A Bright and Wide Color Gamut Reflective Full-color LCD using Diffused Light Control Technology

Takahiro ISHINABE and Tatsuo UCHIDA
Dept. of Electronics, Graduate School of Engineering, Tohoku University,
Sendai 980-8579, Japan
TEL:+81-22-795-7119, e-mail: ishinabe@ecei.tohoku.ac.jp

Keywords: Reflective LCD, Diffused light control, High reflectivity, Wide color gamut

Abstract

A development of low power display is an important problem from a point of reduction in worldwide energy consumption. In this research, we aimed to achieve a high quality and low power paper-like reflective full-color display and investigated the design rules for the light diffusing film, LC-cell structure, front lighting systems based on the diffused light control technology. As a result, we successfully obtained the high quality reflective liquid crystal display with a high reflectivity, a wide color gamut and a high motion picture quality.

1. Introduction

With the development of a highly sophisticated information society, displays are becoming a key device and are indispensable to man-machine interface. For this reason, full-color liquid crystal displays (LCDs) has been used in a variety of applications. In the future, with the spread of sophisticated portable terminals, the market is expected to demand full-color LCDs that have even lower power consumption, high image quality, and the ability to display high quality images regardless of the environment.

The transmissive LCDs have suffered from a low contrast ratio in a bright environment and Uchida et al. proposed a reflective color LCD which has a reflector inside the LCD panel and color filters$^{1)}$. Since a reflective color LCD does not use a backlight, power consumption can be reduced, and in addition, a high quality image can be displayed in a bright environment, thereby providing seamless continuity of display as the viewer moves from one environment to another.

However, reflective LCDs have problems of a low contrast ratio and narrow color gamut compared to the transmissive LCDs, as a result, its application has been restricted to an extremely small field. Therefore, an improvement of the image quality of reflective LCDs has been a serious problem.

In order to realize high quality reflective LCDs, an improvement of reflectivity by the optimum control of the diffused light is indispensable and we have previously proposed the control method of diffused light by designing the shape of the surface micro structure of the reflector. However, this method limited the incident light angle range and degraded a image quality of the reflective LCDs. Therefore, a consideration of both the direction of the incident light and the diffused light angle range is important to realize the high quality reflective LCD.

In this paper, we discussed the improvement of the reflectance and color gamut of reflective LCDs by the diffused light control technology considering the incident light angle range. In addition, we also discussed the new front lighting system with high contrast ratio.

2. A Bright Reflective LCD by the Diffused Light Control Technology

In the case of the outdoor use or the digital camera applications, the incident angle of light becomes large compared to the indoor use and PDA applications. As a result, the effective reflectivity becomes small even in the bright environment.

We have previously clarified that the distribution of the diffused light can be controlled by the optimization of the probability of inclination angle of the micro-structure of reflector. In addition, we newly developed the control method of the incident light angle range by controlling the average of the inclination angle of micro-structure.

Figure 1 shows the probability of the inclination angle of micro-structure for the large incident light of -45degrees. The average of the inclination angle is 15.8degrees. Figure 2 shows the shape and the inclination angle of micro-structure. This micro-structure can be fabricated by the injection technology.

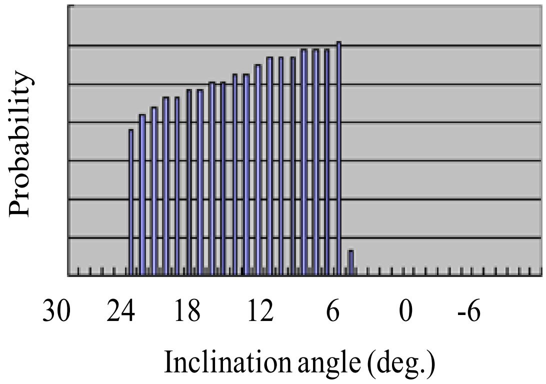


Fig. 1 The probability of the inclination angle of micro-structure for the large incident light.

