11.2: Improved Contrast Ratio in IPS-Pro LCD TV by Using Quantitative Analysis of Depolarized Light Leakage from Component Materials

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Abstract

The degree of imperfection was defined as the independent intrinsic index of the degree of degraded contrast ratio for each component. The scattering index of liquid crystal layer gives an effective guideline for reducing light leakage intensity. By using this guideline, we have made an IPS-Pro LCD with a uniform contrast ratio of 1500:1 within ±16.5° of polar angle.

1. Introduction

A high contrast ratio is the one of most important characteristics in liquid crystal television applications. Moreover, a wide viewing angle contrast ratio is also important for HD-TV applications in particular. Since the aspect ratio of HD-TVs is 16:9, we have to watch a screen with a viewing angle of ±16.5°, as shown in Fig.1. Therefore, a uniform contrast ratio is required within ±16.5° of the polar angle to the screen. We believe that in-plane switching liquid crystal displays (IPS-LCDs) are the most promising candidate for satisfying the specification because of their intrinsic wide viewing angle characteristic. However, to satisfy the need for a high contrast ratio, the native contrast ratio at the front view (0° of polar angle) of conventional IPS-LCDs should be improved.

To find a way to increase the contrast ratio, we investigated cell structures of IPS-Pro ("Pro comes from the Latin "provectus", meaning an innovation), which can increase the maximum transmittance in the white state.[1][2] Furthermore, the minimum transmittance in the black state should be decreased to achieve high contrast ratio. The transmittance in the black state is increased by light leakage due to the scattered light caused by some scattering media in liquid crystal panels. These results come from the light of backlight units, which is diffused light with a specific radiation distribution. The diffused light scatters because of the scattering media in the panels. Since the scattering media are placed between crossed polarizers, the scattered light depolarizes the incident polarized light. The depolarized light causes light leakage in the black state.

We quantitatively analyzed the factors that degrade the minimum transmittance in the black state by using the degree of imperfection derived from the degree of polarization (DOP).[3] As a result, we found that color filter substrates and the liquid crystal layers significantly degrade the black state quality. By directly measuring scattering light, we obtained a guideline for improving these components. We achieved the higher contrast ratio of IPS-Pro by using advanced materials.

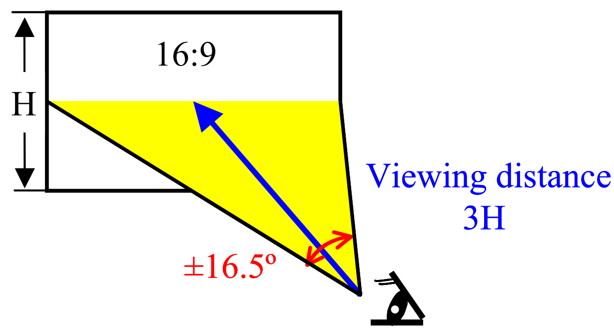

Figure 1. Viewing angle characteristic of HD-TV.

2. Degree of Imperfection in Polarization

A schematic of the system we used for measuring the light leakage is shown in Fig. 2. The minimum transmittance, $T_{\min}$, was measured by setting a sample such as a color filter substrate, an electrode substrate, and a homogenous alignment liquid crystal unit cell, between crossed polarizers, and the maximum transmittance $T_{\max}$ was measured by setting a sample between parallel polarizers.

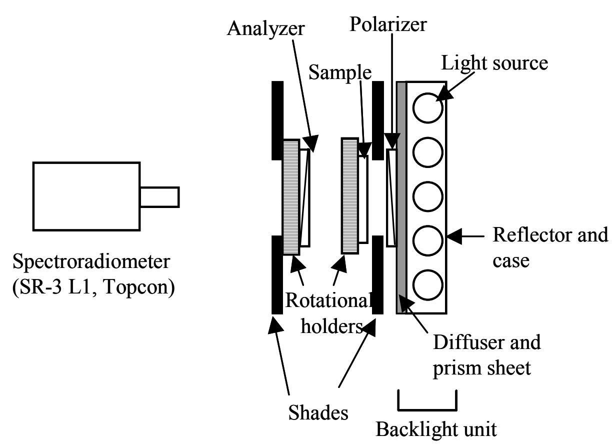

Figure 2. Measured system with backlight unit.

