Bistable Liquid Crystal Device Realized on Microscopic Orientational Pattern

Jong-Hyun Kim[(a)(b)], Makoto Yoneya[(b)], Hiroshi Yokoyama[(b),(c)]

a) Physics, Chungnam National University, Daejeon, Korea , b) Yokoyama Nano-Structured Liquid Crystal Project, Japan Science and Technology Corporation, Tsukuba, Japan, c) Nanotechnology Research Institute, National Institute of Advanced Industrial Science and Technology, Tsukuba, Japan

Abstract

Alignment pattern of checkerboard was constructed by the stylus of atomic force microscope. Orientational bistability of the nematic liquid crystal was realized on that frustrated surface alignment. Macroscopic orientational switching between two perpendicular directions took place by an appropriate in-plane electric field. The threshold electric fields decreased in both switching directions as temperature increased. The focused laser heated up only the limited domains in the cell including a light-absorbing medium. Irradiating the laser concurrently with an appropriate electric field, we switched the selected unit domains in the alignment pattern. The switched domains maintained stably the switched direction without the disturbance from the exterior. Extending and repeating this process, we realized extremely fine devices of bistable switching.

1. Introduction

Until recent, the researches on the liquid crystal (LC) alignment were focused on the realizing the qualitative uniform alignment. It contributed as a fatal factor to the spectacular success of liquid crystal display (LCD). We adopted the other approach using the Atomic force microscope (AFM), which is the one of most sensitive tool which observes the surface properties. Using the stylus of AFM not as a tool for measuring, but as a tool for controlling the surface property, it was possible to align liquid crystal on the polyimide layer [1]. We call this as the nano-rubbing technique. In addition[1] to the ability to bring pretilt angle with uni-directional scanning as the conventional rubbing does, nano-rubbing has freedom in the scanning, especially in controlling the scanning direction and size [2]. It is relatively easy to modify the surface with the certain alignment design compared to the conventional rubbing with which it is practically impossible to do.

Using the design of alignment pattern of specific rotation symmetry, we devised an orientational bistability and tri-stability of nematic liquid crystal (NLC) [3-5].

For the bistability, an orientational checkerboard pattern, which satisfied four fold rotation symmetry, was inscribed on the alignment layer using the AFM [4,5]. Neighboring unit square domains are in mutually orthogonal alignment in the pattern. The NLC orients along the scanning direction just above the pattern for the anchoring of the surface. However, as the LC gets remote from the surface, their orientations get merged into average orientation with the distance of domain size. So, the NLCs had possibility to orient into equally stable macroscopic orientations along the two diagonal axes of the checkerboard for the symmetry of the pattern. Electro-optic switching took place between above two stable states by applying appropriate in-plane electric field.

For the tri-stability, the uniform pattern covered with parallelograms of three different scanning directions was used [3]. The pattern satisfied 6-fold rotation symmetry and resulted in tri-stability with the same scenario of bistability of 4-fold rotation symmetry. Moreover, it also switched stably into another orientation by appropriate electric field. The threshold field showed very similar value to the bistability. As it has three different states, it shows more information than the bistability.

In the bistability, the threshold electric field of switching decreased with the temperature increasing in nematic phase. Individual domain happened to switch between two stable orientations independently to the neighboring ones. Combining these two

a) Electronic mail : jxk97@cnu.ac.kr

experimental results, particular domains were addressed using laser heating concurrently with electric field. As the unit domain of μm size was the unit pixel, so the device concluded in a very fine and bistable NLC device [6].

In this paper we would like to describe the process for getting this bistable NLC device and some issues of fine bistable NLC device.

2. Experimental Preparation

We mention about the experiment briefly. The LC cell was consisted of two glass substrates. Although one substrate contained two sets of two parallel electrodes to apply in-plane electric field along two perpendicular directions, the other didn't. The distance between electrodes was about 200μm. Both slides were spin-coated with a polyimide (SE150, Nissan Chemicals.) and thermally treated. LC aligns planar on this polyimide with alignment process.

On the substrate of electrode containing, orientational checkerboard was scribed in the center of the electrodes by the AFM (SPA500, Seiko Instruments Inc.) with 23nN load force in contact mode. The scanning density was 100line/μm. A scanning direction is 45degree rotated to a possible electric field direction. The checkerboard pattern size was about 90μm × 90μm and a unit domain of square was in the range of 0.6μm × 0.6μm ~ 10μm × 10μm. The other substrate without electrode was rubbed enough for uniform alignment by conventional rubbing technique.

