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# The Electro-Optical Properties Using the Flexoelectric Effect in Nematic Cells

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# THE ELECTRO-OPTICAL PROPERTIES USING THE FLEXOELECTRIC EFFECT IN NEMATIC CELLS

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Abstract We investigated the flexoelectric effect in the HAN cell and the SPLAY cell using nematic LCs (Liquid Crystals) with negative dielectric anisotropy for application to LCDs (Liquid Crystal Displays). The electric field is applied in the substrate plane. Simulations were carried out for the electro-optical characteristics by using the continuum theory. The theoretical model includes the anchoring energies and the dielectric energy.

## INTRODUCTION

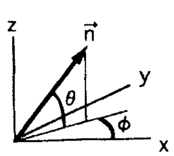
Since the suggestion by Meyer that there can be a linear coupling between nematic curvature strain and external electric field,[1] studies of the flexoelectric effects have been developed mainly from the fundamental point of view.

However, few investigations were reported from the viewpoint of its application to display devices. Using the flexoelectric effect, the electro-optical switching in cholesteric LCs were proposed by J.S. Patel *et al*[2], and the bistable switching mode for nematic LCs with SiO evaporation films were proposed by G. Durand *et al*[3].

We investigate here the flexoelectric effect in nematic LCs with negative dielectric anisotropy (MBBA) apply this effect to display devices. The electric field is applied parallel to the surface. HAN cells and SPLAY cells were used in this study since the flexo polarization was induced for the director orientational strain without applied field. In this report, T–V characteristics of numerical calculated results and some experimental results are shown. The theoretical model includes the influence of the polar and azimuthal anchoring energy and dielectric energy.

## THEORY

The $z$ axis is normal to the substrate surface. $\theta$ and $\phi$ are the polar and azimuthal angles of the director $\vec{n}$, respectively. It is assumed that the electric field is uniformly applied parallel to the surface along y axis. The director exists in the $x - z$ plane without an applied electric field.




$$\vec{n} = (\cos\theta\ \cos\phi\ , \cos\theta\ \sin\phi\ , \sin\theta\ )$$
$$\vec{E} = (0, E_y, 0)$$

Fig. 1 Angle $\theta$ and $\phi$ in the $(x, y, z)$ frame

The flexo polarization $\vec{P}$ is expressed by

$$\vec{P} = e_{11}(div\ \vec{n})\ \vec{n} + e_{33}(rot\ \vec{n}\ \times \vec{n}), \tag{1}$$

where $e_{11}$ and $e_{33}$ are the flexoelectric coefficients associated with splay and bend. So, the flexoelectric free energy density $f_{flexo}$ is given by

$$\begin{aligned} f_{flexo} &= -\vec{P}\cdot\vec{E} \\ &= -\frac{1}{2}E_y[\{(e_{11}-e_{33})+(e_{11}+e_{33})\cos 2\theta\ \}\sin\phi\ (\frac{\partial\theta}{\partial z}) \\ &\quad + e_{33}\sin 2\theta\ \cos\phi\ (\frac{\partial\phi}{\partial z})]. \end{aligned} \tag{2}$$

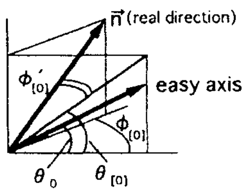
The elastic free energy density $f_{elas}$ is

$$\begin{aligned} f_{elas} &= \frac{1}{2}\{(K_{11}\cos^2\theta + K_{33}\sin^2\theta)(\frac{\partial\theta}{\partial z})^2 \\ &\quad + \cos^2\theta\ (K_{22}\cos^2\theta + K_{33}\sin^2\theta)(\frac{\partial\phi}{\partial z})^2\}. \end{aligned} \tag{3}$$

The dielectric free energy density $f_{diel}$ is

$$\begin{aligned} f_{diel} &= -\frac{1}{2}\vec{E}\cdot\vec{D} \\ &= -\frac{1}{2}(\Delta\varepsilon\cos^2\theta\ \sin^2\phi + \varepsilon_n)E_y^2. \end{aligned} \tag{4}$$

The polar and azimuthal surface anchoring energies $W_{\theta 0}$, $W_{\phi 0}$ at $d = 0$ are written as;




$$W_{\theta 0} = \frac{1}{2}A_{\theta 0}\sin^2(\theta_{[0]} - \theta_0), \tag{5}$$

$$W_{\phi 0} = \frac{1}{2}A'_{\phi 0}\sin^2\phi'_{[0]}. \tag{6}$$

Fig. 2 The geometry of $\phi'_0$

Where azimuthal anchoring energy $W_{\phi 0}$ is defined using $\phi'_{[0]}$ in Fig. 2;

$$\sin^2\phi'_{[0]} = 4\cos^2\theta_{[0]}\ \sin^2\frac{\phi_{[0]}}{2}(1-\cos^2\theta_{[0]}\ \sin^2\frac{\phi_{[0]}}{2}). \tag{7}$$

