Comparison between Reflective LCDs with Diffusive Micro Slant Reflector (DMSR) and Bump Reflector

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ABSTRACT

A reflective TFT-LCD with an internal asymmetric diffusive micro slant reflector (DMSR) is developed to enhance the light efficience[1-3]. The DMSR structure is optimized to obtain a desired light distribution cone with asymmetric characteristics. In this paper, we will compare the optical properties of a reflective TFT-LCD panel with a DMSR structure and those of a reflective LCD with symmetric bump structure reflector. Since the light intensity distribution of a reflective LCD depends strongly on the behavior of the incident light source, we used two different incident light sources for illumination. One is collimated light, and other is diffused light. The conoscope is then used to understand the light distribution of the panels in all directions. When the collimated light source is used for illuminating the reflective LCD panel, the brightness of a LCD panel with DMSR is about 2 times of that of a LC cell with a symmetric bump type reflector. If the incident light is the diffusive type, the reflectance of a bump reflector will be independent of the viewing angles. However, the diffusive property of the new DMSR design will redistribute the reflected light so that an asymmetric viewing cone can be generated to increase the brightness in this area. The asymmetric property of the cone is a result of the slant structure. The experimental results demonstrate that the DMSR structure can redirect the collimated light in a designated area. Due to the effect of DMSR, the peak of reflected light is shifted away from the surface specular reflection and the light distribution is wider. Normal environment contains both the collimated and diffusive light. With the DMSR structure, we can utilize both light sources and make our panel much brighter, suitable for many information applications.

1. INTRODUCTION

The increasing demands of portable information tools with high information content, such as personal digital assistants, hand-held personal computers, and digital still cameras, have created a new market for high quality and low power consumption flat panel displays. Full-color reflective LCDs (RLCD) with merits of low power consumption, light weight, compact size and good legibility under the sunlight are the most suitable devices for such market requirements. Several types of reflective LCD mode have been proposed such as PCGH mode, PDLC mode, ECB mode, MTN mode and R-OCB mode. However, it is obviously that most of them did not show favorable performance when compare with a transmissive LCD or CRT. Among these LCD modes, MTN mode has shown high contrast ratio and high brightness. ERSO/ITRI has spent a great amount of effort in the development of single-polarizer MTN-RLCD[4-7] due to its advantages of high contrast, high brightness and high productivity. MTN mode also has some other attractive features, such as low operation voltage, wavelength insensitivity, wide viewing angle, and fast response. Recently, we have developed an internal diffusive micro slant reflector (DMSR) structure. It is well to change the diffusive property of the reflector and to improve the

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light efficiency of a reflective LCD. In this paper, we will compare the optical properties of a 6.4" reflective TFT-LCD panel with a DMSR structure and that of a reflective LCD with a symmetric bump reflector. The 6.4" reflective LCD panel with DMSR structure has a VGA resolution and an aperture ratio of 59%. It shows 2~4 times brightness enhancement compared with that of a mirror reflector. In addition, the contrast ratio is over 20:1 in the angles from 0 to 30 degrees. When combined with color filters, this structure shows reflectivity of 42% (~ 75% of newspaper) relative to a Lambertian white standard, measured at display's normal direction under -30° collimated illumination condition. This configuration provides a much brighter image, compared with those with internal micro bump-diffusive structures[8-9] in the designated area. However, the internal symmetric bump reflector can has a more uniform light distribution when the panel is illuminated by a diffusive light source. When collimated light source is used to illuminate the panel, bump reflector also can obtain a uniform light distribution in a larger area then that with a DMSR structure.

