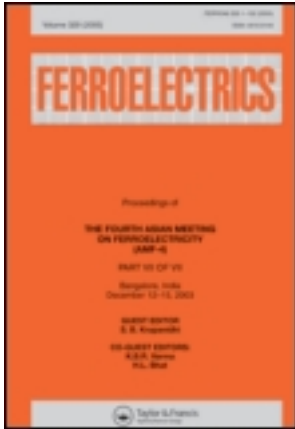


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“V-shaped” electro-optic characteristics in FLC gels

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The effects of polymer network formed under UV irradiation with electric field application ($\pm 50\text{V}, 5\text{Hz}$) to ferroelectric liquid crystal (FLC) molecules orientation and electrooptic characteristics have been studied. The polymer network formed in SmC^* phase is anisotropic and fibrils-like, and a typical striped texture was observed in the cell. The FLC gels exhibit a symmetric V-shaped electrooptic characteristics with thresholdless voltage and high contrast ratio (40:1). A theory explanation of the unique properties is given by establishing a molecular orientation model and conducting a computer simulation. A good fitting of the electrooptic dynamic response of FLC gels has been obtained by introducing a potential (bulk anchoring energy) originated from the photo-cured polymer network.

Keywords: FLC Gels; electrooptic characteristics; V-shaped

INTRODUCTION

Surface stabilized ferroelectric LCDs^[1](SSFLCDs) have shown great

promise in applications for its bistability, wide viewing angle, and fast switching speed. However, it lacks gray scale capabilities which should be one of the most important factors for high performance LCDs. Its bistability makes it difficult to provide light intensity control by arranging an applied voltage. Thus a spatial domain switching in a pixel or temporal averaging scheme must be adopted^[2,4], but these methods will limit the resolution and the speed of SSFLC-based display. Therefore, a new type of device configuration is needed for achieving an intrinsic gray scale. Recently, the so called “thresholdless V-shaped switching” in chiral smectic liquid crystal has been a subject for intense studies by many research groups which electrooptic characteristics indeed exhibits such intrinsic gray levels^[5,7]. However, this kind of studies mainly focus some special ferroelectric liquid crystals with high spontaneous polarization ($\geq 100\text{nc/cm}^2$) which have the smectic X* liked LC phase^[8,10]. Unfortunately, this high P_s will be a problem to the application with active matrix (AM) or thin film transistor (TFT) addressing methods.

In this present research, we actually succeeded in obtaining “V-shape switching” characteristics with a common FLC of low spontaneous polarization value about 29.0nc/cm^2 by fabricating ferroelectric liquid crystal gels which form an anisotropic polymer network in the cell utilizing UV irradiation under an AC electric field ($\pm 50\text{V}, 5\text{Hz}$). The FLC gels exhibit uniform striped texture with good contrast ratio higher than 40 and symmetric V-shape E-O curve without threshold, which can

make greyscale intrinsically available.

EXPERIMENTAL

The ferroelectric liquid crystals (FLC) mixture used in experiment is SCE-9(supplied from Merck Ltd.). This mixture shows the transition temperatures K -10□ SmC* 59□ SmA 79□ N* 91□ Iso. The monomer is a mixture of liquid crystalline diacrylate (form Jilin University). Its chemical structure is shown as follows:

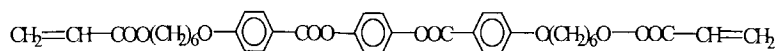


FIGURE 1. The chemical structure of the LC diacrylate

The fabrication process of the FLC gels cells is as follows: the polymer monomer and photoinitiator IRG-184 (provided by KaYaKu Ltd.) were dropped into the FLC at 3wt% concentration in a dark room with minimum lighting conditions. The mixture was stirred for 30 minutes on magnetic stirrer and filled into 2μm thickness cells in the isotropic state. The cells consist of two glass substrates coated by ITO electrodes and PI orientation layers which can cause a low pretilt angle about 1°. The PI rubbing direction on two glass surface was parallel; Then the temperature was lowered slowly controlled by a computer, especially at the phase transition point from SmA-SmC*. Subsequently, the cells filled with FLC-Polymer composite were exposed to an ultraviolet light

source ($T=58^{\circ}\text{C}$, $I=20.0\text{mw}/\text{cm}^2$, $t=30\text{min}$) for curing the monomer to form polymer networks meanwhile an AC electric field ($\pm 50.0\text{V}$, 5.0Hz) was applied. After preparation of FLC gels panels, the structure of polymer network was investigated by scanning electron microscope (SEM) measurement. The molecule texture of cells was studied with the polarized microscope. Meantime the EO performance of the device was measured with our laboratory-made LCD parameter tester.

