Title	Dynamic response of electro-optic effect in free-standing ferroelectric liquid crystal film
Author(s)	Uto, Sadahito; Ohtsuki, Hideyo; Ozaki, Masanori et al.
Citation	Applied Physics Letters. 1996, 69(11), p. 1503-1505
Version Type	VoR
URL	https://hdl.handle.net/11094/75845
rights	
Note	

Applied Physics Letters

Dynamic response of electro-optic effect in free-standing ferroelectric liquid crystal film

Cite as: Appl. Phys. Lett. **69**, 1503 (1996); https://doi.org/10.1063/1.117985
Submitted: 16 April 1996 . Accepted: 15 July 1996 . Published Online: 04 June 1998

Sadahito Uto, Hideyo Ohtsuki, Masanori Ozaki, and Katsumi Yoshino

Dynamic response of electro-optic effect in free-standing ferroelectric liquid crystal film

Sadahito Uto, Hideyo Ohtsuki, Masanori Ozaki, and Katsumi Yoshino[a)]
Department of Electronic Engineering, Faculty of Engineering, Osaka University, 2-1 Yamada-Oka, Suita, Osaka 565, Japan

(Received 16 April 1996; accepted for publication 15 July 1996)

A study of an electro-optic response in a free-standing ferroelectric liquid crystal film has been carried out. The response time becomes shorter with increasing electric field and, especially at a certain threshold of electric field, it changes in stepwise by three orders of magnitude. The response time of the faster kind of response that appears in the higher field region is several hundred milliseconds and is about one thousand times faster than the slower kind of response at lower fields. © *1996 American Institute of Physics.* [S0003-6951(96)02137-7]

Ferroelectric liquid crystals have been attracting considerable attention in the field of electro-optic devices because of quick electro-optic effects. So far, various types of electro-optic effects using light scattering or birefringence change by field have been reported, such as, the deformation of helicoidal structure[1,2] and the transient scattering mode[3] as the former types, and the surface-stabilized ferroelectric liquid crystal (SSFLC),[4] the soft mode ferroelectric liquid crystal (SMFLC),[5] and the deformed helical ferroelectric[6] as the latter types. All of them have used the normal cells in which liquid crystal is sandwiched between two glass plates.

On the other hand, a free-standing (FS) film has been studied as a thin two-dimensional liquid crystal system in which the smectic layers are oriented parallel to the FS film surface, that is, phase transition and regularly arrayed spontaneous disclination lines in FS films have attracted attentions.[7–13] Recently, the electro-optic behavior of FS film has also been reported by us.[14] However, electro-optic effects of FS film have scarcely been studied, especially concerning a dynamic response.

In this work, a study of a dynamic electro-optic response in a free-standing ferroelectric liquid crystal film is carried out, and a discontinuous dependence of electro-optic response on applied electric field is reported. According to polarized optical microscopic observations, a speculation about a mechanism of the response is presented.

The ferroelectric liquid crystal used in this study was (*R*)-4-(1-butoxycarbonyl-1-ethoxy) and 4-[4-(*n*-octyloxy)phenyl]benzoate (1BC1EPOPB).[15] All experiments were carried out at 65 °C in the SmC* phase. Free-standing film was prepared across two aluminum plates that were also used as electrodes to apply the uniform electric field to the FS film. Two polyethyleneterephthalate (PET) sheets were set between the aluminum plates, as shown in Fig. 1. The sample was loaded in the free area surrounded by the Al plates and PET sheets. The gap length between the Al plates was 2 mm. One of the PET sheets can slide along the electrode to expand the FS film. By this procedure the thickness of the FS film can be varied. The FS film was contained in an oven that allows light transmission.

For the electro-optic measurements, the beam of a He–Ne laser ($\lambda=632.8$ nm) impinged on the FS film with an incident angle of 45° and perpendicular to the applied field after passing through a polarizer and a $\lambda/4$ compensator. The diameter of the beam was about 1.5 mm. The optical axis of the compensator was fixed with an angle 45° with respect to the incident plane of the FS film. The transmitted light was detected by a photomultiplier after passing through an analyzer. If we know a single layer thickness and principal refractive indices of liquid crystal, the thickness of the FS film can also be calculated by this ellipsometry.[16] In this study, the single layer thickness of 1BC1EPOPB was estimated with x-ray diffraction as 3.4 nm. The principal refractive indices of 1BC1EPOPB have not been measured yet, therefore, we used common values in FLC of 1.49 and 1.64 for ordinary and extraordinary lights, respectively. However, it should be mentioned that evaluated FS film thickness does not change notably even if the refractive indices change slightly.