2. DEVICE CONFIGURATIONS

To obtain a reflective LCD with high resolution and no parallax, a diffusing reflector with rough surface must be placed inside the panel. Therefore, the design of the surface structure of the internal diffusing reflector will dominate the optical properties of a reflective LCD panel. As we known, the internal reflector used in conventional reflective LCD is a flat mirror type or a symmetric bump structure type. In those structures, the brightest portion of a reflected image is severely affected by the specular reflection of the top surface of the LCD panel. In such instance, the distribution of the reflected image close to the specular reflection is wasted because it does not have enough contrast ratio in these directions. Thus, the overall brightness and contrast is not satisfactory enough. Recently, we have developed a diffusive micro slant reflector (DMSR) structure. The DMSR structure can scatter the ambient light into a desired light distribution cone with asymmetric characteristics. When the DMSR structure is used in a LCD panel, the brightest portion of the reflected image is shifted to the normal observer's direction, away from the specular reflection of the top surface. Therefore, the ambient illuminating light could be used more efficiently to increase the brightness and contrast in the desiged viewing direction. The normally white mixed-mode TN (MTN) mode[5-7] is adopted because of its large tolerance to cell-gap variation caused by the DMSR structure.

The basic configuration of reflective LCD with MTN LC mode and DMSR structure is shown in Figure1. This device is composed of a polarizer, a quarter-wave retardation film, a MTN liquid crystal cell, a set of micro color filters and an asymmetric diffusive micro slant reflector. The DMSR is coated with a metallic thin film, such as aluminum or sliver, on the inner side of the bottom substrate of the LC cell. The other reflective LCD panel that we used to compare with this new reflective LCD with DMSR structure is composed of a polarizer, a quarter-wave retardation film, a MTN LC and a symmetric bump structure reflector. The bump struture is also deposited with a metallic thin film on the inner side of the bottom substrate of the LC cell. Figure 2 illustrates the configuration of reflective LCD with bump reflector. This bump reflector is more suitable to be used in a diffusing illuminating condition.

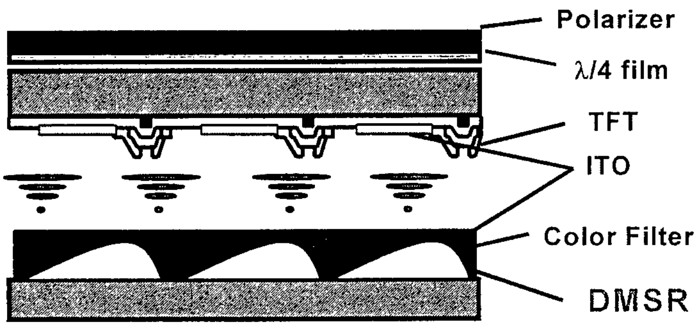

Fig. 1 The basic configuration of a color reflective TFT-LCD with the internal DMSR structure.

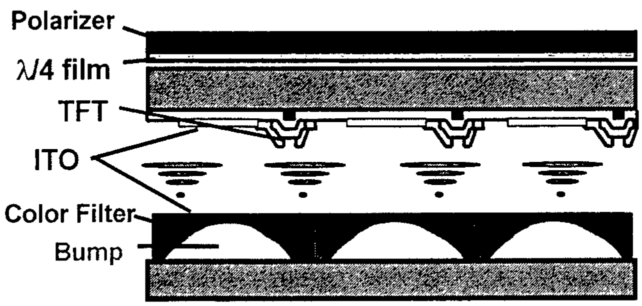

Fig. 2 The basic configuration of a color reflective TFT-LCD with a internal Bump structure reflector.

3. THE DMSR AND BUMP REFLECTOR FABRICATION PROCESSES

The photolithographic method is applied to generate the diffusive micro slant structure. First, the photoresist is coated on the raw glass substrate. Then the photoresist is exposed by a multi-step exposure method to create the MSR structure. After that, a second exposure is applied to obtain a bump structure on the MSR surface. Finally, appropriate control of the developing and baking condition will result in a well slant-bump structure. The slant-bump structure could achieve an intelligent asymmetric scattering property. The diffusive property is strongly influenced by the detail procedure of the exposure processes, since the photoresist used here is very sensitive to the photolithography processes. In order to using this slant-bump structure in a reflective LCD, aluminum is then deposited onto the diffusive micro slant surface to complete the DMSR process. Figure 3 shows the profile of the proposed DMSR structure measured by an atomic force microscope.

