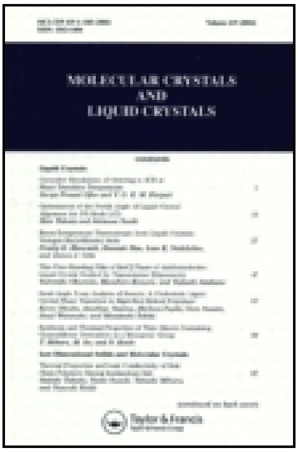

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Reflective Electrically Controlled Birefringence Mode LCDs

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REFLECTIVE ELECTRICALLY CONTROLLED BIREFRINGENCE MODE LCDs

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Abstract
The reflective electrically controlled birefringence mode LCDs (R-ECB) are examined for the case of normal incidence. As the result, it was found that the R-ECB device have possibility of bright display.

INTRODUCTION

Liquid crystal displays need backlight for bright display. Because almost incident light is absorbed by polarizers, color filters and TFT, and is reflected on glass surface and transparent electrodes. Low power consumption is one of main merits of the liquid crystal displays. Therefore elimination of backlight gives long operation of buttery driving. One of the solutions of this problem is a reflective display modes without backlight. Development of electronic portable information instruments is important in future information society.

In the reflective modes, TN, STN, GH and PDLC modes were proposed and available for practical use. These modes have some problems such as low reflectivity and complex material design of elements. In this paper, a reflective electrically controlled birefringence LCDs (R-ECB) is proposed. The R-ECB mode has merits that it needs only one polarizer without chirality dopants or dye and is manufactured by adopting conventional techniques.

PRINCIPLE OF R-ECB LCDs

The configuration of the reflective electrically controlled birefringence LCDs (R-ECB) is shown in Figure 1[1]. The device consists of a polarizer, a liquid crystal layer with positive dielectric anisotropy and a reflector. In this device, the retardation of liquid crystal is adjusted to satisfy the condition of optical quarter wave plate at off state. At first, linear polarized incident light is converted to circular polarized light by the liquid crystal layer. After that, it is reflected by the reflector and passes through the quarter wave plate of the liquid crystal layer again. This results that the polarization plane of the light rotates 90 degrees and becomes perpendicular to the incident light plane. Then the polarized incident light is absorbed by the polarizer and dark state is obtained. At on state, the retardation of the liquid crystal layer becomes zero, so that the light is totally reflected to

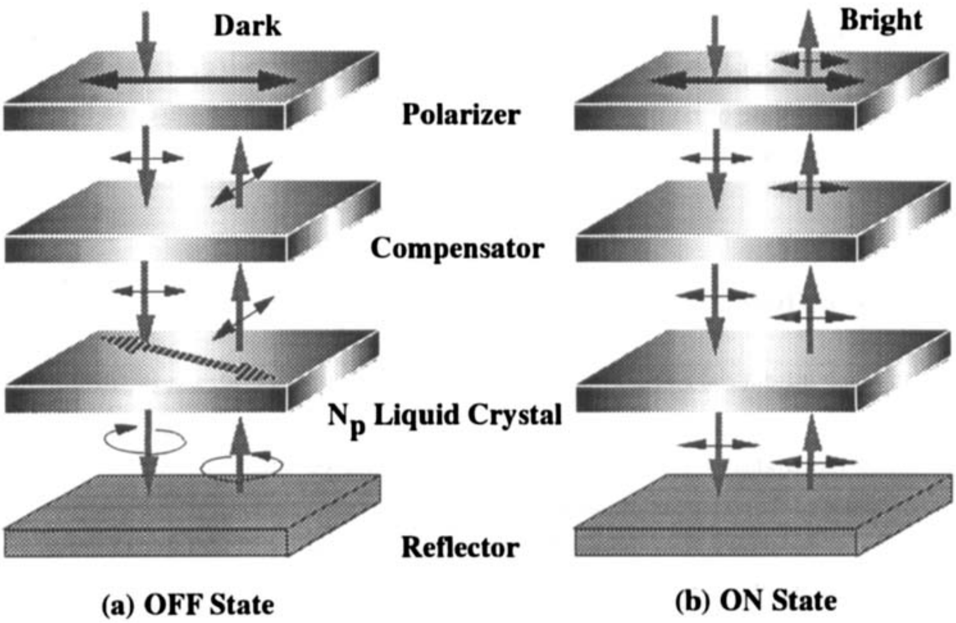

FIGURE 1 Priciple of the R-ECB with N_p liquid crystal.

the viewer. The compensation layer works to get wide viewing angle cone and high contrast black & white display.

