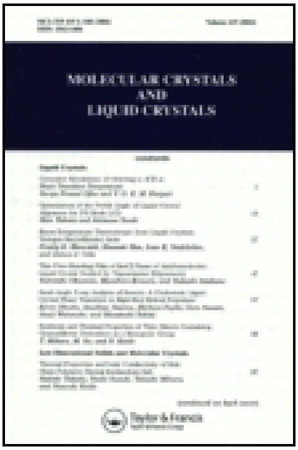

Molecular Crystals and Liquid Crystals Science and Technology. Section A. Molecular Crystals and Liquid Crystals

Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gmcl19

Erasable Patterning in Ferroelectric Liquid Crystal with N*-SmC* Phase Sequence by Optical Heating

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Version of record first published: 04 Oct 2006

Mol. Cryst. Liq. Cryst., 1999, Vol. 331, pp. 273-280
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Erasable Patterning in Ferroelectric Liquid Crystal with N*-SmC* Phase Sequence by Optical Heating

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We have proposed the optical patterning in a ferroelectric liquid crystal with the N* – SmC* phase sequence and successfully demonstrated it. In a homogeneously aligned cell with a rubbing treatment, two smectic layer structures can be selected by applying an electric field during the phase transition from N* to SmC*. The pattern was recorded through the phase transition under applying a dc electric field. The partial phase transition was induced by the illumination of a laser. The influence of illumination time, i.e., the thermal conduction in a patterning process also has been investigated. This optical patterning have a erase, addition, subtraction and inversion function of binary images.

Keywords: optical patterning; ferroelectric liquid crystal; smectic layer

INTRODUCTION

Ferroelectric liquid crystals (FLCs) with Isotropic (Iso.) – chiral nematic (N*) – smectic A (SmA) – chiral smectic C (SmC*) phase sequence have mainly been studied for the application to a liquid crystal display. The material with this phase sequence is suitable for realizing a unidirectional alignment of a smectic layer structure. This is because a unidirectional alignment, in which the layer normal is parallel to the rubbing direction, is easily realized at the phase transition from N* to SmA.

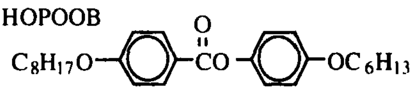
On the contrary, FLCs with Iso. – N* – SmC* phase sequence have mostly been studied not for the practical but for the fundamental point of view[1-4]. At the phase transition from N* to SmC*, liquid crystal molecules are inclined to keep the director parallel to the rubbing direction. This indicates that two domains coexist in the SmC* phase. Each domain has a layer structure with the layer normal in opposite direction from the rubbing direction. In other words, using the rubbing cell, a unidirectional layer structure cannot be obtained under the general condition. This characteristic of the FLCs with the N* – SmC* phase sequence prevents their application to a display device.

Therefore, we have studied FLCs with the N* – SmC* phase sequence in the practical view point. In this paper, we present a erasable patterning by optical heating in the FLC with the Iso. – N* – SmC* phase sequence[5], and report the influence of illumination time and the operation of a binary image.

EXPERIMENTAL

The achiral liquid crystal material used in this study was 4'-(hexyloxy)phenyl-4-octyloxy-benzoate (HOPOOB) in Fig. 1, which indicates following phase sequence: Iso. – N – SmC. HOPOOB was doped with a chiral molecule, 4'-(1-methyl-heptyloxy-carbonyl)phenyl-4-n-hexyloxy-benzoate (Merk, S811) to induce the ferroelectricity, and a dye molecule G241 (Nippon Kanko Shikiso) to improve the efficiency of laser absorption in the concentration shown in Fig. 1. The phase sequence and phase transfer temperatures of the mixture are also shown in Fig. 1.

HOPOOB



HOPOOB(97wt%) + S811(2wt%) + G241(1wt%)

Iso. ⟶ N* ⟶ SmC* ⟶ Crystal
90°C 58°C 30°C

FIGURE 1 The molecular structure of HOPOOB, concentration, phase sequence and phase transition temperatures of the mixture used in this study.

The sample was sandwiched between two Indium-Tin-Oxide (ITO) glass plates, whose surfaces were coated with polyimide and rubbed. The cell gap was 2μm. The thickness of ITO glass plates was 100μm in order to decrease the heat capacity. For optical heating, an Ar ion laser light (488nm) of a TEM_{00} beam with 280μm diameter on the sample and $440mW/mm^2$ power was used. The sample cell in the hot bus was kept at 15°C below the phase transition temperature from N* to SmC*, T_{NC}.