The cell was constructed with two substrates with about 10μm or 50μm gap adjusting the scanning directions and the rubbing direction of two substrates. The cell was injected with a NLC of 5CB (4-n-pentyl-4'-cyanobiphenyl) at isotropic phase to avoid the flowing effect. The sinusoidal electric field of 1kHz was applied up to several V/μm between two parallel electrodes. The field strength was adjusted to the appropriate level with temperature, unit domain size and variation of different positions. The switching behavior and LC texture were observed through polarizing optical microscope controlling the cell temperature and orientation.

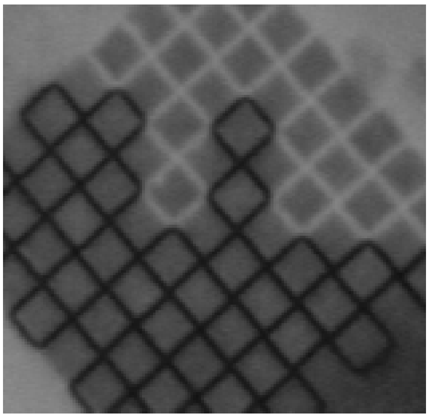

Figure 1 Image consisted of different switching sets. Different switching domains are divided by brightness of the boundary. The unit domain size is 10μm×10μm. For the pattern of smaller unit domain, the difference in the boundary reflected into the brightness contrast of the two different regions.

3. Domain Switching

NLC switched responding to the appropriate electric field (several V/μm) on the checkerboard pattern at the nematic phase and maintained that orientation without external effect. With changing the field direction perpendicular to the previous one, we obtained the state of the other orientation.

Some domains, sometimes a unit domain, happened to switch between two states apart from neighboring ones and maintained the state as Figure 1. This indicated the potentiality to realize a high resolution

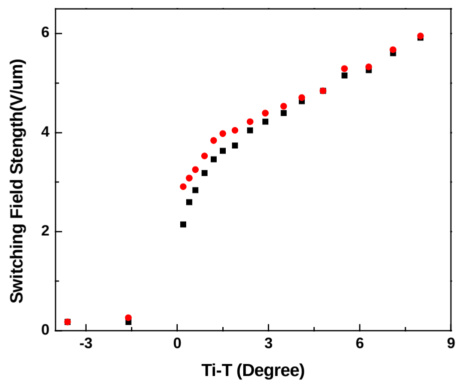

Figure 2. Temperature dependence of the threshold field. The square and circle indicate opposite switching directions. The unit domain was 5μm × 5μm.

device controlling limited domains of micrometer-size. By comparing extrapolation length (d_e), the ratio of elastic constant to the anchoring strength, to unit domain size (d), we can examine the stability. For our experimental range, $d_e << d$ is satisfied, so the isolated switching is stable.

As the temperature increased, the threshold field was decreased in both switching directions as Figure 2. The decreasing rate was large near the phase transition. However, threshold field did not reach completely to zero even the temperature of bulk isotropic phase up to several degree above the transition. It proved the surface origin of the bistability. The threshold fields of both switching directions were not the same reflecting the broken equivalence of the surface alignment on the pattern.

We added heat-able medium into cell as two methods. One is adding light absorbing dye in LC. The other way is using the light absorbing polyimide for alignment layer. The heating concentrated near the surface, the effective region for switching, for the latter one and it was suitable for controlling the very tiny domains.

To confirm the heating with the laser light, 5CB was mixed with a dye (G471 of Hayashibara biochemical laboratories, Inc) by 1wt%. The maximum absorption of the dye is at 550nm. The change of LC temperature was observed with irradiating the laser of wavelength 532nm. The temperature rising was linearly proportional to the laser power. It indicated the lacking of evident nonlinear or side effects.

