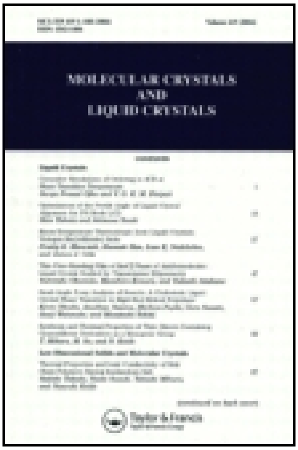

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Optimization of the Pretilt Angle of Liquid Crystal Alignment for Ips Mode Lcd

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OPTIMIZATION OF THE PRETILT ANGLE OF LIQUID CRYSTAL ALIGNMENT FOR IPS MODE LCD

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The in-plane switching (IPS) mode liquid crystal display (LCD) panels with different pretilt angles and alignment directions are prepared, and their electro-optical properties and viewing angle characteristics are examined. The examination shows that parallel alignment with a pretilt angle of about 3 brings about a panel with very wide viewing angle characteristics and little color shift in relation to that viewing angle. The pretilt angle of 3* can be achieved by conventional alignment film for Twisted Nematic mode LCD, and higher productivity of IPS-mode LCD panels in consequently expected.*

Keywords: in-plane switching mode(IPS); liquid crystal display (LCD); viewing angle

INTRODUCTION

The application field of active matrix liquid crystal displays (AMLCDs) is becoming wider and wider. At the same time, the demand for larger display sizes of AMLCD has become greater. Under such circumstances, the viewing angle characteristics of AMLCD are becoming more important than ever before, and wider viewing angle technology has therefore become extremely weighty. In-plane switching (IPS) mode LCD is one of the most valuable technologies for a wider viewing angle.

The IPS mode is liquid crystal display mode in which the liquid crystal molecules are switched in the plane parallel to the glass substrate by an electric field applied between interdigital electrodes arranged on that glass substrate. Because the liquid crystal molecules are switched in the direction parallel to the glass substrate, the optical contribution of the liquid crystal molecules to the transmitted light through the panel scarcely varies in every direction, resulting in an extremely wide viewing anlge [1,2].

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In the IPS mode, the lower the tilt angle of the aligned liquid crystal molecules, the more plane the liquid crystal molecules switch in the plane parallel to the substrate, resulting in wider viewing angle characteristics [3]. Therefore, in general alignment layers that generate pretilt angles of about 1* or less have been employed. Furthermore, from the viewpoint of smoother and more stable switching in a parallel direction, antiparallel liquid crystal alignment (the pretilt angles on the top and bottom substrates are in the opposite direction, liquid crystal molecules being aligned parallel to each other) has been regarded 25 suitable for the panels of this mode.

Despite the fact that these things are known about the IPS mode, detailed studies on the relationship between the cell conditions, such as the pretilt angle and alignment direction, and viewing angle characteristics have scarcely been done.

This article reports on the optical and electro-optical properties of prototype IPS-mode panels using several alignment films that generate different pretilt angles.

EXPERIMENTAL

Glass substrates and substrates with interdigital electrodes were coated with alignment films, and rubbing was performed on both of those substrates. Three kinds of alignment films, which should generate pretilt angles of about 1, 3, and 5; were used in this experiment. The rubbing directions of each substrate are shown in Figure 1. The substrates were rubbed in a direction 80° to the spacing direction of each interdigital

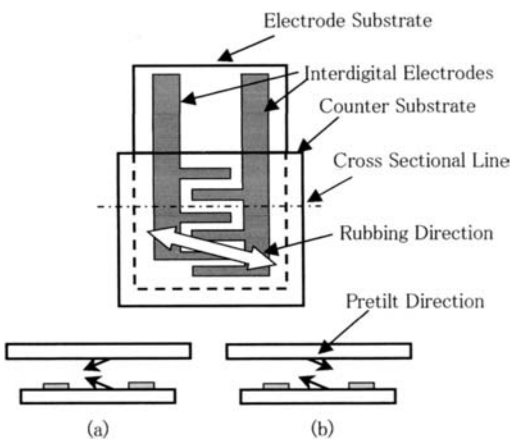

FIGURE 1 LCD cell configuration: (a) Parallel Alignment, (b) antiparallel alignment.

electrode. In assembling the prototype panels, two kinds of alignment types, namely parallel alignment (pretilt angle appearing in the same direction, as can be seen in Figure 1(a)) and antiparallel alignment (pretilt angle appearing in the opposite direction, as can be seen in Figure 1(b)), were employed.

