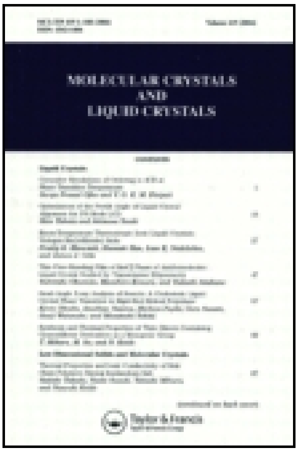


Molecular Crystals and Liquid Crystals
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gmcl18

Electrooptical Switching of Ferroelectric Liquid Crystals in Electrically Distorted Chevron Structure

M. Isogai [a] , M. Oh-e [a] , T. Kitamura [a] & A. Mukoh [a]

[a] Hitachi Research Laboratory, Hitachi, Ltd., 4026 Kuji-cho, Hitachi-shi, Ibaraki-ken, 319-12, Japan

Version of record first published: 24 Sep 2006.

To cite this article: M. Isogai , M. Oh-e , T. Kitamura & A. Mukoh (1991): Electrooptical Switching of Ferroelectric Liquid Crystals in Electrically Distorted Chevron Structure, Molecular Crystals and Liquid Crystals, 207:1, 87-96

To link to this article: http://dx.doi.org/10.1080/10587259108032090

Mol. Cryst. Liq. Cryst., 1991, Vol. 207, pp. 87–96
Reprints available directly from the publisher
Photocopying permitted by license only

Printed in the United States of America

ELECTROOPTICAL SWITCHING OF FERROELECTRIC LIQUID CRYSTALS IN ELECTRICALLY DISTORTED CHEVRON STRUCTURE

M. ISOGAI, M. OH-E, T. KITAMURA and A. MUKOH
Hitachi Research Laboratory, Hitachi, Ltd.
4026 Kuji-cho, Hitachi-shi, Ibaraki-ken, 319-12 Japan

Abstract X-ray diffraction studies on the field induced distortion of the layer structure in ferroelectric liquid crystals are reported. Depending on the liquid crystal materials and alignment layers, electric fields produced reversible or irreversible distortions. Bistable electrooptical switching was observed only in the samples with the irreversibly distorted layer structure. Experimental results on the light transmissions indicated that a bookshelf-like structure was formed in the above bistable sample. It seemed that this structure formation was essential to the bistability of the ferroelectric liquid crystals.

INTRODUCTION

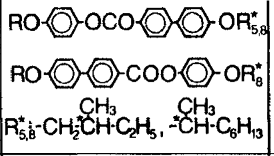
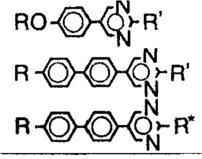
Ferroelectric liquid crystals (FLCs) have attracted considerable attention because of their potential applications to electrooptical devices. The switching behavior has been extensively investigated regarding theoretical and experimental aspects by many workers [1-5]. Recent X-ray experiments indicate that a chevron layer structure is formed in FLC cells prepared with planar boundary conditions and the director reorientation under an electric field should be investigated assuming this layer structure[6-8]. It has also been reported that the initial chevron structure is not stable and a quasibookshelf structure is irreversibly taken under an electric field with low frequency [9,10]. Several models presented on the director reorientations in a rigid layer structure[4,5] then should be slightly modified accordingly. In this paper, we report the X-ray diffractions of FLCs under an applied electric field. The frequency and the applied voltage dependence are presented. The FLC materials and alignment layer difference in the smectic layer distortions are also reported and the relation between bistability and the layer structure is discussed.

EXPERIMENTAL

Two FLC materials, Compound A with large spontaneous polarization (Ps) and relatively high viscosity and Compound B with relatively small Ps and low viscosity, were used (Table I). Both compounds are in the Sc* phase at room temperature and all the X-ray experiments were carried out at 23°C without any temperature control. Each material was sandwiched between two, rubbed polyimide film coated ITO glass plates. Glass thickness was about 0.1mm and the transmittance of X-rays (Cu Kα line) was about 20%. Silica beads were used as spacers and sample cells of 1.8-2.5μm were fabricated.

The X-ray scattering measurements were made using a Rigaku RU-200 (60kV,200mA). On the experimental procedure and the scattering geometry, we followed former papers [6-8]. That is, the Bragg angle of each material was measured at first. Next, a detector was set at the Bragg angle and then the X-ray diffraction was observed by rotating the sample cell.

