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THRESHOLD PROPERTIES OF SSFLC IN TERMS OF POLARIZATION STRUCTURES

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Abstract
Bistability of the surface stabilized ferroelectric liquid crystal (SSFLC) is one of the most important factors of display performances. The electrooptical switching is based on the bistability which provides threshold characteristics to the SSFLC display device. The threshold properties of the SSFLC device which has a layer structure of liquid crystal molecules and provides an in-plane molecular switching are assumed to be governed by not only a surface anchoring but also a bulk structure itself. We show some experimental results which suggest a contribution of ferroelectric liquid crystal's bulk structure to the electrooptical threshold properties. Layer structures: the bookshelf and the chevron geometries are one of the main bulk factors. Our experimental results clarified that the polarization switching behavior was intrinsically different between the bookshelf and the chevron structures. The bookshelf geometry also shows a possibility of gray shades.

INTRODUCTION

An electrooptical threshold is the intrinsic properties for liquid crystal display devices. An electrooptical switching induced by the coupling between an external electric field and an induced polarization as in common in a nematic liquid crystal is mainly governed by the interaction between the liquid crystal molecules and the interface layer for the molecular alignment, that is the surface anchoring effect. In the surface stabilized ferroelectric liquid crystal whose electrooptical switchings are attributed to the polarization switching of ferroelectric phase liquid crystals, the polarization switching properties are assumed to be the most influential factor of the electrooptical threshold.[1] The surface anchoring effect particularly the liquid crystal molecular alignment by buffing techniques have been reported in terms of memory capability of the SSFLC.[2] Polarization switchings, however, are provided by the liquid crystal bulk properties. Because the polarization switching itself comes from the bulk properties.[3,4] Consequently we have to consider both of the surface effect and the bulk properties to discuss the electrooptical threshold properties in the FLCs. Here we discuss the influence of smectic liquid crystal layer structures on the electrooptical

electrooptical threshold in terms of the polarization switchings. To understand the polarization switching properties of the SSFLC, we investigated the cell gap, external compressive [5,6] and expansive influences on the polarization switching peak current, and the time resolved permittivity. The electrooptical threshold properties are also main factors for the gray shade capability. Here we introduce an example of the gray shade capability using the special FLC material and the molecular alignment material.

EXPERIMENTAL

1. FLC Materials

Two FLC mixtures were prepared for the experiments. One is Merck mixture: ZLI-4851-100, the other is the naphthalene-base mixture. In our SSFLC cells, ZLI-4851-100 presented typical zigzag defects, resulting in a chevron layer structure. The naphthalene-base mixture panel showed no zigzag defects and the X-ray diffraction profiles suggested the quasi-bookshelf layer structure. [7]

2. FLC Cells

The sample cells were prepared according to usual preparation method using ZLI-4851-100 and the naphthalene-base mixtures. Anti-parallel rubbed polyimide films which provide low pretilt angle were used for the liquid crystal's molecular alignment. Panel gaps were varied from 1.4 to 3.3 μ m using silica ball particles. The panel gaps were measured by the microscopic spectrometer (Ohk TFM-120 AFT) after the FLC was injected into the cell.

3. Measurements

To investigate the polarization structure of each sample cell which is assumed to be one of the main factors of electrooptical threshold properties, we measured each sample cell's panel gap dependence of molecular tilt angle, permittivity, polarization switching current, and optical response time. We also investigated the influence of pressure on the spontaneous polarization by measuring the polarization switching current. Pressure applications to the sample cell was carried on by the push-pull gauge. The pressure was applied to each sample cell by pressing a 2 mm square stainless pad. A negative pressure on the sample cell was fulfilled by using a vacuum chamber. The time resolved permittivity measurement of the sample cell in relevant to the polarization switching was measured by the specially fabricated measuring unit.[8] The molecular tilt angle was measured by the polarized microscope detecting the minimum transparent light intensity ranging from 400 to 750 nm wavelength under the application of 0.1 Hz, $\pm$10 V rectangular waveform voltage. The optical response time was detected as 10 - 90% transmittance change by applying 100 Hz, +10 V rectangular waveform voltage. The time resolved permittivity measurment was carried on detecting the transient dielectric constant led by polarization switching by the probe 10 kHz sign waveform voltage duplicated probe 10 Hz triangular waveform voltage at room temperature.

