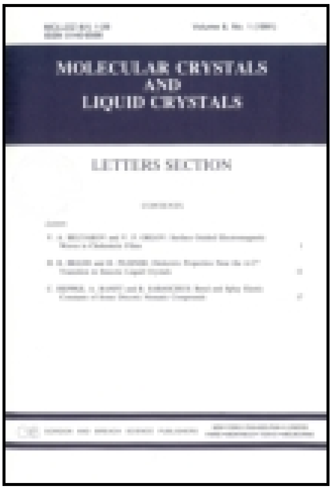

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Application of Ferroelectric Liquid Crystals to Optical Devices

J. Akaogi[a], Y. Koizumi[ab], M. Ono[ab] & H. Furue[a]

[a] Department of Materials Science and Technology, Tokyo University of Science, Katsushika, Tokyo, Japan

[b] Funai Electric Advanced Technology Research Institute, Tsukuba, Ibaraki, Japan

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Application of Ferroelectric Liquid Crystals to Optical Devices

J. AKAOGI,[1,*] Y. KOIZUMI,[1,2] M. ONO,[1,2] AND H. FURUE[1]

[1]Department of Materials Science and Technology, Tokyo University of Science, Katsushika, Tokyo, Japan
[2]Funai Electric Advanced Technology Research Institute, Tsukuba, Ibaraki, Japan

Liquid crystals (LCs) are attractive for optical devices, such as lenses because of their large birefringence and high response to external field. However, the low-speed response of nematic LCs often becomes an obstacle to the progress of LC devices. In this study, we research the lens effect of ferroelectric LC by using a voltage-gradient cell. As a result, it is found that in order to obtain the lens effect in FLC, the wide cell gap, the large tilt angle and/or the large birefringence of FLC materials are necessary to increase the birefringence variation under the gradient voltage in addition to the monostabilization of FLC media.

Keywords Ferroelectric liquid crystal; lens; wide cell gap; polymer stabilization; birefringence; voltage gradient cell

1. Introduction

Liquid crystals (LCs) are attractive for optical devices such as displays, optical modulators, and lenses because of large birefringence and high response to external field. The optical properties of LCs are easily controllable electrically. However, the low-speed response of nematic (N) LCs used extensively for display applications often becomes an obstacle to the progress of LC devices. Therefore, it is necessary to replace a conventional NLC with new LC material in order to realize high-speed performance of LC devices. A leading candidate is ferroelectric LC (FLC) [1–5]. Devices with μs-order response time can be realized by using FLCs. An LC lens has major advantages such as high-speed response, compactness, light weight, and low electrical consumption in comparison with a mechanical lens. LC lenses fabricated using NLCs have been reported by many research groups [6–12]. In order to realize a high performance of the lens effect, it is necessary to set the thickness of the LC film or the LC cell gap large. We undertake to apply FLC to the lens to realize a much faster electro-optical response. In this study, we research the lens effect of FLC by using a voltage-gradient cell.

*Address correspondence to Junichi Akaogi, Department of Materials Science and Technology, Tokyo University of Science, Katsushika, Tokyo 125-8585, Japan. Tel.: +81-3-5876-1717; Fax: +81-3-5876-1614. Email: hfurue@rs.noda.tus.ac.jp

Table 1. Properties of FH-8002N.

Properties	
Phase sequence	Cryst.(-19)SmC*(62)SmA(76)N*(82)Iso. [°C]
Spontaneous polarization	25nC/cm2 (at room temp.)
Tilt angle	22° (at room temp.)