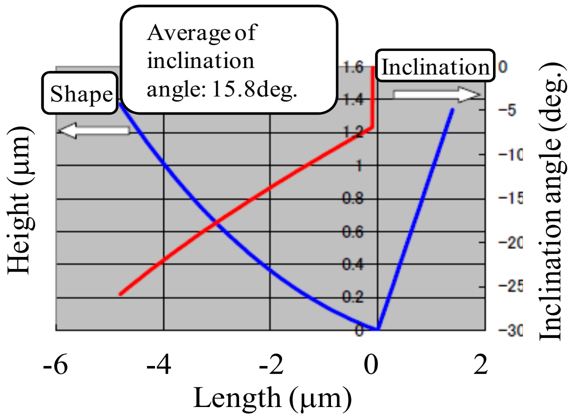


Fig. 2 The shape and the inclination angle of micro-structure.

Figures 3 and 4 show the viewing angle dependence of reflectivity and the photograph of our new reflective LCD. The incident angle is -45degs. The high reflectivity is successfully obtained in the normal direction in the case of large incident light.

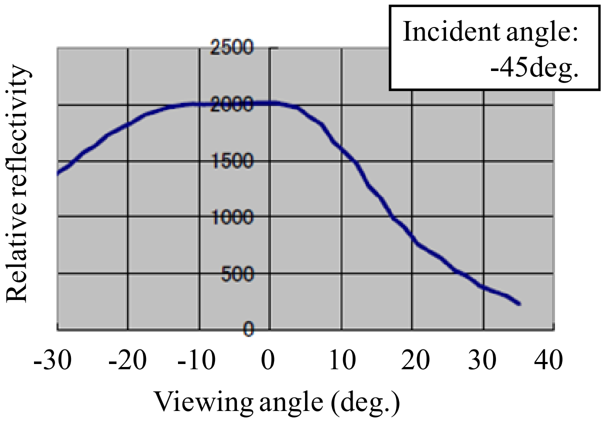


Fig. 3 Viewing angle dependence of reflectivity of reflective LCD using optimized diffusing reflector.

(a) Conventional (b) New reflective LCD

Fig. 4 New reflective LCD optimized for large incident light (Incident angle: -45deg).

3. High Quality Reflective color LCD with High Reflectivity and Wide Color Gamut

The diffused light control that is discussed in the previous section can be also realized by the optimization of diffusing area of light diffusing film. We have proposed the reflective full color LCD using mirror reflector and light diffusing film as shown in fig. 5 [2)].

Figure 6 shows the viewing angle dependence of diffusing intensity as a function of incident angle. This figure illustrates that the incident angle dependence of diffusing intensity and distribution are extremely small and all reflected light is diffused to an observation area and high reflectivity is obtained.

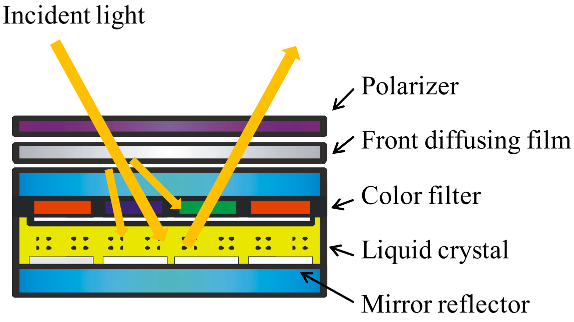


Fig. 5 Reflective color LCD using front diffusing film and mirror reflector.

According to these results, we fabricated the reflective full-color LCD using wide gamut color filters. Figures 7 and 8 show the viewing angle dependence of reflectivity and the photograph of our reflective LCD, respectively. The incident angle is -15degs. We realized the high quality reflective full color LCD with high reflectivity of 60%, high contrast ratio of 60:1 and wide color gamut of 55%.

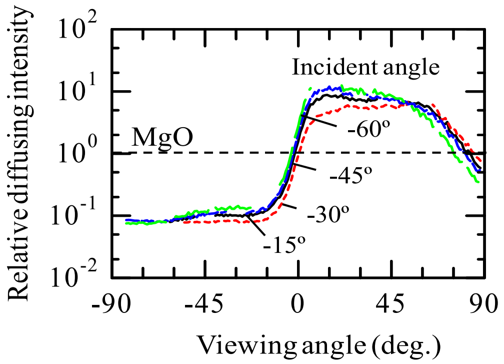


Fig. 6 Incident angle dependence of diffusing distribution of the diffused light control film.