MEASUREMENTS

1. Polymer network structure

To investigate the polymer network structure formed in the gels, firstly the cell was dissolved in the hexane solvent for several days, we split the cells with great care in order not to disrupt the structure of the polymer network. The samples were investigated with SEM to clarify the polymer network structure. The SEM photograph was shown in Fig2. From the photo, we can see that the size of most polymer network is less than $10\ \mu\text{m}$. Meantime the polymer network is anisotropic and fibrils-like. The fibrils are parallel to the rubbing direction. The polymer networks can provide a strong bulk anchoring strength to orient the FLC molecules^[11]. Under such condition, the free FLC molecule is dominated by the polymer network not the surface orientation film.

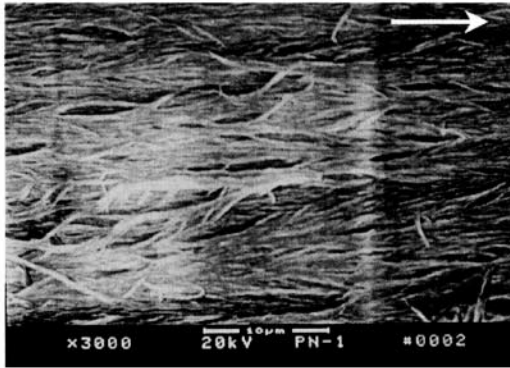


FIGURE 2. Anisotropic polymer network structure formed in the FLC Gels observed by scanning electron microscope, the arrow indicates the rubbing direction.

2. Texture observation

The molecular orientation texture of the gels was studied by polarized microscope and shown in Fig3. A uniform alignment is obtained in the cells. Furthermore, only a particular striped texture of uniform state has been observed. The width of stripes is about $10\mu\text{m}$. The striped lines are parallel to the rubbing direction and coincide with the FLC layer normal. The striped texture is stable and can be remained after the cells were cooled down to the room temperature. This predominant appearance of stripped texture is associated with quasi-bookshelf structure^[12] and corresponding with the deformation of the liquid crystal layer, which has been explained with the elastic free energy theory in our another paper^[13].

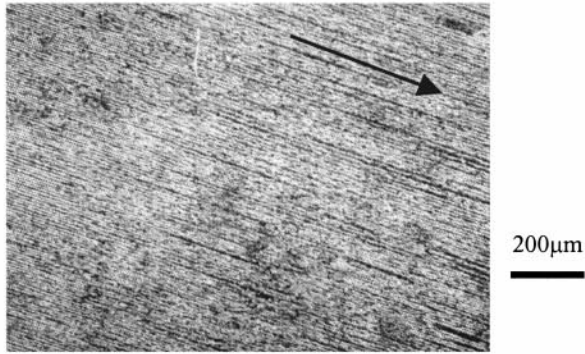


FIGURE 3. Texture of FLC Gels under polarized microscope, Arrow is the rubbing direction

3.EO characteristics measurements

The electrooptic characteristics of the FLC gels cells was studied with our homemade LCD parameter tester. The measurement setup and driving bi-pulse waves are shown in the Fig.4. The FLC gels device exhibits a well symmetric “V” shape E-O curve without threshold, which can make grayscales easily as shown in Fig.5. Furthermore, our FLC gels panels exhibit good contrast ratio more than 40, which is mainly due to the quasi-bookshelf layer structure and uniform texture without Zig-Zag defects in the cells.

