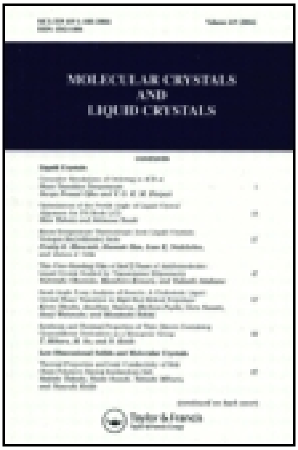

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DESIGNING OF SMECTIC LAYER ALIGNMENT BY OPTICAL PATTERNING USING SMECTIC LAYER ROTATION

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We have proposed and demonstrated two optical patterning methods for designing smectic layer alignment based on smectic layer rotation induced by applying asymmetric voltage pulses. Patterning was realized by the application of the asymmetric voltage pulses and selective laser irradiation. Two dependences of rotation rate were utilized: a dependence on temperature in the SmC phase and a dependence on phase between SmC* and SmA. The pattern consisting of more than two layer alignments has been realized. The pattern with two stripes at 90° to each other was used to examine the effects of anisotropy on the proposed methods, and it was found that there were the anisotropic properties in the proposed methods.*

Keywords: ferroelectric liquid crystal; layer alignment; optical patterning; smectic layer rotation

INTRODUCTION

Ferroelectric liquid crystals (FLCs) and antiferroelectric liquid crystals exhibit a smectic layer structure. The application of an external electric field deforms the smectic layer structure on the axis vertical to a substrate between the chevron and the bookshelf or quasi-bookshelf structure [1,2].

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In the plane parallel to the substrate, the smectic layer is reoriented and uniformly rotated by applying an ac electric field of sufficient amplitude [3–10]. Rotation of the smectic layer is induced by the application of asymmetric voltage pulses, and the layer rotates gradually [8–10]. This phenomenon is reversible because the rotation direction depends on the polarity of the applied voltage pulses. Taking advantage of these properties, we previously proposed erasable optical patterning of smectic layer alignment based on smectic layer rotation and demonstrated the patterning and erasing of a binary pattern of layer alignment [11].

In the present paper, we propose and demonstrate the design of patterns consisting of more than two layer alignments based on smectic layer rotation. A pattern with two stripes at right angles to each other is also examined to determine the effects of anisotropy on the proposed technique.

EXPERIMENTAL

FLC CS-1024 (Chisso), which has the isotropic–chiral nematic–smectic A (SmA)–chiral smectic C (SmC*) phase sequence, was used in this study. For experiments on optical patterning, CS-1024 was doped with G-239 dye (Hayashibara Biochemical Laboratories) at 1.3 wt% concentration in order to improve the efficiency of laser absorption. A commercial cell (E. H. C.) was employed, with surfaces treated to ensure uniform planar molecular alignment. The cell gap was 10 μm. The patterning light source was a diode-pumped crystal laser with wavelength of 532 nm and output power of 100 mW. In each experiment, the power of the laser light incident on the cell was controlled with neutral density filters. A sawtooth waveform was used as the asymmetric voltage pulse, generated by an arbitrary waveform generator (33120 A, Agilent) and amplified by a voltage amplifier (F20A, FLC Electronics). The amplitude of the pulse was set at 50 V.

RESULTS AND DISCUSSION

Temperature Dependence of Rotation Rate

Figure 1 shows the temperature dependence of rotation rate for pure CS-1024. The rotation rate was defined as the average angle per asymmetric voltage pulse. The average angle was calculated from the angle between the layer normal at the initial state and that after the application of 100 asymmetric pulses. The asymmetric pulses were applied at a frequency of 3 Hz. As shown in Figure 1, the rotation rate changed gradually in the SmC* phase with temperature, and changed suddenly across the phase transition temperature T_{AC} from the SmA to the SmC* phase.

