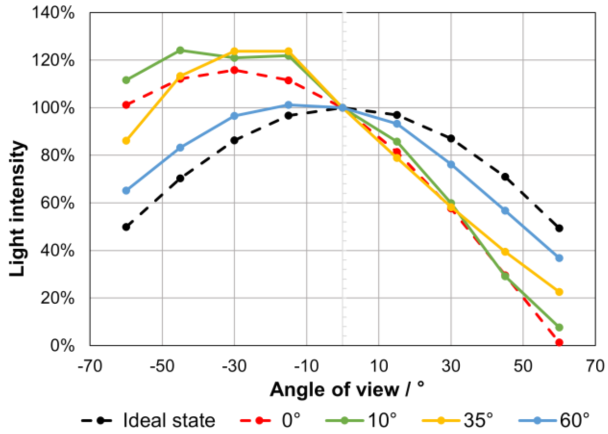
MRS structure: The viewing angle of RLCD with a specular reflective layer is dependent on the angle of incidence of the light source, and the display effect is poor. Therefore, the reflective layer was configured to be an uneven structure (MRS), with the main MRS parameters being the slope angle, width, and spacing of the bumps, as shown in Figure 2 (a). The MRS structure parameters are adjusted to achieve an optimal structure and viewing angle.

Slope angle: The micro bump structure (MRS) is formed by photomask exposure of PFA on the surface of the TFT substrate. The MRS structure parameters are set for simulation as follows: a bump width of 0.3 μm, a bump spacing of 0 μm, a bump pattern of mosaic, and a slope angle range of 0° to 60°. The simulation results are shown in Figure 5 (a). As the slope angle of the bumps increases, the maximum luminance viewing angle approaches the vertical viewing area. The simulation results indicate that the optimal slope angle is 60°.

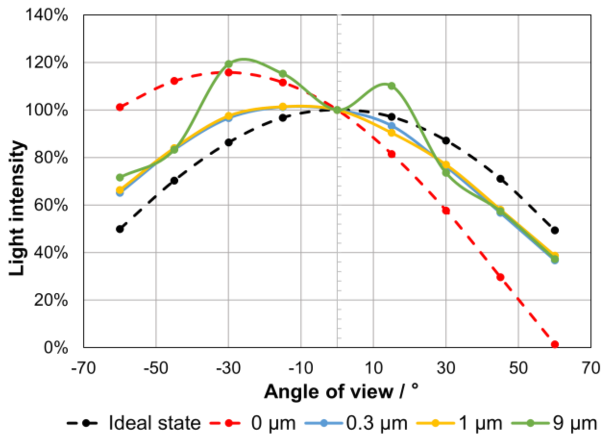
Bump width: The MRS bump slope angle is fixed at 60°, the spacing is set to 0 μm, and the range of the bump width is adjusted from 0.3 μm to 9 μm. The simulation results are in Figure 5 (b). It indicates that when the width of the bump is below 1 μm, the brightness viewpoint left-right symmetry is enhanced. However, it should be noted that the smaller the bump width, the higher the process requirements. Consequently, the bump width of 1 μm is more appropriate.

Bump spacing: By fixing the optimal slope angle and width parameters, changing the bump spacing from 0 μm to 4 μm, the simulated viewing angle results are shown in Figure 5 (c). It is evident that the larger the distance between the bump, the higher the proportion of the mirror surface in the reflective layer, and the diffuse reflection effect decreases. Therefore, the optimal parameters for the MRS structure are a convex slope angle of 60°, a bump width of 1 μm, and a spacing of 0 μm. Under these conditions, the diffuse reflection effect is the maximized, and the brightness viewing angle is basically symmetrical about -6°, with brighter brightness in the vertical viewing angle area.

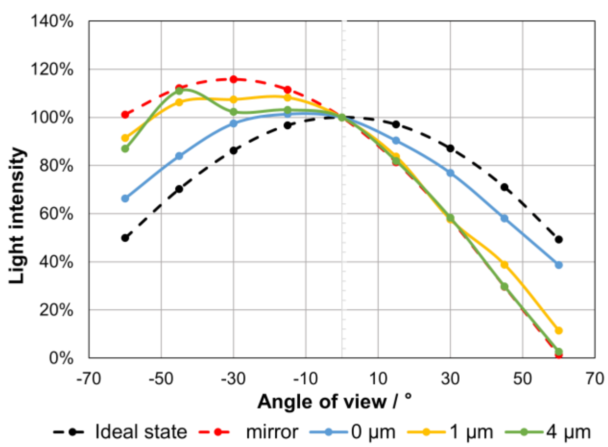
Refractive index of optical adhesive: When the MRS structure is implemented using nanoimprinting, the refractive index of the optical adhesive is also one of the parameters that affect the viewing angle. Under the optimal MRS structural parameters previously identified, the refractive index of the optical adhesive was adjusted, and the simulation results



(a)



(b)



(c)

Figure 5. Distribution of light intensity with MRS (a) slope angle; (b) bump width; (c) bump spacing.

obtained are presented in Figure 6. As the refractive index of the optical adhesive increases from 1.3 to 1.9, the light intensity distribution becomes more symmetrical, and the maximum brightness viewing angle is around -15°. This suggests that when using the nanoimprinting process to achieve MRS, it is advantageous to employ high refractive index optical adhesives to optimize the viewing angles.