The anchoring energies $(W_{\theta d}, W_{\phi d})$ at $z = d$ are described similar to that of $z = 0$. Then, the total energy F is

$$F = \int_0^d (f_{flexo} + f_{elas} + f_{diel})dz + W_{\theta 0} + W_{\phi 0} + W_{\theta d} + W_{\phi d}. \tag{8}$$

By minimizing F in the eqation (8), the Euler–Lagrange eqations of the bulk and surfaces about $\theta$, $\phi$ are derived. From these eqations, field-induced deformations of director orientation were obtained by numerical analysis. Electro-optical properties were calculated with 4 × 4 matrix method. The material parameters of the liquid crystal used (MBBA) are shown in Table 1 and the cell parameters are shown in Table 2. But the actual values of $e_{11}$ and $e_{33}$ of MBBA were unknown. So, in this simulation, tentative values were used.

Table 1. LC material parameters

| $K_{11}$ | $K_{22}$ | $K_{33}$ | $\Delta\varepsilon$ | $\Delta n$ | $e_{11}$ | $e_{33}$ |
|---|---|---|---|---|---|---|
| $\times 10^{-12}$ [N] | | | | | $\times 10^{-12}$[C/m] | |
| 6.4 | 3.6 | 8.2 | -0.5 | 0.27 | *1.0 | *9.0 |

(*:tentative value)

Table 2. pretilt angles and anchoring energy coefficients

| | HAN cell | | SPLAY cell | |
|---|---|---|---|---|
| z=0 | $\theta_0 = 2°$ | $A_{\theta 0} = 1 \times 10^{-3}[J/m^2]$ | $\theta_0 = -10°$ | $A_{\theta 0} = 1 \times 10^{-4}[J/m^2]$ |
| | | $A'_{\phi 0} = 1 \times 10^{-4}[J/m^2]$ | | $A'_{\phi 0} = 1 \times 10^{-4}[J/m^2]$ |
| z=d | $\theta_d = 90°$ | $A_{\theta d} = 1 \times 10^{-4}[J/m^2]$ | $\theta_d = 10°$ | $A_{\theta d} = 1 \times 10^{-4}[J/m^2]$ |
| | | $A'_{\phi d} = 1 \times 10^{-5}[J/m^2]$ | | $A'_{\phi d} = 1 \times 10^{-4}[J/m^2]$ |

For calculations of the optical characteristics, the geometries of polarizers in each cell are shown in Fig. 3. For the HAN cell, with this geometry, when the electric field is applied parallel to the cell, the optical rotatory power is induced with molecular reorientation. So, a white display image is observed. For the SPLAY cell, with this geometry, the optical variation due to the ECB effect is observed. But if directions of polarizers are the same as that of HAN cell, variation of the transmitted light is very small, because rotatory power is canceled at the up and down parts in the cell.

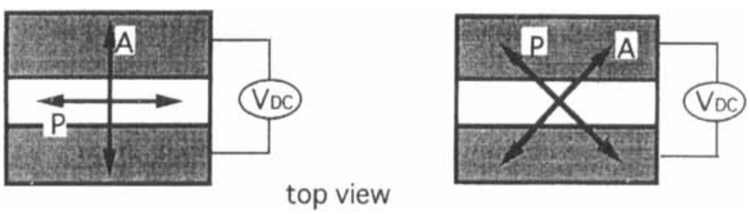



Fig. 3 The geometries of polarizers

## EXPERIMENT

The liquid crystal material used in the experiment is MBBA, and aligned materials are some kind of polyimide. Pretilt angles in the HAN cell are $\theta_0 \approx 2°$, $\theta_d = 90°$, and in the SPLAY cell are $\theta_0 \approx 10°$, $\theta_d \approx 10°$. The thickness of cells are $5 \sim 26\mu m$, the wavelength of light source is $550nm$ and measurement temperature is $30°C$. The D.C. (square pulse with long period) electric field is applied to the cells.