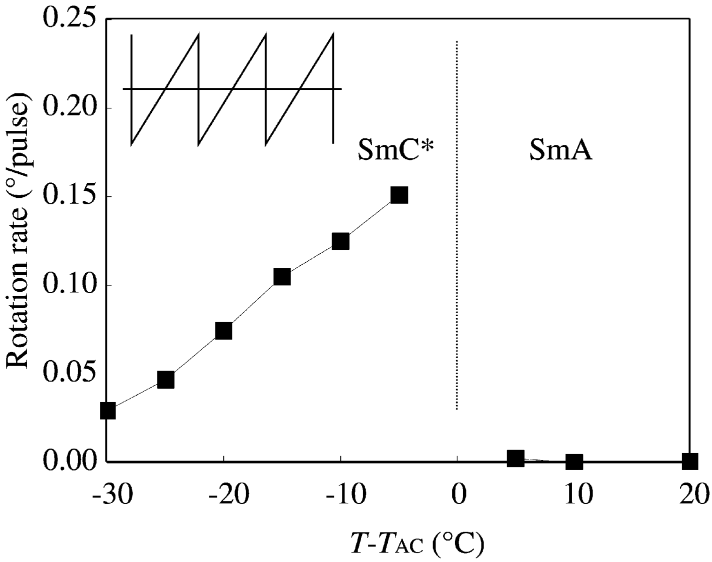

FIGURE 1 Rotation rate as a function of temperature. Inset shows the asymmetric voltage pulses used.

Therefore, there are two dependences of the rotation rate: a dependence on temperature in the SmC* phase, and a dependence on phase.

Proposed Methods

In the SmC* phase, the director of a molecular long axis tilts from the smectic layer normal with a specific angle. The tilt direction from the layer normal is fixed under an external electric field due to interaction between the spontaneous polarization and the external field. However, when domains with different layer alignments coexist, the directors in each domain will differ under a given electric field. Control of the smectic layer alignment in part of a sample therefore corresponds to control of the molecular director. Moreover, the controlled, or designed, layer alignment can be stored without special treatment because the layer alignment is usually stable in the absence of an external field. We have studied the application of smectic layer rotation as a means of patterning of smectic layer alignment. The patterning methods proposed in the present study exploits the temperature dependence of rotation rate to produce the patterns. By partially irradiating the sample with laser as a heating source and applying the asymmetric pulses, the rotation angles of the smectic layer in the irradiated and the non-irradiated area can be different. The phase-dependent variation in rotation rate was previously used by the authors to design a binary pattern [11]. However, noting that there are two dependences of the rotation rate, a dependence on temperature in the SmC* phase and a dependence on phase (see Figure 1), it follows that there are two methods by which such patterning can be achieved.

Phase-dependent patterning utilizes the feature that the rotation rate in the SmA phase is much smaller than that in the SmC* phase in the FLC used. The process is outlined schematically in Figures 2(a) and (b). When the cell is maintained at a temperature just below the phase transition temperature from SmC* to SmA, heating of part of the sample by laser irradiation induces a localized transition from the SmC* phase to the SmA phase. Then, asymmetric voltage pulses are applied to the cell during laser irradiation, and only the smectic layer in the non-irradiated area of the SmC* phase will rotate. Accordingly, the sample, which shows the SmC* in the whole area, with the patterned layer alignment can be obtained after the laser irradiation and the application of the asymmetric pulses are turned off.

Temperature-dependent patterning utilizes the variation in rotation rate with temperature in the SmC* phase. In this method, the temperature of

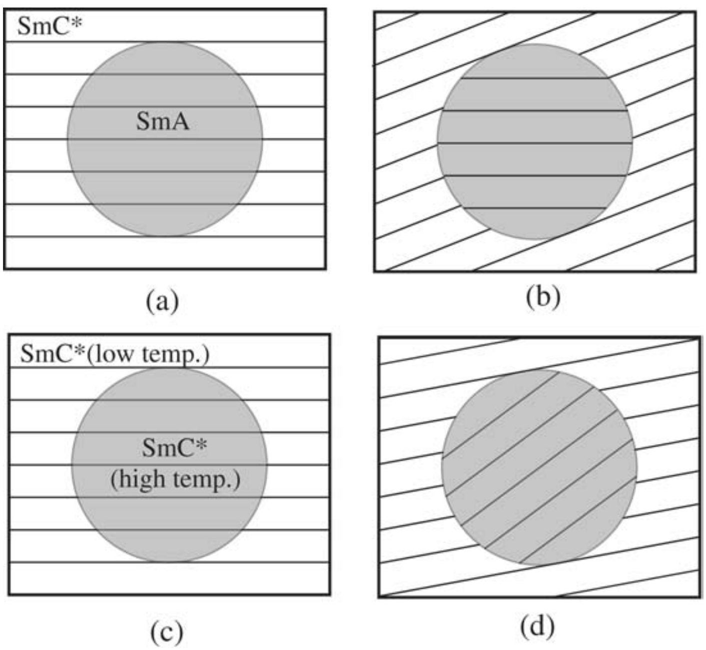

FIGURE 2 Schematics of patterning methods. (a), (b) Phase-dependent patterning. (c), (d) Temperature-dependent patterning in the SmC* phase. Gray regions represent the areas irradiated with laser light.

the cell is maintained sufficiently below T_{AC} such that the temperature of the irradiated area can be controlled over a prescribed range and remain in the SmC* phase. The smectic layers in both the irradiated and the non-irradiated areas then rotate at varying rates under applied asymmetric voltage pulses during laser irradiation according to the temperature dependence. At the end of the process, the rotation angle of the irradiated area will be larger than that of the non-irradiated area. This process is shown in Figures 2(c) and (d). As a result, the designed smectic layer alignment can be realized.