The panel gap of each prototype panel was about 3.5 μm. Liquid crystal material with a dielectric anisotropy of about +8 and a refractive index anisotropy of about 0.08 was filled into each panel.

The pretilt angle of each panel was determined by the crystal rotation method.

Polarizer film was put on each glass substrate of prototype panels that were used in the measurements described below. The polarizing directions of the polarizer films were set parallel to the alignment direction of liquid crystal molecules on one of the substrates and set perpendicular to the alignment direction of liquid crystal molecules on the other substrate. In these conditions, the prototype panels were in a dark state without applied voltage, the so-called normally dark condition.

Driving Voltage

A square wave (0–10 V, 30 Hz) was applied to the panels, and the dependence of transmission on the applied voltage was obtained. The driving voltage of each panel was defined as that which gave maximum transmittance for each panel.

Response Time

The square wave (30 Hz) was applied to the panels every 1 second, and the transmission change was recorded for each panel. The rise time (tr) and the fall time (td) were defined as the times during which the relative transmittance changed from 10% to 90% and from 90% to 10%, respectively, and the response time was defined as tr + td. The square voltage applied here was the driving voltage for each panel.

Transmittance

We measured the transmittance for each panel when the driving voltage was applied. The transmittance values were calculated using the measurement values, including the effect of the aperture ratio between interdigital electrodes.

Contrast Ratio

The contrast ratio was calculated using the luminance values of transmitted light for the OFF state (no electric field applied) and ON state (driving voltage applied). The dependence of the contrast ratio on the viewing angle was measured by a spatial photometer, Ezcontrast 160 (ELDIM).

The definition of the viewing angle coordinate that was used for evaluation of viewing angle characteristics is shown in Figure 2. The viewing angle characteristics were measured in the range of -80° to $+80^\circ$ (in the polar direction) and from 0° to 360° (in the azimuthal direction).

It is difficult to compare the viewing angle characteristics of the prototype panels quantitatively. In this article we define the viewing angle characteristics by the method described below. Figure 3 shows one example for the explanation of the viewing angle defining method. The viewing angle range in which the contrast ratio is over 10 is obtained in all azimuthal angle directions, this viewing angle range being shown by the hatched area in Figure 3. In this case, at the azimuthal angle of about 145° the viewing angle in the polar direction is less than 40°. By using this method, the narrowest viewing angles for the prototype panels with various conditions are obtained and compared with each other.

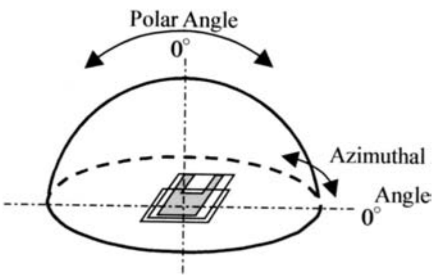

FIGURE 2 Definition of viewing angle.

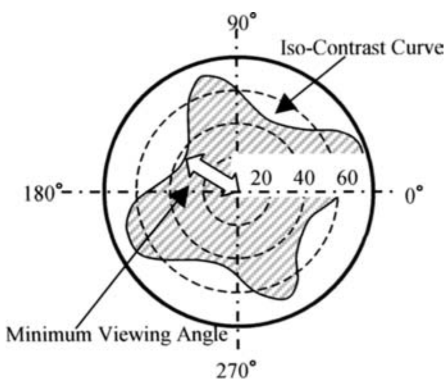

FIGURE 3 Definition of minimum viewing angle.

Color Coordinate

The color coordinates (x, y) were also measured with the spatial photometer, Ezcontrast 160, for each panel in the ON state with the driving voltage applied.

By using this spatial photometer, the color coordinates were measured in the range of from -80° to $+80^\circ$ in the polar angle direction and in the range of from 0° to 360° in the azimuthal angle direction.

