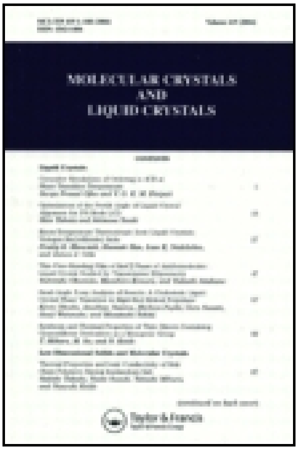

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Fine Bistable Device of Nematic Liquid Crystal Realized on Orientational Surface Patterns

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Fine Bistable Device of Nematic Liquid Crystal Realized on Orientational Surface Patterns

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Orientational bistability of the nematic liquid crystal occurs on the frustrated surface alignment of checkerboard. Macroscopic orientational switching takes place between two states by an appropriate in-plane electric field. The threshold electric fields decreased in both switching directions as temperature increased. The focused laser light could heat up only the selected region in the cell including a light-absorbing medium. Irradiating the laser concurrently with an appropriate electric field, we switched the selected regions in the alignment pattern. The switched region was stable without the disturbance from the exterior. Extending this process, we realized extremely fine bistable devices. Here we mention some issues like the switching domains and the relation between the threshold electric filed and temperature.

Keywords: bistability; high resolution device; nematic liquid crystal

The bistable liquid crystal devices (LCDs) have been actively pursued for the advantages of energy consumption and high image quality with

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relatively simple structure [1–8]. We devised an orientational bistability and tri-stability of nematic liquid crystal (NLC) by exploiting the frustrated surface alignments with applying the same logical path of specific rotation symmetry [9–11]. For bistability, an orientational checkerboard pattern was inscribed on the alignment layer using the stylus of the atomic force microscope (AFM) [9,10]. Neighboring unit square domains are in mutually orthogonal alignment in the pattern. The NLCs had equally stable macroscopic orientations along the two diagonal axes of the checkerboard for the four-fold rotation symmetry of the orientation pattern. Electro-optic switching took place between above two stable states by applying appropriate in-plane electric field. Tri-stability was realized with the uniform pattern covered with parallelograms of three different scanning directions. The pattern satisfied 6-fold rotation symmetry and resulted in tri-stability with the same scenario of bistability of 4-fold rotation symmetry [11]. Moreover, it also switched stably into another orientation by appropriate electric field.

The threshold electric field of switching decreased monotonically in proportion to the temperature increasing in nematic phase. Individual domain happened to switch between two stable orientation independently to the neighboring ones. Combining these two experimental results, specific domains were addressed using laser heating concurrently with electric field as Figure 1. As the unit domain of μm size was the unit pixel, so the device concluded in a very fine and bistable NLC device like Figure 2 [12].

In this paper we would like to describe several issues of fine bistable NLC device. Especially we will touch the switching direction and the relation between the threshold electric field and temperature.

We mention about the experiment briefly. The liquid crystal (LC) cell was consisted of two glass slides. Although one slide contained two sets of two electrodes to apply in-plane electric field along two perpendicular directions, the other didn't. The distance between electrodes was about 200 μm. Both slides were spin-coated with a polyimide (SE150, Nissan Chemicals.) for planar NLC aligning. Orientational checkerboard was scribed in the center of the electrodes by the AFM (SPA500, Seiko Instruments Inc.) with 23 nN load force in contact mode. The scanning density was 100 line/μm. The checkerboard pattern size was about 90 μm × 90 μm and a unit domain of square was in the range of 0.6 μm × 0.6 μm ∼ 10 μm × 10 μm. The other slide without electrode was rubbed enough for uniform alignment by conventional rubbing technique. The cell was constructed with two slides with about 10 μm or 50 μm gap adjusting the scanning directions and the rubbing direction of two slides. The cell was injected with a NLC of 5CB (4-n-pentyl-4′-cyanobiphenyl) at isotropic phase. The sinusoidal