Figure 2 shows a reflective mode with a negative dielectric anisotropy of liquid crystal (N_n-Type). A quarter wave plate is inserted between a polarizer and a liquid crystal layer. At off state, the liquid crystal molecules align perpendicular to the substrate and birefringence effect does not occurred. The linearly polarized incident light becomes circular polarized light and the reflected light becomes linearly polarized light after passing through the quarter wave plate. As the result, the polarization plane of the light rotates 90 degrees and becomes perpendicular to the incident light plane and the reflected light is cut by the polarizer. At on sate, the molecules incline to one direction homogeneously. In this case, the birefringence of liquid crystal adjusted to satisfy the condition of optical quarter wave plate. Therefore, the retardation of the quarter wave plate is compensated by the liquid crystal layer and bright state of the cell is obtained. When the quarter wave plate is inserted between the liquid crystal layer and the reflector, the optical switching is also possible. However, the parallax phenomenon is occurred in oblique direction. So that, the structures of Figure 2 is preferred.

These devices in Figures 1 and 2 are normally black modes. A normally white modes are considered in each case. For example in N_p-type, the liquid crystal layer is inserted as a compensator for the retardation.

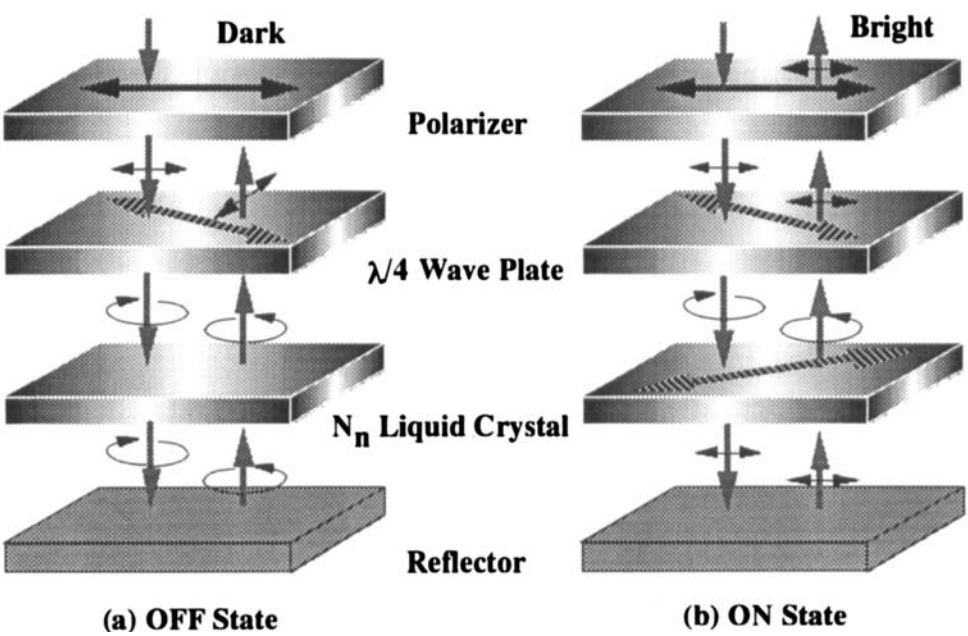

FIGURE 2 Priciple of the R-ECB with N_n liquid crystal.

ELECTRO-OPTICAL PROPERTIES OF R-ECB LCDs

The dichroic ratio of the polarizer which is used in the R-ECB LCD is defied as *Dp*. Let *Tp* and *Ts* be transmittances for the lineally polarized light whose electric vectors are, respectively, parallel and perpendicular to the polarization axis of the polarizer. The following relationship is valid among *Dp*, *Tp*, and *Ts*.

$$D_p = \log T_S / \log T_p \tag{1}$$

Typical values of *Dp* for the polarizers corresponding to the common iodine type is about 42 and the value is used following discussions. The ideal ECB-cell separates the incident light to two vectors. Let *a* be the fraction of polarized parallel to the polarized direction of the polarizer which is expressed as

$$a = \frac{\int_{360}^{830} \sin^2 \frac{\delta}{2} \cdot V(\lambda) d\lambda}{\int_{360}^{830} V(\lambda) d\lambda} \tag{2}$$

where $\delta = 2\pi\Delta n/\lambda$, Δn is the birefringence of liquid crystal, *d* is the thickness of cell gap, λ is the wavelength of incident light, and $V(\lambda)$ is the relative luminous efficiency. Considering the characteristics of the R-ECB cell mentioned above and the properties of polarizers, the transmittances for the normally black mode as shown in Figure 1 are written as

$$T_{off} = \frac{1}{2}\left[a\left(T_p^2 + T_s^2\right) + 2(1-a)T_p \cdot T_s\right] \tag{3}$$

$$T_{on} = \frac{1}{2}\left(T_p^2 + T_s^2\right) \tag{4}$$

$$C = \frac{T_{on}}{T_{off}} \tag{5}$$

where *C* is contrast of the R-ECB cell. The optical properties of the TN-cell and the R-ECB cells are compared in Figure 3[2]. The R-ECB shows almost same properties of the