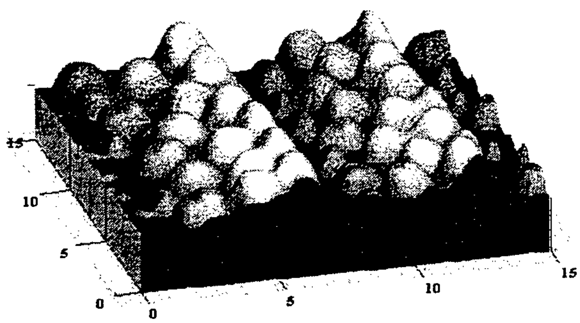

Fig. 3 DMSR profile measured by an atomic force microscope.

The bump structure is also obtained by the photolithography method. The photoresist used for generating bump structure is different from that for preparing DMSR structure. We have developed a single-step exposure method for generating bump structure. In this new method, we don't need an additional overcoating process. And, the shape of bump structure is very sensitive to the developing condition. The shape of bu,p structure will strongly influence the light scattering properties. The profile of this new bump structure reflector measured by an atomic force microscope is shown in Figure 4.

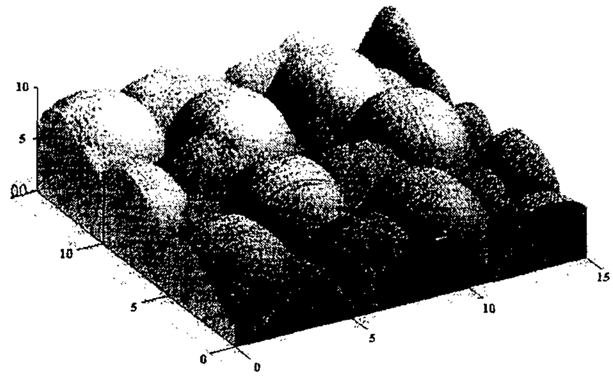

Fig. 4 Bump structure profile measured by an atomic force microscope.

4. OPTICAL PROPERTIES OF TFT-LCD WITH DMSR AND BUMP REFLECTOR

In our reflective LCD panels, the normally white MTN mode is adopted. The liquid crystal used is for low driving voltage and was provided by Chisso Corp.. We used two different optical measurement system to understand the optical performance of these 6.4" reflective TFT-LCDs. One is the Goniometric measurement system, the other is the Conoscopic measurement system.

4.1 Goniometric Measurements

Some of the characteristics of LCD panels are just measured by Goniometric system. The V-R curve of our 6.4" reflective TFT-LCD is shown in Figure 5.

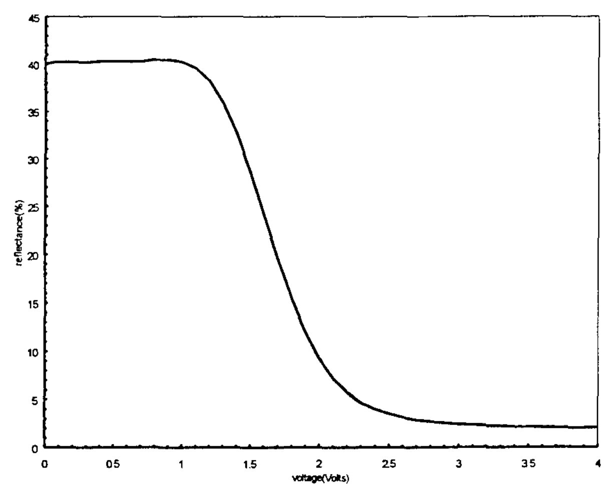

Fig. 5 The V-R curve of ERSO's 6.4" full-color reflective LCD with DMSR.

