Holographic directive reflectors for reflective color LCDs

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Abstract

RGB directive color reflectors were implemented for bright reflective color LCDs. The reflection gain at a white display state was suggested to be 3.5 times as large as the white standard. The color gamut was found to be as wide as the NTSC standard. There observed little color shifts within the directive angle.

Introduction

Transmissive color LCDs are propagating worldwide since they are able to produce flicker-free display of flat structure at lower power consumption compared with a conventional CRT. On the other hand, an environmental consideration of the user rises and the digital network society is coming soon. Research and development of reflective color LCDs with features of lower power consumption, thinner structure and lower weight has been activated, aiming at settling the lifestyle in which mobile terminals are used. Reflective color LCDs have been commercialized with HR-TFT [1], which uses a single polarizer display mode. Since display property of 30% in brightness (B) and contrasts (CR) 20 was obtained, further improvement of reflective luminance is especially of importance in order to display color print better than an average newspaper (B50%, CR5).

1. Comparison with the conventional technology

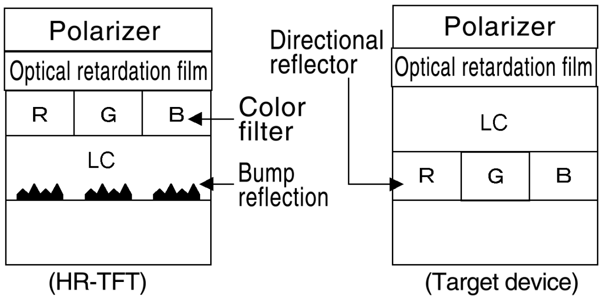

Fig. 1 Structural comparison - HR-TFT and target device.

Fig. 1 shows the comparison between the target device structure (directional reflective color structure) and the HR-TFT structure. The target device shall utilize a directional color reflector with a color filter function and a reflection function of dump reflective electrode, based on a single polarizer display mode.

A micro reflective structure uses the method of superimposing the diffused components on the specular reflection light, which originate on a bumpy surface structure. The technical base of this reflective property is given by Diffraction Theory [2] developed by Beckmann. On the other hand, the approach at the present time is the method in which the reflection angle is converted into the direction of the normal of a reflector by the directive angle. Here, A Multi-layer Dielectric Film Theory [3] and A Coupled Wave Theory by Cogelnec [4] are employed as the starting point.

Because the liquid crystal layer and the glass substrate (refractive index of about 1.5) are arranged on a reflector, reflected light exceeding reflection angle of 42 degrees is reflected again on the air-glass interface and this undesirable cross talk deteriorates the display quality. To avoid this, the off-axis reflective function mentioned above becomes important. However, only the off-axis reflective function, the reflected lights from off-axis reflection resembles the lights reflected from a plane mirror, and thus the display quality is decreased. It is done to provide the directive angle of reflected lights of less than 42 degrees.

The directional reflectors improve the reflective display luminance at the expense of the viewing angle. The viewing angle and the reflection gain shall be discussed in the forthcoming paragraphs. The reflection gains can be calculated as a ratio of reflection intensity of some samples with respect to a white standard sample. Luminous intensity I (= $d\phi/d\Omega$) from a white standard sample can be described as $I_0\mathrm{Cos}[\theta]$ where I_0 shows the intensity in the normal direction, Ω shows a solid angle and θ shows a polar angle. Therefore, when reflective light can be uniformly reflected within the directive angle of θd, the flux reflection gain $\phi g = 1/(\mathrm{Sin}[\theta d])^2$ is obtained assuming the energy conservation rule. The user can see flux that is four times higher than the white standard sample at the viewing range of about 60 degrees for upper and lower, and a right and left angle of $\theta d = 30$ degrees. On the other hand, The intensity reflection gain Ig is given by $1/(1-\mathrm{Cos}[\theta d])$, and a value smaller $(2+\sqrt{3})$ than a flux gain of 4 is obtained within the same directive angle of 30 degrees.

