8.3: A Single Cell-Gap Transflective Color TFT-LCD by using Image-Enhanced Reflector

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Abstract

The image quality of single cell gap transflective color TFT-LCDs can be enhanced by building an image-enhanced reflector above the transmissive region of liquid crystal cell, where both reflective and transmissive portions achieve high optical efficiency, same response time and color saturation. Furthermore, this transflective color TFT-LCD requires only single retardation film, and can achieve ambient light and backlight utilization ratio to 68.4% and 23.9% respectively. With image-enhanced reflector built in, a high image performance display under both bright and dark ambience can be accomplished.

1. Introduction

The transmission-type liquid crystal display (LCD) exhibits a high contrast ratio and good color saturation. However, its power consumption is high due to the need of a back light. At bright ambient, the display is washed out completely. On the other hand, a reflective LCD is using ambient light for reading displayed images. Since it does not require a back light, its power consumption is reduced significantly. However, its contrast ratio is lower and color saturation much inferior to those of the transmission type. At dark ambient, a reflective LCD lost its visibility.

In order to overcome the drawbacks of transmissive and reflective LCDs, two types of transflective LCDs, single[1] and double[2], [3] cell gap, as shown in Figs. 1(a) and (b), have been developed with good legibility under both bright and dark scenes. In the single cell gap approach, the cell gap (d) for reflective (R) and transmissive (T) modes is the same. The cell gap is optimized for R-mode. As a result, the light transmittance for the T mode is lower than 50% because the light only passes the LC layer once. In the double cell gap approach, the cell gap is d and 2d for the R and T pixels, respectively. In this approach, both R and T have high light efficiency. However, the T mode has four times slower response time than that of the R mode. A common problem for the above-mentioned approaches is that R and T pixels have different color saturation. For R pixels, the incident light passes through the color filter twice, but for T pixels light only passes the color filter once. As a result, their color saturation is different.

Therefore, we proposed a novel single cell gap transflective LCD[4], [5], which also allows the backlight to traverse the reflective region twice, similar to the ambient light. To achieve this goal, an Image-Enhanced Reflector (IER) is built upon the transmissive region to guide the backlight to follow the similar path as the ambient light, as presented in Fig. 2.

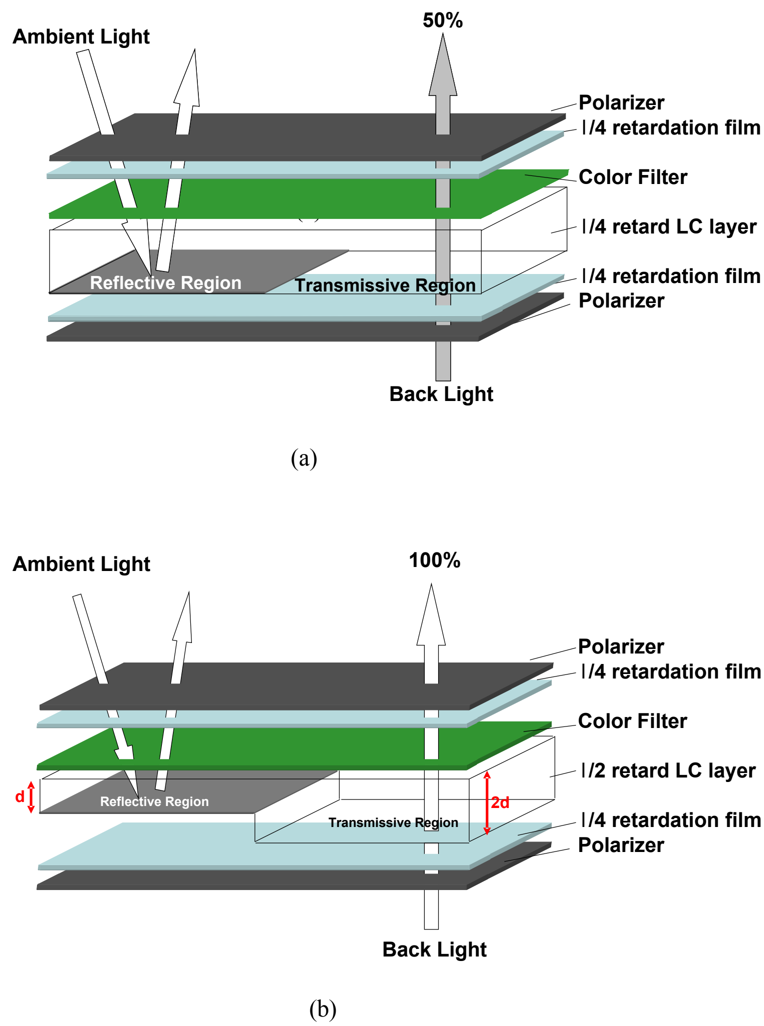

Fig. 1. Schematic plot of transflective LCD using (a) single and (b) double cell gap.