The V-R curve for both DMSR and bump reflector is almost the same. In this measurement, the incident light was illuminated from -30° relative to the normal direction of the panel and the detector was at the normal direction. Based on the liquid crystal material that we used, the threshold voltage is about 1 volt and the saturation voltage can be as low as 3 volts. Fig. 6 shows the reflectivity and contrast ratio as a function of viewing angles. The viewing angles vary from 0° to 60° in the plane of incidence. Due to the effect of DMSR, the peak of reflected light is shifted away from the surface specular reflection and the light distribution is wider. The reflectance at 0° is about 42% (~70% of newspaper) relative to a Lambertian white standard. The contrast ratio is about 20:1.

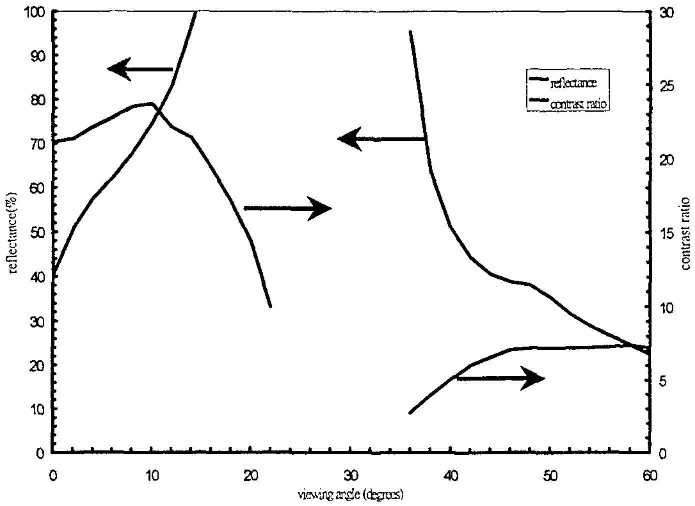

Fig. 6 Reflectance and contrast ratio of reflective LCD with DMSR.

The brightness of reflective LCD with DMSR is about 4 times when compared with that of a LC cell with a mirror type reflector as shown in Figure 7.

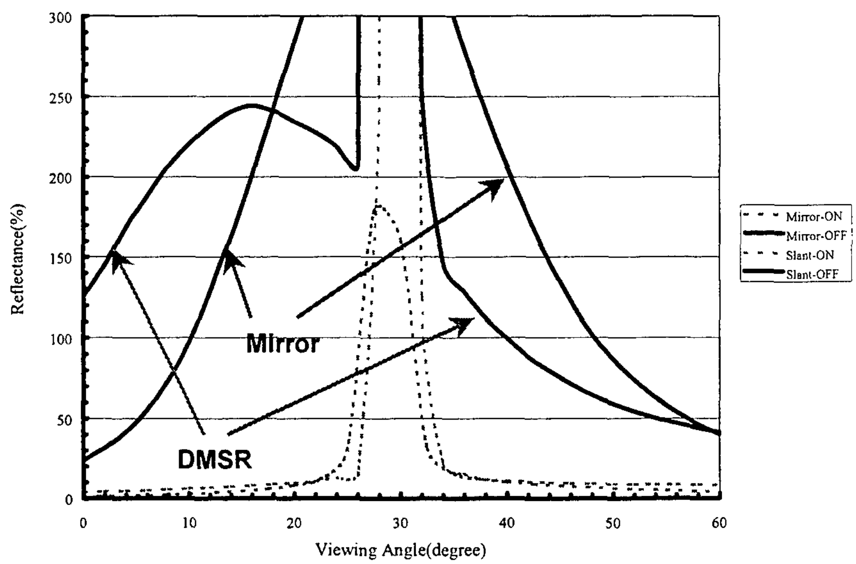

Fig. 7 Light scattering property of DMSR and Mirror reflector+Diffuser

The CIE chromatic behavior of the 6.4" reflective TFT-LCD is shown in Figure 8. Without using a polarizer, the white balance point is very close to the C light source. Because the transmission spectrum of the polarizer suppresses the blue color, the white balance point shifts away from the C light source after the polarizer is used. The reflection spectrum of our 6.4" reflective LCD is shown in Fig. 9. In the figure we can see that the reflective spectrum is very uniform from 380nm to 780nm in the normal viewing direction (B=0). The color becomes yellowish when the viewing angle is increased.