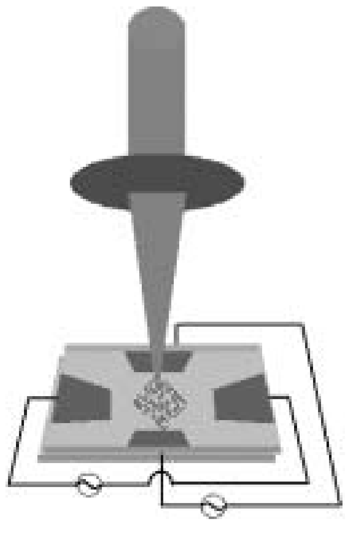

Figure 3. Schematic diagram of the switching experiment with applying electric field and irradiating laser light simultaneously. Cell was maintained at the constant temperature and small limited region in the pattern was irradiated with the focused laser light. For switching the limited region only, both strength of electric field and laser power were controlled.

Moreover, we observed the relation between the laser power and the threshold electric field for several fixed temperatures. The laser power and threshold field behaved inverse proportionally each other to the constant temperature. With increased laser power, the threshold field is reduced. In contrary, the decreased laser power means increased necessary threshold field. To the other constant temperature in nematic phase, the relation between the laser power and the threshold field behaved basically similar way. For the closer temperature to the phase transition, the necessary laser power or threshold field is lower. That is reflecting the decreased threshold electric field with the approaching to the phase transition point.

We used the experimental setup as in Figure 3 for switching. To keep constant threshold (E1), the cell was maintained at a constant temperature (T1). Irradiating light of a certain power (P1) into the selected area and, then, that area was heated up (T2). The threshold field get lower to E2 from E1 (E1 > E2 for T1 < T2). Electric field (E3) in the range of E1 < E3 < E2 was applied along the appropriate direction simultaneously with the incident light (P1). After electric field and the light were turned off, the resultant switched region showed up along the field direction. Finishing the process in that area, these processes were repeated with shifting position to construct what we designed. Actually, the LC in selected area was heated up to isotropic phase because the change of the threshold was prominent near phase transition and it aided the ease discrimination of a switching region.

In experiment, temperature was maintained in the range of 0.5~1.5°C below T_{ni}. The field strength was in the range of 0.5~2V/μm and laser power was around 0.1mW. As the focusing of laser light was shifted position by position, the effective area was changed. 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.

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(b

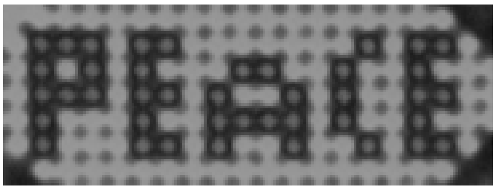

Figure 4. Images under the polarizing optical microscope for two unit domain sizes. The scanning direction of a unit domain had an angle of π/4 or -π/4 to the horizon and the rubbing of the counter slide was controlled along a scanning direction. The orientations of the polarizers were adjusted for clear images. Contrast and brightness of the images were adjusted for clarity. (a) Unit domain : 1.8μm × 1.8μm. With dye-added LC. (b) Unit domain : 4μm × 4μm. With dye-added LC. Cell gap was about 10μm.

We produced the designed images for several domain sizes. With 4μm × 4μm unit domains, dark word of "PEACE" is written in bright background as Fig. 2(b). The image was constructed by addressing domains one by one. The switched domains located not consecutively along the row or column of the checkerboard, but followed along the diagonals. Consequently, the effective unit size is enlarged by $\sqrt{2}$ to a boundary of the unit square. With 1.8μm × 1.8μm unit domains, "PEACE" was written by addressing each individual domain as Fig. 2(a). While the height of a letter consisted of lined-up domains in diagonal, the image appeared continuous since the unit domain was comparable to wavelength of light. As the number of unit domains used in the image are the same for both images in Fig. 2. The image widths are about 96μm for Fig 2(a) and 43μm for Fig. 2(a).

As shown in the Fig. 4(b), the switched domains are not connected directly by the neighboring domains, but connected by diagonally positioned ones. 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 of the theory all the domains should be equivalent as all the individual domains have the same symmetric circumstance. However, there are several factors that distort the perfect symmetric property of the ideal system in actual experimental processes. Especially the flowing effect during LC injection supposed to be the main 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. The symmetry breaking by flowing influences on the directions of macroscopic orientations too.

4. Conclusions

The controlled laser light combined with the appropriate electric field switched the limited domains of the bistable NLC device, which was realized on the orientational checkerboard. Here we described the relation between the threshold electric field, temperature and laser power. As the unit domain behaves like the sub-pixel of the display, So the resolution of this device is extremely high compared to the current LC device.

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