In general, the IPS mode panel has a problem in that tinted bluish or yellowish colors appear when it is observed from oblique directions [4]. To compare these color shifts quantitatively for each prototype panel, we employed the method described below.

The dependence of color coordinates on viewing angles was obtained by measuring the color coordinates at angles from 0° to 360° in the azimuthal angle direction at a certain polar angle. In this experiment, we chose 60° in the polar direction to compare color shifts for each panel with different conditions.

All the color coordinate data that were measured by the above method were recorded on a chromaticity diagram. The distribution of recorded data on the chromaticity diagram was divided into x axis and y axis factors. The distribution width in the x axis (dx) and y axis (dy) directions, was obtained, and these widths were used to compare the degree of color shift for each prototype panel with different conditions.

In the chromaticity diagram, an interval of two or more points doesn't necessarily indicate a difference of colors, quantitatively. However, when we compare two points with (x, y) color coordinates that are located in a very small area of the chromaticity diagram, the width in the x and y directions can be regarded as the color difference, approximately.

In this experiment, the recorded area of color coordinate data on the chromaticity diagram was almost the same for each panel with various conditions, so the extent of color shift can be estimated by comparing these distribution widths, dx and dy, of each panel.

RESULTS AND DISCUSSIONS

Driving Voltage, Response Time, and Transmittance

The tilt angles of antiparallel alignment panels with three kinds of alignment films were 1.6°, 3.4°, and 5.0°, depending on the kind of film used. Further, the average tilt angles of all parallel alignment panels were approximately 0°, regardless of the kind of alignment film used. The pretilt angle appears in the same direction as that shown in Figure 1(a) in the case of parallel alignment, and the effect of the pretilt angle on the upper substrate cancels the pretilt angle on the lower substrate. Therefore, all parallel alignment panels generate 0° tilt angles outwardly or in appearance.

The pretilt angle with three kinds of alignment films were 1.6°, 3.4°, and 5.0°, regardless of the alignment direction. In this article we named the panels that generated the three kinds of pretilt angles (1.6°, 3.4°, and 5.0°) low pretilt (LP), medium pretilt (MP), and high pretilt (HP), respectively.

The dependencies of the driving voltage, response time, and transmittance on the pretilt angle are shown in Figures 4, 5, and 6, respectively. All values in Figures 4, 5, and 6 are those at the point of a 3.5 μm panel gap based on a measurement of the panel gap dependence on the driving voltage, response time, and transmittance. The reason for choosing this panel gap is that, in our previous work, it makes the panel performance better from the viewpoints of coloring and transmittance compared with other panel gaps [5].

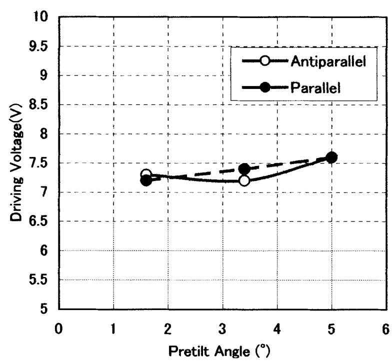

FIGURE 4 Driving voltage versus pretilt angle.

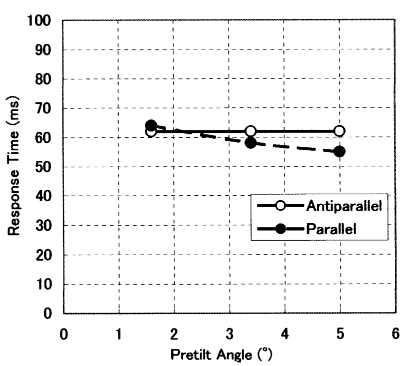

FIGURE 5 Response time versus pretilt angle.

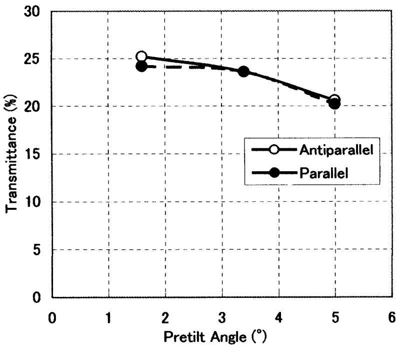

FIGURE 6 Transmittance versus pretilt angle.