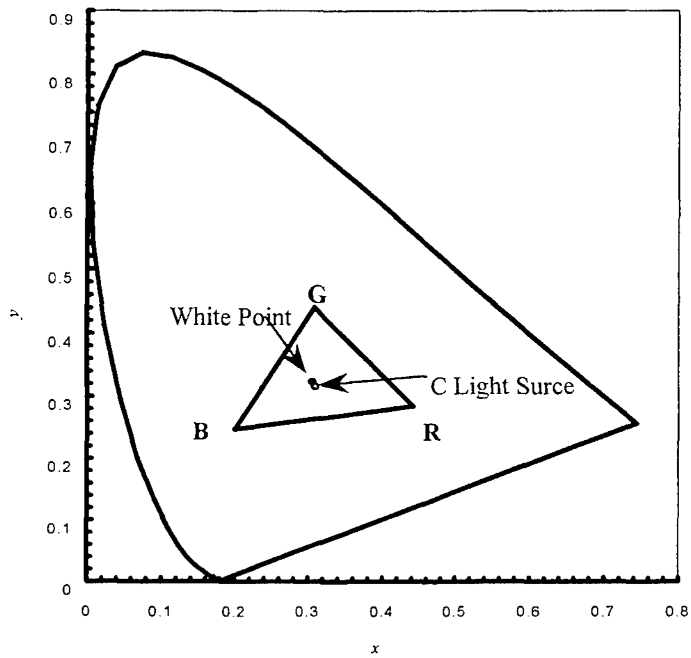

Fig. 8 The Color gamut of 6.4" TFT-LCD with DMSR.

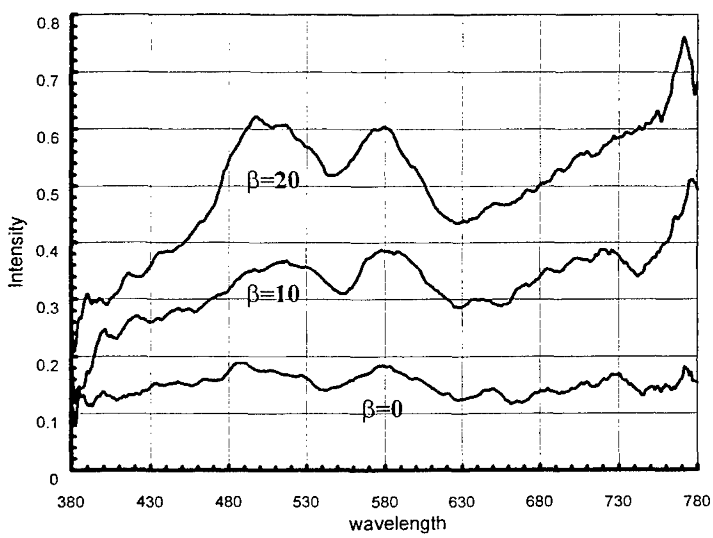

Fig. 9 The reflection spectrum of 6.4" full-color reflective TFT-LCD with DMSR.

When we compare the light distribution of DMSR, bump reflector and GameBoy in the plane of incident. We can find that the brightness of DMSR is about 3 times of that of bump reflector or Gameboy. The measurement is shown in Figure 10.