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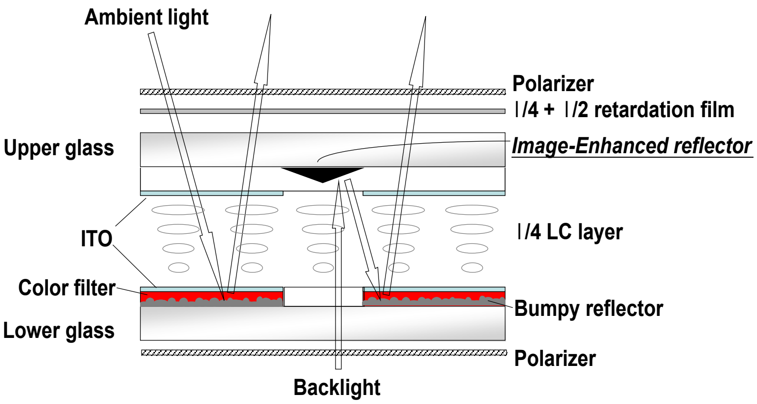
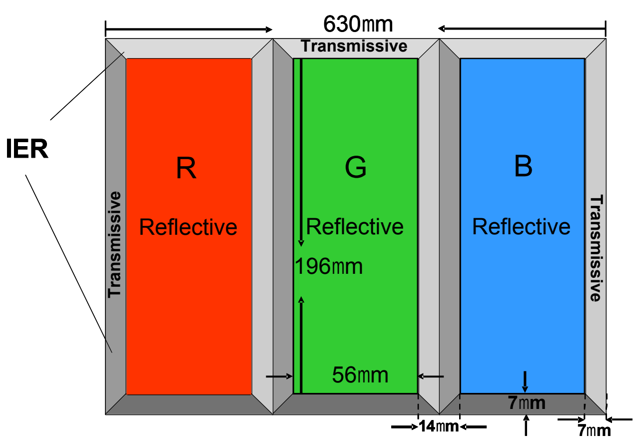


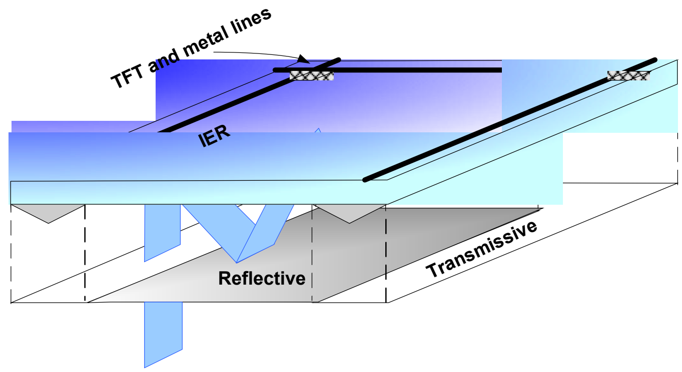
Fig. 2. Cross-sectional plot of the transflective LCD with image-enhanced reflector.

2. Image-enhanced reflector

In this novel structure, the liquid crystal in transmissive region should be designed as a quarter wave plate, and won't be modulated even turns the voltage on. Therefore, the ITO electrodes are not required in transmissive region, and the IER structure can be built around the reflective region to cover the gap between each sub-pixel and increase the area utilization, as shown in Fig. 3(a). TFT, data and scan lines, however, will still partially block the backlight passing through the transmissive region. In order to increase the percentage of backlight utilization, TFT and the metal lines can be built on the top glass and just above the IER structure, as shown in Fig. 3(b). Since the backlight and ambient light follow the similar paths, the optical efficiency, response time and color saturation of the transmissive and reflective regions are similar. In addition, this novel structure can also have high area utilization and with single retardation film.



