Films for Widening the Viewing Angle of LCDs

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Abstract

Optical compensation films are widely used to enlarge viewing angle characteristics for LCDs. A new surface film with an inner light scattering layer was newly developed to improve gray scale inversion. This paper describes technologies regarding these films that enhance the viewing angle characteristics for LCDs.

1. Introduction

LCDs suffer a viewing angle problem, mainly because of optical anisotropy of the liquid crystal layer and light leakage from crossed polarizers. This viewing angle problem can be solved by employing optical compensation films. For example, the TN mode uses the WV film[1]. And the multi-domain VA mode needs a biaxial film[2]. Even the IPS mode requires a low retardation TAC film[3] and sometimes a special biaxial film for large-sized TV applications[4]. These optical compensation films basically increase the off-axis contrast ratio (CR) by optically compensating the liquid crystal layer or crossed polarizers. This leads to wide viewing angle characteristics. However, it is difficult to improve gray scale inversion by using optical compensation films.

Recently, it has been found that use of a front surface film with an inner scatter layer is very effective in improving gray scale inversion[5]. Light scattering at the surface of the LCD averages the light intensity within the range of some solid angle. Careful control of light scattering provides improved gray scale performances with negligible CR increase.

This paper describes technologies regarding optical compensation films, focusing mainly on the WV film, and surface films with an inner scattering layer.

2. WV films for TN

The TN mode is one of the most popular LCD modes since the invention of LCDs. The development of the WV film successfully improved the viewing angle characteristics for the TN mode and greatly helped enlarge the size of TN-LCDs, expanding the market.

The WV film for the TN mode has a polymerized discotic material (PDM) layer coated on a TAC film with controlled optical anisotropy. The PDM layer has a hybrid alignment structure with the tilt angle changing in the thickness direction.

The alignment structure of the PDM layer was thoroughly analyzed using polarized micro-Raman spectroscopy[6]. And then, the parameters of the WV film was further optimized to develop the latest version of the WV film, referred to as WV-EA, which gives a very wide viewing angle, as shown in Fig. 1(b), compared with an uncompensated TN-LCD (Fig. 1(a))[7].

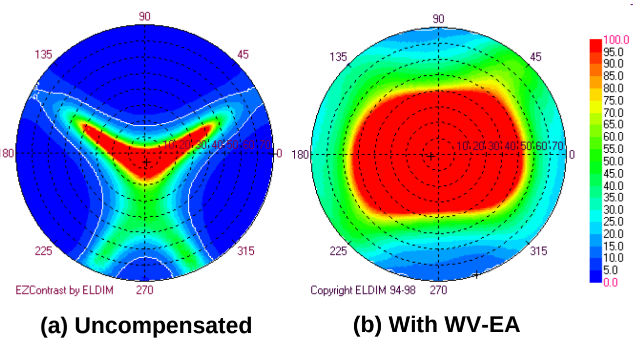


Fig. 1. Measured iso-CR contour for a TN-LCD.

3. WV films for OCB

The OCB mode gives excellent moving picture quality without motion blur because of its fast response time property. The advantage in response time is especially notable at low temperature. In addition, the self-compensating alignment structure of the π cell gives an intrinsic wide viewing angle, which can be more enhanced when combined with an optical compensation film using a discotic material.

The WV film for the OCB mode has a PDM layer with a hybrid alignment structure on a biaxial TAC film[8]. The azimuthal alignment direction of the PDM layer makes an angle of 45 degrees with respect to the slow axis of the biaxial TAC film. The slow axis of the biaxial TAC film is parallel to the transmission axis of the polarizer, so that off-axis light leakage from polarizers becomes minimal. This structure of the OCB-WV film gives excellent viewing angle characteristics for OCB-LCDs, as shown in Fig. 2, which is comparable to those for VA-LCDs and IPS-LCDs.

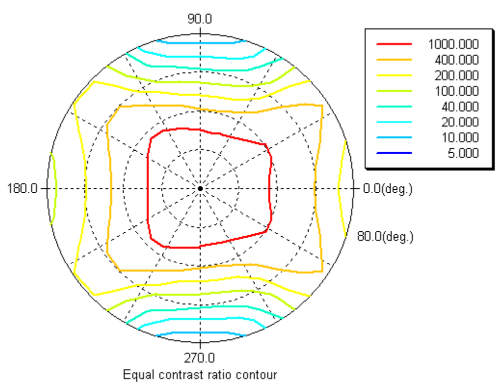


Fig. 2. Calculated iso-CR contour for an OCB-LCD compensated with the OCB-WV film.

4. Front surface film with inner scattering

For the TN mode, gray scale inversion in the lower direction is one of the remaining major problems that is difficult to solve because it is principally caused by the TN liquid crystal layer which has an inclined component of the director in the middle of the layer in the on state.

Gray levels are assigned based on the on-axis light transmittance by changing the applied voltage. Each applied voltage gives a different director configuration. Due to the optical anisotropy of the liquid crystal layer, light transmittance changes depending on the viewing angle. Fig. 4(a) shows a typical angular dependence of light transmittance for different gray levels for the case of the TN-LCD compensated with the WV film. It is found that the order of light intensities for different gray levels interchanges in the lower directions. This phenomenon is called gray scale inversion. The light transmittance for low gray levels decreases rapidly in the lower direction, and low gray levels start to cross at a shallow inclination angle.

The light intensity profiles at two low gray levels are schematically shown in Fig. 3. Level 1 gives a lower light intensity than Level 2 at on axis. However, at a certain incident angle, about 30 degrees in Fig. 4(a), the light intensities become the same. And, beyond the inversion angle, the light intensity for Level 1 becomes higher than that for Level 2 as the incident angle becomes larger.