2. Experimentals

The following materials were used: the NLC and FLC were E8 (LCC) and FH-8002N (DIC), respectively, and the LC alignment film was polyimide RN1199 (Nissan Chemical Industries) that induced a defect-free FLC molecular alignment with the C2-chevron structure [13,14]. The relevant properties of FH-8002N given in the catalogue are shown in Table 1. The conventional FLC cells were fabricated for researching the characteristics of FLC itself as follows: a solution of polyimide was spun onto glass substrates coated with indium-tin oxide (ITO) and then baked. After the thermal treatment, the substrates were rubbed. Then, the FLC was injected in the isotropic phase via capillary action into an empty cell fabricated using a pair of substrates, in which the rubbing directions and the cell gap between the two substrates were set parallel and 10 μm. Furthermore, the voltage-gradient cells were fabricated for researching the lens effect by using the following substrates: the upper substrate was a glass substrate coated ITO, and the lower substrate was a substrate coated with Au and ITO, as shown in Fig. 1. The cell fabricated using those substrates can make a voltage gradient between their substrates. The cell gap was set 10, 13, or 20 μm.

LC cells fabricated by the above method were observed with a conventional polarizing microscope and a 550 nm interference filter. The lens effect was researched by using a laser of 532 nm. The laser spot onto screen was observed using the optical measuring system, as shown in Fig. 2. Two linear polarizers were used for the control of the light intensity and the polarized plane direction of the laser.

3. Results and Discussion

The photographs of the microscopic textures and the laser spots in the voltage gradient cells (cell gap: 10 μm) of NLC and FLC under the application of electric field are shown in

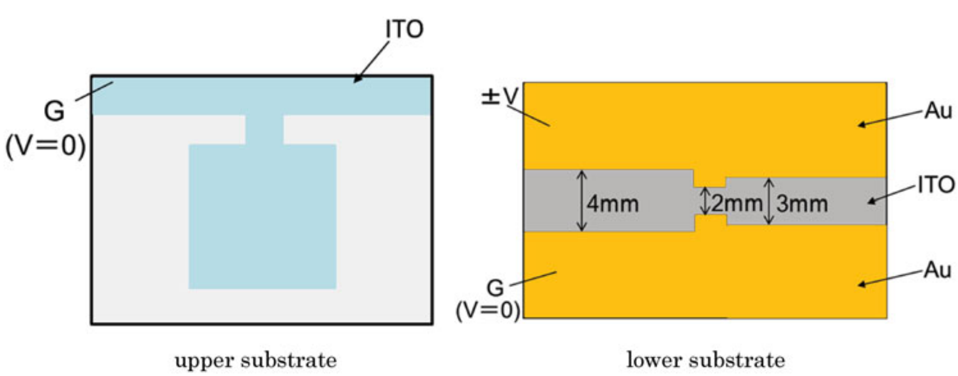

Figure 1. Illustration of substrates used in a voltage-gradient cell.

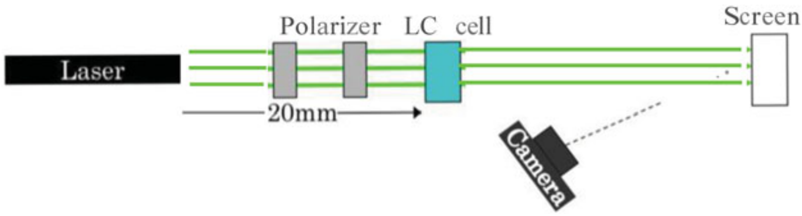

Figure 2. Schematic diagram of an optical system for researching lens effect.