To determine the intrinsic intensity of the light leakage from scattering media, such as color filters and liquid crystal layers, the

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degree of imperfection d was derived from the DOP of the polarizers P as,[3]

$$CR_{psp} = \frac{1+P^2(1-d)}{1-P^2(1-d)} = \frac{T_{\max}}{T_{\min}}, \quad (1)$$

$$d = 1 - \frac{T_{\max} - T_{\min}}{P^2(T_{\max} + T_{\min})}. \quad (2)$$

We obtained the degree of imperfection of color filters d_{cf}, electrode substrates d_{elec}, liquid crystal layers d_{lc}, and polarizers d_p (the d of polarizes was calculated by $d_p = 1 - P^2$). Using Mueller theory, the effective degree of imperfection in liquid crystal displays d_{eff} is determined by the sum of each d of liquid crystal display components as,

$$d_{eff} = d_{cf} + d_{elec} + d_{lc} + d_p. \quad (3)$$

Using these values, we quantitatively analyzed the factor of contrast ration in liquid crystal panels, as shown in Fig. 3. The color filters and liquid crystal layers occupied 90% of the total degree of imperfection. It is necessary to reduce the transmittance in the black state through investigation of materials and process technologies on color filters and liquid crystal layers.

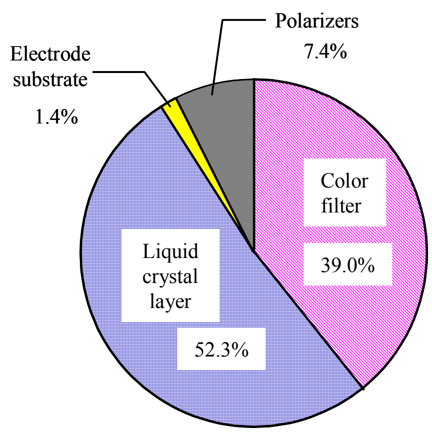

Figure3. Ratio of degree of imperfection in IPS-Pro LCD.

3. Color Filters

The light leakage of color filters is caused by the scattered light due to pigment particle cohesion in color filter layers.[4] Since the scattered light is caused by Rayleigh light scattering phenomenon, the intensity depends on the size of pigment particle cohesion. The pigment particle cohesion in the actual color filter layers can be observed by using a scanning transmission electron microscope (STEM).[4] Figure 4 shows the photo images of two kinds of actual green filter layers. The pigment particle cohesion is represented by the white and light gray regions in the STEM (HD-2000) images because the uneven distribution of bromine, copper, and nickel atoms, which are composed atoms of green pigments, was observed in those areas by analyzing atom-mapping images. The areas of pigment particle cohesion of CF (B) were obviously smaller than those of CF (A).

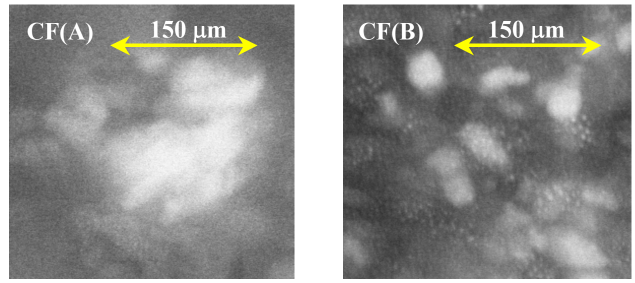

Figure 4. Cohesion of pigment particles in green filter layers.