Table I. FLC Materials Used in Experiments

	Compound A	Compound B
Main Components	 $R^{*}_{5,8}$: $-CH_2-\overset{CH_3}{\overset{*}{C}H}-C_2H_5$, $-\overset{CH_3}{\overset{*}{C}H}-C_6H_{13}$	
Phase Transition (°C)	$S_1 \xrightarrow{5} S_{C^*} \xrightarrow{67} S_A \xrightarrow{80} N^* \xrightarrow{89} I$	$Cr \xrightarrow{-4} S_{C^*} \xrightarrow{63} S_A \xrightarrow{80} N^* \xrightarrow{92} I$
P_S (nC/cm^2)	92.0 (25°C)	18.8 (25°C)
Mol. Tilt θ	31.0 (25°C)	22.0 (25°C)
Viscosity (Pa·s)	3.81 (25°C)	0.359 (25°C)
Bistability	rubbed Polyimide (strong anch.)	obl. evap. SiO (weak anch.)

EXPERIMENTAL RESULTS AND DISCUSSION

Table II lists the experimental results on the layer spacing, initial layer structure and layer tilt angle in each material cell. The molecular length of the main components is reflected in the layer spacing of each material. The X-ray scattering profiles for initial samples showed typical patterns of the chevron layer structure. The director orientation structures were considered to be uniform states, based on polarizing microscope observations. The uniform orientation in the chevron layer structure is depicted in Fig. 1. Since the layer tilt angle is smaller than the molecular tilt angle (Table II), the cones which express the director motions on the upper and lower sides of the chevron structure intersect at the center of the cell, as shown in the figure. Two intersections indicate the possible director orientations. The cone angle 2β is defined as the angle between two director orientations, as shown in Fig. 1, and is given as a function of θ and δ as follows,

$$\beta = \cos^{-1} (\cos \theta / \cos \delta).$$

Table II. Initial Layer Structures

	Compound A	Compound B
Director Orientation	Uniform	Uniform
Layer Spacing	30.9 Å (23 °C)	28.1 Å (23 °C)
Layer Structure	Chevron	Chevron
Layer Tilt Angle δ	24.8° (23 °C)	19.9° (23 °C)
Cone Angle 2β	38.4°	19.2°

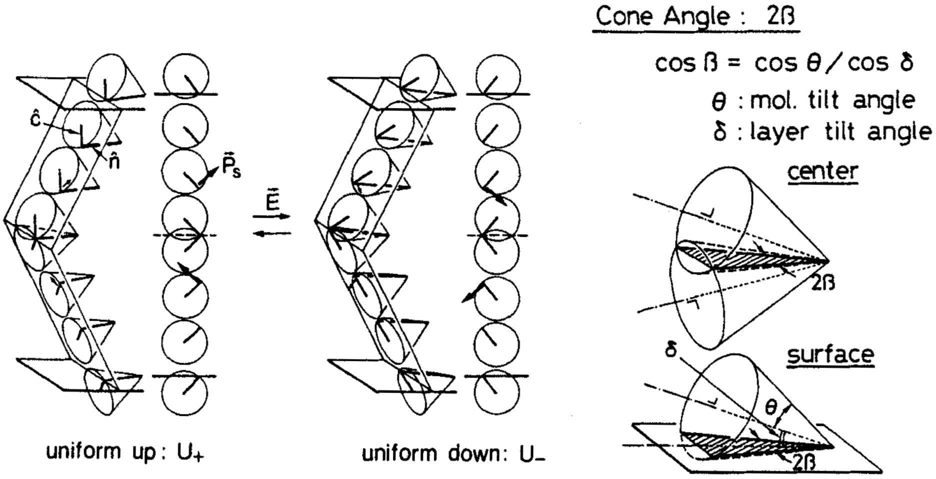


Figure 1. The initial chevron layer structure and the uniform orientation states.