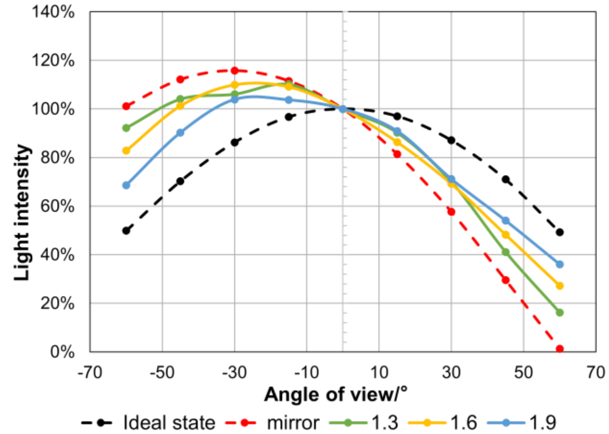


Figure 6. Distribution of light intensity with different refractive index of optical adhesive on MRS.

Diameter of Ag particle: When the MRS structure is obtained by etching on the silver layer, there will form spherical Ag particles on the silver surface. The main structural parameters of Ag particles are diameter and spacing. Therefore, it is essential to simulate Ag particles of varying sizes and spacing, and systematically observe the impact of these factors on the viewing angle. And the simulation results are shown in Figure 7. From the results, it can be seen that the viewing angle is more suitable when the spacing of the Ag particles is 0 μm. Meanwhile, as the diameter of the Ag particles decreases, the distribution of the reflected light intensity becomes more uniform, and the brightness viewing angle becomes more symmetrical about the vertical direction. It is worth noting that the maximum brightness viewing angle around 0° is observed when the Ag particle diameter is 0.3 μm.

By optimizing the structural parameters of MRS formed under different processes, the optimal parameters were obtained, as shown in Figure 8. Based on the simulation results, it can be concluded that the most effective process for MRS structure is to roughen the silver layer. Especially when the Ag particle diameter is 0.3 μm and the spacing is 0 μm, the viewing angle improvement effect is the best. With this parameter setting in the simulation model, the brightness of viewing angle is approximately symmetrical about 0°, exhibiting an optimal display effect.

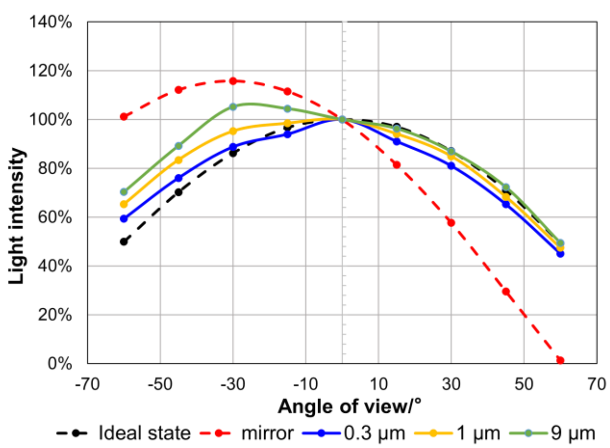


Figure 7. Distribution of light intensity with different diameter of Ag particle on MRS.

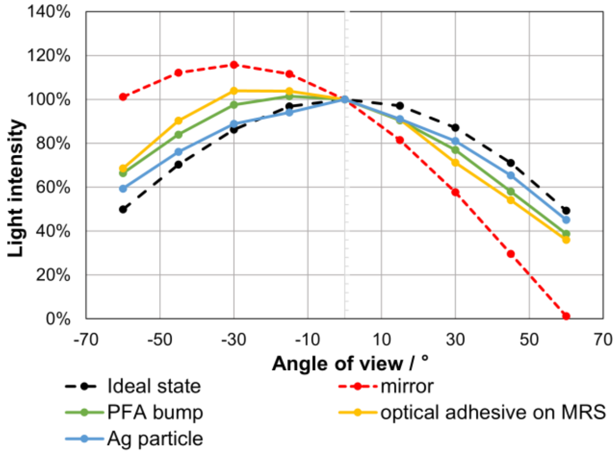


Figure 8. Distribution of light intensity with MRS structure by different processes.

4. Conclusion

This paper develops an optical simulation method that can be used to simulate the reflectivity and viewing angle of reflective LCD. Using this method, the optimal MRS structure parameters were obtained, thereby enhancing the viewing angle of the RLCD. In the case of the reflective layer that is a mirror, the brightness viewing angle of the RLCD is limited by the incident angle of the light source, resulting in poor display performance. However, when the reflective layer is designed with a bump structure featuring a mosaic arrangement (with a width of 1 μm, a slope angle of 60°, and a spacing of 0 μm), the brightness viewing angle is significantly improved compared to the RLCD with a mirror reflective layer. Furthermore, when the surface of the reflective layer is arranged in a mosaic of Ag particles with a diameter of 0.3 μm, a significant enhancement in the viewing angle is achieved, and the brightness viewing angle is approximately symmetrical about 0°. Consequently, by improving the structure design of MRS, it is possible to effectively reflect light rays with larger incident angles to a viewing angle near 0°, increase the utilization rate of light sources, make the viewing angle more symmetrical around 0°, and effectively improve the display effect.

5. References

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