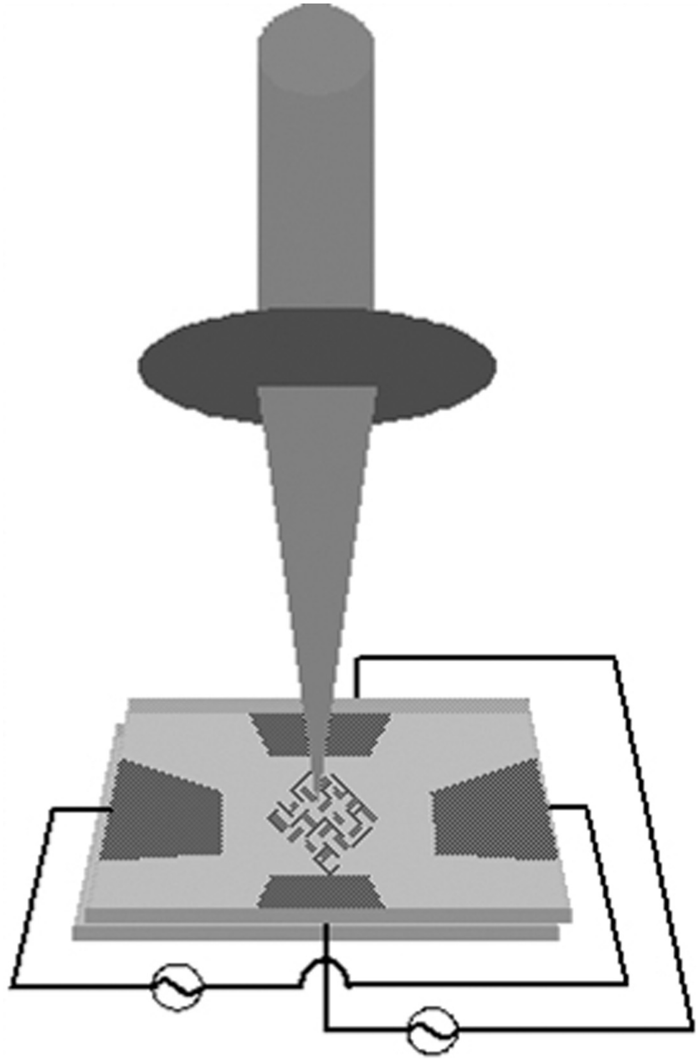


FIGURE 1 Schematic diagram of the switching experiment with applying electric field and irradiating laser light simultaneously. Cell was maintained at the constant temperature and small limited region in the pattern was irradiated with the focused laser light. For switching of laser irradiated region only, we controlled both strength of electric field and laser power.

electric field of 1 kHz was applied up to several volt/μm between two parallel electrodes. The strength of the electric field adjusted to the appropriate level with temperature, unit domain size and variation

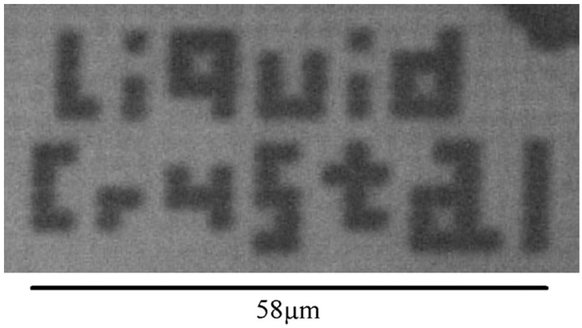


FIGURE 2 The image of “Liquid Crystal” was made through switching the unit domains of $1.8\,\mu m \times 1.8\,\mu m$. Contrast and brightness of the images were adjusted for clarity by software and adjusting the polarizers of microscope. For constructing this image we switched each domain step by step shifting position. The switching condition is similar to the previous one [12]. Temperature was kept in the range of $0.5 \sim 1.5^{\circ}C$ below phase transition. The field strength was in the range of $0.5 \sim 2\,V/\mu m$ and laser power was around 0.1 mW. At the beginning laser beam waist for electric field was about $1.3\,\mu m$. However, the beam waist varied during experiment with shifting the position. Laser light was circular polarized to avoid polarization dependent absorption. Switching conditions were adjusted point by point as characteristics of each position and temperature varied slightly.

of different positions. The switching behavior and LC texture were observed through polarizing optical microscope controlling the cell temperature.

NLC switched responding to the appropriate electric field on the checkerboard pattern at the nematic phase and maintained that orientation even the field turned off. At the higher temperature, the threshold field was decreased in both switching directions [12]. Near the phase transition, the decreasing was steep. However, threshold field was not zero even the temperature of bulk isotropic phase, at least, up to several degree above the transition, indicating surface origin of this bistability. The threshold fields of both switching directions were not the same reflecting the broken equivalence of the surface alignment on the pattern.

To confirm the heating with the laser light, 5CB was mixed with a dye (G471 of Hayashibara biochemical laboratories, Inc) by 1 wt%. The maximum absorption of the dye is at 550 nm. The change of LC temperature was observed with irradiating the laser of 532 nm. For measuring the relation between laser power and temperature rising, at first we maintained the cell at a certain temperature and irradiated laser light increasing the power until detecting