The spectral property of the light leakage caused by color filters was observed using an optical system, as shown in Fig. 2. The light leakage was defined as the transmittance of the color filter placed between the crossed polarizers. The transmittance was obtained by dividing the measured spectrum by the spectral radiance of the backlight unit. Figure 5 shows the light leakage spectra of CF (A) and (B). The maximum transmittance wavelengths shifted to a shorter wavelength. These results show that the light leakage is governed by the scattered light because the Rayleigh light scattering is proportional to $1/\lambda^4$. Moreover, these results demonstrated that the light leakage intensity was reduced by using a filter with small pigment particle cohesion, i.e., the degree of imperfection of CF (B) was able to reduce 60% than that of CF (A).

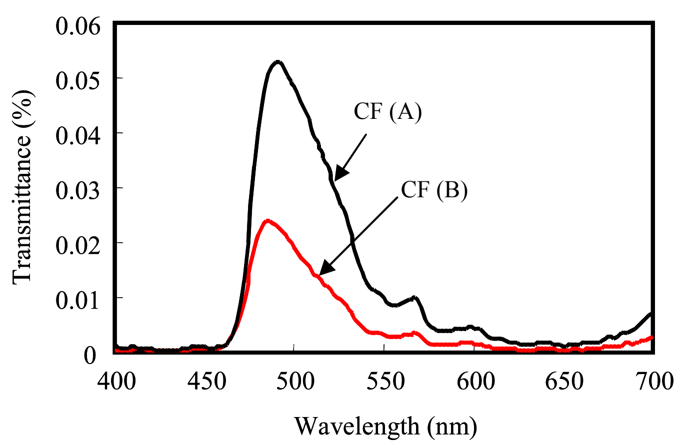

Figure 5. Light leakage spectra of color filters placed between crossed polarizers.

4. Liquid Crystals

To examine the degree of light leakage intensity from the liquid crystal layer, we observed the transmitted light of the liquid crystal panel at higher temperature than the nematic-isotropic transition temperature of the liquid crystals, i.e., the liquid crystal liquefied. As a result, the transmittance was dramatically reduced. Although the liquid crystal layers are well-known scattering media, the effect of light scattering on light leakage in the black state in liquid crystal displays has not been discussed enough. We show that the correlation between the light scattering intensity of the liquid crystal layer and the light leakage intensity, which is the transmitted light of the liquid crystal layer placed between crossed polarizers.

4.1 Measurement of Scattered Light

Homogenously aligned liquid crystal cells were fabricated with alkaline free glass substrates with a thickness of 0.7 mm. A polyimide alignment layer was formed on each glass substrate. The thickness of the liquid crystal layer was determined by silica or polymer beads dispersed in the sealing paste. There is no spacer in the liquid crystal layers.

Figure 6 shows a schematic system for measuring light scattering in a liquid crystal layer. The outgoing scattering light in the normal direction of the unit cell was measured with a semiconductor laser beam with an incidence angle of θ. The laser beam, with a wavelength of 651.8 nm and an intensity of 2.7 mW was transmitted into the center of the liquid crystal cell. The intensity of the scattered light was measured using a luminance meter at different incidence angles. The incident light of the laser was polarized parallel to the alignment direction of liquid crystal layers.

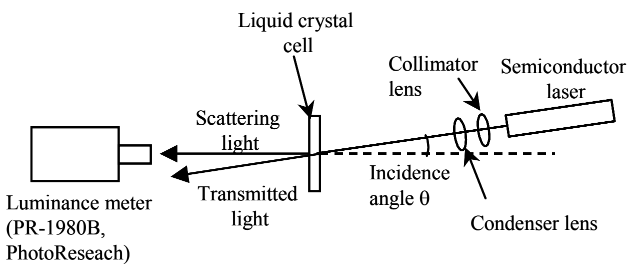

Figure 6. Measured system for scattered light with semiconductor laser.