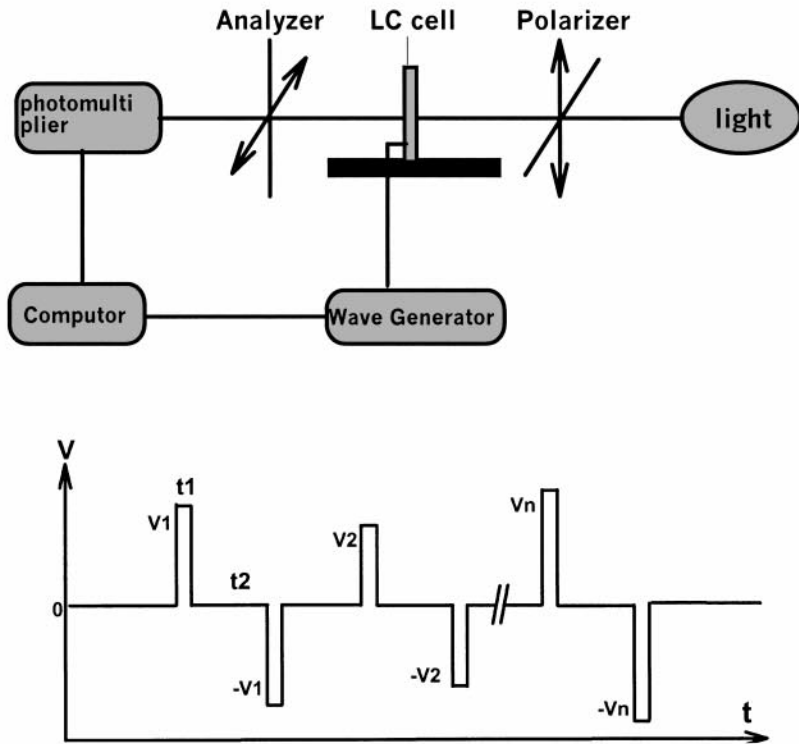


FIGURE 4. Experimental setup and driving waves for the measurements of E-O characteristics of FLC Gels

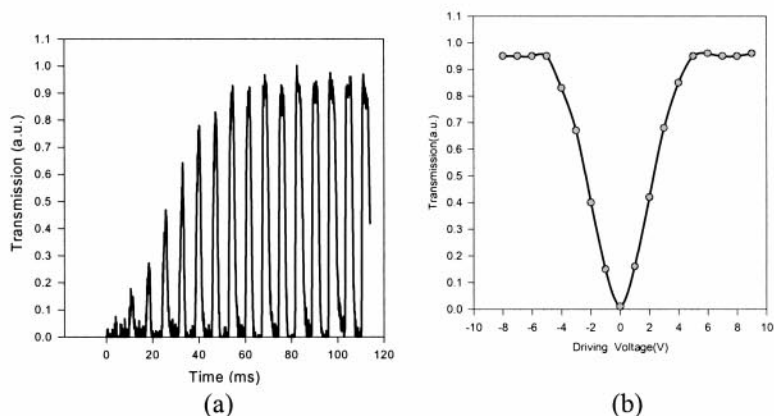


FIGURE 5. The electro-optical properties of FLC Gels (a) transmittance responds with different pulse (b) transmission change with driving voltage

Above phenomena may be explained as follows: as the polymer monomer was UV cured in the SmC* phase with high electric field application ($\pm 50\text{V}, 5\text{Hz}$), for the strong electric field effect ($2.5 \times 10^7 \text{Vm}^{-1}$), the chevron layer structure of ferroelectric liquid crystal should be changed into bookshelf layer structure^[14]. Consequently the FLC molecules have controlled the configuration of the formed polymer network. After the polymerization, because of the strong interaction between the polymer network and FLC molecules^[15], The polymer network in turn affects the orientation of FLC molecules and may play a role in suppressing the formation the chevron layer structure and hence maintain the bookshelf layer structure during the course of cooling

within SmC* phase. This process is shown in Fig.6.