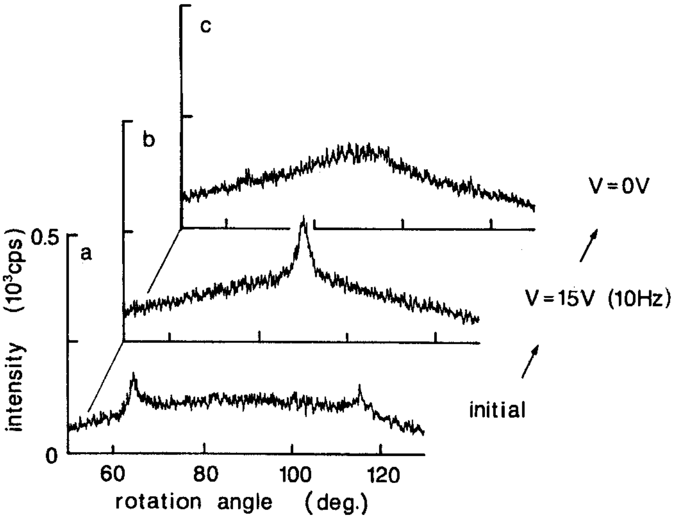


Figure 2. X-ray scattering profiles for Compound A of the samples (a) initially, (b) under a 15V square wave field of 10Hz and (c) after the electric field was removed.

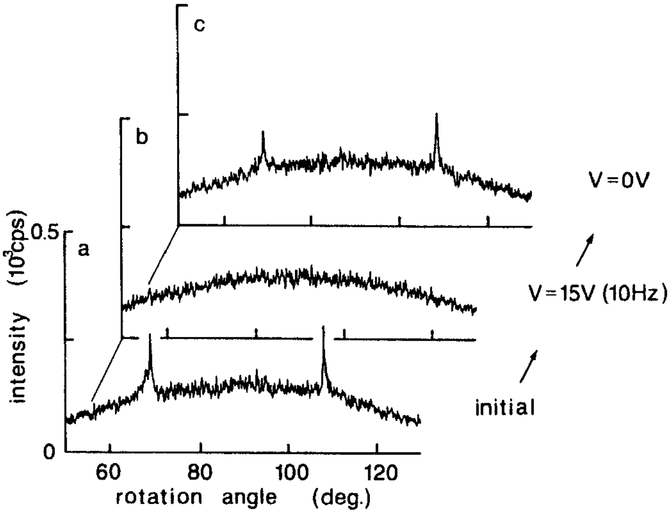


Figure 3. X-ray scattering profiles for Compound B of the samples (a) initially, (b) under a 15V square wave field of 10Hz and (c) after the electric field was removed.

Calculated results of the cone angles are also listed in Table II. There was a big difference between the two materials. Domains corresponding to uniform up and down states were observed by the polarizing microscope and the direction of the molecular alignment in each domain was determined by rotating the sample. The experimental values of the cone angle were consistent with the calculated ones.

Figures 2 and 3 show the respective X-ray diffraction patterns for Compounds A and B initially, under an electric field and after the electric field was removed. In the case of Compound A, the double peaks corresponding to the chevron structure disappeared and the center peak corresponding to the bookshelf structure appeared by applying the 15V/10Hz square wave (Fig. 2(b)). After the electric field was removed, the center diffraction peak became broader but did not disappear. On the other hand, no peak was observed under the same electric field in the case of Compound B (Fig. 3(b)). Furthermore, almost the same X-ray scattering profile as the initial state appeared after removal of the electric field. That is, an irreversible layer distortion occurred in the sample with Compound A, while it was reversible with Compound B. In the former case, the chevron - bookshelf - quasibookshelf structure change occurred, but in the latter case, the chevron - distorted chevron (quasibookshelf) - chevron structure change occurred.

Figure 4 shows the frequency dependence of the X-ray diffraction patterns for Compound A. A sharp center peak was observed at 10 to 100Hz but this disappeared at 500Hz. No peak corresponding to the chevron structure was observed at any frequency. This characteristic indicated that several milliseconds was required to reform the layer structure from the chevron to the bookshelf one. The applied voltage dependence of the center peak

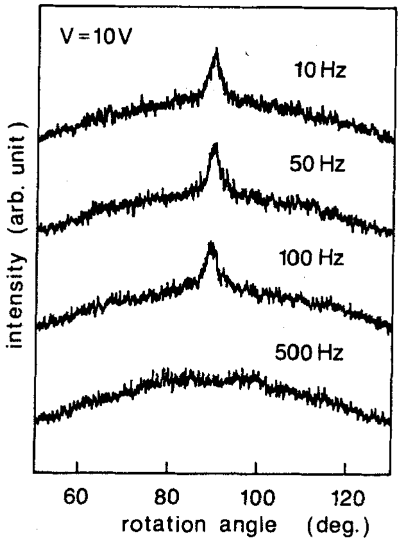


Figure 4. The frequency dependence of the X-ray scattering profiles for Compound A.

intensity is depicted in Fig. 5 as a function of the frequency. Here, the center peak grew according to the applied voltage and saturated at about 10V for 10Hz and 15V for 20Hz. However, there was no big difference in the threshold voltage and the saturated voltage between 10 and 20Hz. The origin of the layer distortion was thought to be the electrostatic torque caused by the electric field and the spontaneous polarization. Therefore the response time for the layer distortion should be inversely proportional to the applied voltage. This seems to be inconsistent with the results in Fig. 5, although the mechanism is well explained.

