40.2: Application and Effects of Orientation Control Technology in Electronic Paper Using Cholesteric Liquid Crystals

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Abstract
We confirmed that, for electronic paper that uses the cholesteric liquid crystal method, a high reflectance and contrast ratio were obtained by applying cross-rubbing of appropriate rubbing strength to a high pretilt angle alignment layer.

1. Objective and Background
In recent years, electronic paper has been actively researched. Moreover, products which make use of electronic paper, such as Amazon Kindle and Sony Reader, are appearing on the market, mainly in the United States, and the market size has expanded rapidly in the last few years. Against this background, we have researched and developed electronic paper using cholesteric liquid crystals. The FLEPia portable terminal was launched by Fujitsu Frontech Ltd. in April 2009[1], based on our study results. A special feature of this portable terminal is its ability to display colors and it has three modes in which the number of colors displayed is 64, 4096, and 26 000 respectively. Other features are its eight-inch 768×1,024 dot display and driving speeds of 1.8/5/8 seconds.

Currently, there are needs for electronic paper to have higher reflectance and a higher contrast ratio in color. We believe that a high reflectance and high contrast ratio can be achieved by controlling the orientation of the cholesteric liquid crystals, and have accordingly been conducting various types of research. As a result, we have confirmed that an excellent reflectance and contrast ratio can be achieved by combining an alignment layer with a rubbing process[2]. We demonstrate here orientation control technology that can be used to improve the display characteristics of electronic paper that utilizes cholesteric liquid crystals. Our results help to improve the display characteristics in the field of cholesteric liquid crystal electronic paper, which can readily be used to display colors. Advances in the use of color can be expected within the electronic paper market, and this is likely to lead to an expansion in the utilization of color electronic paper employing the cholesteric liquid crystal method.

2. Results and Discussion
For electronic paper employing the cholesteric liquid crystal method, we clearly determined the direction of rubbing, rubbing strength, and pretilt angle appropriate for the cholesteric liquid crystals. We were thereby able to obtain the display properties of high reflectance and contrast ratio, as explained below.

2.1. Manufacturing method and approach
The methods of applying the electronic paper alignment layer and rubbing process are shown in Figure 1. For general liquid crystal displays, the alignment layer is mainly deposited by flexographic printing. In this printing, it is comparatively easy to control the film thickness and the area of spread. A special feature of this method is that it can be applied to large-scale panels. We printed the polymer alignment layer on a flexible film substrate using flexographic printing, and achieved a film thickness that was constant over the prescribed print area. The rubbing process was performed using the usual method, in which the roller, whose surface is covered with buffing, is rotated while making physical contact with the alignment layer.

In order to determine the orientation control conditions that are appropriate for the cholesteric material, we investigated how the reflectance, contrast ratio, and rubbing margin characteristics varied with rubbing direction, rubbing strength, and the pretilt angle of the alignment layer. Figure 2 shows the method we used to evaluate the optical characteristics. The best direction for rubbing was determined from among three types, which will be described later. For rubbing strength, we employed a rubbing density index, which will be described later. We changed the parameters comprising the rubbing density, evaluated the change in reflectance, and determined the best conditions. With regard to the pretilt angle of the alignment layer, several kinds of soluble polymer alignment layer with different pretilt angles were prepared, and the characteristics of each were investigated. These polymers can be deposited by low temperature baking at around 150℃ or less, and can be used comparatively easily with film substrates of a low melting point.

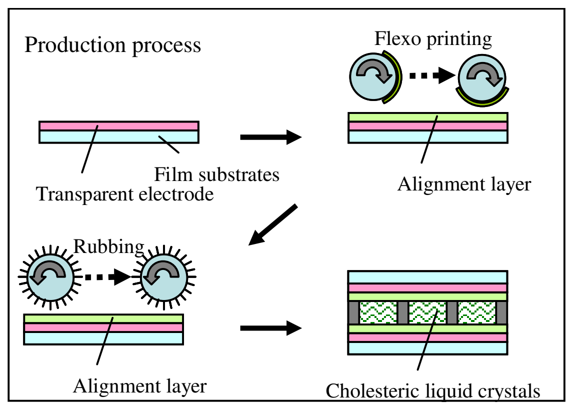

Figure 1. Production process.