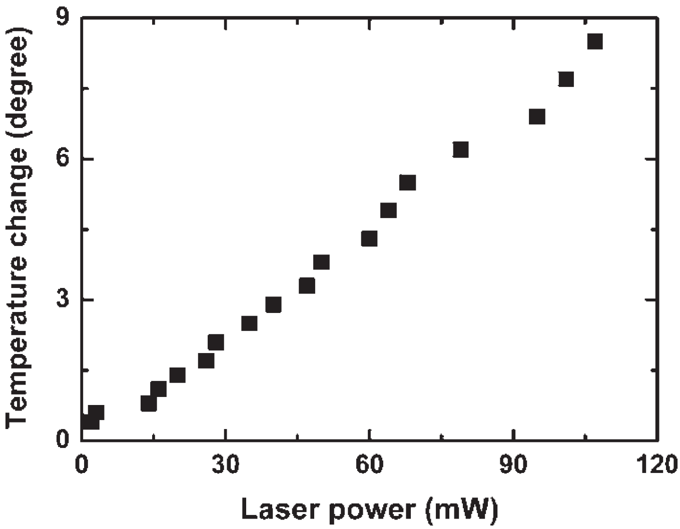


FIGURE 3 Temperature rising to the irradiated laser power. In this laser power range the LC heating was almost linearly proportion to the laser power. The beam waist was about 26 μm.

the phase transition from nematic to isotropic. Then we obtained a data point of that fixed temperature and corresponding laser power for heating. With repeating for different fixed temperature we drew the relation between the temperatures and the laser powers. Heating was linearly proportional to the laser power within our power range for lacking of evident nonlinear or side effects as Figure 3.

And we observed the relation between the laser power and the threshold electric field for switching with several fixed temperatures as in Figure 4. To the constant temperature, the relation between the laser power and threshold field showed inversely proportional behavior each other. So, if the laser power is increased, then the necessary threshold field is reduced. In contrary, the decreased laser power means increased necessary threshold field. And to the changed constant temperature of nematic phase, the relation between the laser power and the threshold field showed basically similar behavior. For the closer temperature to the phase transition, the necessary laser power or threshold field is lower. That is reflecting the decreased strength of the threshold electric field for switching with the approaching from the lower temperature to the phase transition point.

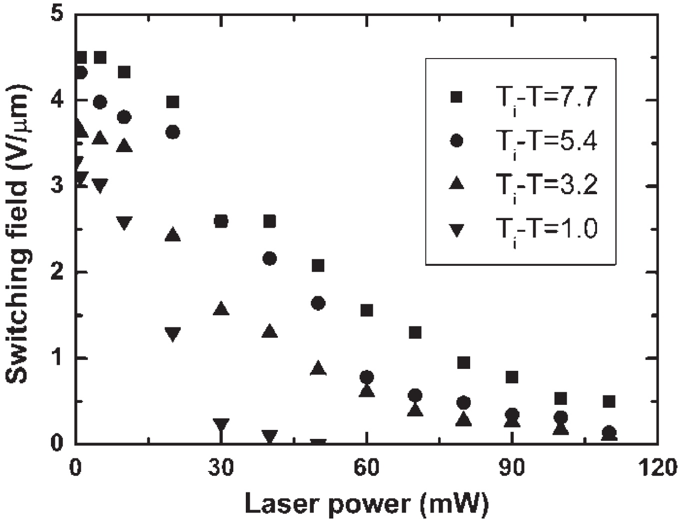
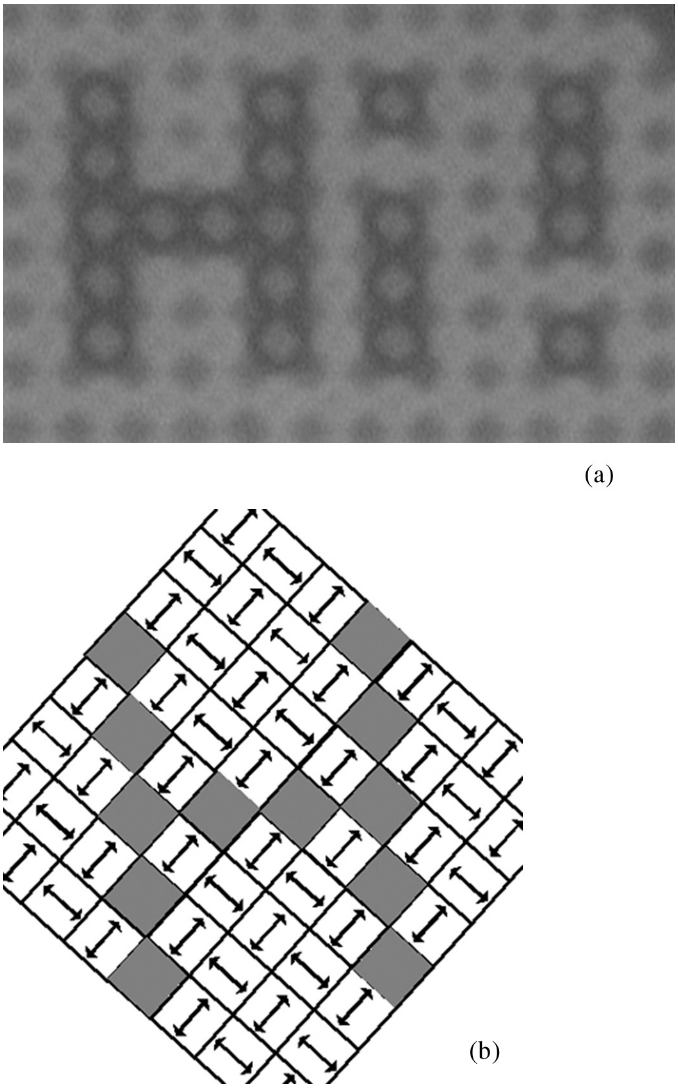