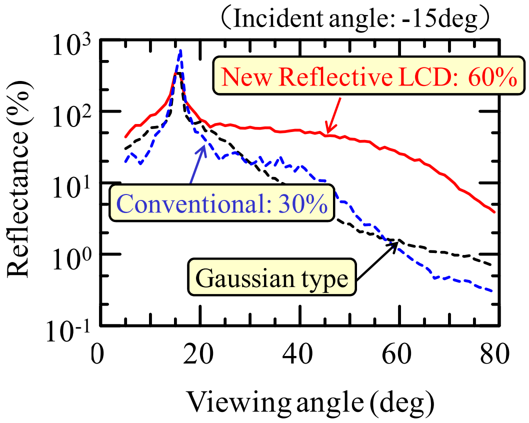
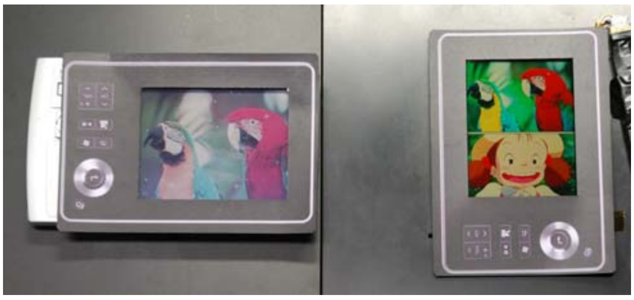


Fig. 7 Viewing angle dependence of reflectance.



(a) Conventional (b) New Reflective LCD

Fig. 8 New reflective color LCD with high reflectivity and wide color gamut.

4. High Contrast Front Lighting System

Since a reflective color LCD uses ambient light as its light source, in an environment where ambient light is not sufficiently bright, image quality deteriorates. Consequently, there remains a need to improve visibility under a dark environment in order to achieve high image quality.

In order to solve this problem, a front lighting system has been proposed as an auxiliary lighting system for use in a dark environment [3]. As shown in Fig. 9, in a front lighting system, light from a light source is incident to a light guide and is reflected by the rough top surface of the light guide, which then emits light at an angle close to the direction normal to the LCD panel [4, 5]. However, as also shown in Fig. 9, the front lighting system has a problem that light reflected from the bottom surface of the light guide and the surface of the LCD panel is emitted in the same direction as the displayed image and is visible to the observer, causing a drop in contrast ratio.

To solve this problem, we propose a new front lighting system as shown in Fig. 10, consisting of a wedge prism light guide and a forward scattering film placed inside the reflective LCD. This front lighting system emits light from the light guide at an angle inclined to the LCD panel. Inside the LCD panel, this incident light is scattered by the forward diffusing film, so that the image emitted from reflective LCD is at an angle normal to the LCD panel. This is expected to prevent light reflected from the bottom surface of the light guide and the surface of the LCD panel from being visible to the observer, providing a reflective LCD that can produces an image of high contrast ratio.

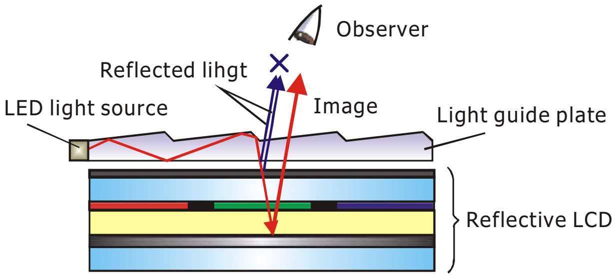


Fig. 9 Reflective LCD using a conventional front lighting system.

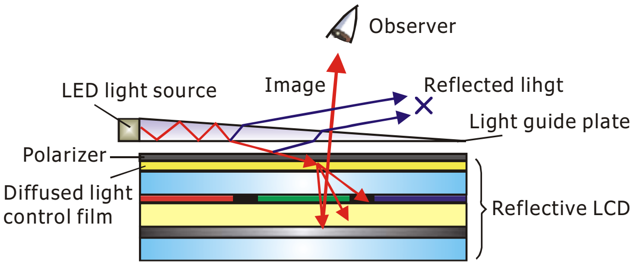


Fig. 10 Reflective LCD using a new front lighting system using wedge prism light guide plate.