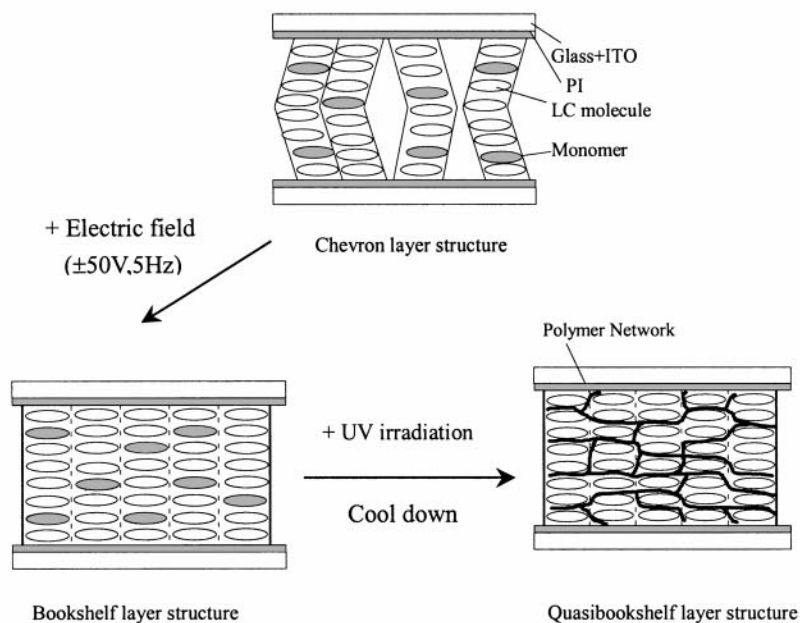


FIGURE 6. The formation process of polymer network under UV irradiation with AC electric field effect

MOLECULAR ORIENTATION MODEL FOR FLC GELS

So far our FLC gels have shown the attractive characteristics suggesting potential for active matrix (AM) or thin film transistor (TFT) addressing displays, a physical explanation of the unique properties of this device is

necessary to provide. With the aim of explaining the phenomena, we established a molecular orientation model and conducted a computer simulation.

1.Free energy consideration of FLC gels

In the calculation process, we formulated the free energy equations to simulate the EO dynamic response of FLC gels by introducing a potential (a bulk free energy) originated from the photo-cured polymer network. Except for the formula of network stabilization, other formulations for the system have been done based on the formulae developed by Nakagawa *et al*^[16] who deals with the spatial variation of c-director and present nematic-like expressions.

The coordinate system for the FLC molecule and the angular relation of molecular director (n-director), c-director and the idle bookshelf molecular layer structure (proved by the typical striped texture in the experiment) is shown in Fig.7

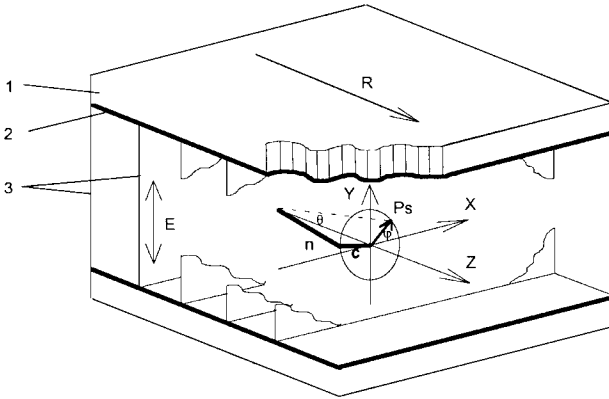


FIGURE.7 The coordinate system for the FLC Gels. The smectic layer coincides with (x,y) plane and the z axis is perpendicular to layers. The c director is n director projection on to the smectic layer . 1-substance plane 2-orientation layer 3-smectic layer E-electric field R-rubbing direction

The actual forms of n and c are as follows:

$$\vec{n} = (\sin\theta\cos\varphi, \sin\theta\sin\varphi, \cos\theta), \quad \vec{c} = (\cos\varphi, \sin\varphi, 0)$$

Here the total free energy is given by

$$F = \int_0^d (f_b + f_s) dy$$

Where d is the thickness of the FLC medium, f_b stands for the bulk energy density, and f_s is the contribution from the surface anchoring effect. f_b includes the contributions not only from elastic energy f_{elas} , dielectric energy f_{die} , and the coupling energy density f_{ps} between spontaneous polarization and electric field but also from the polymer network stabilization f_{poly} . The formula of each term is as follows:

(I) elastic free energy density f_{elas}

$$f_{elas} = \frac{1}{2} \left(\frac{\partial \varphi}{\partial y} \right)^2 \sin^2 \theta \left[K_1 \cos^2 \varphi + (K_2 \cos^2 \theta + K_3 \sin^2 \theta) \sin^2 \varphi \right] \\ + \frac{\partial \varphi}{\partial y} q_0 (K_2 - K_3) \sin^3 \theta \cos \theta \sin \varphi + \frac{q_0^2}{2} \sin^2 \theta (K_2 \sin^2 \theta + K_3 \cos^2 \theta)$$

Where K_1 , K_2 and K_3 are the splay, twist and bend elastic constants respectively. $q_0 = 2\pi/p$, p is the pitch of smectic material.