A dynamic electro-optic response upon application of rectangular wave form of voltage was measured. Since the birefringence of the thin FS film was too small to detect by using only the crossed polarizers, we also used the $\lambda/4$ compensator, and regulated the polarizer and the analyzer to be the minimum transmission intensity when the negative field was applied. Figure 2 shows typical transmission responses of the FS film with 28 smectic layers, when an applied field is switched from positive to negative. It should be noted that the response speed is quite different depending on the applied field. While almost 1 s is required for the transmission change at lower electric field as shown in Fig. 2(a), several hundred μs are required at high field as in Fig. 2(b). It has

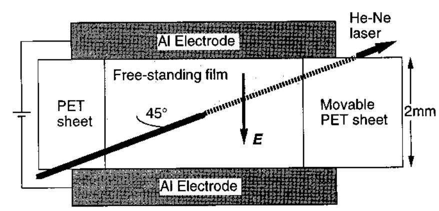

FIG. 1. The free-standing film geometry. At first, the movable sheet is closed and the FLC is supplied to the gap between the two sheets. The FS film is made by sliding the movable sheet.

[a)]Electronic mail: yoshino@ele.eng.osaka-u.ac.jp

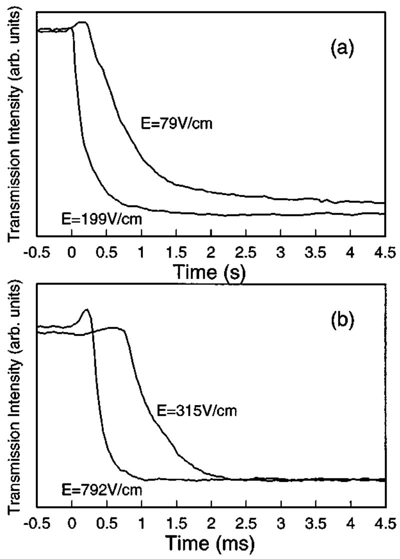

FIG. 2. Transmission curves of the free-standing film for the various applied field.

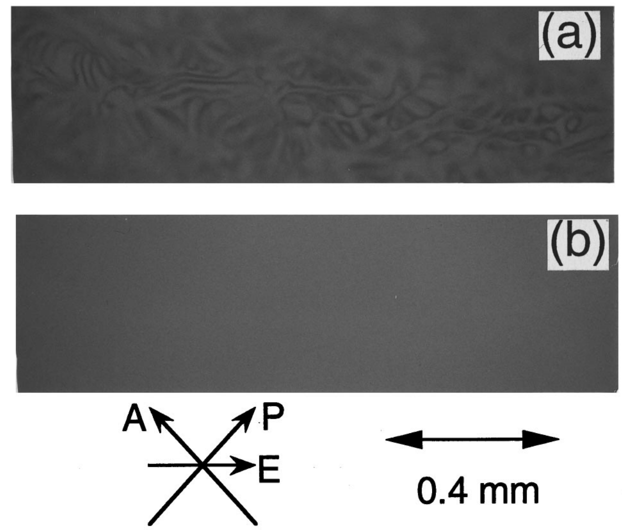

FIG. 4. Polarizing microscopic photographs of the free-standing film immediately after the field reversal from positive to negative: (a) for 0.05 kV/cm in the lower field region and (b) for 0.5 kV/cm in the higher field region.

been confirmed that the molecule can be sufficiently oriented even by low field.[14]

Figure 3 shows a field dependence of the response time that is defined as the time required for the transmission change from 10% to 90%. It should be mentioned that the response time discontinuously changes at about 0.2 kV/cm. The rise time at the higher field region is about one thousand times faster than that at the lower field region. This suggests that there are two types of the electro-optic switching in the FS film and they are distinguished at threshold field E_{th}.

In order to clarify the origin of the above anomalous effect, the FS film with 28 smectic layers under a rectangular field of frequency of 0.05 Hz has been observed using a polarizing microscope. The direction of the observation was the same as the direction of the incident light used in the electro-optic measurement discussed above. That is, the film normal was inclined by 45° and the applied electric field was always perpendicular to the direction of the observation. Figure 4 shows the polarizing optical microphotographs of the FS film just after the field reversal from positive to negative. The angle between the applied electric field and the azimuthal angle of the crossed polarizers was 45°.

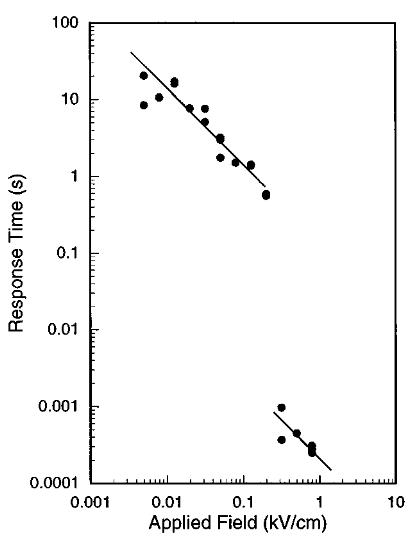

FIG. 3. Field dependence of the response time. Both lines in this figure are in proportion to E^{-1}.