A comparison of all values of the antiparallel alignment panels and those of the parallel alignment panels in Figures 4, 5, and 6 shows that the dependence of each property on the pretilt angle is nearly the same. These three kinds of electro-optical properties scarcely depend on the alignment direction.

According to Figures 1(a) and 1(b), the liquid crystal molecule in the parallel alignment panel in the OFF state is supposed to be aligned in the splay configuration, and the liquid crystal molecule in the antiparallel alignment panel in the OFF state is supposed to be aligned in the so-called book shelf configuration. A comparison of these two configurations makes one expect that the molecular motion responding to the applied electric field and the optical properties must be different due to the different elastic strain and different actual anisotropy of the refractive indexes. However, the pretilt angles were comparatively small in this experiment, and these differences must also be too small to show any significant effect.

Considering the influence of the pretilt angle on these three kinds of electro-optical properties, the driving voltage and response time scarcely change by varying the pretilt angles. However, the transmittance decreased remarkably with the increase of the pretilt angle. When the pretile angle was 1.6°, the transmittance was approximately 25%, and when the pretilt angle was 5.0°, the transmittance was about 20%.

The IPS mode inherently needs to employ a pair of interdigital electrodes, which is also a handicap for realizing a higher aperture ratio. Therefore, the decrease in transmittance is a problem that should be noted. In the IPS mode, transmittance in the ON state depends on the magnitude of the birefringence change generated by the direction of the liquid crystal molecule responding to the applied voltage. Therefore, as the pretilt angle becomes larger, the value of the birefringence change that is generated by the applied voltage deviates from the optimum value [6].

Viewing Angle Characteristics

The viewing angle characteristics (iso-contrast contours) of the prototype panels evaluated in this experiment are shown in Figure 7.

In this figure, the iso-contrast contours of LP, MP, and HP are shown from top to bottom, the left column corresponds to antiparallel alignment panels, and the right column corresponds to parallel alignment panels.

Figure 7 shows that the iso-contrast curves of the antiparallel alignment panels shift toward the right with the increase of the pretilt angle. In other words, when observation is made from the left side, the contrast ratio decreases with the increase of the pretilt angle. On the other hand, the

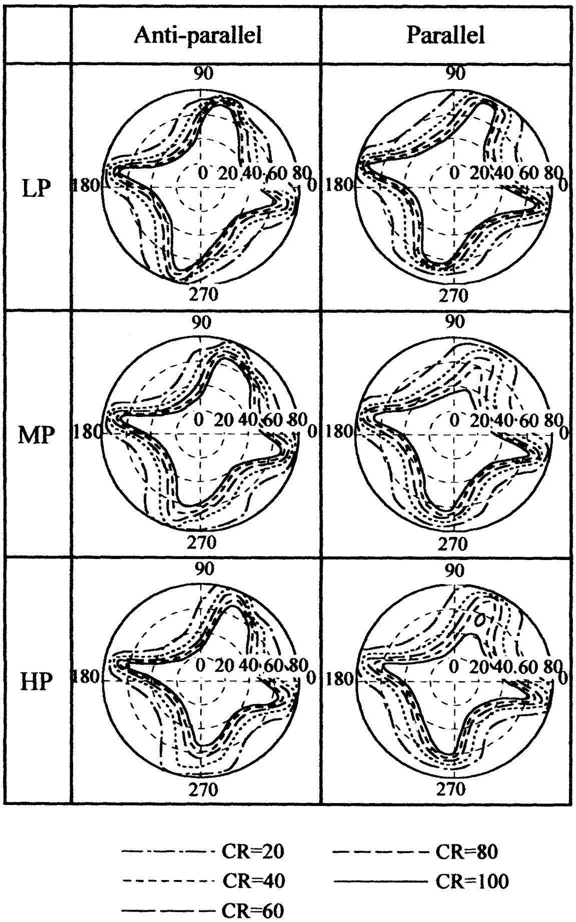

FIGURE 7 Iso-contrast contours of LP, MP and HP panels.

iso-contrast contours of parallel alignment panels scarcely change their shape, which maintain a balance even with a variation of the pretilt angle, and the high-contrast ratio region becomes smaller in every direction almost equally with the increase of the pretilt angle.