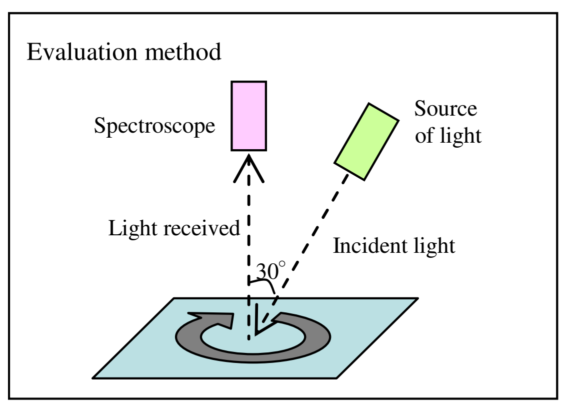

Figure 2. Evaluation method.

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2.2. Characteristic properties

2.2.1. *Rubbing pattern*

There are considered to be three kinds of rubbing pattern, as shown in Figure 3. However, insufficient research has been performed regarding how the viewing angle characteristics in cholesteric liquid crystal electronic paper change as the rubbing pattern changes. Therefore, we first investigated the viewing angle characteristics for each of the three kinds of rubbing pattern. The results confirmed there were marked differences. Figure 4 shows the assessment data. We confirmed a tendency for high reflectance to occur when the azimuthal angle formed with respect to the direction of rubbing is 90°. The direction of the molecular major axis of the liquid crystals lines up roughly in parallel with the direction of the rubbing as the rubbing process proceeds. It is thought that, for this reason, the refractive index (reflectance) of the liquid crystal molecule with respect to incident light is higher in the direction perpendicular to rubbing than in the parallel direction. In addition, we confirmed that the effect by which reflectance in the perpendicular direction is increased is more pronounced for the surface substrate than the back substrate. In this way, for parallel and anti-parallel rubbing, the azimuthal angles at which the surface substrate and back substrate show high reflectance overlap. This means that although, as shown in Figure 4, there is a peak azimuthal angle at which reflectance is high, the reflectance away from the peak is too low. This in turn means that the viewing angle characteristics are unfavorable. However, for cross-rubbing, the azimuthal angles giving high reflectance in the surface substrate and back substrate fall at right angles, so that whatever the azimuthal angle, a certain level of reflectance is achieved, with high reflectance for the surface substrate being in the perpendicular direction. We therefore judge that, in consideration of the viewing angle characteristics, cross-rubbing represents the most favorable rubbing pattern.

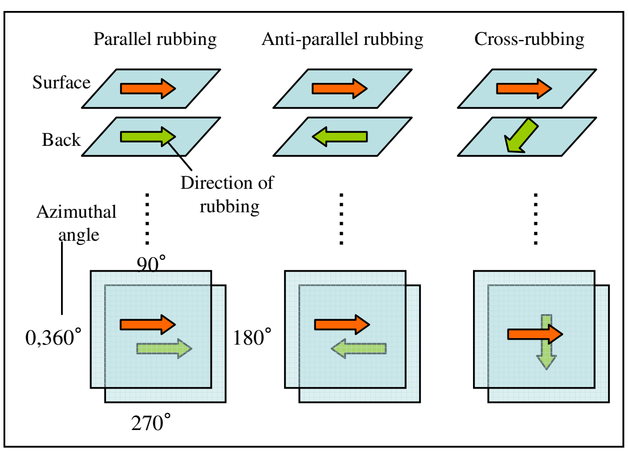

Figure 3. Rubbing patterns.

2.2.2. *Improvement of reflectance*

Next, we confirmed how reflectance changed when rubbing strength changed for cross-rubbing. The main parameters controlling rubbing strength are number of rubbing motions, stage speed, rotational frequency of the roller, pushing amount and roller radius. The rubbing density (Equation (1)), which incorporates these parameters, was used as the index for measuring rubbing strength[3].