The layer distortion mechanism is shown in Fig. 6 schematically. The director changes direction during several tens of microseconds. But the spontaneous polarization is not parallel to the electric field because of the layer tilt at this stage. Electrostatic torque remains after the director reorientation is finished for the same reason, and produces the layer distortion. The direction of the distortion is depicted in Fig. 6 using small arrows. A small distortion takes place during several hundred microseconds and a large distortion, such as the formation of the bookshelf structure, does in several milliseconds, provided that the bookshelf structure formation is restricted to certain materials. At this stage, let's suppose that the reverse field is applied. The director, and therefore the spontaneous polarization would reorient rapidly. The directions of the polarization as well as the electric field are reversed but the direction of the torque does not change. That is, the same force which causes the layer distortion acts all the time when the square wave field is applied excluding the time for the director reorientation. In the low frequency case, the time for the reorientation is negligibly small compared to the pulse width, therefore the voltage which induces the layer distortion is not strongly dependent on the frequency. On the other hand, since the pulse width comes close to the reorientation time in the high frequency case, the torque is not sufficient and the layer is not distorted.

Next, the difference in the layer distortions between two materials is discussed. The spontaneous polarization of Compound B is about one third that of Compound A, hence the electrostatic torque should also be one third under the same electric field. Then, a 30V/10Hz square wave was applied to the sample with Compound B and X-ray scat-

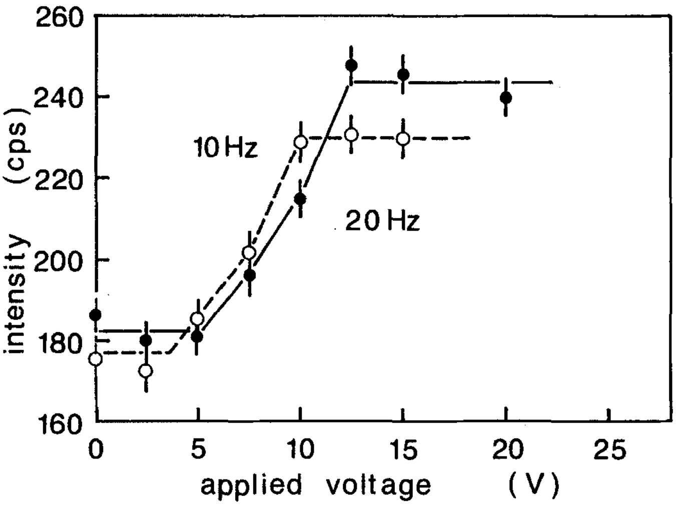


Figure 5. The X-ray intensity of the center diffraction peak vs. the applied voltage for 10Hz and 20Hz.

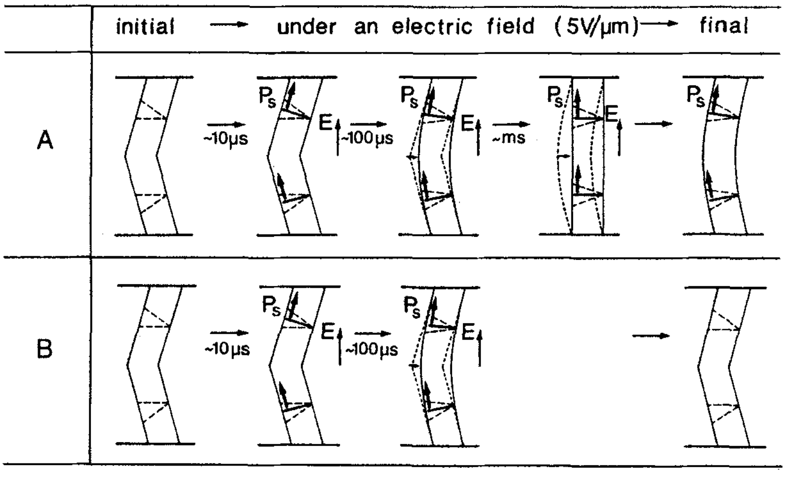


Figure 6. Schematic of layer distortion for Compound A and B.