While a uniform state in which the molecules are uniformly oriented by the applied electric field is observed in the higher field region than E_{th}, a multidomain texture is observed in the lower field region, as shown in Fig. 4. The difference of the observed textures should be concerned with the origin of the discontinuous property of the response speed, and the mechanisms of this switching can be speculated as follows.

When the polarity of the applied field is reversed, the c director begins to be reoriented to minimize the electrostatic energy $g_p = -\mathbf{P}_s \cdot \mathbf{E}$. The rotational sense of the c director in the film, however, has local variation, so that uniform texture is divided into domains in which the c-director points in the different directions, resulting in the formation of disclinations. In the case of the lower field, these disclinations are squeezed into π wall or circular π wall by the applied field.[11] That is, favorable domains in which g_p is minimum spread with squeezing other domains with high g_p. However, domains and disclinations do not disappear immediately since the electrostatic effect due to the low field is too small to dominate the elastic energy. Namely, the optical switching is attributed to the alternation of the favorable domain under the field and is accompanied by the movement of the disclination. In other words, the behavior of c director at lower field with keeping the domain structure is associated with the helical deformation at the low field that cannot wind the helix. This is the switching mechanism in the lower field region.

On the other hand, at higher applied field than E_{th}, the electrostatic energy overcomes the elastic energy and the kinks of c director at disclination are broken by applied field, so that the molecules are reoriented at once without complicated procedures such as the domain squeezing and spreading. Therefore, the switching at the higher field corresponds to the polarity reversal in the common sandwich cell, which is associated with the Goldstone mode.

Consequently, in this discussion, it can be concluded that the threshold field of the response speed is concerned with the field strength that can break the kink of the *c* director. The response speed in the high field region may be mainly limited by viscosity; on the other hand, in the lower field region, more complicated consideration including a distortional energy of orientation and flexoelectric effect concerned with a bend deformation may be needed. Detailed mechanisms are now under investigation.

This work can be summarized as follows. (1) Dynamic electro-optic response of thin free-standing ferroelectric liquid crystal film was studied. (2) The discontinuous dependence of the electro-optic response on the applied field was found. (3) From the polarized optical microscopic observations, it was clarified that there are two types of reorientation processes. (4) The origin of the discontinuous dependence of the electro-optic response and the switching mechanisms were discussed.

The authors thank H. Taniguchi and Dr. K. Satoh of Daicel Chemical Industries, Ltd. for providing the ferroelectric liquid crystal material used in this study. A part of this work was supported by a Grant-in-Aid for Scientific Research from the Ministry of Education, Science, Sports and Culture.

[1] K. Yoshino, K. G. Balakrishnan, T. Uemoto, Y. Iwasaki, and Y. Inuishi, Jpn. J. Appl. Phys. **17**, 597 (1978).
[2] M. Ozaki, S. Kishio, K. Yoshino, N. Mikami, R. Higuchi, and T. Sakurai, Proc. 6th Meet. Ferroelectric Materials and Their Applications, Kyoto 1987 [Jpn. J. Appl. Phys. **26**, Suppl. 26-2, 110 (1987)].
[3] K. Yoshino and M. Ozaki, Jpn. J. Appl. Phys. **23**, L385 (1984).
[4] N. A. Clark and S. T. Lagerwall, Appl. Phys. Lett. **36**, 899 (1980).
[5] G. Andersson, I. Dahl, P. Keller, W. Kuczynski, S. T. Lagerwall, K. Sharp, and B. Stebler, Appl. Phys. Lett. **51**, 640 (1987).
[6] L. A. Beresnev, L. M. Blinov, and D. I Dergachev, Ferroelectrics **85**, 173 (1988).
[7] C. Rosenblatt, R. B. Meyer, R. Pindak, and N. A. Clark, Phys. Rev. A **21**, 140 (1980).
[8] D. H. V. Winkle and N. A. Clark, Phys. Rev. A **38**, 1573 (1988).
[9] S. M. Amador and P. S. Pershan, Phys. Rev. A **41**, 4326 (1990).
[10] R. B. Meyer and P. S. Pershan, Solid State Commun. **13**, 989 (1973).
[11] R. Pindak, C. Y. Young R. B. Meyer, and N. A. Clark, Phys. Rev. Lett. **45**, 1193 (1980).
[12] J. Maclennan, Europhys. Lett. **13**, 435 (1990).
[13] Ch. Bahr and D. Fliegner, Liq. Cryst. **14**, 573 (1993).
[14] S. Uto, H. Ohtsuki, M. Terayama, M. Ozaki, and K. Yoshino, Jpn. J. Appl. Phys. **35**, L158 (1966).
[15] H. Taniguchi, M. Ozaki, K. Yoshino, K. Satoh, and N. Yamasaki, Ferroelectrics **77**, 137 (1988).
[16] Ch. Bahr and D. Fliegner, Phys. Rev. A **46**, 7657 (1992).