2. Directional reflector fabrication

A double beam interference exposure method is applied to achieve an off-axis reflective function. The micro lens array was placed in the reference beam side in order to obtain a uniformly diffused reflection profile. The double beam experiment is shown in **Fig. 2**. The curved surface of the micro lens array was the one of spherical shape. As a result, the curved interference fringes are formed in a thin film of a recording medium. A holographic recording medium purchased from DuPont is employed as a directive reflector material. The fabrication process is described in **Fig. 3**. An Argon laser (488 nm in wavelength), a SHG-YAG laser (532 nm in wavelength) and an Argon laser (514.5 nm in wavelength) were used for the formation of B, G, and R reflectors, respectively. After interference exposure, an ultraviolet irradiation (for 1J) and a heat treatment (120˚C, 2H) are performed to stabilize the hologram structure. In the formation of an R reflector, a process to swollen the curved fringe before irradiating ultraviolet rays is introduced, and then the ultraviolet illumination and heat treatment procedures are given similarly. A vacuum chuck type hot plate was used since the swollen process requires a precise control of diffusion temperature and time.

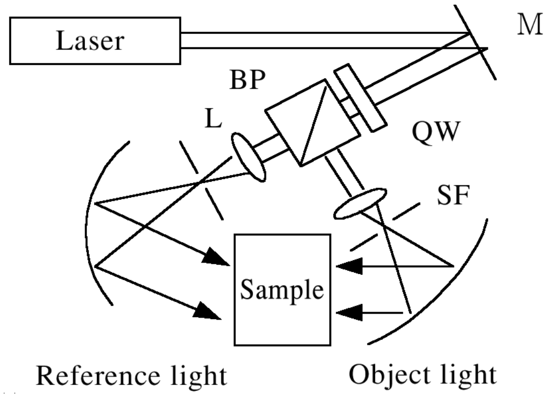

Fig. 2 Double beam exposure experiment.

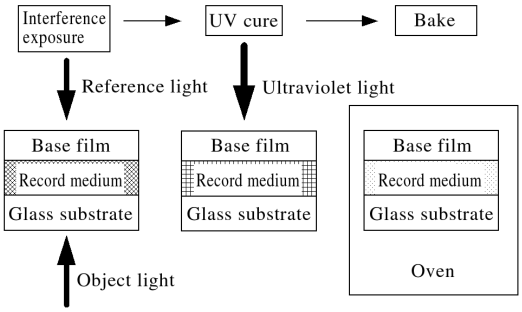

Fig. 3 Fabrication process of directive films.

3. Directional reflection characterization

Evaluating profile characteristic of reflected lights requires a great amount of time if it is measured under the condition of the spot illumination and spot detection. Here, an area receiving optical method 5) was adopted, using a CCD under the spot illumination. On the following discussions, the characteristic was evaluated on the source of light value converted to the illuminant D65 though a Xenon lamp.

A reflective profile of a G directive reflector for incident 30 degrees, divided with the profile of a standard white for the same incidence, is shown in **Fig. 4**. A reflection gain profile with a shape of + is obtained at the polar angle of zero degrees for the incident direction of the polar angle of 30 degrees and the azimuth angle of 180 degrees. It is considered feasible to improve the uniformity of the refection profile and to make the directive angle about 10 degrees wider by using an optimized lens array, which is still under investigation.

The reflection gain spectra referred as a white standard are shown in **Fig. 5** for RGB directional reflectors prepared this time. When the reflection gain Yw in a white display state was calculated by using the three stimulus functions together with these spectra, Yw = 350 (Yw = 100 of a white standard) was obtained. This means the pixellated directive reflector within the directional angle is 3.5 times brighter than the white standard. Each color coordinate of the RGB reflective films was found to be comparable with the NTSC standard. Wider color reproducibility in the reflective color filter is secured than those of the transmissive color filters, as shown in **Fig. 6**, and it is understood to be able to expect the color reproducibility of the NTSC standard even in the reflective display.