tering experiments were carried out. The results showed that no bookshelf structure was produced for Compound B even under 30V. That is, the difference in the layer distortion is not due to the torque, but to other factors. Then, attention is given to the elasticity of the materials. The elastic constant of Compound A is much larger than Compound B from the electrooptic response[11]. A large spontaneous polarization also increases the effective elastic constant[12,13]. In the material with large elastic constant, the uniform director orientation is favorable and the deformed orientation structure is restricted by coupling of the spontaneous polarization and the deformation induced local field. Suppose that there is the same difference in the elasticity for the layer distortion as in the elasticity for the director orientation discussed above. Compound A has a large elastic constant, therefore the layer is hard and does not bend easily. When the distortion energy exceeds the surface pinning energy, the layer structure becomes the bookshelf structure. On the other hand, Compound B has a small elastic constant, and the layer bends easily. The distortion energy never exceeds the surface pinning energy, the bookshelf structure is not formed and the initial chevron structure is reformed after the electric field is removed.

Finally, the relation between bistability and the layer structure is discussed. Bistable electrooptical switching was observed in the sample cell of Compound A,but no of Compound B. The two states in the bistable switching for Compound A were considered to be uniform states. The cone angle, i.e. the angle between the two stable director orientations was 60.2°. Considering the initial cell was only 38°, as shown in Table II, there was a big difference between the operating cell and the original cell. This was due to layer distortions and was consistent with the results of X-ray scattering. In this system, we concluded that the director reorientations occur in the distorted layer structure, i.e. the quasibookshelf structure. Theoretical calculations also supported the electrooptical switching in the quasibookshelf structure.

Other experimental investigations on the Compound B showed that the bistable behavior was observed in the cell with an SiO oblique evaporated film as the alignment layer. The X-ray scattering profiles of the cell showed irreversible layer distortions, however the sharp center peak was not observed. In this case, the pinning energy of the surface was considered to be much smaller than for the case of a polyimide surface and the distortion energy would become comparable.

CONCLUSION

X-ray diffraction studies on the field induced distortion of the layer structure in ferroelectric liquid crystals were carried out, and electrooptical switching of two ferroelectric liquid crystal materials was examined. Experimental observations indicated that an electric field induced the director reorientation and the layer distortion in FLC materials. The distortion, in the materials with a large spontaneous polarization (Ps) and presumably a large elastic constant for director distortion, was irreversible and the bookshelf structure was formed under an electric field with low frequency. On the other hand, the distortion in materials with a small Ps and low viscosity was reversible, and the chevron structure was reformed after the electric field was removed. Bistable behavior of FLCs was observed in the cell with the irreversively distorted layer structure, i.e. quasibookshelf structure. Above experimental results indicate that an irreversible layer distortion is required for the bistability, in another word a quasibookshelf layer structure is necessary for the bistable switching. This assumption have to be checked and proved actually. More profound studies will be done and the bistability mechanism will be clarified. Future problems are to clarify the relations between the bistability and the layer distortions and to establish a new model in which the director reorientation and the layer distortion occur simultaneously.

ACKNOWLEDGMENTS

The authors would like to acknowledge Dr. Kondo for his useful suggestions. The authors also thank Mr. Hanawa and Mr. Kawabata for their experimental assistance.

REFERENCES

1)M.A. Handschy et al.: Phys. Rev. Lett. 51 (1983) 471
2)J. Pavel: J. Phys. (Paris) 45 (1984) 137
3)A. Jakli et al.: Mol. Cryst. Liq. Cryst. 43 (1989) 43
4)J.E. Maclennan et al.: Liq. Cryst. 7 (1990) 753
5)J.E. Maclennan et al.: Liq. Cryst. 7 (1990) 787
6)T.P. Rieker et al.: Phys. Rev. Lett. 59 (1987) 2658
7)Y. Ouchi et al.: Jpn. J. Appl. Phys. 27 (1988) L725
8)Y. Ouchi et al.: Jpn. J. Appl. Phys. 27 (1988) L1993
9)Y. Sato et al.: Jpn. J. Appl. Phys. 28 (1989) L483
10)W.J.A.M. Hartman and A.M.M. Luyckx-Smolders: J. Appl. Phys. 67 (1990) 1253
11)M. Isogai et al.: Proc. The 6th Int. Display Res. Conf. 12.5 p.472 (1986)
12)K. Okano: Jpn. J. Appl. Phys. 25 (1986) L846
13)M. Nakagawa and T. Akahane: J. Phys. Soc. Jpn. 55 (1986) 1516