Development of Reflector for HR-TFTs

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Abstract

A novel method to estimate and design a reflector for reflective color LCDs has been developed. This method is based on the assumption that the surface shape of bumps on the reflector could be practically replaced with a set of multiple micro-flat mirrors.
Light scattering characteristics of a reflector can be calculated from the slope angle distribution of these micro-flat mirrors. This led us to propose the ideal bump shape of the reflector for reflective color LCDs.
Analyses of actual reflectors verify this method, and an approximately ideal reflector was fabricated by optimizing the bump shape.

Introduction

In recent year, the network infrastructure for data communication has been constructed rapidly. Under such circumstances, demand for mobile information tools which assist personal management has been increasing.
Liquid crystal display (LCD) is one of the most promising devices for mobile information tools which need to be thin, light in weight and low power consumption.
Although the transmittable type LCD, currently the mainstream, has achieved an excellent display image, the backlight system accounts for 80-90% of the entire LCD power consumption, and 60-70% of the thickness and about 50% of the weight. And surrounding light reflects on the surface of the substrate in daylight, which causes decrease in visibility. So it is not necessarily best for the mobile information tools.
On the contrary, a reflective type LCD utilizes surrounding light instead of the backlight to display the image. So it is possible to make it thin, light in weight and have low power consumption. Stronger surrounding light produces better images, a reflective type LCD has an advantage for outdoor use. It is one of the most suitable displays for mobile information tools.
So far, the reflective type LCD has been used only for a monochrome display such as display in electronic calculators, and color reflective type LCD was not of practical use. The reason was a color filter made the intensity light decrease to about 1/3 compared with the monochrome one . Additionally its brightness was not at an acceptable level.
There are another losses of light on the composition elements of reflective type LCD besides the color filter. Calculated efficiency of the light of LCD, in taking account of the following factor, result in about 10-13%; absorption of polarizer, reflectance of reflective electrode, aperture ratio of the pixels and reflectance of the glass surface, etc.[1)]
Design of the light scattering property is very important on reflective type LCD since it determines how effectively reflective light is transferred to the direction of the eyes.
It is necessary to design oh light scattering property of the incident light suitably in order to produce a clear view of image on the reflective type display. When characters are written on the mirror, the characters are not seen easily because the images of fluorescent light or our own faces reflect and hinder the view. On the other hand, excessive scattering reduces a light intensity per solid angle and decreases brightness.
Therefore, optimum control of the scattering characteristic is required to produce clear and bright image on a

display.

While several structures are considered to realize reflective type LCD, we have adopted the structure that the reflector acts as the electrode to drive a liquid crystal and that has micro bumps on its surface (micro reflective structure = MRS). This structure allows the bright image with high aperture ratio and no double image attributed to the parallax.[2)~5)]

In this report, the development of the reflector for bright reflective type LCD, especially the method for designing an ideal reflector bump shape for scattering characteristic control shall be discussed.

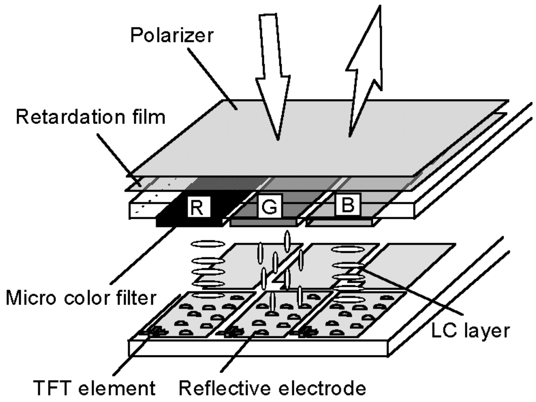

Fig. 1 Schematic figure of refrective type color LCD.

1. Optical scattering of reflective type LCD

When the surface shape of the reflector with micro bumps is estimated, it is easy to measure the cross section shape and the pitch of the bumps. It is, however, difficult to discuss accurately light scattering characteristic of the reflector from these fragmentary data.

Then, the relation between the bump shape and light scattering characteristic has been analyzed in this report by the following new techniques.

It was assumed that the bumps on the surface of the reflector are composed by multiple micro flat mirrors as shown in **Fig. 2**, and light scattering model of reflective type LCD was assumed as shown in **Fig. 3**.

That is, the refractive indices n(glass) of glass and refractive indices n(LC) of liquid crystal are the same 1.5 respectively, and the air refractive indices n(air) is 1.