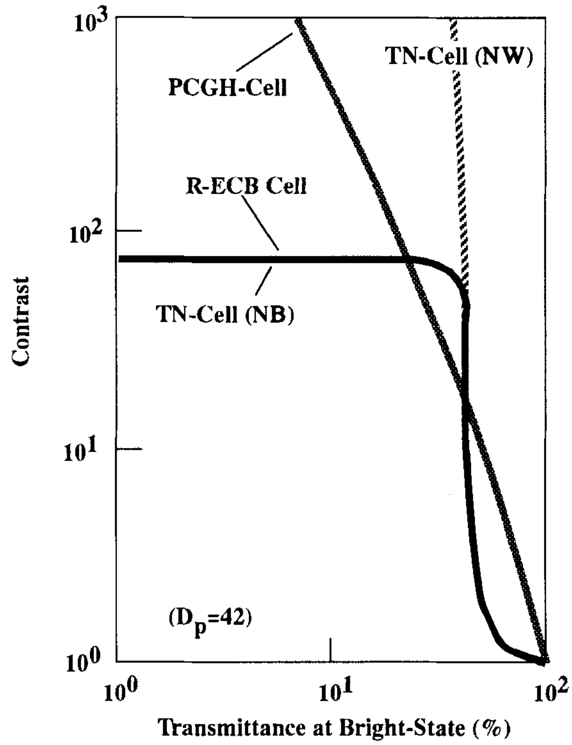

FIGURE 3 Optical properties of the TN and R-ECB cells.

negative type TN display. As the R-ECB have no polarizer between liquid crystal layer and reflector, the parallax phenomenon is not occurred and no chiral dopants is needed.

REFLECTOR

In this device, the design of reflector is very important. The surface of the reflector must diffuse the light in order to expand the viewing angle cone. On the other hand, the surface must be flat for the uniform alignment of liquid crystal molecules and uniform applied electrical field. At first, the glass substrate with rough structure for diffusing incident light was examined. The glass substrate was ground by carbon random #2000, and dipped into HF. Al is evaporated on it for reflection. The substrate was dipped into PVA solution in order to get homogeneous alignment. The applied voltage dependence of transmittance of the R-ECB with the substrate was measured as shown in Figure 4. In this case, adjustment of a quarter wave plate is not set. In ideal R-ECB mode, the transmittance changes between zero to 100 %. In this cell, the variation of transmittance is only few percents. The SEM image of the substrate is shown in Figure 5. The surface is damaged by the grind process. In this case, the cell thickness are different in each position and the retardation also changes. In addition, uniform molecular alignment can not be obtained in this case. Because the rubbing process affects only on the shallow area, and deep area has no effect on uniform alignment. The model of the surface cross section is shown in Figure 6(a). The rough surface affects the uniformity of the cell thickness and liquid crystal molecular alignment. The transmittance in Figure 4 is averaged in whole area, so that it does not depend on the applied voltage. The surface must be flat for molecular alignment. On the other hand, the surface of reflector must be diffuse the incident light. To satisfy these conditions, the ideal structure of the substrate is considered as shown in Figure 6(b). In this case, the surface is covered by thick surface surfactant to flattened the surface of alignment layer. Figure 7 shows the applied

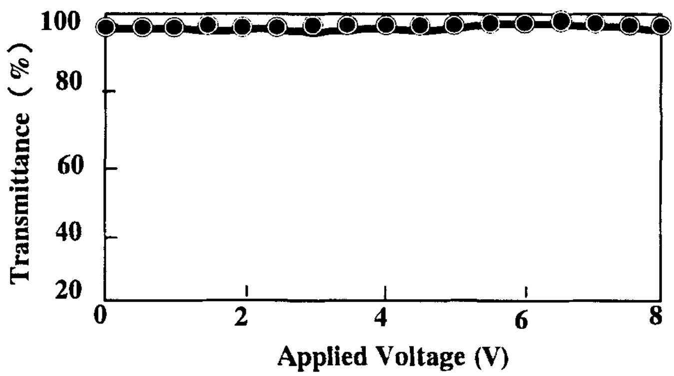

FIGURE 4 Applied voltage dependence of transmittance of the R-ECB with the rough substrate.