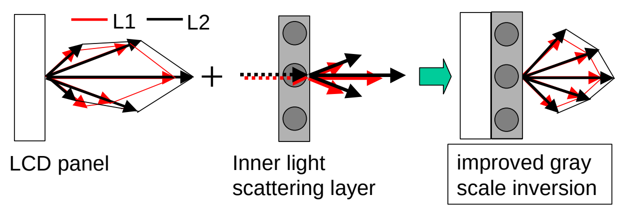


Fig. 3. Concept of improving gray scale inversion using inner light scattering.

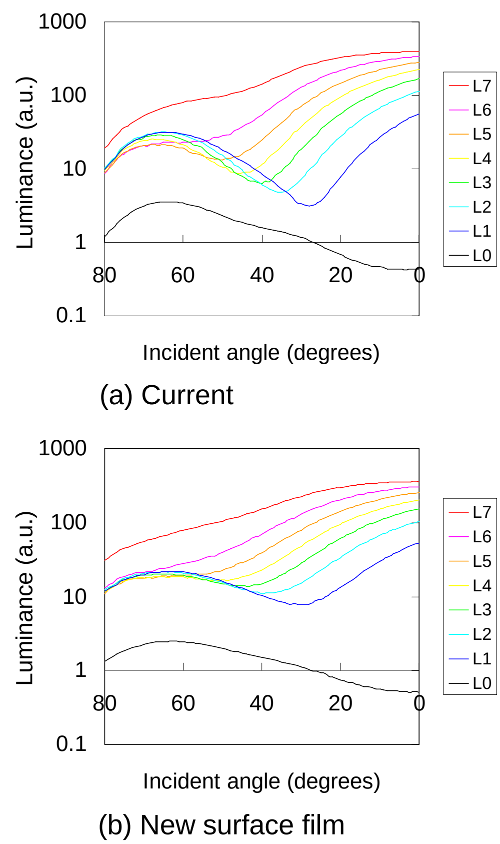


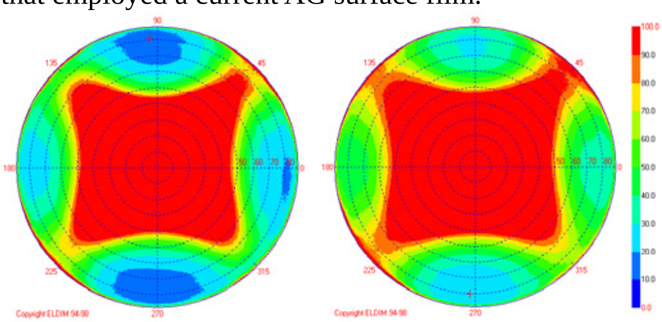
Fig. 4. Light transmission curves for gray levels in the lower direction for a TN-LCD with (a) a current surface film and (b) the new surface film with an inner light scattering layer.

Our idea for improving this gray scale inversion problem is to make use of an inner light scattering layer on the outermost surface to obtain averaged light intensity within the range of a certain solid angle. A rough surface, such as anti-glare (AG), is also known to scatter light but it is unfavorable for this purpose because it might increase black-state luminance under bright ambient light, deteriorating the image quality. To scatter light without increasing the black-state luminance, inner light scattering is preferable.

The inner light scattering layer is coated on the TAC film, which is used as a protective film for polarizer, and is placed on the outermost surface. The inner light scattering layer contains particles in a resin matrix. Light scattering results from the refractive index difference between the particles and the matrix.

However, even an inner light scattering layer leaks a small amount of light in the black state. There is a tradeoff relationship between the gray scale inversion improvement and the CR. To make these compatible, the light scattering profile should be optimized. As a result of our study, it was found that the scattered light intensity at the scattering angle around 30 degrees contributed most to the improvement of gray scale inversion. On the other hand, light scattered at large angles decreases the on-axis CR. To enlarge the gray scale inversion angle without substantially decreasing the CR, such parameters as the particle diameter, relative refractive index and the density of particles are optimized. In combination with the inner scattering layer, use of the WV film is recommended to obtain a higher CR.

To evaluate the performance, we prepared a TN-TFT-LCD panel compensated with the WV-EA film. Half of the screen was replaced with the newly developed surface film with an inner light scattering layer. We measured the optical performances and compared with those with another half of the screen that employed a current AG surface film.



(a) Current (b) New surface film

Fig. 5. Iso-CR contours for a film compensated TN-LCD with (a) a current surface film and (b) the new surface film with an inner light scattering layer.

The newly developed surface film improves the gray scale inversion, as shown in Fig. 4(b). Compared with Fig. 4(a), the incident angle of gray scale inversion is increased Fig. 5 shows that the new surface film gives a wider CR viewing angle with a sufficiently high on-axis CR.

5. Impact

The development of WV-EA has expanded TN-LCD applications towards large-screen, wide-format PC monitors. The newly developed front surface film with an inner light scattering layer improves the problem of gray scale inversion of TN-LCDs. This will allow more applications, such as TN-LCD-TVs, which are cost competitive compared with VA and IPS. As a personal LCD-TV, TN with the WV film and the front surface film could be the choice.

OCB-LCDs excels in displaying moving pictures without motion blur and in low temperature operation. When compensated with the OCB-WV film, the OCB-LCD has excellent viewing angle characteristics comparable to those of VA and IPS. The front surface film promises more improved viewing angle performance to OCB.

6. Summary

The latest version of WV films, referred to as WV-EA, successfully improved viewing angle characteristics for the TN mode. The remaining problem of gray scale inversion in the lower direction was improved using a newly developed front surface film. This front surface film also improved the CR viewing angle.

The OCB-WV film gives wide-viewing-angle characteristics for the OCB mode, making it possible to realize fast-response-time LCDs that is applicable to outdoor use as well as home use.

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8. References

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