RESULTS AND DISCUSSIONS

1. Cell gap influence on molecular alignment

First of all we observed the cell gap influence on molecular alignments both of the chevron and the quasi-bookshelf layer structure cells. The quasi-bookshelf layer structure cells whose pretilt angles are almost zero degree showed no particular difference in molecular alignments in the range from 1.0 to 3.0 μ m cell gaps. The chevron layer structure cells whose pretilt angles are less than 3 degrees, however, showed obvious differences as shown in Fig. 1. The thicker cells such as 3.3 μ m , 2.8 μ m exhibit typical zigzag defects. The zigzag defects reduce in 2.4 μ m cell. In 1.4 μ m cell, however, no typical zigzag defect but smectic A like striped pattern was observed. All of the sample cells presented normal optical swichings under the application of external pulse voltage regadless to the molecular alignment differences.

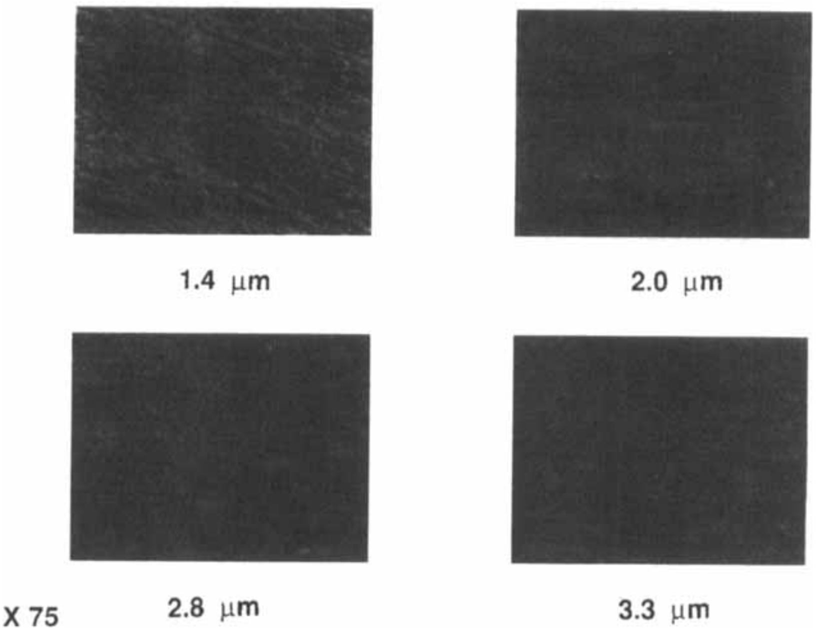

Figure 1 The molecular alignments of the chevron layer cells. The molecular alignments are dependent on the LC layer thickness.

2. Cell gap influence on the polarization switching current

The quasi-bookshelf layer structure cells provided by the naphthalene-base FLC mixture show no particular difference in molecular alignment. Next, we observed the polarization switching current of the cells by applying triangular waveform voltage. Figure 2 represents the polarization switching currents in conjunction with the bistability of the cells. The bistability was measured by applying $\pm$20 V; 400 μ s pulse voltage. The interval between +20 V and -20 V pulses is 500 ms as shown in Fig.2. This figure suggests that the polarization switching current is dependent on the cell gap. The bistability which is relevant to the memory effect of display device is also dependent on the cell gap. As long as the four cell gaps are compared as shown in Fig. 2, only 1.7 μ m gap cell provides a perfect memory that means no decay in transmittance. The polarization switching current of the

1.7 μ m gap cell is different from that of other three gaps cells. The 1.7 μ m gap cell gives rise to the smallest current peak value and the widest half width of the current peak.

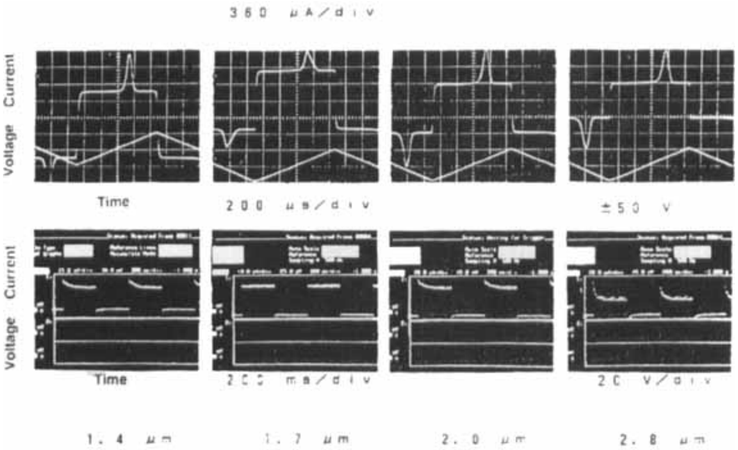

Figure 2 Polarization switching currents and memory effects of the naphthalene-base FLC cells. The cell gap variation is 1.4 to 2.8 μm.