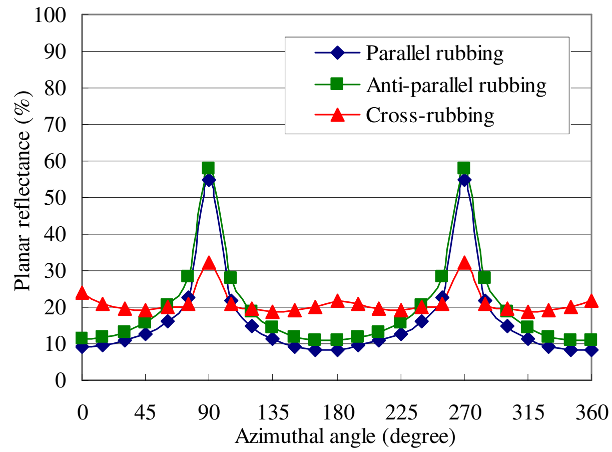

Figure 4. Planar reflectance for different rubbing patterns.

$$L = Nl(1 + 2\pi rn / 60v) \qquad [3]$$

L is the rubbing density. N is the number of rubbing motions. l is the pushing amount. r is the radius of roller. n is the rotational frequency of roller. v is the stage speed.

The results demonstrate a marked dependency, as shown in Figure 5. Up to a rubbing density of around 0.8, reflectance increases with increasing rubbing density. When the rubbing density is low, the directions of the liquid crystal molecules do not fall in one direction and so, since the reflected light is scattered, the reflectance is low. As the rubbing density is increased, the liquid crystal molecules become progressively aligned in one direction and it is assumed that the reflected light therefore converges to some extent, giving increased reflectance. However, when the rubbing density exceeds 0.8, the liquid crystal molecules align to an excessive extent and the surface takes on a condition that is close to that of a mirror. The result is that, with the exception of reflection in the specular direction, the reflectance falls. The difference in the state of the liquid crystals can be confirmed by observing them with a microscope. The state of the liquid crystals when the rubbing density is 0.8 or less is shown in Figure 6 and the state when the density is 0.8 or more is shown in Figure 7. In

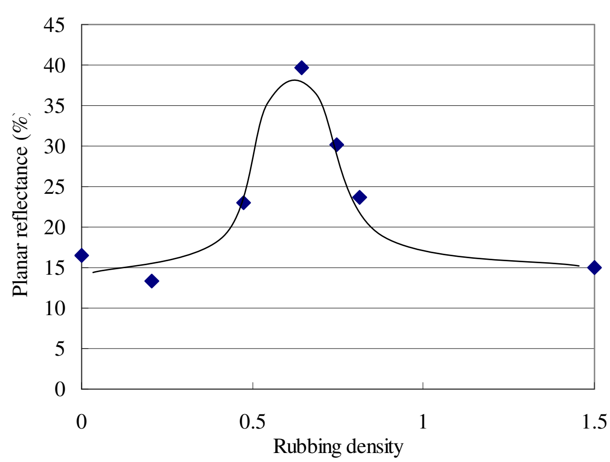

Figure 5. Planar reflectance against rubbing density.

Figure 6, the liquid crystal molecules are not aligned, so the domains are small, but in Figure 7, the molecules are aligned and domains that are around 100-μm in size can be seen.

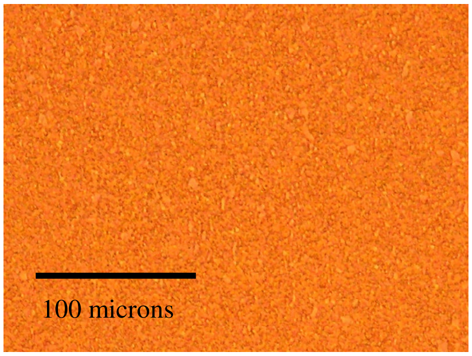

Figure 6. Texture for low rubbing density.

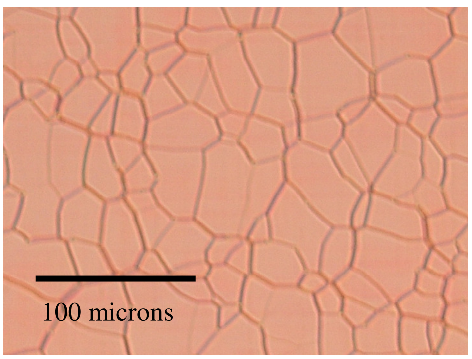

Figure 7. Texture for high rubbing density.