(II) dielectric energy density f_{diel}

$$f_{diel} = -\frac{1}{2} \varepsilon_{\perp} (1 + e \sin^2 \varphi) \left(\frac{dV}{dy} \right)^2 \\ e = (\varepsilon'_{//} - \varepsilon_{\perp}) / \varepsilon_{\perp} \quad \varepsilon'_{//} = \varepsilon_{\perp} \cos^2 \theta + \varepsilon_{//} \sin^2 \theta$$

Here, $\varepsilon_{//}$ and ε_{\perp} are the principal dielectric constants along the director n and perpendicular to it, respectively.

(III) spontaneous polarization energy density f_{ps}

$$f_{ps} = P_s \cos \varphi \cdot \frac{dV}{dy}$$

(IV) polymer network stabilization energy density : f_{poly}

Actually, it's difficult to present the expression to describe the bulk anchoring energy contributed by the complicated polymer network. In order to solve the problem, we put forward the concept of polymer network field shown in the Fig.8. We consider that the interaction, which the liquid crystal molecules are affected by the bulk anchoring force from network, is a kind of field-like effect, and we definite the N vector as the direction of network field that is the same as the rubbing direction. Therefore, the stabilization free energy contribution from the

polymer network comes from the coupling interaction between liquid crystal n-director and polymer network field director N. Further the suggested form of f_{poly} is

Where θ stands for the tilt angle of FLC molecule and the definition of φ and φ_N are the azimuthal angles of molecular director and network filed vector respectively (mainly considered in the simulations), which are illustrated in Fig.8. W_p is the coefficient of the interaction effect between the n director and N director.

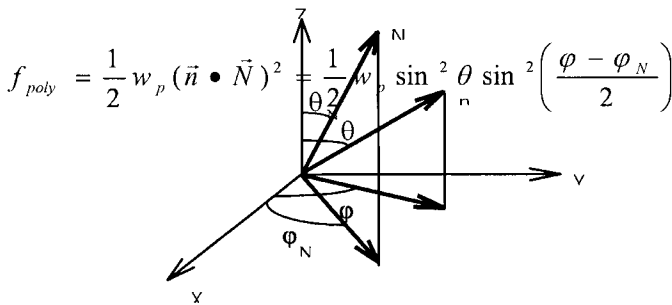


FIGURE. 8 The coordinate system for the n-director and polymer network field director N with their projection onto the smectic molecule layer (x,y)

Next, the surface free energy density f_s is put into following the

$$f_s = -g_1 \cos^2(\varphi - \varphi_s) - g_2 \cos(\varphi - \varphi_s)$$

expression given by Amaya *et al.*^[17].

Where g_1 and g_2 are nonpolar and polar interaction coefficients between the FLC molecules and the bounding surface, φ_s is the pretilt angle of c-director on the cell surface.

$$F(\varphi, V) = \int_0^d (f_{elas} + f_{diel} + f_s + f_{p_s} + f_{poly}) dy$$

Finally, the total free energy for the FLC gels is given as:

2.c-director distribution in FLC gels

In this subsection, we intend to find the molecular director distributions in the gels by minimizing F with respect to φ with Poisson's equations $\delta F/\delta \varphi = 0$ based on above equation. During the calculation, some simplification has been taken, such as one elastic constant approximation with $K_1=K_2=K_3$ and mean dielectric constant. Furthermore, in order to make the calculation process more efficiently and accuracy, we adopted the finite element analysis^[18,19] to determine the c-director's distribution. Tab.1 shows the FLC material parameters used in the computer simulation. Finally, the azimuthal angle φ of c director distribution inside the cell was obtained and shown in Fig.9. The results provide that the azimuthal angle are symmetrical in comparison with the middle of the cell, when no electric field is applied to the cell ($V_0=0$). The configuration of FLC molecules orientation consists two parts. One is the twist state near the bounding surface, the

other is rather homogeneous uniform state, which the molecule almost has a same angle. This outcome may be caused by the balance between the bulk anchoring strength of polymer network and surface anchoring strength. Moreover, when the absolute value of voltage increases, the twist part tends to grow larger from the two orientation surfaces, whereas, the rest part of the cell is still uniform with a certain changed angle.