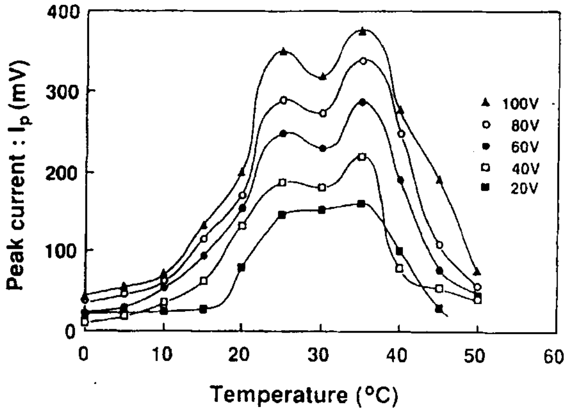

Figure 3 The temperature dependence of polarization switching current peak value Ip for various triangular waveform voltages, The voltages are peak to peak value.

For further investigation of the relationship between memory capability and molecular alignment, we measured the temperature dependence of the polarization switching current peak value Ip using the 1.7 μ m gap cell . Figure 3 shows the result. This figure presents that Ip increases between 10 to 40°C and the Ip peak splits to two above +30 V application. The temperature range 10 to 40°C which provides large Ip value stabilizes memory effect so that sufficient polarization switching is assumed to be one of the necessary conditions for the perfect memory effect. Figure 3 also indicates that there are some polarization structures in the FLC presented by two peaks above 30 V application. The existence of two peaks suggests that there are some particular polarization structures in the FLC which make a difference in easiness of polarization switching, that is, electrooptical threshold properties of the FLC cell.

3. Molecular tilt angle

The existence of particular polarization structure in the FLC dependent on the cell gap indicates that the molecular tilt angle in the SmC* phase will be modified. Figure 4 shows that the molecular tilt angle varies with LC layer thickness in the quasi-bookshelf cell. Particularly in higher temperature range; 35℃, 40℃, tilt angle is significantly dependent on the layer thickness. Figure 5 also shows the LC layer thickness dependence of the molecular tilt angle of the chevron layer cells. In the chevron layer, however, the LC layer thickness dependence of the tilt angle is smaller than that of the quasi-bookshelf layer.

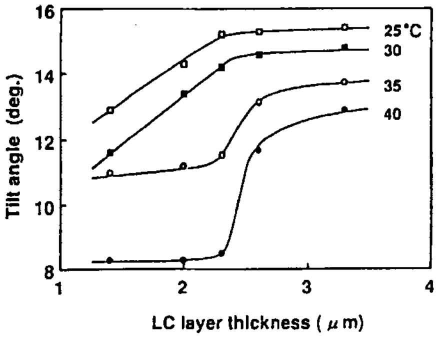

Figure 4 The LC layer thickness dependence of the molecular tilt angle of the naphthalene-base FLC cell.

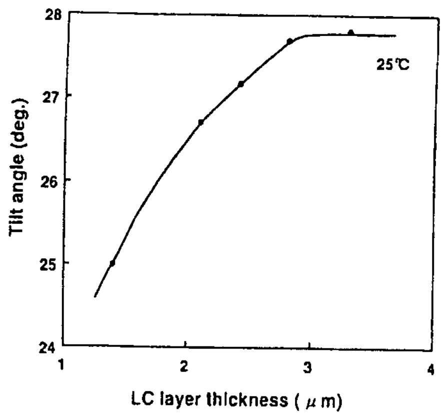

Figure 5 The LC layer thickness dependence of the molecular tilt angle of the chevron layer cell.

4. The time resolved permittivity measurement

The cell gap influence on the polarization switching currents clarifies the difference of polarization structures in the layer structure between the quasi-bookshelf and the chevron. This difference of the polarization structure indicates some differences in the electrooptical threshold properties between the bookshelf and the chevron layer structures.