As the rotation direction is determined by the polarity of the applied voltage pulses, the stored pattern can be erased by using asymmetric voltage pulses with the opposite polarity. The experimental results of erasure were shown in the previous report [11]. Of course, by re-heating to the isotropic phase and re-cooling to the SmC* phase, the sample will return to the uniform layer alignment in the case of a rubbed cell. Erasure can also be realized by utilizing the property that the layer rotation saturates at a certain angle between the rubbing direction and the layer normal in the rubbed cell [9]. Thus, by applying a sufficient number of asymmetric voltage pulses to the multidomain sample, uniform layer alignment with layer normal at the saturated angle with respect to the rubbing direction can be realized.

Designing of Pattern Consisting of Three Layer Alignments

If we design the smectic layer alignment by the simple use of the proposed method, only the binary pattern, which consists of two layer alignments, can be obtained, as shown in Ref. [11]. The designing of more than two layer alignments, however, can be realized by the following procedure. This is based on the method using the dependence of the rotation rate on the phase. Figure 3 shows the procedure for designing a pattern with three layer alignments. This procedure involves two writing processes, and it is necessary that the irradiated areas in the two writing processes are different. The areas irradiated in both writing processes will not undergo layer rotation. In areas not irradiated in either writing process, the rotation angle is largest. In the other areas irradiated in one of two writing processes, the rotation angle is small. Figure 4 shows a polarizing microphotograph of the sample treated by the procedure. In this experiment, asymmetric voltage pulses, whose frequency and the number were 5 Hz and 50 respectively, were applied in both writing processes, and the cell was kept at 1°C below T_{AC}. Under polarizing microscope, the transmission intensity was observed to differ between the three domains. This result indicates that design of smectic layer alignment by smectic layer rotation has the possibility of the applications to the multi-level optical memory, optically addressed spatial light modulator and other similar applications.

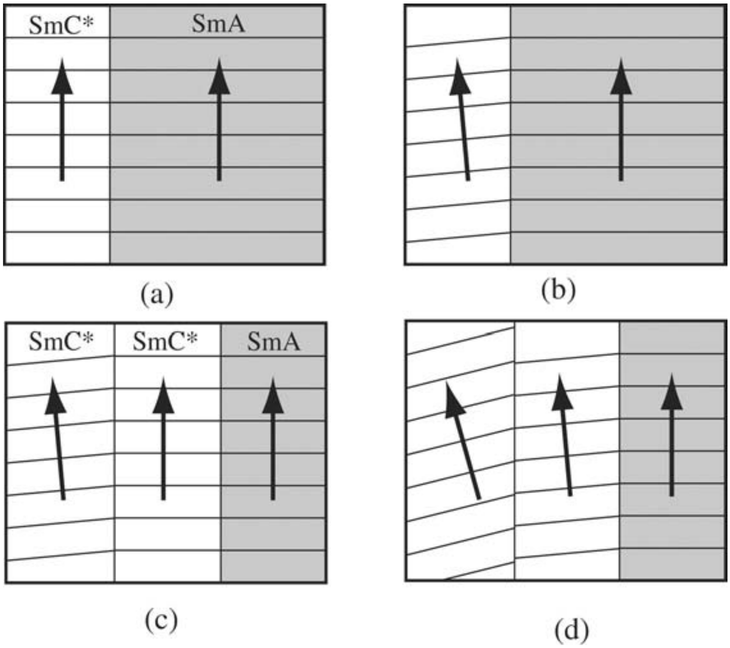

FIGURE 3 Schematics of procedure for designing three layer alignments. (a), (b) First writing process. (c), (d) Second writing process. Gray regions represent the areas irradiated with laser light and arrows represent the layer normal.