FIGURE 4 The relation of the threshold electric field and irradiated laser power for several constant temperature. The beam waist was about 85 μm. The switching was measured with the behavior of several domains in the pattern.

As shown in the Figure 5, the switched domains are not connected directly by the neighboring domains, but connected by diagonally positioned domains. The domains next to the switched ones would not switch stably to the other orientation even with applying appropriate field in direction and strength and strong laser irradiation. This means all the domains can be divided into two sets of switch-able and non-switch-able. Domains of each set connected diagonally. In principle all the domains should be equivalent in the view point of theory as all the domains have the same symmetric character. However, in real experiment there are several factors that distort the perfect symmetric property of the ideal system. Especially the flowing effect is the key for the asymmetric response as the NLC flowing brings breaking the symmetric property between flowing direction and perpendicular direction to the flowing even the LC was injected at isotropic phase. This means that the threshold field along the flowing is lower than that to the perpendicular [12]. The symmetry breaking by flowing influences on the angle between macroscopic orientations too.

As the flowing during LC injection was not perfectly uniform along one direction on the pattern, so we sometimes found mixing of



(a)

(b)

FIGURE 5 (a) Image of "Hi!" made by controlling the unit domain one by one. (b) The domains of the image "H" was mapped on the schematic diagram of the orientational checkerboard. Dark boxes indicated the switching into other stable state as Figure 5(a) and the others kept the original state. The switched domains connected along diagonal directions. The unit domain size is $4\,\mu m \times 4\,\mu m$. The scannings are along $\pi/4$ or $-\pi/4$ directions to the horizon as the arrows indicated. Dye (G471)-added LC (5CB) was injected into the cell at isotropic phase. Experimental conditions were similar to the Figure 2. The orientations of the polarizers were adjusted for clear images.

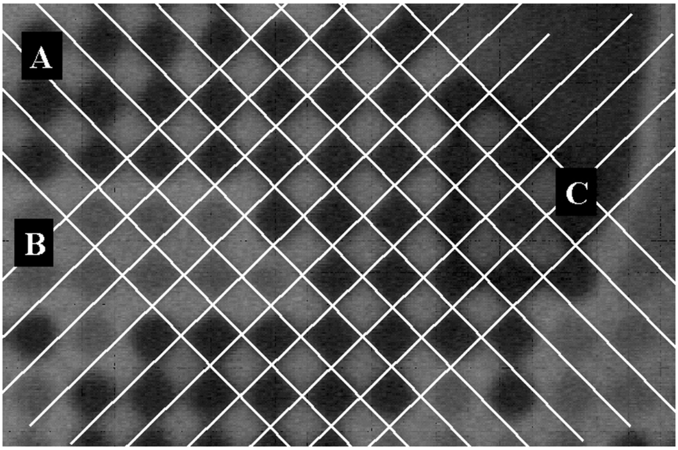


FIGURE 6 Image consisted of different switching sets. Different switching domains are divided into Region A, B, and C according to the switched domains and switching orientation. This kind of behavior sometimes was found in the region near the boundary of the pattern. The unit domain size is $4\,\mu m \times 4\,\mu m$. This texture was usually found near the boundary of the scanning pattern.

switch-able and non-switch-able set. Figure 6 show the mixed switching of different sets. The state of Region A is the background state in a uniform switching. Most of domains switched into the state of Region B from the state of Region A, in other words dark domains switch into other direction and result in bright domains. But we can switch some domains of the other set like limited Region C. Here the bright domains, not dark domains switched into less bright domain. It indicates that well controlled bistability have capability of expressing three gray level, not two gray level. Moreover, the isolated switching of a unit domain is stable and it is justified by the smaller extrapolation length than the unit domain size [12].

In conclusion, the laser light combined with the appropriate electric field addressed the domains of the bistable NLC device, which was realized on the orientational checkerboard. Here we described the relation between the threshold electric field and temperature. They are inversely proportion each other at the constant temperature. The switched domains of the image were connected along the diagonal direction as the switching domains are divided into two sets for the asymmetric response. We mentioned the possibility of expressing more than just two level of brightness for bistable device.

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