We tried to understand the dynamics of polarization switching process in relevant to the threshold properties of the FLC display device. We can obtain some polarization switching characteristics from the observation of the polarization switching current by applying pulse or triangular waveform voltage.[9] The polarization switching current phenomenon, however, is intrinsically detected by the charge transportation. The dynamics of the optical axis of liquid crystal molecules directly connects with the electrooptical properties in conjunction with the threshold properties. The time resolved permittivity measurement can follow the dynamics of liquid crystal molecules under the external applied field.

The time resolved permittivity measurement was reported to study the dynamic process of the polarization switchings. Duplicated prove voltages on a triangular waveform voltage can detect the momentary cell capacitance in the polarization switching measurement, obtained capacitance peaks present the polarization switching profiles. The contribution to the cell capacitance in a low frequency region is almost restricted to the polarization switching. Thus, the time resolved permittivity measurement offers the fine time resolved polarization switching behavior. The exact signal separation from between the triangular and the probe sign waveform voltages is the most important. In our experiments, the frequency of the triangular waveform was set to 10 Hz, the probe sign waveform was selected to 10 kHz.

Figurse 6 and 7 present the time resolved permittivity of the quasi-bookshelf and the chevron layer cells. In the time resolved permittivity measurement, obtained capacitance peaks present polarization switching profiles. As mentioned above, in an FLC the contribution to the cell capacitance in a low frequency region is almost restricted to the polarization switching. Both of the FLC materias engaged in this experiment show a slightly negative dielectic anisotropy. Thus, a permittivity maximum should appear when the applied triangular voltage changes its sign. The minimum permittivity should appear when the polarization is parallel to the substrate. Uniformity of the polarization switchings can be obtained by the peak width. Figures 6 and 7 suggest that the quasi-bookshelf cell has a simple polarization structure compared to the chevron cell. It is obvious that the chevron structure contains a complicated local polarization structure, resulting in a wide permittivity peak.

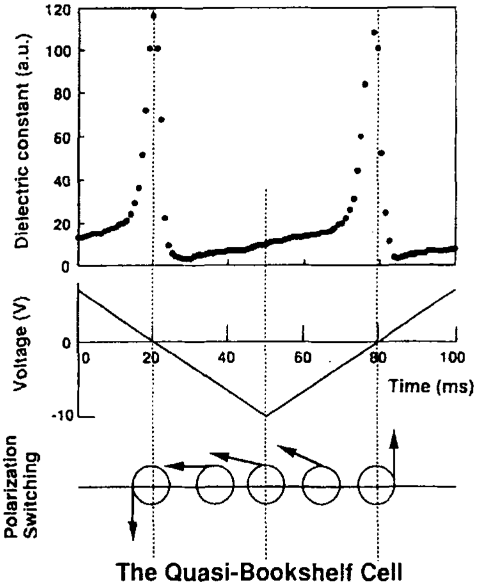

Figure 6 Polarization switching characteristics of the quasi-bookshelf cell in the view point of time resolved permittivity measurement.

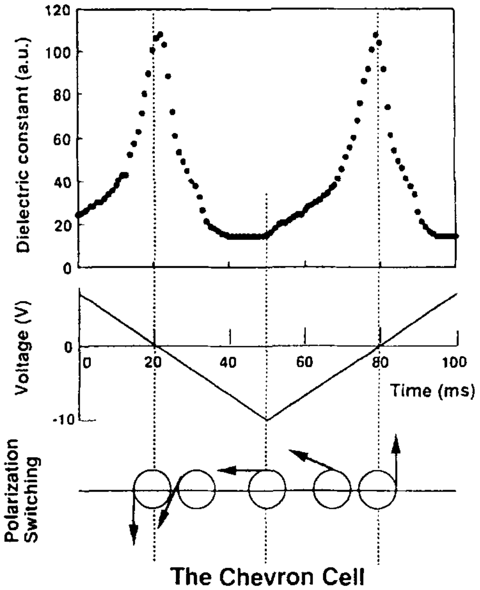

Figure 7 Polarization switching characteristics of the chevron cell in the view point of time resolved permittivity measurement.