Table 1. Parameters of FLC material adopted in simulation

P_s	θ	K	ϵ	Δn
$29.0\text{nC}/\text{cm}^2$	23°	$4.0 \times 10^{-11} \text{ N}$	5.0	0.15

3.Simulations of EO characteristics

Based on the director distributions we obtain, the electro optical behavior of FLC gels has been simulated by the Berreman 4×4 matrix method. In Fig.10, we show the optical transmission of the cell between crossed polarizers as a function of increasing voltage for different polymer network stabilized strength. The smectic cone angle is taken to be $\theta = 23^\circ$. The results show that the electro-optic curve is really V-shaped like without thresholdness as expected, at the same time, a symmetrical property has been observed due to the symmetrical director distribution in the cell we have calculated. All above simulation results are satisfied with experiments well. Furthermore, the curve has a trend to become less steeper following the increasing of network anchoring

strength. It means the same transmission should be obtained with a higher voltage to fight against a larger polymer network anchoring force. This outcome is certainly reasonable.

DISCUSSION AND CONCLUSIONS

From above studies, The formed configuration of polymer network can be controlled during the polymerization process. In our experiments, the smectic layer structure has been changed into the quasi-bookshelf layer structure under high electric field effect. Meantime, this good configuration is transferred into the polymer network. In return, the FLC molecular orientation has been adjusted in the gels by the strong interaction provided from polymer network.

It's shown that presence of anisotropic polymer network in FLC gels has great effects on the FLC molecules alignment and switching behaviors. The electro-optic curve of FLC gels device is like "V-shaped", which can make grayscales intrinsically available. So it's easier to get gray scales than common SSFLC device. The FLC gels exhibit uniform texture with good contrast ratio higher than 40. Therefore, Our FLC gels devices have a good application potential for thin film transistor (TFT) addressing owing to rather lower value of spontaneous polarization.

A theory explanation of the unique properties of FLC gels has been given by establishing a molecular orientation model and conducting a computer simulation. During the calculation, the complicated

interaction force to the free FLC molecules originated from the photo-cured polymer network has been treated as field like effect. A good fitting has been obtained under our treatments to simulate the electro-optic dynamic response of FLC gels. From the simulation results, we can find that FLC molecules orientation configuration in gels is actually the combination of the twist part closing to the cell surface and uniform bookshelf alignments in the inner part of the cells. This may be the essential reason to produce the "V-shaped" electro-optic properties of FLC gels.

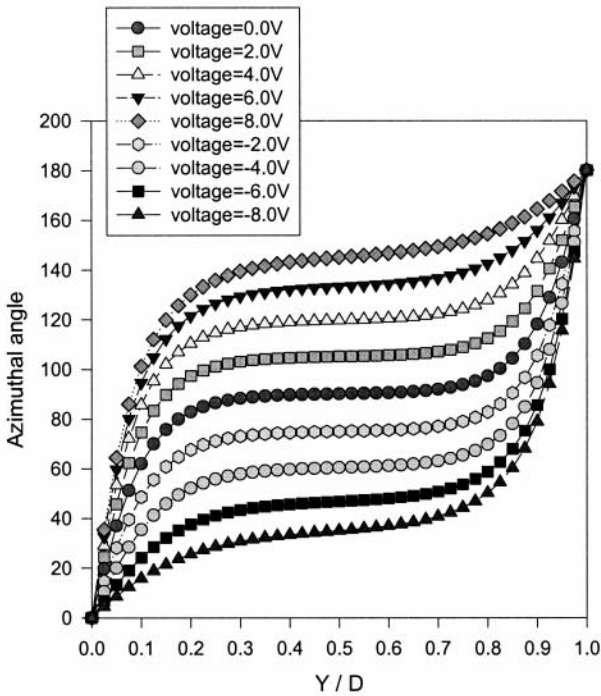


FIGURE 9. Azimuthal angle φ distribution in the FLC gels cell for different applied voltage, cell thickness $D=2.0\mu\text{m}$, Y is the position in the cell, Polymer network anchoring strength is taken as $W_p d=5.0 \times 10^{-4} \text{J/m}^2$.