In the ON state, all viewing angle characteristics of the luminance (iso-luminance contours) are almost uniform in every viewing angle. For example, the iso-luminance contours of both antiparallel- and parallel-alignment HP panels are shown in Figures 8(a) and 8(b), respectively. Therefore the change of iso-contrast contours that depends on the pretilt angle or the alignment direction should be caused by the viewing angle dependence of the luminescence in the OFF state.

The iso-luminance contours of HP panels in the OFF state are shown in Figure 9. Figures 9(a) and 9(b) indicate the results that were obtained from the antiparallel and parallel alignment panels, respectively. Figure 10 shows the angular dependences of the luminance in the OFF state in the range from 145° to 325° in the azimuthal direction. Figures 10(a) and 10(b) indicate the results that were obtained from the antiparallel and parallel panels, respectively. Figures 9(a) and 10(a) show that, in

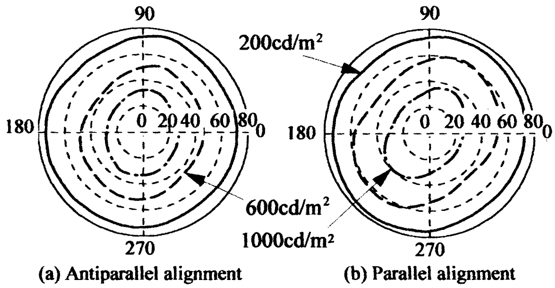

FIGURE 8 ISO-luminance contours of ON state.

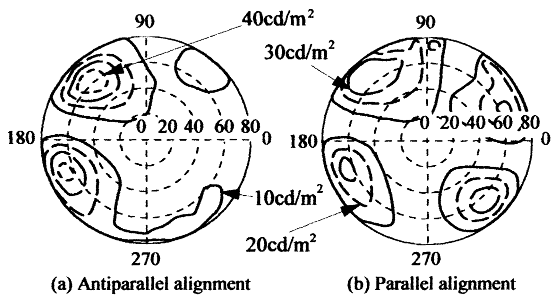

FIGURE 9 Iso-luminance contours of OFF state.

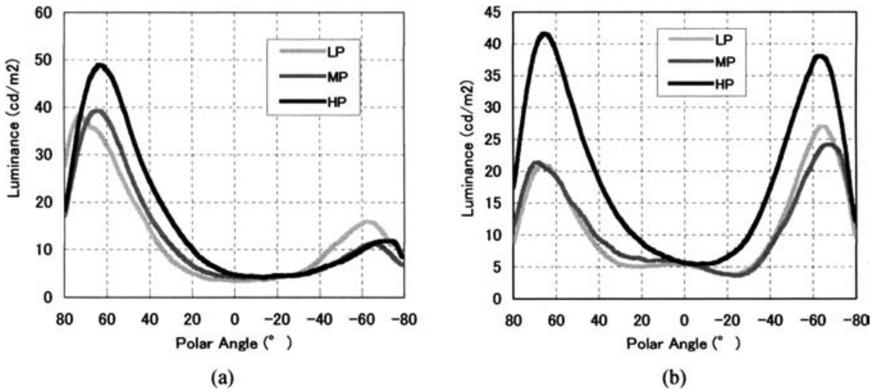

FIGURE 10 Luminance (OFF state) versus polar angle (cross section of 145°–325° in azimuthal direction) (a) Antiparallel alignment, (b) Parallel alignment.

the antiparallel alignment panels, the viewing characteristics remarkably differ between viewing from the left and right side. When liquid crystal molecules are observed from their tilted raised direction (from the left side), optical contribution largely changes by the variation of the viewing angle and the transmittance becomes larger. On the other hand, when liquid crystal molecules are observed from the opposite direction, the transmittance does not become larger. As this tendency should become more visible with the increase of the pretilt angle, the contrast ratio becomes smaller when a panel with a high pretilt angle is observed from the left side.