A minimum permittivity of the chevron cell is obtained at the applied triangular voltage changes its intensity from increase to decrease or decrease to increase as shown in Fig. 7. It's reasonable because the polarization should be parallel to the glass substrate when the applied voltage intensity switches from increase to decrease or vice versa. The quasi-bookshelf cell, however, shows that its minimum appears right after the polarization switching. Both of the quasi-bookshelf and the chevron cells represent the existence of linear response portion just before the polarization switching. The electrooptical threshold in relevant to the polarization switching is assumed to be provided by the drastic change from linear response to the non-linear response as indicated in Figs. 6 and 7. The linear response portion in Fig. 7 is interpreted as an ionic current. However the linear part in Fig. 6 is not interpreted as an ionic current because of an incompatibility with applied voltage intensity change. Even though the time differentiation of the applied voltage changes its sign, the permittivity still linearly increases as shown in Fig. 6. Consequently, this linear portion is not due to ionic effect. Judging from the time resolved permittivity, the polarization switching of the chevron cell happens more continuous than that of the quasi-bookshelf cell as illustrated in Figs. 6 and 7, respectively. In the chevron cell, after the polarization switching, the switched polarization gradually changes its direction according to the increase of applied triangular waveform voltage until the polarization becomes parallel to the substrate. Once the polarization is parallel to the substrate, the situation is maintained until the time differentiation of the applied voltage changes its sign. The polarization again linearly changes its direction until some degrees by the increase of applied voltage, then the switching occurs. As indicated in Fig. 7 in a course of periodical polarization switchings, a unit cycle of the switchings of the chevron cell is from the maximum applied voltage to the minimum voltage. In the quasi-bookshelf cell, the polarization becomes parallel to the substrate immediately after the polarization switching. Then the polarization changes its direction monotonously until next switching occurs regardless of the dV/dt change. Consequently a unit cycle of the quasi-bookshelf cell is between the polarization switchings. Although figures 6 and 7 show the existence of linear response area, the movement of the polarization in the linear portion of the quasi-bookshelf cell is much smaller than that of the chevron cell. The narrow peak width and the smaller linear response indicate that the electrooptical threshold of the quasi-bookshelf cell is more critical than that of the chevron cell in terms of the polarization switching properties.

5. Polarization switching behavior under the compression environment

The cell gap influence on the polarization switching behavior mentioned above suggests that the polarization switching is affected by the inner compression of the cell. To understand the compression and expansion effects on the polarization switching, we measured the polarization switching current under the pressure. Figure 8 shows the result of the quasi-bookshelf cell and the chevron cell. This figure clarifies that the spontaneous polarization under the pressure is entirely different between the quasi-bookshelf and the chevron cells. In the quasi-bookshelf cell, the influence of the pressure is rather small. In contrast, the chevron cell affects a large influence of the pressure. The large influence of the pressure in the chevron cell indicates that the pressure modifies the polarization structure. In the quasi-bookshelf cell, even though the spontaneous polarization decreases with increase of the pressure, the decrease of the spontaneous polarization under the pressure of 3 kg/cm2 is less than 40% of the non-pressure environment. The difference in the pressure effect shown in Fig. 8 is assumed to be due to the layer structure. The quasi-bookshelf layer structure is thought to absorb the external pressure in some extent. The mechanical strength of the layer structure under the pressure, however, is thought to be governed by an easiness of layer movement.10 It is assumed that the easiness of layer movement is decided by the surface anchoring. In the case of strong surface anchoring, when a compression is applied to the liquid crystal layer, the layer movement is difficult due to the fixing effect of the surface anchoring. Therefore we investigated the polarization switching behavior at the surface area. We supposed that if the polarization switching is strongly stricted at the surface, the anchored liquid crystal molecules at the surface suppress the polarization switchings of the inner part of the cell. Thus, the applied voltage dependence of spontaneous polarization in a polarization switching peak current measurement will lead to the suppression situation. Figures 9 and 10 were obtained by changing the applied triangular waveform voltage. Significant difference is observed in comparison with Fig. 9 and Fig. 10. The quasi-bookshelf cell shows a small voltage dependence of the spontaneous polarization. Above 5 volts region the spontaneous polarization is almost saturated in the quasi-bookshelf cell. The chevron cell, however, shows a large voltage dependence. Figure 10 presents that the spontaneous polarization increases with the increase of applied voltage up to 20 volts. This suggests that there are some suppressed portions in the chevron cell in terms of the polarization switchings. This suppressed area may be the surface anchoring area. The difference in the compression effect between the quasi-bookshelf and the chevron cells is attributed to the difference in the surface suppression of the polarization switchings. It is obvious that the compression environment does not significantly suppress the polarization switching in the quasi-bookshelf cell. Thus, we fabricated the special FLC panel using the adhesive apacer particles. The purpose of this panel structure is to realize a tenacious FLC display device. We used the thermosetting epoxy resin particle as a spacer particle in the FLC cell. This particle can fix two glass substrates. Once the substrates are fixed the cell gap can be maintained constant.[11] In this panel, an inner compression is supposed to be increased at the polarization switchings. Figure 11 is the fabricated FLC display using the quasi-bookshelf FLC material with the adhesive spacer particles. Thanks to the compression free switching properties, it shows a rather good image quality as listed in Table 1.