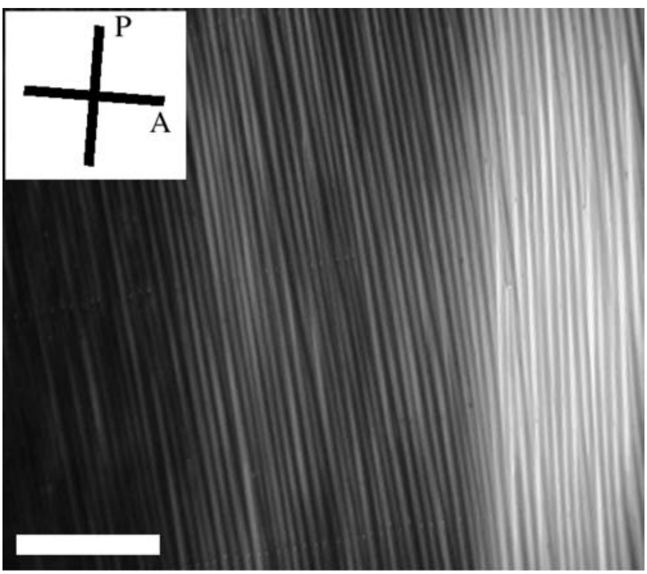

FIGURE 4 Polarizing microphotograph of sample patterned in three layer alignments under an applied dc voltage of 20 V. The length of the scale is 300 μm.

Designing of Stripe Pattern

Liquid crystals are anisotropic in a number of physical properties, which may affect the proposed methods. To test this, the layer alignment was imposed in orthogonal stripe patterns. The laser beam was changed into the stripe pattern through the mask, whose pattern consists of two stripe elements at 90° to each other. The two stripe-directions of the mask were set parallel and perpendicular to the layer normal in the initial state.

For the phase-dependent patterning method, some of the results suggested that the layer structure might influence the writing property. Figure 5(a) demonstrates this tendency strongly (100 asymmetric voltage pulses were applied in this experiment). The layer normal at the initial state is vertical in Figures 5(a) and (b). The edges of stored patterns

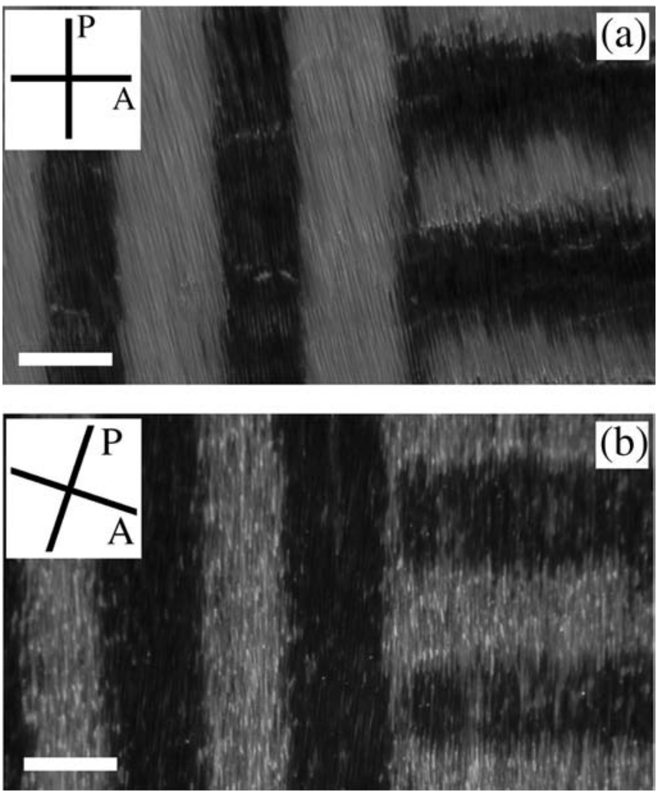

FIGURE 5 Polarizing microphotographs under applied dc voltage of 10 V. (a) Sample designed by phase-dependent patterning. (b) Sample designed by temperature-dependent patterning in the SmC* phase. The lengths of the scales are 300 μm.

perpendicular to the initial layer normal were blurred compared to those parallel to the initial layer normal.

In the experiment for the temperature-dependent patterning method the cell was maintained at 12°C below T_{AC}, and 150 voltage pulses were applied. The polarizing microphotograph of this experiment is shown in Figure 5(b). Similar to the phase-dependent patterning method, the edges perpendicular to the initial layer normal were not as sharp as those parallel to the initial layer normal.

These results indicate that the proposed methods may be influenced by the anisotropy of some of the physical properties of the smectic phases. Further detailed research in this area will therefore be required.

CONCLUSION

We have proposed and demonstrated methods for designing smectic layer alignment based on temperature- and phase-dependent smectic layer rotation. A multidomain cell was designed, and this result indicates the potential applications in areas such as multi-level optical memory and optically addressed spatial light modulators. Moreover, the effect of anisotropy was also noted.

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