PRINCIPLE OF PATTERNING

There is a degeneracy of two smectic layer structures in the SmC* phase following the N* phase with a rubbing cell as shown in Fig. 2 [1]. Assuming that the cell gap is thin enough to unwind a helical structure in both the N* and the SmC* phases, the long axis of liquid crystal molecule is parallel to the rubbing direction in the N* phase. After the phase transition from N* to SmC*, the molecules tilt away from the normal of the smectic layer appeared in the SmC* phase. The strong anchoring from the rubbing treatment, however, keeps the molecular director parallel to the rubbing direction through the phase transition from N* to SmC*. Consequently, layer structures tilted with respect to the rubbing direction are realized since the direction of tilting is not defined. That is, two layer structures, in which each layer normal tilts in the opposite direction from the rubbing direction, coexist in the SmC* phase.

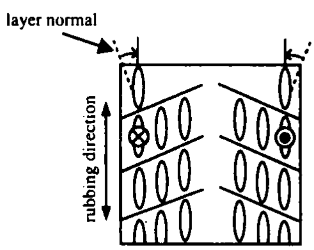


FIGURE 2 Two layer structures in the SmC* phase.

If an electric field is applied during the phase transition from N* to SmC*, the only one layer structure is obtained. The normal of this layer structure tilts away from the rubbing direction in the direction given by the relationship between the sign of the spontaneous polarization and the direction of applied electric field. Using the combination of the application of an electric field and the phase transition from N* to SmC*, the unidirectional layer structure is obtained throughout the sample cell.

As described above, the application of an electric field during the phase transition gives only the unidirectional layer structure throughout the sample cell instead of patterning. Therefore, we proposed the principle of patterning using the N* – SmC* phase transition by optical heating with the help of the application of an electric field[5]. In the SmC* phase, a layer structure is normally stable under applying an electric field except the case just below T_{NC}. Accordingly, the type of a layer structure realized in the SmC* phase depends the applied field at the phase transition from N* to SmC*. The part of the sample is heated by optical heating of short illumination time, that is, it is heated to the N* phase and cooled back to the SmC* phase. It is notice that the rest, which was not illuminated by a laser light, remain in the SmC* phase during this process. In other words, if the sample is illuminated by a laser light under applying an electric field, only the layer structure in the illuminated part is recreated under the influence of applied electric field, that is, can be switched.

Figure 3 shows the schematic of the patterning by optical heating. In these figures, we assume that the sample has a spontaneous polarization with a positive polarity. Figure 3 (a) shows the state after the phase transition from N* to SmC* under applying a dc electric field of a negative polarity, –E. The unidirectional tilted layer structure is realized throughout the sample. If the sample is partially heated to above T_{NC} by the illumination of a laser light under a positive electric field +E, the sample becomes the N* phase as shown in Fig. 3 (b). When the sample in the illuminated region revert to the SmC* phase under applying +E after the illumination is turned off, another type of a layer structure should be recreated in the illuminated region as shown in Fig. 3 (c). As a result, the pattern of the laser spot is recorded in the sample and this layer structure is memorized as shown in Fig. 3 (d). Furthermore, to erase this pattern, the negative electric field –E is applied in the stage of Fig. 3 (b), and then the initial state can be obtained again.

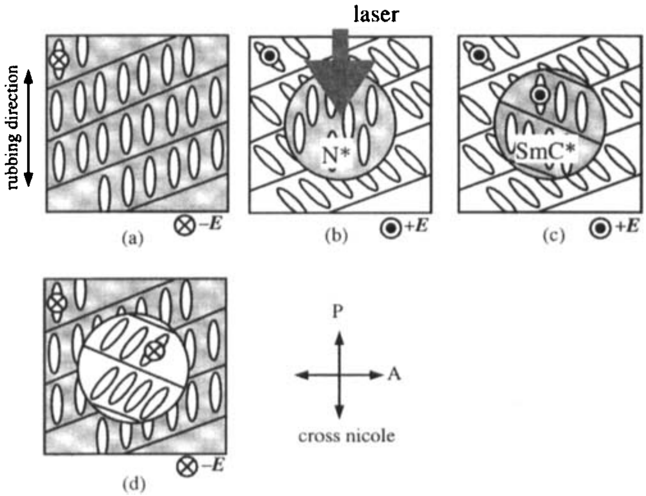


FIGURE 3 The schematic of the principle of optical patterning.

RESULTS AND DISCUSSION

Influence of Illumination Time

In order to decrease the heat capacity, the thin glass plates were used for the sample cell. To examine the influence of thermal conduction, the illumination time dependence was investigated under the same condition of the power of the Ar ion laser, the experimental temperature and so on. Figure. 4 shows this result. The illumination times of 1/1, 1/2, 1/4, 1/8 and 1/15 sec were used in this experiment. From this result, though the sample cell consists of the thin glass plates, the thermal conduction influenced the size of the recorded pattern.