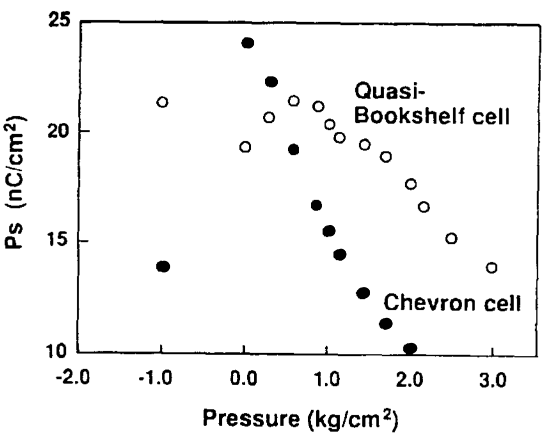

Figure 8 Spontaneous polarization change under the effect of expansion and compression of the quasi-bookshelf and the chevron layer cells.

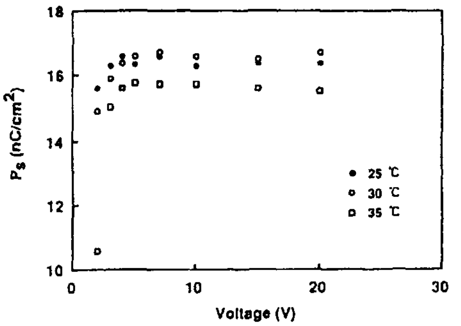

Figure 9 Polarization switching suppression effect due to the surface anchoring of the liquid crystal molecules. The quasi-bookshelf cell shows a small suppression effect.

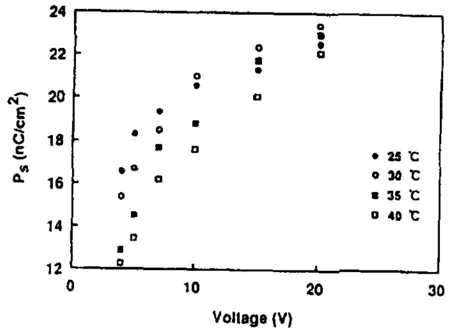

Figure 10 Polarization switching suppression effect due to the surface anchoring of the liquidcrystal molecules. The chevron cell shows a large suppression effect.

Table 1 Characteristics of the prototype

Number of pixel (dot)	1024 X 768
Pixel pitch (mm)	0.20 (130 dpi)
Pixel size (mm)	0.185 X 0.185
Display area (mm)	204.785 X 153.585
Colors	Black & White
Contrast ratio (Ambient brightness > 500 lx)	21 : 1
Screen writing time (ms)	192
Screen brightness (cd/m²)	425 (White)
Viewing angle (Contrast ratio > 10:1)	± 60
Mechanical shock	Available for portable use

6. Gray shade capability in terms of polarization switching

Gray shade capability is one of the most important characteristic properties for display devices in terms of the image quality. The uniformity of polarization switchings in the quasi-bookshelf cell derived from above discussions is quite interesting in the view point of gray shade capability. The polarization switching threshold is clear in the quasi-bookshelf cell as shown in Fig. 6. The polarization switchings take place including the surface area in the quasi-bookshelf cell as indicated in Fig. 9.

We investigated the gray shade capability using the quasi-bookshelf cell in the view point of the uniformity of polarization switching. The result is shown in Fig. 12. Several degrees of stable gray shades were obtained from 0 volt to 15 volts. Careful observation of the polarization switchings suggests that the polarization switches completely by applying the each gray level voltage. Then after removed the applied voltage, the switched polarization returns as an average to some extent decided by the applied voltage level. The detail mechanism of the gray shade capability is under investigation.