## RESULTS

Simulated results of T–V characteristics for HAN cells and SPLAY cells are shown in Fig. 4 and Fig. 5, respectively. The thickness of cells were varied. The change of

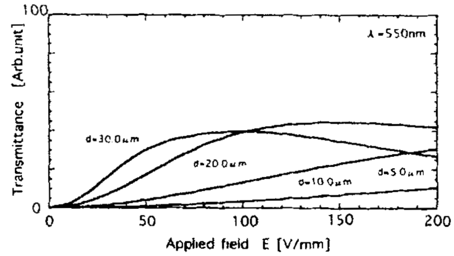



Fig. 4 Calculated results of the T–V characteristics for the HAN cell dependence on the cell thickness

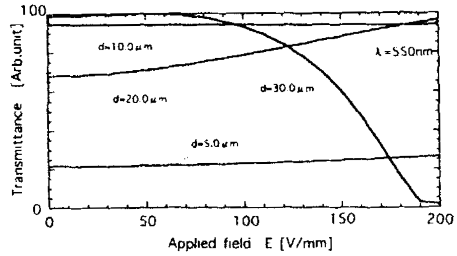



Fig. 5 Calculated results of the T–V characteristics for the SPLAY cell dependence on the cell thickness

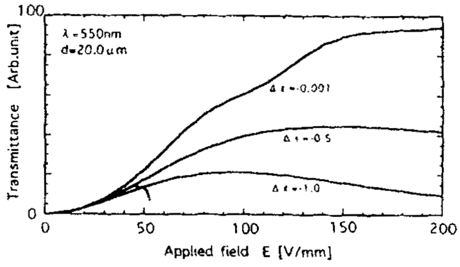



Fig. 6 Calculated results of the T–V characteristics for the HAN cell dependence on the dielectric anisotropy

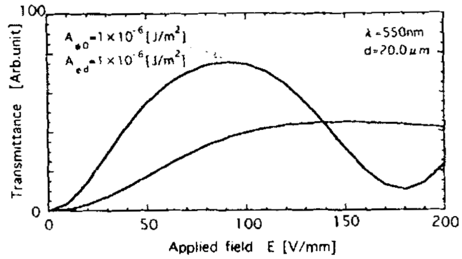



Fig. 7 Calculated results of the T–V characteristics for the HAN cell dependence on the anchoring energy

transmittance in HAN cells occurs at a lower applied field compared with that of SPLAY cells. The largest change of transmittance is obtained for the SPLAY cell of 30 $\mu m$ thick, in this case. But it is found that when the cell thickness is less than 30 $\mu m$, the transmittance shows little change. It is considered that the effective anchoring strength becomes stronger when the cell thickness becomes smaller, so director deformation is restrained.

Fig. 6 shows the dependence of the T–V characteristics on the dielectric anisotropy for the HAN cell. It is found, when the value of $|\Delta\varepsilon|$ is large, the director deformation is restrained due to induced dielectric torque by an applied field. Fig. 7 shows the simulated result for the reduced azimuthal anchoring energy. The director is easier to deform when the azimuthal anchoring strength becomes smaller.

Experimental results of T–V characteristics of HAN cells and SPLAY cells are shown in Fig. 8, Fig. 9, respectively. In the experiment for the SPLAY cells, almost no change of transmittance is observed at thinner cell. The simulations and the experimental results show agreement qualitatively, but show some differences quantitatively. It seems that values of parameters used in the simulation are not in agreement with real values. Further, it also seems that these characteristics are affected by electric double layers due to impurity ions.



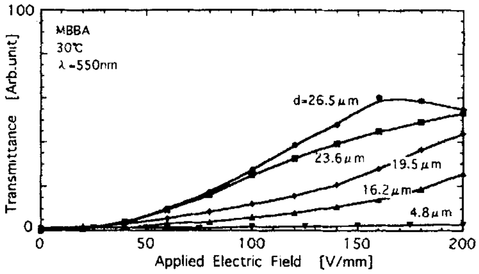



Fig. 8 Experimental results of the T–V characteristics for the HAN cell dependence on the cell thickness

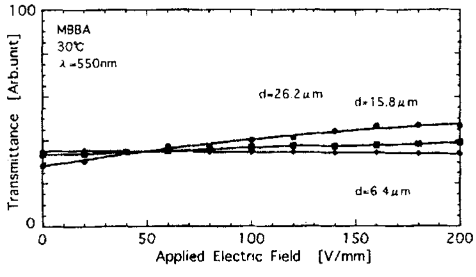



Fig. 9 Experimental results of the T–V characteristics for the SPLAY cell dependence on the cell thickness

When the applied field becomes higher or the cell thickness becomes larger, unstable domains appear and increase. These phenomena are now under study. It seems to be so-called flexo-domains.

## CONCLUSION

- The theoretically calculated results and experimental results of the flexoelectric effects for the HAN cell and the SPLAY cell of nematic LC with $\Delta\varepsilon < 0$ were shown.
- For the HAN cell, larger variation of the T-V curves is observed as the cell thickness is larger, the value of $|\Delta\varepsilon|$ is smaller and the azimuthal anchoring is lower. But, as the cell thickness becomes larger, unstable domains tend to occur at lower applied voltages.
- The flexo coefficients have to be measured and determined for more accurate simulations.
- More chemically stable LC materials than MBBA are needed for experiments.

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