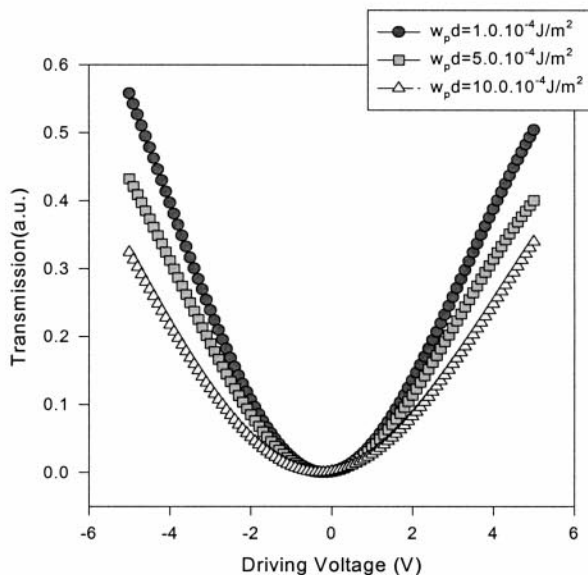


FIGURE.10 Simulation results of electro-optic properties of FLC gels under different polymer network anchoring strength ($d=2.0\mu\text{m}$ and $P_s=29.0\text{ nC/cm}^2$)

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References

- [1] Clark.N.A., and Larger Wall.S.T., Appl.Phys.Lett., 36, L69(1980).
- [2] W.J.A.M.Hartmann, Ferroelectrics 122, 1 (1991)
- [3] H.Pauwels, A.de Meyere and J.Fornier, Mol.Cryst.Liq.Cryst. 163, 469 (1995)
- [4] J.Fornier, A.de Meyere and H.Pauwels, Ferroelectrics 179, 165 (1996)
- [5] A.Fukuda, Proc.of Asia Display'95.Hamamatsu, 61 (1995)
- [6] S.Inui, N.Imura, T.Suzuki, H.Iwane, K.Miyachi, Y.Takanishi and A.Fukuda, J.Mater.Chem., 6, 71 (1996)
- [7] P.Rudquist, J.P.F.Largerwall, M.Buivydas, et.al. J.Mater.Chem., 9, 1257 (1999)
- [8] L.E.Maclennan, P.Rudquist, R.Shao, et.al. Proceedings of SPIE 3800, 136 (1999)
- [9] Panarin, Yu., Panov, V.; Kalinovskaya, O.E.; Vij, J.K. Ferroelectrics 246, 941 (2000)
- [10] P.Rudquist, S.T.Lagerwall, N.A.Clark, et.al., ILCC 2000, 24-28 July, Sendi, Conference Abstracts, 863 (2000)
- [11] R.A.M.Hikmet, H.M.J.Boots, Liquid Crystals, Vol.19, No.1, 65., (1995)
- [12] A.B.Davey, and W.A.Crossland, Mol.Cryst.Liq.Cryst. Vol. 263 325 (1995)
- [13] Li Jianjun Ling Zhihua Huang Ximin and Ma Kai Proc.of SPIE Vol.3560, 56 (1998)
- [14] Y.Sato, T.Tanaka, H.Kobayashi, et.al.,Jpn.J.Appl.Phys.Vol.28, L483 (1989), A.Mochizuki, K.Motoyoshi, and M.Nakatsuka, Ferroelectrics, 122, 37 (1991);
- [15] Y.K.Fung, D.K.Yang , et.al , Liquid Crystals., Vol.19, No.6, 797 (1995)
- [16] M.Nakagawa, M.Ishikawa and T.Akahane, Jpn.J.Appl.Phys.27, 456 (1988)
- [17] P.G.Amaya, M.A. Handschy and N.A.Clark, Opt.Eng.23, 261 (1983)
- [18] A.Sugimura., G.R.Luckhurst and Z.Ou-Yang, Phys.Rev.E. 52, 681

681(1995)

- [19] H.Wohler, M.Fritsch, G..Haas and D.A.Mlynski Proc.of Japan Display'89 , 376 (1989)