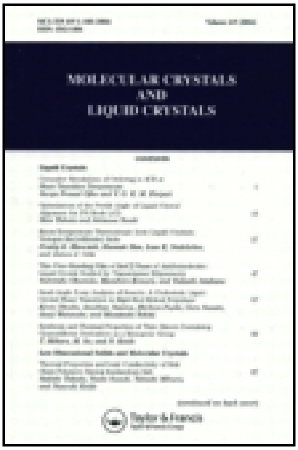

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A bistable device of a nematic LC showing the sign reversal of the dielectric anisotropy

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A BISTABLE DEVICE OF A NEMATIC LC SHOWING THE SIGN REVERSAL OF THE DIELECTRIC ANISOTROPY

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A bistability of nematic liquid crystals was devised on the pattern of checkerboard-like local rubbing; the alignment of the liquid crystal on neighboring domains was orthogonal each other. 4-fold symmetry of the pattern and liquid crystal frustration forced bulk director to orient along one of two average directions of the local rubbings. A liquid crystal orientation was switched to the other by in-plane electric field. To realize bi-directional switching it was needed to apply electric field along two different directions using two pairs of electrodes. In this experiment we used a liquid crystal, which changes the sign of dielectric anisotropy to frequency of electric field. It has a merit of reducing number of electrodes into two, meaning simple electrodes structure. We successfully switched between two orientations with changing frequency of applying field.

Keywords: bistability; dielectric anisotropy; liquid crystal; nematic

INTRODUCTION

Using the atomic force microscope (AFM) as a tool for the nano-rubbing technique, it was possible to align liquid crystal (LC) on the polyimide layer [1–3]. In addition to bring pretilt angle with uni-directional scanning as the conventional rubbing does, nano-rubbing has freedom in scanning,

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especially in controlling the scanning direction and size. So modifying surface property along a certain design, this is really hard work for the conventional rubbing, can be realized without difficulty [4,5]. In other aspects, there are limitations on size for the limited scanning size and on the throughput for the slow speed.

We devised an orientational bistable device of the nematic liquid crystal (NLC) on the polyimide layer fabricating a pattern of checkerboard-like local rubbing using AFM nano-rubbing as Figure 1 [5,6]. As the local rubbing of a domain is orthogonal to the next domains, so the alignment directions of LC on neighboring two unit domains are orthogonal each other too. The NLCs get uniform in the bulk by the elastic frustration and the orientation of the NLCs in the bulk is determined by the symmetry of the pattern. In this case there are two average directions of local rubbing and NLCs aligns along one of the two orientations. NLCs switch between these orientations responding to in-plane electric field as Figure 2. The size of unit domain was 2.0 μm × 2.0 μm and the pattern size was approximately 90 μm × 90 μm. The scanning density was 100 line/μm and the load force was 23 nN.

It was necessary to prepare two pairs of electrodes to apply electric field along different two directions for orientational switching. It brings complexity in the electrode structure and the limitation in the size of

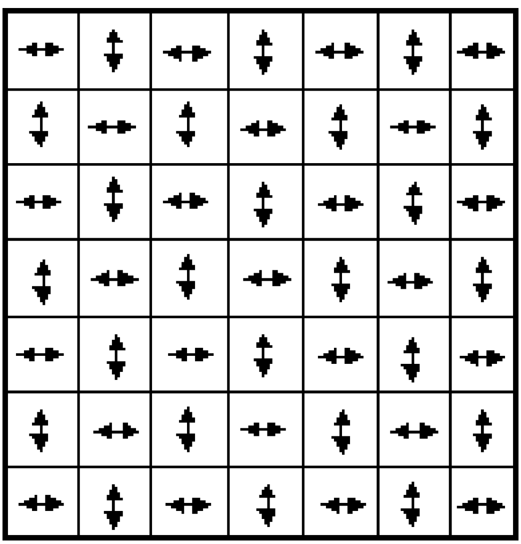

FIGURE 1 Orientational checkerboard pattern on the alignment layer. The AFM scanning direction was along the line in each domain.