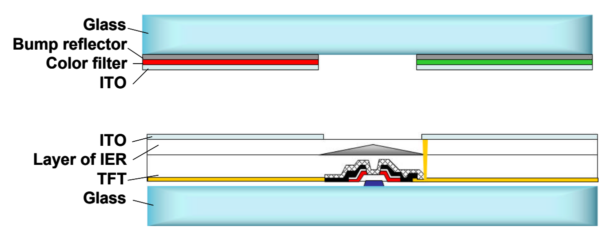
(a)



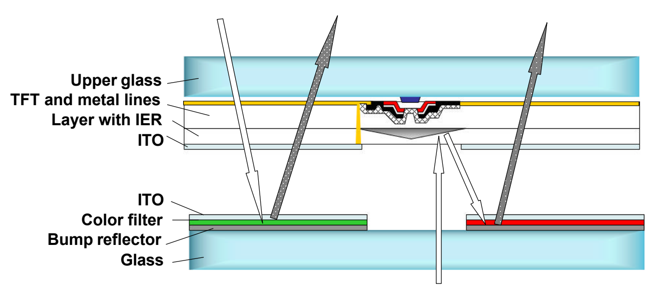
(b)

Fig. 3. Top view of a single cell gap transflective LCD employing (a) image-enhanced reflector around reflective portion, where the dimension is for a typical RGB pixel, and (b) TFT and metal lines on top glass for efficient area utilization.

The fabrication process of this novel structure is compatible with conventional TFT process. As shown in Fig. 4(a)., the only extra process is to fabricate the layer of IER upon the TFT and metal line. The reminder steps are almost the same with conventional process. The only difference is the reflector should be built on the top glass. However, while using this novel transflective LCD, the whole structure should be rotated upside down, as shown in Fig. 4(b). Therefore, the bump reflector can reflect the ambient light, and IER can reflect the transmissive light to enhance the image quality of the transflective LCDs.



(a)



(b)

Fig. 4. Cross-section plot of (a) fabricating and (b) using the novel transflective LCD.

3. Results

A simple transflective color TFT-LCD configuration, whose parameters listed in Table. I, was used to simulate and design the image-enhanced reflector. The angle of IER is set as 15° and will reflect the transmissive light to be 30° to the normal, which is the same angle as most of the ambient light incidence. By optimizing both the width of IER and the distance from IER to bottom reflector with the optical simulator ASAP, the light utilization ratio of the transflective TFT-LCD with IER can be optimized. Fig. 5 shows the ambient and the backlight utilization ratio with different IER width. Reasonably, enlarging the width of IER can increase the backlight utilization ratio efficiently, yet the ratio of ambient light is reduced. According to the conventional specification of 4-inches panel, the backlight utilization ration should be higher than 20%. Therefore, the width of IER is chosen to be 14μm, which achieves 23.89% backlight and 68.43% ambient light utilization ratio.

Table. I. Parameters of designed panel and image-enhanced reflector.

IER Width (mm)	8	14	20
Reflective region utilization(%)	81.4	68.4	56.1
Transmissive region utilization(%)	14.3	23.9	32.2
Total area utilization(%)	95.7	92.3	88.3

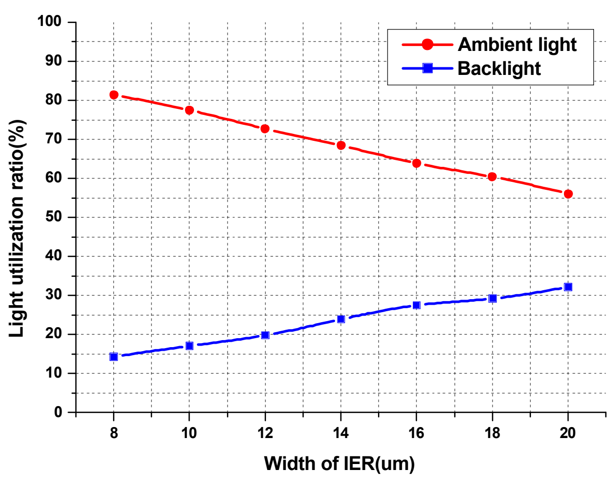


Fig. 5. IER width versus ambient light and backlight utilization ratio.

The NTSC ratio of transmissive region in conventional and the novel transflective LCD was calculated and displayed in Fig. 6. By using IER structure, the transmissive light passes through the color filter twice which is the same as reflective light. Thus, the NTSC ratio can be increased to 19% that is much larger than conventional one, and can be matched with reflective region.