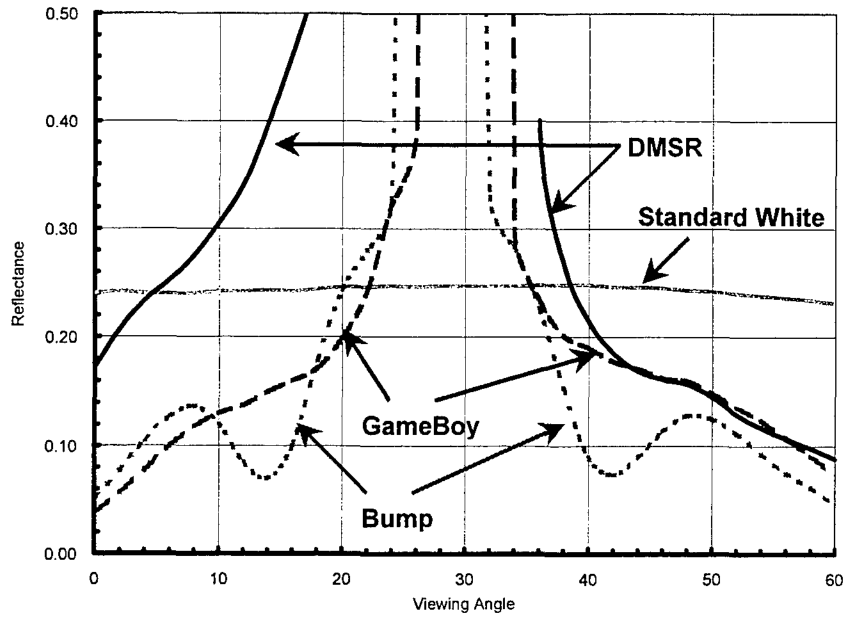

Fig. 10 Light scattering distribution of DMSR, bump and GameBoy.

The other important issue that must be considered is that the influence of DMSR asymmetric structure when illuminate from different direction with respect to the arrangement of DMSR structure. Figure 11 illustrates that when the illuminating light is rotated to 70°, the bightness of DMSR in most portions of the viewing angle is smaller than that of bump reflector(GameBoy).

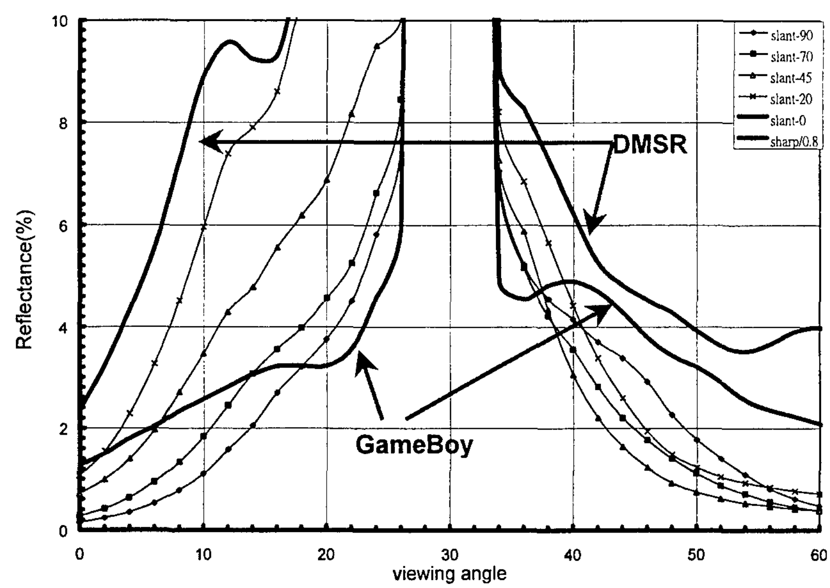

Fig. 11 Light scattering distribution for several different light incident conditions with respect to the direction of DMSR.

4.2 Conoscopic Measurements

In order to compare the light distribution in the whole space. We then used the conoscope to understand the optical distribution of our panel in all directions. CONOSCOPE (autronic-Melchers) and EZcontrast (ELDIM) are used to measure the light distribution of reflective LCD with DMSR and bump reflector. The light intensity distribution of reflective LCD depends strongly on the behavior of the incident light source. First, we used the collimated light as the incident light source. Fig. 12a shows the distribution of the reflected light intensity. Here the collimated light was located at an angle of 30 degrees relative to the normal axis of the panel. We then observed the light distribution at the cross section passing through the light source. The reflective intensity as a function of the viewing angles is shown in Fig. 12b. It clearly shows that there is a strong specular peak at –30 degrees. Besides that, some light is reflected in the region between 0 and 20 degrees. This demonstrates that the DMSR structure can only redirect the collimated light in a designated area. In general, the reflector with bump structure is optimized to obtain a light scattering distribution with symmetric characteristics. The reflective TFT-LCD with a bump reflector shows well uniform reflectance over a wide range of viewing angle symmetrically. This measurement result is shown in Figure 13.