It is known that the color of a holographic reflector shifts towards blue as the viewing angle increases. **Fig 7** shows that there is a little color shift as the receiving angle is moved in the direction (ϕ = 0 - 180) in the hologram recording plane. The figure also shows that there is no color shift when the receiving angle is moved in a direction (ϕ = 90 - 270) orthogonal to the plane at the incidence angle of 30 degrees. This shows that each reflection spectra of RGB reflectors does not change greatly within the directional angle. There is a very small spectral intensity for RGB reflectors outside of the directive angle. Thus, there is a considerable reduction in reflection intensity for the RGB reflectors before the color shifts becomes eminent outside of the directive angle. This is an intentional effect. The color shifts, when the receiving angle is fixed at 0 degrees and the direction of incident angle is changed from 30 degrees to 45 degrees, is summarized in **Fig. 8**. While R and B reflector stayed unchanged in the color coordinates, the G reflector shifted slightly to yellow but mostly remained is in the range of green color coordinates. As for the reflection gain at a white display state, brightness decreased from 3.5 to 1.3 times by the

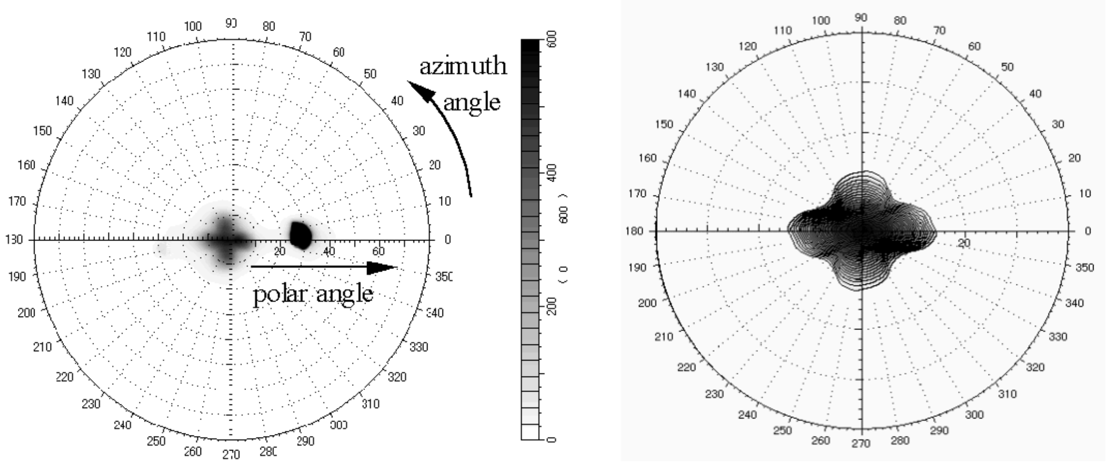

Fig. 4 Reflection gain profile (L : Raw data, R : Enlargement) .

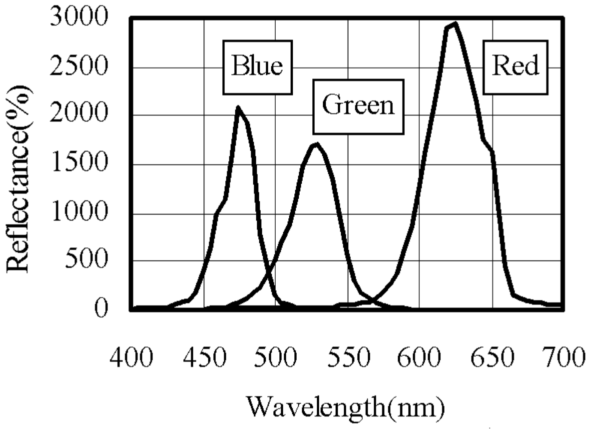

Fig. 5 Reflection gain spectra.