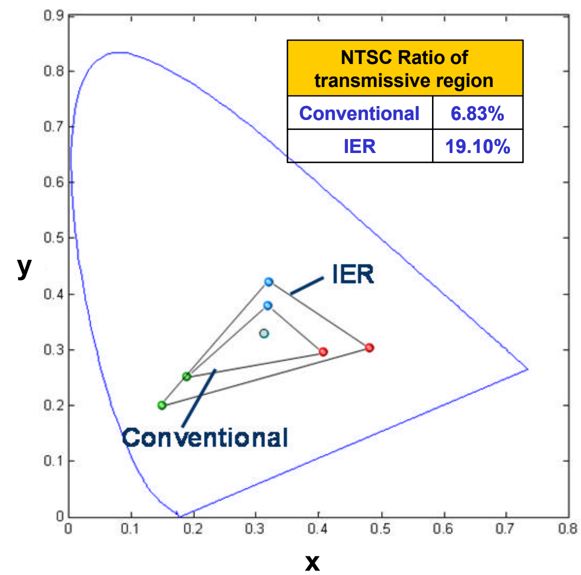


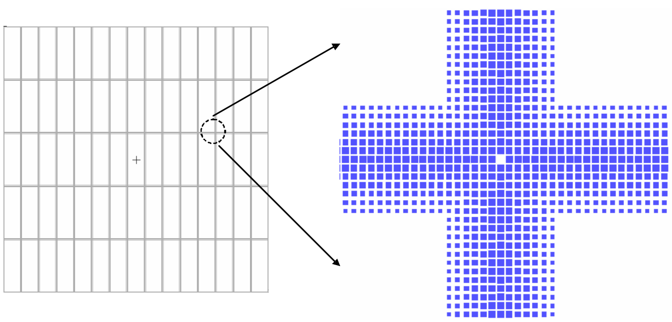
Fig. 6. The calculated NTSC ratio of transmissive region in conventional and with IER's transflective LCD.

The light efficiency in transmissive and reflective regions was also been calculated, that the parameters and results were listed in table. II. By considering the efficiency of polarizer, opened aperture ratio, transmittance of liquid crystal layer and color filter, reflection of bottom reflector and IER, the final efficiency of transmissive and reflective light were 2.8% and 8.45%, respectively, which is much higher than single cell gap structure and also very competitive with double cell gap one.

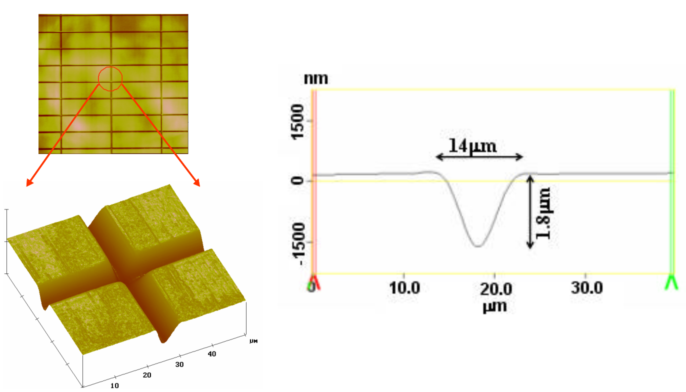
Table. II. Parameters to calculate the light efficiency of transflective LCD with IER structure and the results.

Mode	Transmissive	Reflective
Polarizer x2	38%	38%
Aperture ratio (area utilization)	24%	68%
Efficiency of LC layer (Homogeneous mode)	96%	96%
Color filter	37%	37%
Bottom Reflector	93%	93%
Image Enhanced Reflector	93%	None
Final light efficiency	2.80%	8.45%

One way to fabricate the image-enhanced reflector for the 4-inches transflective TFT-LCD is to use a gray-tone mask exposed by excimer laser, and the result measured by AFM is shown in Fig. 7. The width of the image-enhanced reflector is 14 µm and the depth is 1.8µm, which is close to the designed. Further, the image-enhanced reflector will be combined with single cell-gap transflective TFT-LCD, then the light utilization efficiency, brightness, contrast ratio and color saturation will be measured and compared with the conventional transflective LCDs. Accordingly, the single cell-gap transflective TFT-LCD by using image-enhanced reflector is anticipated to enhance the image quality.



(a)



(b)

Fig. 7. (a) The designed mask pattern and (b) fabricated image-enhanced reflector.

4. Conclusions

The significance this novel structure is to solve the key issues of transflective LCDs, such as low optical efficiency in transmissive portion, different response time, and inadequate color saturation. Additionally, single cell-gap, single retardation film and high area utilization are also the advantages of the transflective LCD using image-enhanced reflector. Our results demonstrate that a much better image quality with excellent legibility under both bright and dark ambient conditions for transflective LCDs can be achieved by the image-enhanced reflector.

5. Acknowledgements

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