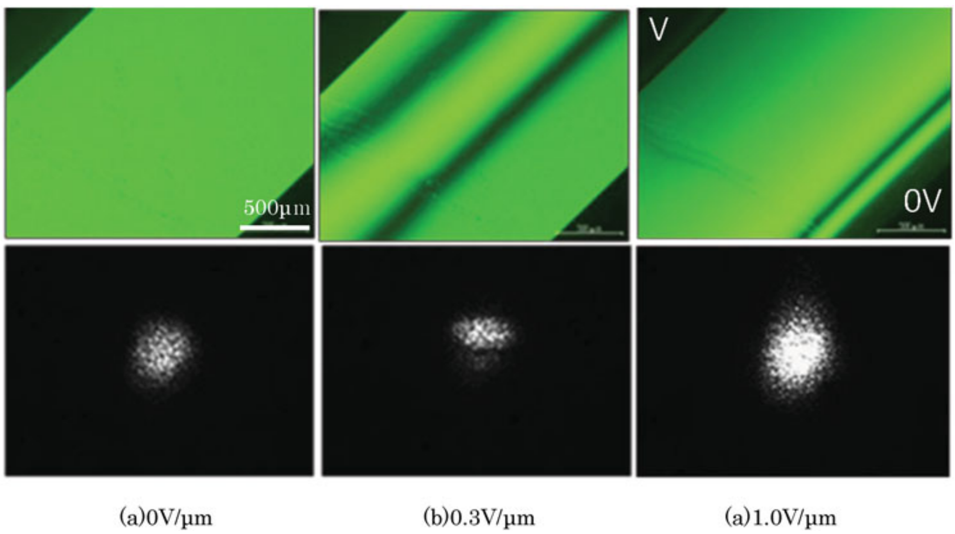

Figure 3. Photographs of microscopic textures and laser spots in a voltage gradient cell of NLC (cell gap: 10 μm).

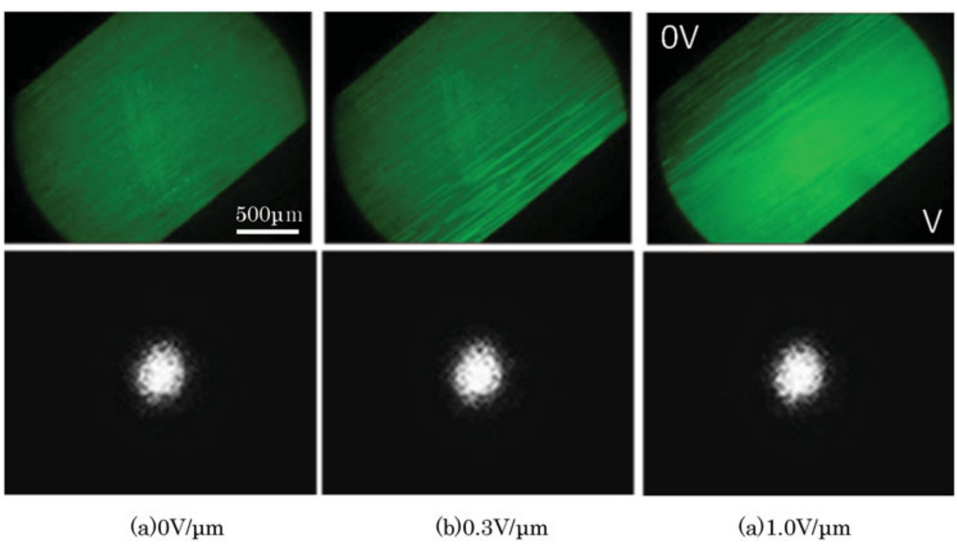

Figure 4. Photographs of microscopic textures and laser spots in a voltage gradient cell of FLC (cell gap: 10 μm).