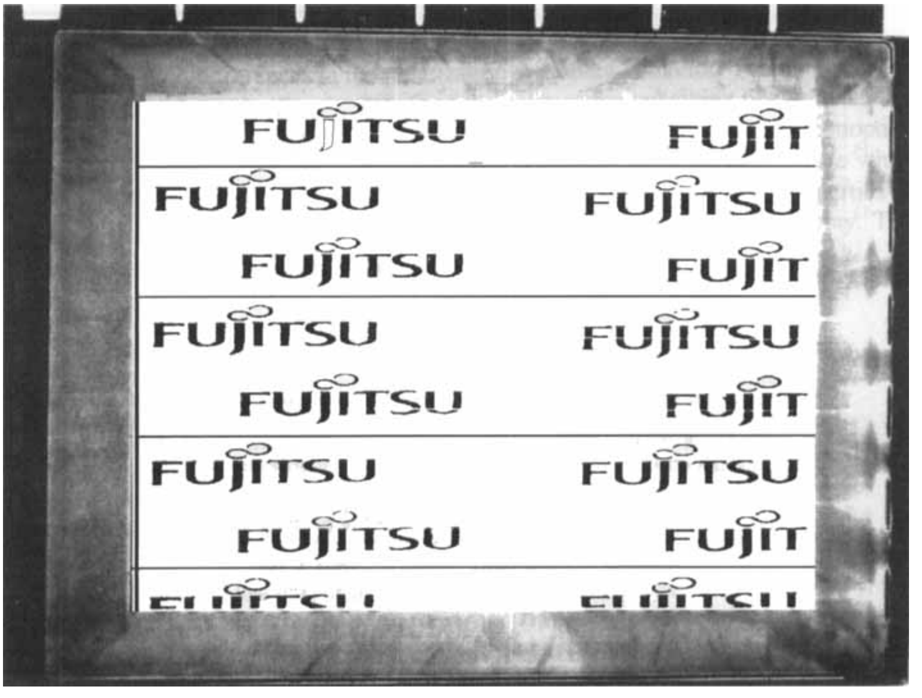

Figure 11 The FLC prototype using the quasi-bookshelf layer geometry. This prototype shows a rather good contrast ratio without a black-matrix under the ambient brightness of more than 500 lx.

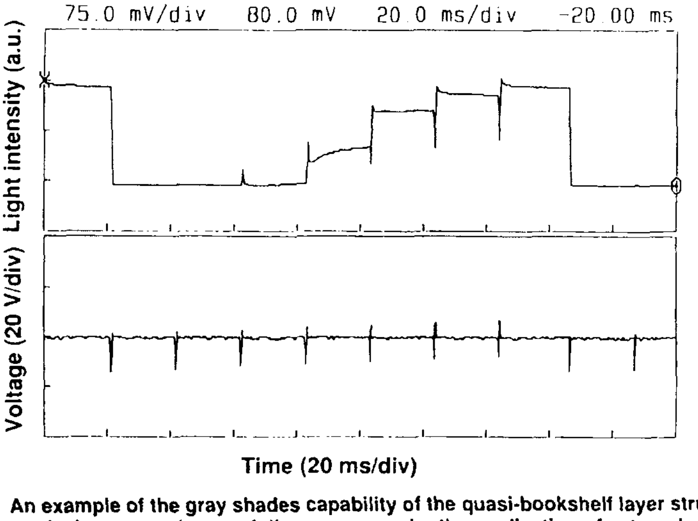

Figure 12 An example of the gray shades capability of the quasi-bookshelf layer structure cell. The electrooptical resonse shows a full response under the application of external voltage. Right after removing the applied voltage, the light intensity changes to the appropriate level which is decided by the voltage level.

CONCLUSION

Threshold properties of the SSFLC cells are investigated in terms of the polarization switching characteristics. The layer structures: the quasi-bookshelf and the chevron structures show some differences in the polarization switching behavior. The time resolved permittivity measurement clarifies the details of the polarization switching phenomena. The direction of polarization right after the polarization switching indicates the electrooptical threshold properties in the FLC display device. The naphthlene-base FLC mixture which shows the quasi-bookshelf layer structure presents rather critical threshold properties so that the good threshold characteristics are confirmed by the fabricated FLC display. This special FLC material also suggests the capability of gray shades.

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