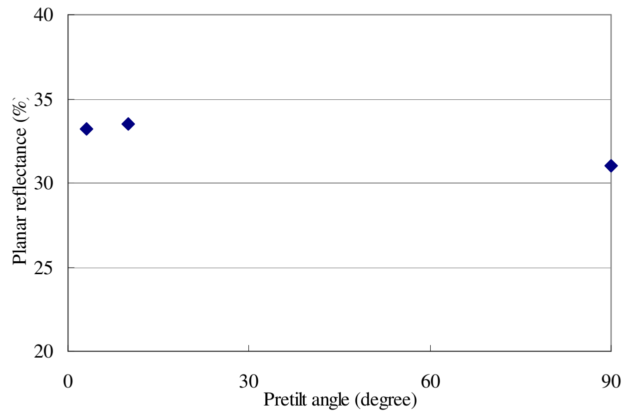

Figure 8. Dependency of planar reflectance on pretilt angle.

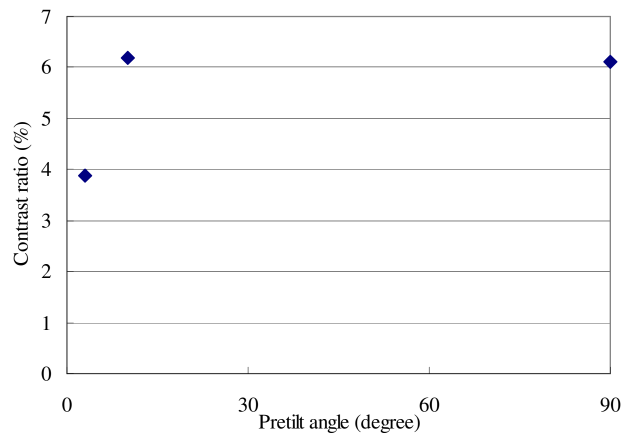

Figure 9. Dependency of contrast ratio on pretilt angle.

2.2.3. Influence of alignment layer

Finally, we investigated the properties of alignment layers with different characteristics. To date, there have been few examples of research into the characteristics of alignment layers for electronic paper that utilizes the cholesteric liquid crystal method, and useful results were obtained in the current study. The dependency of reflectance on pretilt angle is shown in Figure 8, the dependency of contrast ratio on pretilt angle is shown in Figure 9 and the influence of pretilt angle on reflectance, contrast ratio, and rubbing strength margin is shown in Table 1. Pretilt angle means the pretilt angle with respect to the nematic liquid crystal. Alignment layers with a low pretilt angle have strong directivity and this gives rise to increased planar reflectance, but since focal conic reflectance also increases, the contrast is low. In addition, since even a little rubbing results in the liquid crystal molecules becoming aligned parallel with respect to the substrate, it is difficult to control directivity and the rubbing strength margin is narrow. Therefore, this arrangement is not suitable for mass production. When the pretilt angle for the alignment layer is close to 90°, the liquid crystal molecules do not readily align in a parallel direction with respect to the substrate. Although this results in low planar reflectance, focal conic reflectance is also low, giving a comparatively high contrast ratio. Moreover, since for this type of alignment layer the liquid crystal molecules do not readily align in a parallel direction with respect to the substrate, strong rubbing is required to achieve directivity, making for a wide rubbing strength margin. Since moderate directivity is obtained for high pretilt angle-type alignment layers, which possess a certain level of pretilt angle, planar reflectance is high

Table 1. Influence of alignment layer

	Pretilt angle of alignment Layer		
	Low, –3°	High, –10°	Perpendicular, nearly equal to 90°
Planar reflectance	✓	✓	×
Contrast ratio	×	✓	✓
Margin of rubbing strength	×	✓	✓

but focal conic reflectance is not, giving an excellent contrast ratio. Also, since directivity is not obtained without a certain level of strong rubbing, a reasonably large rubbing margin is achieved. It can therefore be concluded that high pretilt angle-type alignment layers are suitable for use in electronic paper utilizing the cholesteric liquid crystal method.

3. Conclusions

The results of the current study provide improvements in the reflectance of electronic paper that uses the cholesteric liquid crystal method, and shows that a high contrast ratio can be achieved. These improvements can be obtained by applying a soluble polymer alignment layer with a pretilt angle of around 10° between the liquid crystal and electrode layers, and performing cross-rubbing with a rubbing density of around 0.8 to the alignment layer. The corresponding improvements represent an increase in performance for electronic paper using the cholesteric liquid crystal method and demonstrates the possibility of expansion in its use as a power saving, lightweight display component for portable display terminals and as a component for use in public service advertisements.

4. References

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