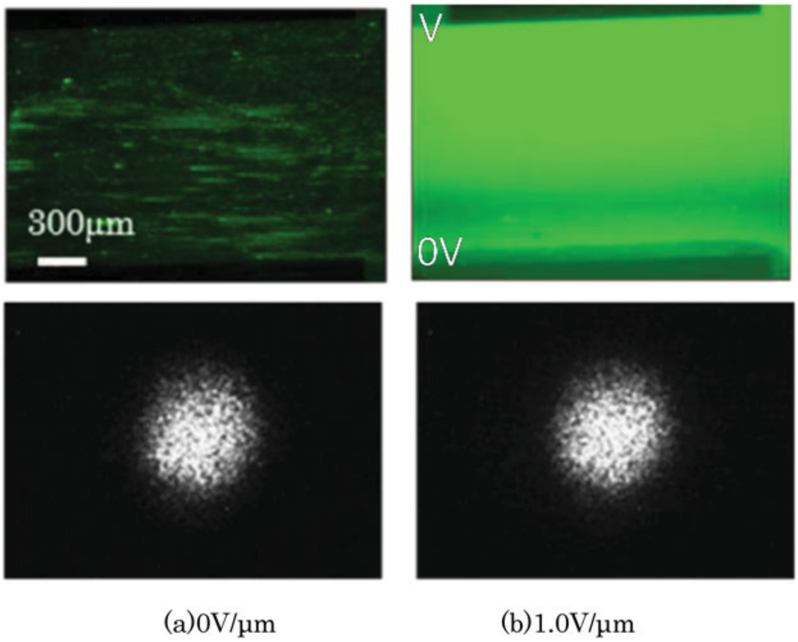

Figure 5. Photographs of the microscopic textures and the laser spots in a voltage gradient cell FLC (cell gap: 13 μm).

Figure 6. Photographs of the microscopic textures and the laser spots in a voltage gradient cell of FLC (cell gap: 20 μm).

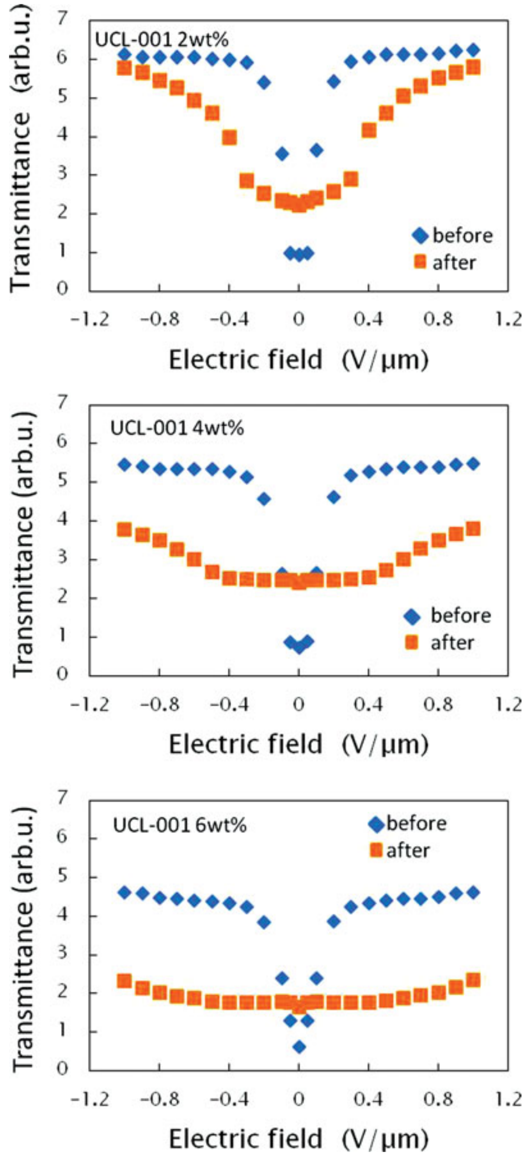

Figure 7. Electro-optical characteristics of FLC doped with mesogenic photocurable monomer before and after UV photocure.

Figs. 3 and 4, respectively. In the NLC cell, a fringe pattern appears by applying an electric field. The fringe spacing becomes narrow and fringe pattern gradually shifts to the lower right corner in the texture with the increase of the applied electric field, and then, the lens effect can be observed in the laser spot in the case of 0.3 V/μm. On the other hand, in the FLC cell, the optical gradation can be observed but it is almost bistable, and the fringe pattern does not appear in the textures. As a result, the lens effect is not almost observed in the laser spot. It is considered that the amount of birefringence variation is small compared with NLC due to the different switching mechanism between FLC and NLC. Futhermore,