The light shall be reflected by the plane which slope angle is θm, and in addition, be refracted in the direction of qair by the interface of the glass and air. At this time it satisfies Snell's law (1) and Fresnel's law (2).

Here, "a plane of incidence" is defined an incident light vector and a reflective light vector. A|| and T|| are an amplitude of parallel polarized light element to the plane of incidence in the liquid crystal and that in the air, respectively. A⊥and T⊥are an amplitude of perpendicular polarized light element to the plane of incidence in the liquid crystal and that in the air, respectively.

As mentioned above, the scattering light intensity distribution can be obtained by summing the slope angle distribution of various micro flat mirrors. Oppositely, if an ideal scattered light intensity distribution is defined, required slope angle distribution could be obtained. The shape of bump is assumed to be symmetrical to the axis in the vertical direction of the substrate for calculating easily.

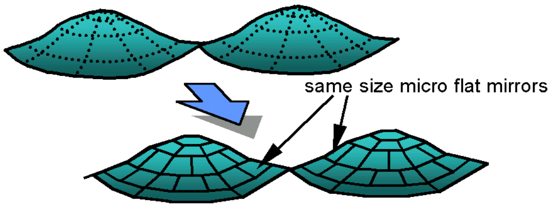

Fig. 2 Schematic figure of surface shape used to calculate the scattering property. These are composed by many same size micro flat mirrors.

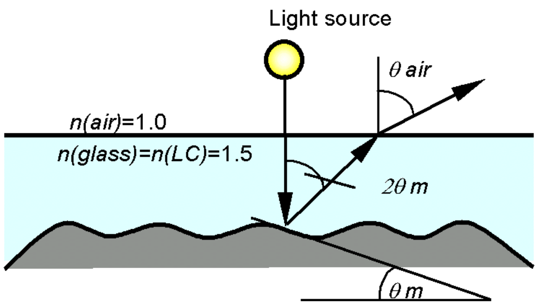

Fig. 3 Schematic diagram of reflector used to calculate the scattering property.

$$n(LC)\cdot\sin(2\theta_m)=n(air)\cdot\sin(\theta_{air}) \qquad (1)$$

$$T\parallel=\frac{2\sin(\theta_{air})\cos(2\theta_m)}{\sin(2\theta_m+\theta_{air})\cos(2\theta_m-\theta_{air})}A\parallel$$

$$T\perp=\frac{2\sin(\theta_{air})\cos(2\theta_m)}{\sin(2\theta_m+\theta_{air})}A\perp \qquad (2)$$

2. Ideal slope angle distribution

In this chapter, ideal scattered light intensity distribution will be defined, and the model of ideal shape of bump is obtained by the calculation.

It is important to realize uniform brightness all over the screen for any displays. In order to realize uniform brightness on the reflective type LCD, it is necessary to have a complete scattering property shown by the broken line of **Fig. 5**. In this case, a very dark display is only obtained because of decreased light intensity to each solid angle as mentioned above.

Then, the reflected light must be limited to within the specific range, and controlled to uniformly scatter in the range to improve brightness in the specific viewing angle.

Let us think about the scattering characteristics that are required to achieve brightness of newspaper as a target.

The incidence light to a newspaper is evenly scattered at almost all azimuth and its scattering intensity is about 60% of MgO (standard white). To make scattering light intensity of reflective type LCD, of which efficiency is 10-13%, equal to a newspaper, the range of scattering of "Hemispherical screen" must be limited to 15%-20 % as shown in **Fig. 4**.

That is, the property to uniformly irradiates from a normal reflective direction up to 25 degrees as indicated with the solid line of **Fig. 5**, corresponds to an ideal scattering light distribution for the reflective color LCD.

In order to obtain a reflector with such an ideal scattering light distribution, we will explain how to calculate the required bump slope angle distribution, in using the optics system shown in **Fig. 4**.

Parallel light is entered from a normal to the reflector, if a reflector scatters with constant intensity for the range in the corn angle of 25 degrees (Area S), the intensity for each unit area of the scattering light is constant.