When the illumination time was 1/15 sec, the patterning was impossible. It is, however, notice that the patterning under the illumination time of 1/15 sec is possible using the higher power of the Ar ion laser.

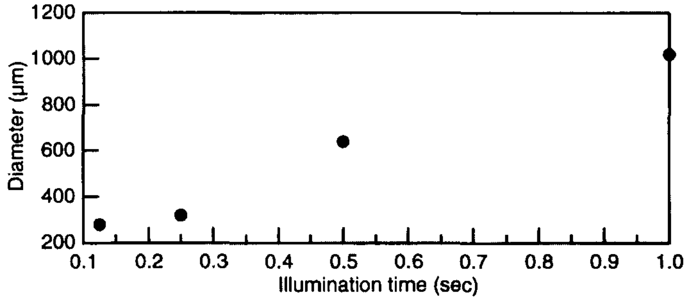


FIGURE 4 The diameter of the recorded pattern as a function of the illumination time.

Patterning and Erasing

Figure 5 (a) shows the polarizing micrograph of the sample under the application of −10V dc electric field after patterning, which corresponds with Fig. 3 (d). This result indicates that the spot of the Ar ion laser was recorded on the sample. The micrograph after erasing the pattern is shown in Fig. 5 (b). These figures show that the recorded pattern was completely erased and the initial state was obtained again.

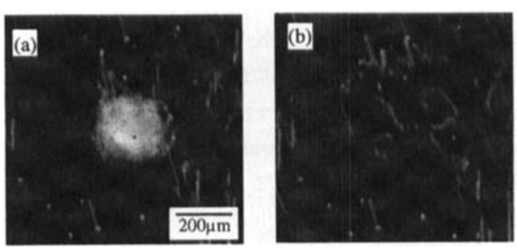


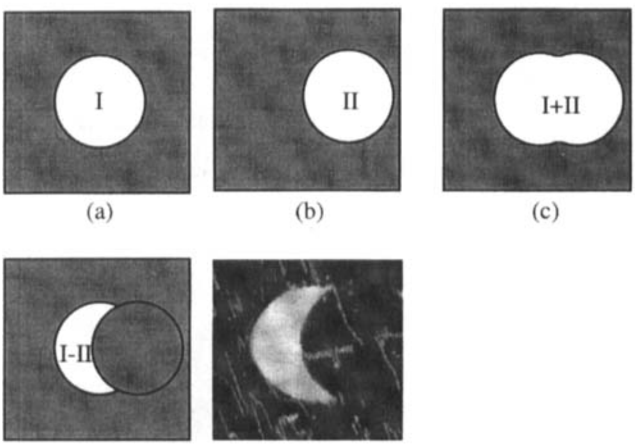
FIGURE 5 The micrographs of the sample under the application of −10V. (a) After patterning. (b) After erasing.

Operation of Binary Image

The continuous patterning processes are equal to the addition of binary images. For example, if you use the laser spot I and II in Fig. 6 (a) and (b) for the continuous patterning, you can get the added pattern of I and II as shown in Fig. 6 (c).

Moreover, if a different shape of the laser spot is used at erasing, the subtraction will be realized. At first, the laser spot I in Fig. 6 (a) is used for patterning. Then, the different laser spot II in Fig. 6 (b) is used for erasing. As a result, the subtracted pattern should be obtained as shown in Fig. 6 (d). Figure 6 (e) is the micrograph of the result of the subtraction.

Additionally, the inversion of the recorded pattern is easily realized by inverting the polarity of the applied voltage, as shown in Fig. 3 (c) and (d).



(d) (e)

FIGURE 6 The schematic of operations in binary images.
(a) The laser spot I. (b) The laser spot II. (c) The added pattern I+II.
(d) The subtracted pattern I–II. (e) The result of subtraction.

CONCLUSION

We proposed the optical patterning in the FLC with N* – SmC* phase sequence and successfully demonstrated it. The pattern was recorded through the phase transition from N* to SmC* under applying a dc electric field in the part of the sample. The partial phase transition was induced by the illumination of a laser. This optical patterning have the erase, addition, subtraction and inversion function. Hence, there are possibilities of the application to the memory device and image processing device of a binary image.

Acknowledgments

This work was supported by a Grant-in-Aid for General Scientific Research from the Ministry of Education, Science, Sports and Culture (No. 09450143). One of authors (K. N) was funded by the Japan Society for the Promotion of Science (JSPS) (No. 5052).

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