In order to displaying a high-contrast image with a uniform brightness by using our wedge-shaped front lighting system, the correct evaluation of the brightness of the light emitted from the wedge-shaped prism light guide plate is required. We derived a relationship between the brightness of light emitted from the light guide and the brightness of light incident from the light source.

In addition, we found that the brightness of the light emitted from a light guide depends on the distribution of emitted light from a light source, and the high uniformity of luminance is achieved by optimizing the angle distribution of light source brightness and its angular range. We fabricated micro diffusing structure at the light guide edge and optimized angle distribution of light source brightness.

In accordance with the above discussion of design, we test-produced a front lighting system consisting of a wedge-shaped prism light guide and a forward scattering film inside a reflective LCD. We measured the contrast ratio of our front lighting system. The refractive index of the wedge-type light guide prism was 1.5, and the wedge angle is 2 degrees. These results confirmed that our new front lighting system has a contrast ratio of 500:1 or higher. On the basis of the above results, we estimated the contrast ratio of a reflective LCD using our front lighting system. As shown in Fig. 11, whereas a previous type of reflective LCD using a front lighting system had a contrast ratio of 20:1 or less even after the contrast ratio of reflective LCD was increased to some extent, the reflective LCD using our front lighting system has succeeded in increasing the contrast ratio to 100:1 or higher.

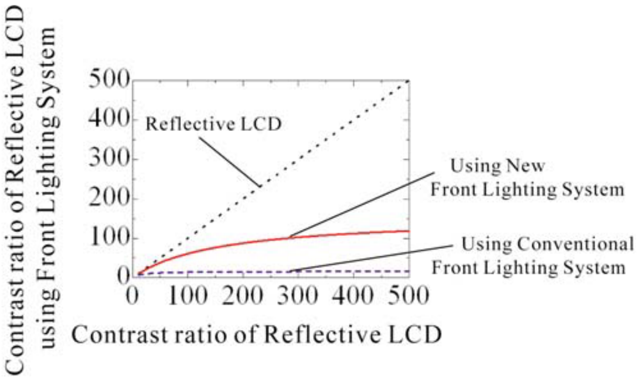


Fig. 11 Estimation of the contrast ratio of a Reflective LCD using a front lighting system.

Figure 12 shows a photograph of a reflective LCD using our front lighting system under a dark environment. For comparison, the conventional type of reflective LCD using a front lighting system is also shown. Figure 12 confirmed that the reflective LCD using our front lighting system gives a better image than the conventional system.

(a) Conventional (b) New lighting system

Fig. 12 Reflective LCD using frond lighting system in dark room.

4. Conclusion

(1 line spacing)

A consideration of the direction of incident light and the diffused light is indispensable and high quality reflective color LCD with high reflectivity and wide color gamut is realized by the diffused light control technology. We proposed a new front lighting system consisting of a wedge-shaped prism light guide and a forward scattering film inside a reflective LCD. Our reflective full color LCD has low power consumption, and seamless high image quality regardless of the viewing environment, making it very promising as a display for use in next generation portable information terminals.

5. Acknowledgement

Part of this research was supported by SCOPE Program under the Ministry of Internal Affairs and Communications.

6. References

1. T.Uchida, T. Katagishi, M. Onodera and Y. Shibata: Trans, IEEE, Electron Devices, ED-33, p. 1207 (1986).
2. CT. Uchida, T. Ishinabe, T. Nakayama, M. Suzuki and T. Miyashita: Japanese Journal of Applied Physics, Vol. 43, No. 12, 2004, pp. 8094-8100 (2004).
3. C. Y. Tai, H. Zou and P. K. Ta: SID 95 Digest Papers, pp.375-378 (1995).
4. H. J. Cornelissen, H. Greiner and M. J. J. Dona: SID99 Digest Papers, pp.912-915 (1999).
5. Y. Yingbao, M. Ochiai, M. Hatanaka and T. Akutagawa: Proc. of the IDW, pp.391-394 (2000).