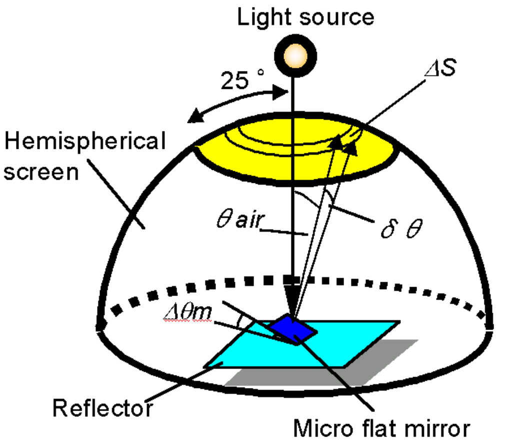

Fig. 4 Schematic diagram of optical system used to determine the model of ideal reflector.

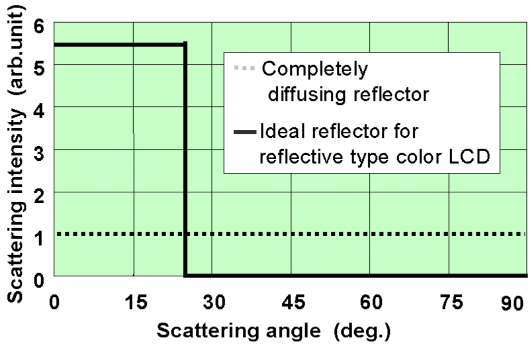

Fig. 5 Scattering properties of a completely diffusing refractor and an ideal refractor for LCD.

Let us think about a micro area ΔS on a hemisphere screen in **Fig. 4**, and consider it as a group of multiple micro flat mirrors light reflecting angle of θm - θm + Δθm to the micro area. If intensity of scattering light for each unit area on S is constant, the existence rate of the mirror P (Δθm) with the slope of θm - θm + Δθm could be described as a ratio of Area S and Micro Part Area ΔS.

$$p(\Delta\theta_m) = \frac{\Delta S}{S} \qquad (3)$$

$$\Delta S = 2\pi r^2 \int_{\theta air}^{\theta air + \delta\theta} \sin\theta \, d\theta \qquad (4)$$

Where "r" is a radius of a hemisphere screen here.

From formula (1), (2), (3) and (4), the required slope angle distribution for the ideal reflector could be calculated as shown in **Fig. 6**.

Thus, it is understood that the ideal slope angle distribution of the reflector for the reflective type color LCD is; there is little flat part, the existence rate increases up to 8° but no larger slope angle than this is not existing.

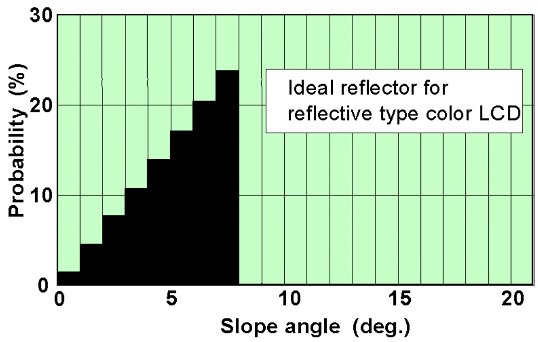

Fig. 6 Slope angle distributions of an ideal refractor for refrective type color LCD.

3. Result of experiment

In the foregoing paragraph "the ideal bump's slope angle distribution" was obtained by the calculations. In this chapter, the results of optimization with analyzing the bump's shape of the actual reflectors shall be discussed. The reflector surface shape with 3-dimensional smooth bumps was analyzed with an interference microscope (made by WYCO: RST Plus).

With this instrument, the range of 78.2μm x 58.4μm was decomposes into xyz coordinates of about 2200 points with horizontal resolution of 425nm x 493nm, a height resolution of 3Å, and micro planes defined with three mutually adjoined points.

By calculating a normal vector about each plane and by totaling the direction of the polar angle, the slope angle distribution of the smooth bumps could be obtained.

Fig. 7 is a measurement result of the slope angle distribution in two kinds of typical reflectors. Next, the light scattering intensity distribution calculated from the slope angle distribution is shown in **Fig. 8**. On the other hand, the scattering light intensity distribution shown in **Fig. 9** was obtained by an actual optical system (made by Otsuka Denshi: LCD-5000), whose light source is an expanding angle of 6°.

It was verified that the measurement accuracy of the shape of bumps and the scattering characteristic calculation method was appropriate because profiles of **Figs. 8** and **9** correspond to each other.

In reviewing **Fig. 7**, the existence rate of small areas in the slope angle of Type A reflector is higher than the ideal shape shown in **Fig. 6**. This causes unbalanced characteristics that the brightness of direction of 0°- 10°only is high and any other directions become dark as shown in **Figs. 8** and **9**.