The scattered light intensity depends on incidence angle. The total scattered light intensity was defined by integrating the scattered light intensity with incidence angles to 5 to 25º and was proportional to the thickness of liquid crystal layer.

4.2 Light Leakage and Total Scattered Light Intensity

The light leakage intensity was measured by an optical system, as schematically shown in Fig. 2. The light leakage was defined as the transmittance of the liquid crystal layer placed between crossed polarizers. The transmittance was obtained by dividing the measured value by the intensity of the backlight.

The correlation between the light leakage intensity and the total scattered light intensity is shown in Fig. 7. We found that the light leakage intensity strongly depends on the total scattered light intensity. Reducing scattered light intensity is important in reducing light leakage intensity.

This correlation gave us valuable information about the light leakage phenomenon. For example, we do not have to consider complicated geometries between the polarized plane of incident laser beam and the director of liquid crystal layers. Generally, the light scattering was analyzed by considering precise geometries. [3] The complexity has interfered with our standing of the effect of light scattering on light leakage. However, we discovered a simple relationship between the measured scattered light and light leakage intensities. This is because the diffused light comes from backlight, i.e., the light is incident on a liquid crystal layer from all directions. The incidence light condition is crucially different from past experimental condition.

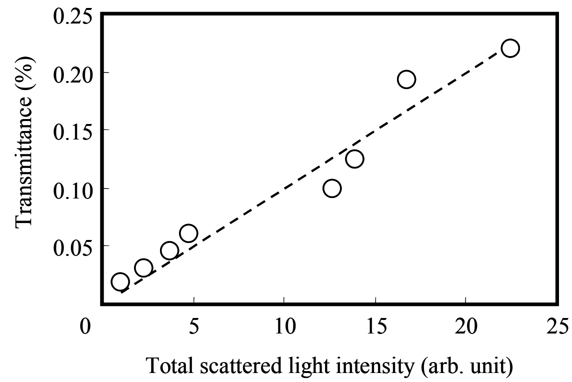

Figure 7. Correlation of total scattered light intensity with light leakage intensity.

4.3 Derivation of Scattering Index and Correlation of Light Leakage Intensity with Scattering Index

We introduced a one constant approximation of a differential scattering cross-section per unit solid angle Ω as follows,[5]

$$\frac{d\sigma}{d\Omega} \approx \left(\frac{\pi\varepsilon_\alpha}{\lambda^2}\right)^2 \frac{k_B T}{kq^2}, \tag{4}$$

where ε_α is the dielectric anisotropy at optical frequencies, k_B is the Boltzmann constant, q is the wave vector, and k is the supposed elastic constant ($k_{11} \approx k_{22} \approx k_{33}$). Since equation (4) was given to estimate the degree of magnitude of the scattering cross-section, the formation was extremely simple. The dielectric anisotropy at optical frequencies is described by refractive indexes,

$$\varepsilon_\alpha = n_e^2 - n_o^2 = (n_e - n_o)(n_e + n_o) = \Delta n(n_e + n_o), \tag{5}$$

where n_e is the extraordinary refractive index, n_o is the ordinary refractive index, and Δn is their difference. We constructed a specific variable (S_{lc}) as the scattering index of liquid crystals and S_{cell} as the scattering index of liquid crystal cells,

$$S_{lc} = \frac{\{\Delta n(n_e + n_o)\}^2}{K}, \tag{6}$$

$$S_{cell} = \frac{\{\Delta n(n_e + n_o)\}^2}{K} \cdot d, \tag{7}$$

where $K = (k_{11} + k_{22} + k_{33})/3$ is the mean elastic constant and d is the thickness of the liquid crystal layer.

Figure 8 shows the correlation between the light leakage intensity and S_{cell}. The transmittance was clearly proportional to S_{cell}, as shown by the broken line representing the linear approximation with 0.0008% of the y-intercept, which corresponded to the transmittance of the crossed polarizers.