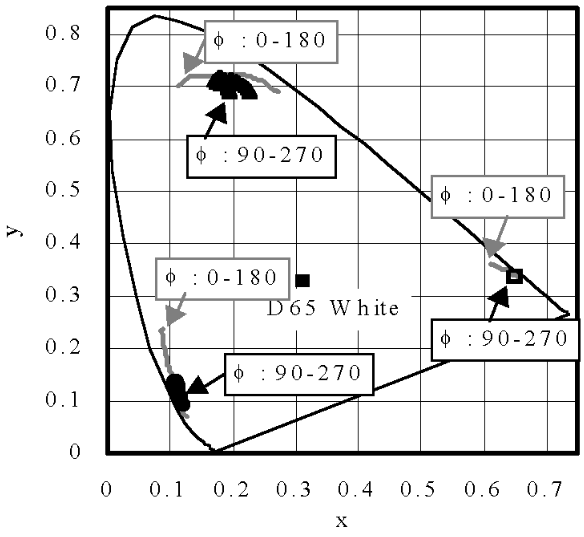

Fig. 7 Color shift as a function of receiving angles.

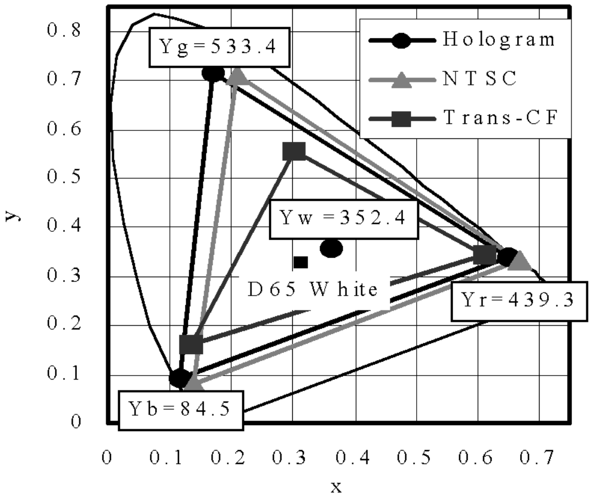

Fig. 6 Comparison of color gamut.

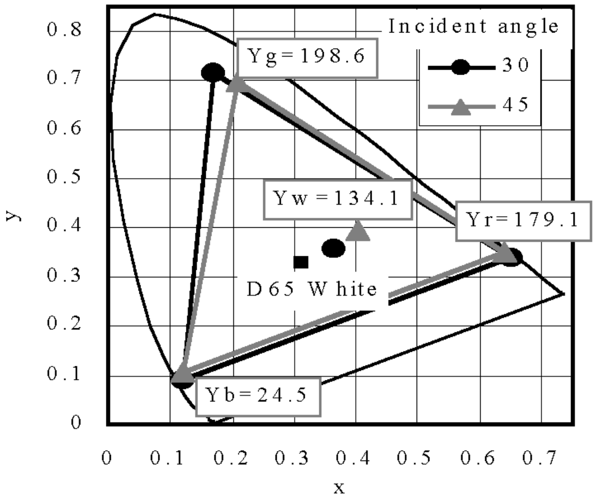

Fig. 8 Color shift as a function of incident angles.

change in the angle of incidence. The reason for this is that the present directive angle is small.

Conclusion

The directional reflectors prepared this time can be used to implement a brightness of 60% (corresponding to a gain of 0.60) in devices with a single polarizer since a reflection gain of 3.5 was verified. Moreover, the color reproducibility of the NTSC standard seems to be within the range of our future target. It will be necessary to understand the amount of the phase changes of reflective lights at the directive reflectors quantitatively to obtain a high contrast (CR > 15) display in the future.

Reflective full-color LCDs will be able to make a great contribution for the future information society and will be helpful to solve global issues such as energy saving and environmental protection. Another technical issue that remains to be solved for reflective LCDs is a relatively slow liquid crystal response, transmissive LCDs also face.

Acknowledgements

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