Figures 9(b) and 10(b) show that the luminance in the OFF state of the parallel alignment panels becomes larger with the increase of the pretilt angle, although these panels provide almost uniform angular dependences of luminance in all viewing directions. As the pretilt angles in the parallel alignment panels are canceled between the pretilt angles near the upper and the lower substrates, the asymmetrical iso-luminance contours, which are obtained for antiparallel alignment panels, should not be obtained. Therefore, in parallel alignment panels the iso-contrast curves do not shift to the right with the increase of the pretilt angle.

We tried to compare these shifts of iso-contrast curves quantitatively. For all iso-contrast contours, the viewing angle region that is in the range of a contrast ratio over 10 was obtained by the method explained for Figure 3.

From these iso-contrast curves, the azimuthal angle that exhibits the narrowest viewing angle is obtained, and its value in the polar angle direction is used for comparison of each panel (refer to Figure 3 and the section "Contrast Ratio" above).

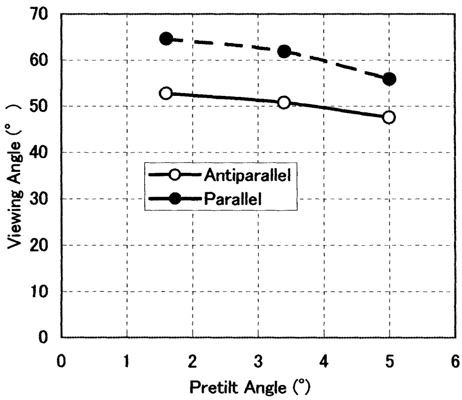

FIGURE 11 Viewing angle versus pretilt angle.

The dependence of the viewing angles that was obtained by the above-mentioned method for the pretilt angle is shown in Figure 11.

A comparison of the viewing angle characteristics that are influenced by the liquid crystal alignment directions tells us that the viewing angle of the antiparallel alignment panels is smaller than that of the parallel alignment panels by about 10°. In the antiparallel alignment panels, the iso-contrast contours show asymmetric shapes, and an oblique observation from the left side of the panel provides a comparatively smaller viewing angle. This effect on the viewing angle determined for the antiparallel alignment panels (Figure 11) results in a smaller value.

The above-mentioned results tell us that, for the IPS mode panel with parallel alignment employed, a viewing angle of over 60° can be achieved, even when the pretilt angle is not about 1°.

Color Shift

In IPS-mode panels, the display images are tinted with bluish or yellowish colors when observed from oblique directions, and this phenomenon should be mainly related to the alignment of the liquid crystal molecules [7].

Therefore, we obtained the relationship between the alignment direction of liquid crystal molecules (parallel or antiparallel alignment), and the color shift that is observed at 60° (polar angle direction), changing in the azimuthal angle direction from 0° to 360° (refer to the section "Color Coordinate above". Figure 12 shows examples of these plots exhibiting the color shift (LP panel with parallel alignment). Figure 12 shows that, when observed from 60° (polar angle direction), the plots on the chromaticity diagram changed from the yellow to the blue region via the white region.

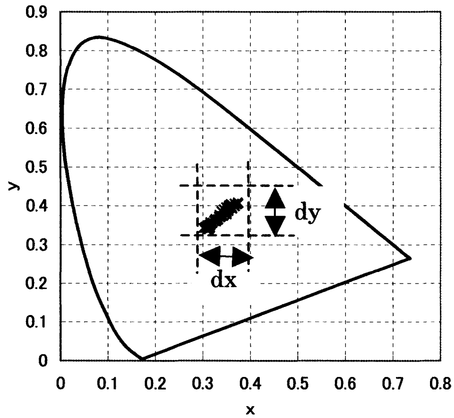

FIGURE 12 Color distribution by changing azimuthal angle (LP panel of parallel alignment) Definitions of dx and dy.

To compare the color shift of each prototype panel quantitatively, the expansion of the color coordinate (x, y) plots were divided into two factors (x and y axis directions) and the distribution of width in each axis direction (dx, dy) was obtained for each panel.

Figure 13 shows the dx and dy dependence on the pretilt angle.