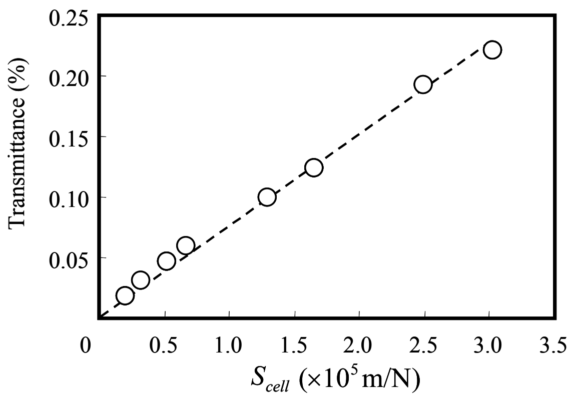

Figure 8. Correlation of light leakage intensity with scattering index of liquid crystal cells.

The result shows that the reduction of S_{lc} can reduce the light leakage intensity, i.e., liquid crystals with low Δn or with high K are effective in the light leakage reduction. If liquid crystals with low Δn are used, the thicker layer of liquid crystal will be required in order to maintain the high transmittance in the white state. Therefore, in the actual IPS-Pro LCDs, increasing the mean elastic constant of liquid crystals seems like the better approach. We chose the new liquid crystals having high elastic constant to reduce the light leakage intensity. When this study began, the degree of imperfection of the conventional liquid crystals was 0.00186. By using higher elastic constant, the degree of imperfection of new liquid crystals was 0.00106.

5. Conclusion

Figure 9 shows the degree of imperfection of each component and the contrast ratio in the actual 32-inch IPS-Pro LCDs with their components. LCD (A) was the first prototype; the contrast ratio was 560:1. LCD (B) was the first mass-produced LCDs in 2004; the contrast ratio was 850:1. Using improved color filters, liquid crystal and polarizers, which were obtained through quantitative analysis, we achieved the contrast ratio 1500:1 in a prototype LCD (C). The contrast ratio at front view was 1500:1, and the value was maintained in ±16.5°, as shown in Fig. 10.

6. Acknowledgements

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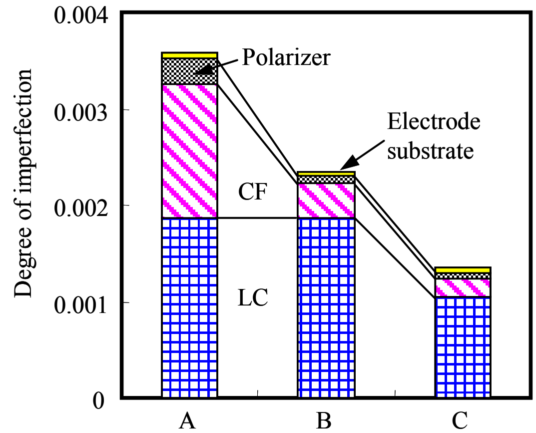

Figure 9. Degree of imperfection and contrast ratio of LCDs.

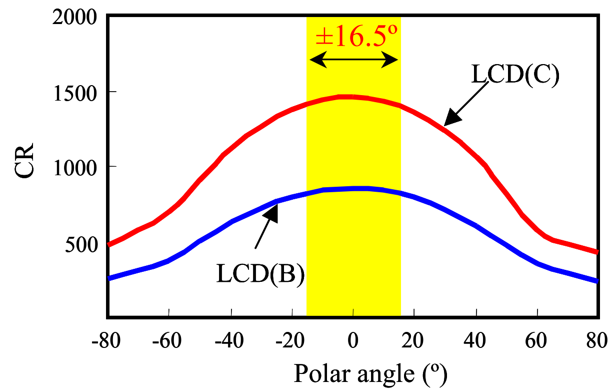

Figure 10. Viewing angle characteristics in horizontal direction of contrast ratio. .

7. References

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