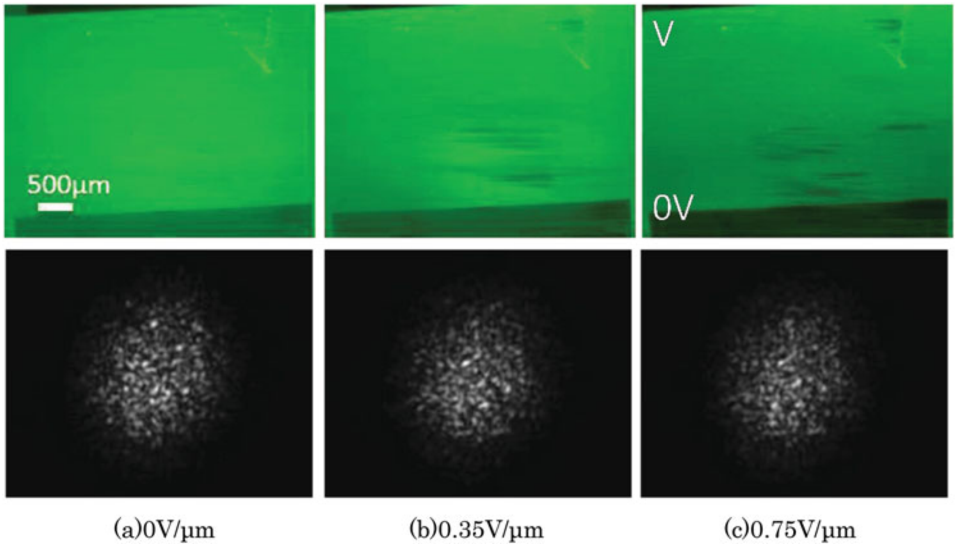

Figure 8. Photographs of microscopic textures and laser spots in a voltage gradient cell of polymer-stabilized FLC fabricated using 2 wt% UCL-001.

the bistable switching of FLC molecules give rise to discontinuous birefringence variation. Therefore, in order to obtain the lens effect, the thicker cell gap is needed for FLC cell. Then, the photographs of the microscopic textures and the laser spots in the cases of 13 and 20 μm cell gap are shown in Figs. 5 and 6, respectively. It is found that the optical variation of the texture becomes more obvious as increasing the cell gap. However, the bistable switching almost remains even in 20 μm cell gap. As a result, the laser spot pattern is hardly changed and the lens effect cannot be obtained.

Since it is thought that the discontinuous birefringence variation due to the bistable switching of FLC is a reason that the lens effect cannot be obtained, we try to monostabilize the FLC by polymer stabilization technique. Figure 7 shows the electrooptical characteristics in the conventional cells of FLC doped with mesogenic photocurable monomer UCL-001(DIC) before and after UV photocure (365 nm, 20 mW/cm^2, 1min). It is found that the transmittance variation becomes continuous by the polymer stabilization. However, the transmittance variation becomes small due to the increase of the switching voltage of FLC molecules as the increase of polymer concentration. Figure 8 shows the photographs of the microscopic textures and the laser spots in a voltage- gradient cell of polymer-stabilized FLC fabricated using 2 wt% UCL-001 (cell gap: 10 μm). It is found that the optical variation of the texture is continuous due to the monostabilization of FLC mediun by the polymer stabilization. However, the fringe pattern as shown in the case of NLC does not appear. As a result, although the laser spot pattern can be changed, the obvious lens effect as seen in the case of NLC cannot be obtained. Therefore, it is concluded that in order to obtain the lens effect in FLC, the wide cell gap, the large tilt angle and/or the large birefringence of FLC materials are necessary to increase the birefringence variation under the gradient voltage in addition to the monostabilization of FLC media.

4. Conclusions

We researched the lens effect of FLC by using a voltage-gradient cell. Although the optical variation of the texture becomes obvious as increasing the cell gap, the bistable switching almost remains and the lens effect cannot be obtained even in 20 μm cell gap. Since it is thought that the bistable switching of FLC is a reason that the lens effect cannot be obtained, we try to monostabilize the FLC by polymer stabilization technique. As a consequence, the birefringence variation of FLC becomes continuous by the monostabilization. However, althought the laser spot pattern can be changed, the obvious lens effect as seen in the case of NLC cannot be obtained. Therefore, it is concluded that in order to obtain the lens effect in FLC, the wide cell gap, the large tilt angle and/or the large birefringence of FLC materials are necessary to increase the birefringence variation under the gradient voltage in addition to the monostabilization of FLC media.

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