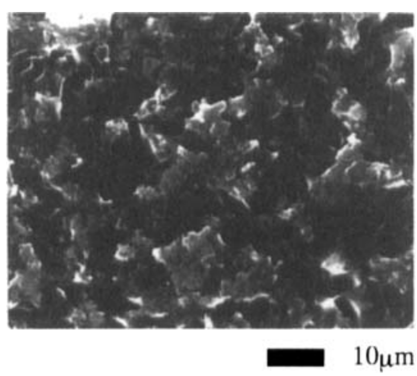

FIGURE 5 SEM image of the rough substrate.

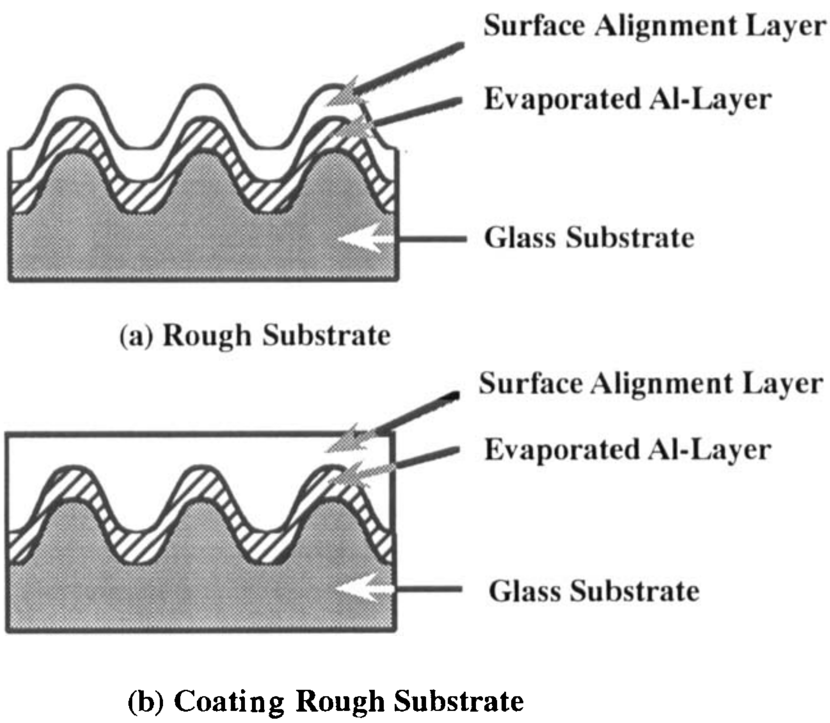

FIGURE 6 Cross sections of the reflector.

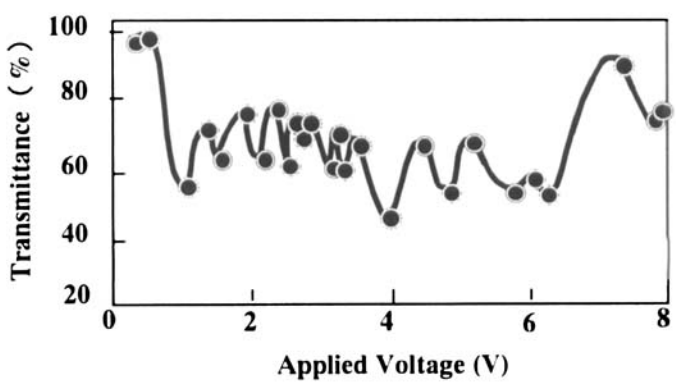

FIGURE 7 Applied voltage dependence of transmittance of the R-ECB with coating rough substrate.

voltage dependence of the transmittance of the coating substrate. The variation of transmittance is about 50% and the improvement of the property is observed. To improve these properties, the diffuse surface is covered by transparent medium to get flat surface for the alignment of the liquid crystal molecules. After that, ITO layer is formed on the surface. The properties of the reflected mode R-ECB suggest to realize a bright reflective display mode.

CONCLUSION

The reflective electrically controlled birefringence mode LCDs (R-ECB) was proposed in this paper. As the results, it is clarified that the R-ECB has possibility of bright display. In this device, the reflector must satisfy two conditions, i.e. optically diffused surface and flat surface for liquid crystal molecular alignment.

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