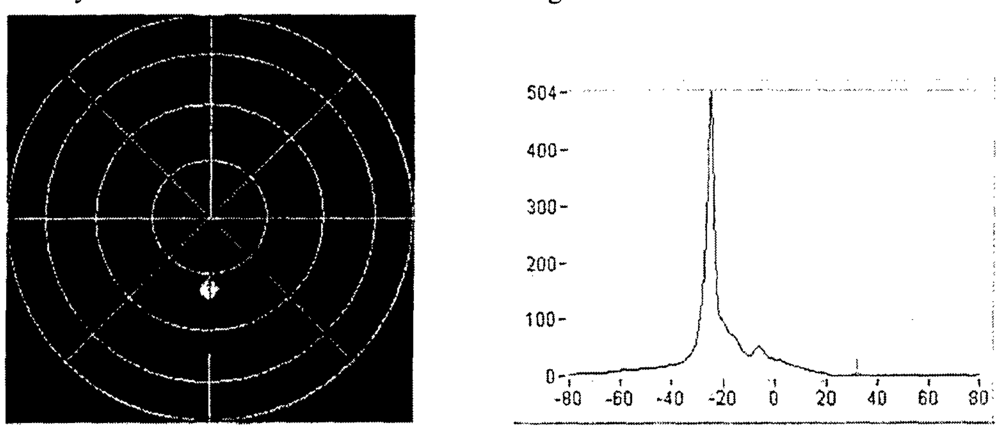

Fig. 12 (a) Reflected light intensity distribution for collimated light source. (b) One cross section.

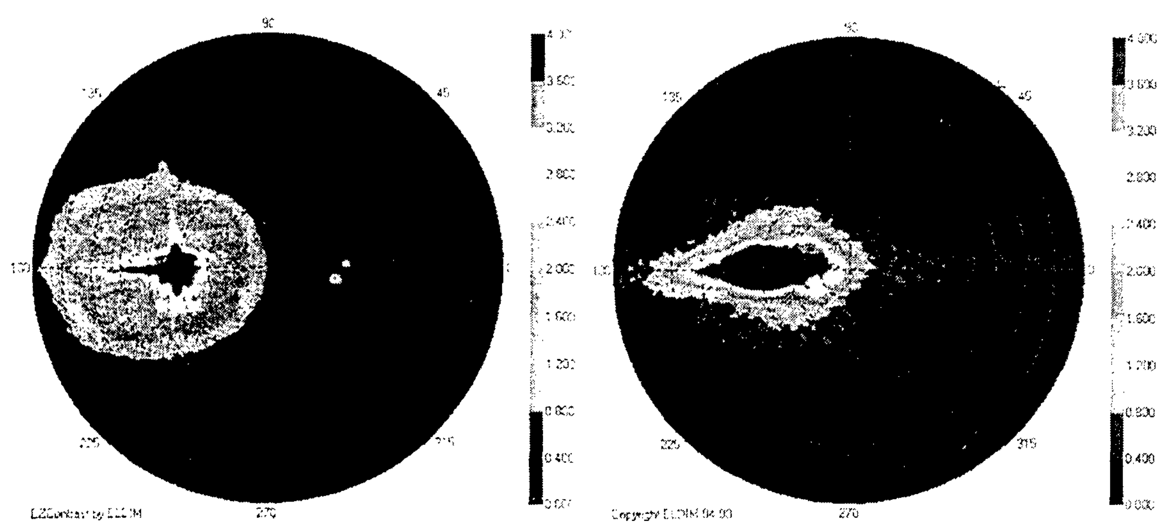

Fig. 13 Illuminating by collimated light source, reflected light distribution of (a)bump reflector (b) DMSR