This figure shows that, for the antiparallel alignment panels, the color shift (dx, dy) does not depend on the pretilt angle, the color shift showing nearly the same values when the pretilt angle is changed. Oppositely, in the parallel alignment panels, the color shift slightly decreased with the increase of the pretilt angle.

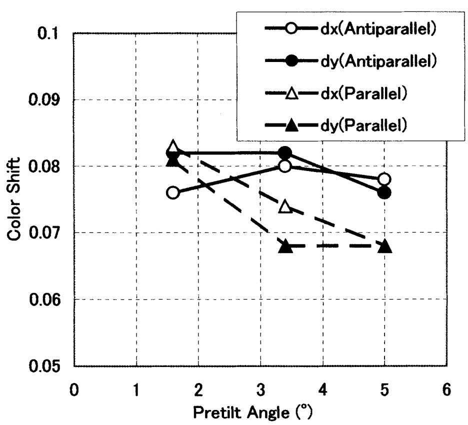

FIGURE 13 Color shift versus pretilt angle.

These color shifts were the results in the ON (voltage applied) state for each panel. The alignment of liquid crystal molecules in the ON state, under a voltage-applied condition, can be assumed to be changed only in the plane parallel to the substrate, and the alignment of liquid crystal molecules should be kept in the initial state (voltage not applied) in the direction perpendicular to the substrate. In other words, when voltage is applied through interdigital electrodes, the liquid crystal alignment in the direction perpendicular to the substrate should maintain splay alignment in the parallel alignment panel and bookshelf alignment (uniaxial alignment) in the antiparallel alignment panel. Under these assumptions, the color shift tendency can be explained as follows below.

In the antiparallel alignment panel, the liquid crystal molecules are aligned in uniaxial direction. Therefore, by varying the observation direction, the birefringence values are changed remarkably and the angular dependence of color shift becomes more visible. Furthermore, the liquid crystal alignment should be the bookshelf alignment regardless of the pertilt angle. Therefore, the color shift scarcely depends on the pretilt angle.

In the parallel alignment panel, on the other hand, when the pretilt angle is very small, the liquid crystal alignment should also be regarded as the bookshelf alignment approximately, somewhat similar to the alignment of the antiparallel alignment panel. Therefore, the color shift becomes comparatively larger by varying observation directions.

However, as the pretilt angle becomes larger, the liquid crystal alignment can change from the bookshelf to the splay alignment. In the splay alignment, the color shift should become smaller, because the angular dependence of the birefringence of the liquid crystal layer should be canceled in the perpendicular direction.

These experimental results stated so far indicate that the MP or HP prototype panels in which liquid crystal alignments are parallel, show little color shift, and these kinds of panels are supposed to provide good display images.

Summary of Experimental Results

The experimental results in this article can be summarized under the following 4 points:

1. The driving voltage and the response time scarcely depend on the pretilt angle.
2. The transmittance of the HP panel was lower than that of the LP and MP panels.
3. Parallel alignment panels provide a viewing angle large than that of panels with antiparallel alignment, and this tendency does not depend

on the pretilt angle. MP and LP panel with parallel alignment can achieve a wide viewing angle of over 60°.
4. Parallel alignment panels with MP or HP alignment film shows comparatively little color shift.

The 4 points above lead us to the fact that the use of parallel alignment and alignment film that generates medium-level pretilt angles can achieve good display images with very wide viewing angles.

CONCLUSION

To optimize the pretilt angle and the alignment direction (parallel or anitparallel alignment) for alignment films of IPS-mode panels, prototype panels that have different alignment conditions are fabricated, and measurements of various optical and electro-optical properties were performed on these panels.

Experimental results show that the medium pretilt angle (about 3.4°) and parallel alignment are suitable for IPS-mode panels to obtain fine display images, such as those having higher transmittance and wider viewing angle characteristics with comparatively little color shift.

The properties of the alignment film optimized in this report are well matched to the alignment films for ordinary Twisted Nematic-mode panels. Accordingly, the usage of the same alignment film and the same manufacturing process for both IPS-mode and TN-mode panels can make actual panel manufacturing possible with only a suitable choice of alignment direction in the rubbing process. It has been revealed that IPS-mode panel productivity can be maintained at a high level with the employment of the ordinary alignment film for the TN-mode panel.

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