On the other hand, slope angle distribution of Type B reflector, 8° or less is almost near the ideal distribution. However, planes having 9° - 15°slope angle, which is beyond of the ideal distribution, exists.

Figs 8 and **9** show that the Type B reflector obtains almost the same reflective intensity up to about 25°. A scattering characteristic near the ideal is achieved.

The lights which reach the direction of 25°- 40°are reflected by the planes witch have slope angle of 9°or more.

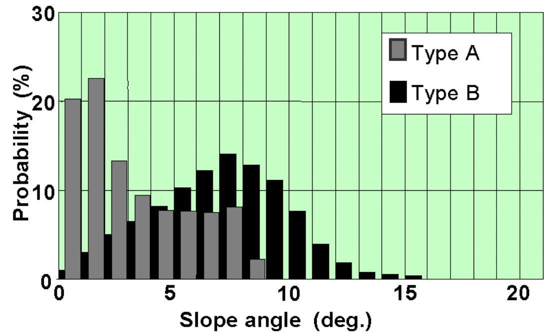

Fig. 7 Slope angle distributions of actual reflectors.

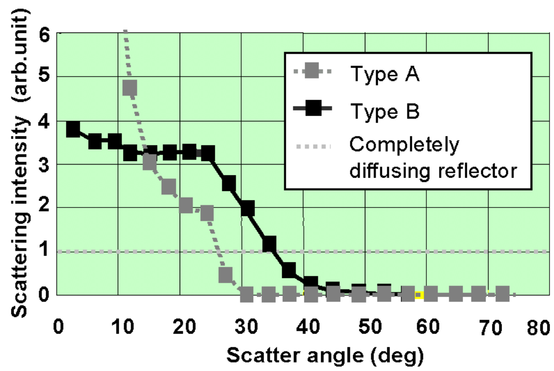

Fig. 8 Scattering light distributions of actual reflectors which were calcurated from slope angle distributions.

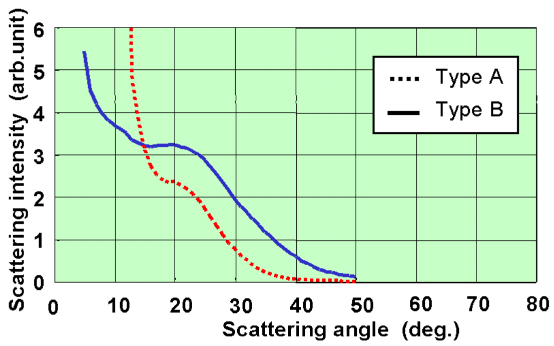

Fig. 9 Scattering light distributions of actual reflectors which were measured by optical detection system.

Conclusion

A novel method to estimate and design the reflector for a reflective type LCD was proposed, based on the discovery that the shape of surface bumps on the reflector is actually a concurrence of multiple micro-flat mirrors. Light scattering of the reflector was calculated from the slope angle distribution of these micro-flat mirrors.

In using the above-mentioned analysis method, the model of the ideal slope angle distribution to obtain ideal scattered light intensity distribution was established.

By comparing the scattering characteristic measured in the actual optical system and the scattering characteristics calculated from the slope angle distribution, the validity of the above evaluation method is verified. In addition, by optimizing the shape of the bumps, an almost ideal reflector was obtained.

In using the reflector developed as explained, the liquid crystal display mode "HCR method" which uses one polarizer, and an optimized color filter, we succeeded in developing a high-quality reflective type LCD “HR-TFT”. Table 1 shows the specifications of HR-TFT.

Table 1 Specification of HR-TFT.

Display size	27.7cm(11.3inch)
Dot format	800(H)×RGB×600(V)dots
Drive system	Active drive(a -Si)
Number of color	260,000
Contrast ratio	20:1(0 to 30 degree)
Brightness	30%(0 to 30 degree ;ref. MgO)
Respons time	50msec

HR-TFT, with no backlight system, has the features of long time operation with batteries, and thin and light body. HR-TFT is, therefore, a very promising device in the liquid crystal industry for various new fields of mobile applications as well as for the mobile information tools.

Acknowledgment

The author wishes to express his gratitude to Professor Tatuo Uchida of the Electrical Engineering Dept. of Tohoku University and to those in the Liquid Crystal Display Development Group and TFT Liquid Crystal Display Group for their kind guidance and cooperation in conducting this study.

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(received June 25, 1999)