If the incident light is the diffusive type, the light intensity distribution is shown in Fig. 14. The diffusive light source is generated by using the collimated light at the normal direction, so a specular peak can still be observed at 0 degree in Fig. 14b. In the conoscopic measurement, the reflectance will be independent of the viewing angles for both the bump reflector and a Lambertian white standard. The diffusive property of our DMSR design will redistribute the reflected light at larger angles so that a viewing cone can be generated to increase the brightness. This cone is from –60 degrees to 40 degrees. The asymmetric property of the cone is a result of the DMSR structure. That also causes the reflectance in the region of the negative angles greater than that in the other direction. Fig. 14a is the ISO-luminance contour of our panel. It clearly shows that the bottom-right part will be the best viewing region. Normal environment contains both the collimated and diffusive light. With the DMSR structure, we can utilize both light sources and make our panel much brighter, suitable for many applications mentioned above.

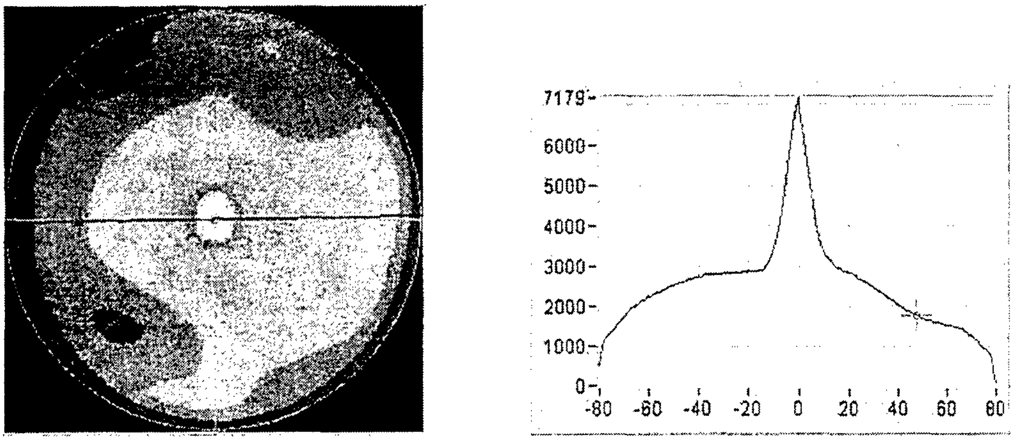

Fig. 14 (a) Reflected light intensity distribution for diffusive light source. (b) One cross section.

5. CONCLUSION

We have compared the optical properties of reflective LCDs with an asymmetric DMSR and that with a symmetric bump reflector. A reflective TFT-LCD with an internal asymmetric diffusive micro slant reflector (DMSR) is developed to enhance the light efficience. The DMSR structure is optimized to obtain a desired light scattering distribution cone with asymmetric characteristics. The reflective TFT-LCD with a DMSR exhibits high reflectance and high contrast ratio over a wide range of viewing angle. In general, the reflector with bump structure is optimized to obtain a light scattering distribution with symmetric characteristics. The reflective TFT-LCD with a bump reflector shows well uniform reflectance over a wide range of viewing angle symmetrically. If the incident light is the diffusive type, the reflectance of a bump reflector will be independent of the viewing angles. However, the diffusive property of the new DMSR design can redistribute the reflected light so that an asymmetric viewing cone can be generated to increase the brightness in this area. The asymmetric property of the cone is a result of the DMSR structure. Normal environment contains both the collimated and diffusive light. With the DMSR structure, we can utilize both light sources and make our panel much brighter, suitable for many information applications. The DMSR structure can get better performance than the bump reflector in the viewing angle range from normal direction to 60 degrees.

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