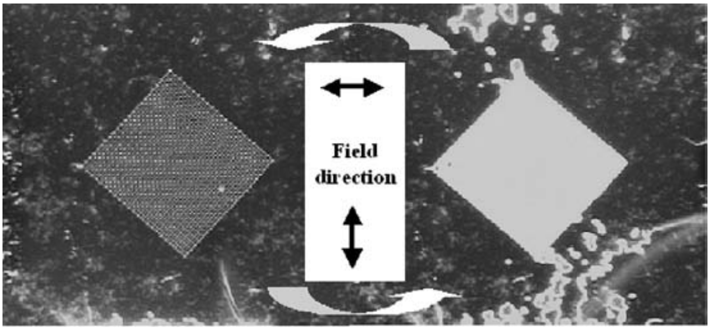

FIGURE 2 Bistable switching with two pairs of electrodes. The electrodes are hidden on the outside of the images. These polarizing optical microscope images were from a cell combined of two substrates: a uniformly rubbed substrate and nano-rubbed one. The dark texture was parallel state and the bright was twist state.

the pattern and electric field strength. To overcome these issues, here we show the possibility of the reducing the number of the electrodes using a particular NLC.

EXPERIMENT AND RESULTS

The basic experimental procedures were the same to those of the bistability using two pairs of electrodes. The cell structure was as Figure 3. One substrate had a pair of electrodes to apply in-plane electric field. The other substrate didn't. Both substrates were spin-coated with the polyimide (SE-150, Nissan Chemical) and baked at 180°C for an hour.

The checkerboard pattern was inscribed in between electrodes on the electrodes coated substrate as Figure 3. An AFM (SPA-500, Seiko Epson) was used for nano-rubbing. The nano-rubbing was controlled at the contact mode with the load force of 23 nN. The two scanning directions were adjusted by 45° to the possible electric field direction. The scanning density was 15 line/μm or 30 line/μm. The unit domain size was 4.0 μm × 4.0 μm or 2.5 μm × 2.5 μm. The pattern size was about 90 μm × 90 μm. Part of the pattern was on the electrodes as the distance between the electrodes was shorter than the length of the pattern and was hidden by the electrodes. The other substrate was rubbed uniformly along 45 degree direction to the electric field direction with the conventional rubbing. Both substrates were fixed by the double-sided tape to keep the cell gap. The NLC was

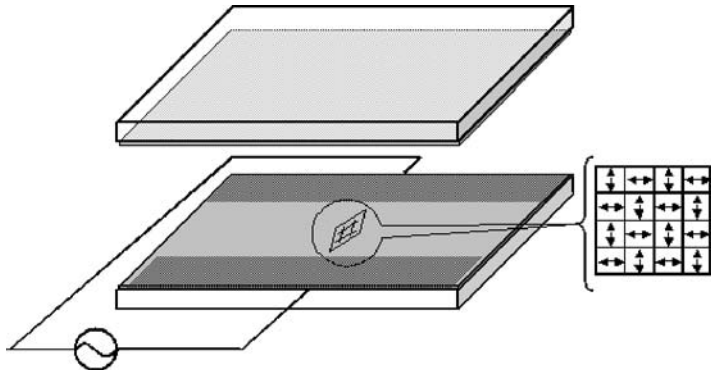

FIGURE 3 Cell structure for the realizing bistability with two electrodes. The dark regions of the bottom substrate are the electrodes. The upper substrate was uniformly rubbed.

injected along the perpendicular to the electric field at a higher temperature, still in nematic phase, to reduce the flowing effect.

We used a specific NLC (gift from Merck), which has the property of the sign reversal of dielectric anisotropy with the frequency of the electric field. At low frequency it has positive dielectric anisotropy (about 4.5 at 1 kHz) and it changes into negative at high frequency (about −4.7 at 30 kHz). The dielectric anisotropy is zero at the frequency of 7.3 kHz. The director responds to the electric field rotating along the field direction at low frequency and to the perpendicular at high frequency. We applied sinusoidal electric field with changing the frequency. We put the LC cell in the polarizing optical microscope at room temperature with adjusting the polarizers to get maximum contrast between two possible bistable states.

Figure 4 shows the switching behavior of the pattern consisted of $2.5\,\mu m \times 2.5\,\mu m$ unit size. Scanning density was 15 line/μm. We applied 35 V/μm at 1 kHz and 34 V/μm at 30 kHz (These values were not real threshold field. These were just the maximum field strength applied to the cell to obtain Figure 4. Some domains responded to the smaller field strength and the others did near this field strength.) In the figure, the black regions are the electrodes for applying the electric field.

Figure 5 shows the switching behavior with different electric field strength. With low field strength at low frequency, the directors in the bulk responded to the field by rotation along the field direction, however it returned back to the original orientation as the surface director didn't respond enough. As the field strength increased, some domains showed switched texture after turning the field off. More increased field strength

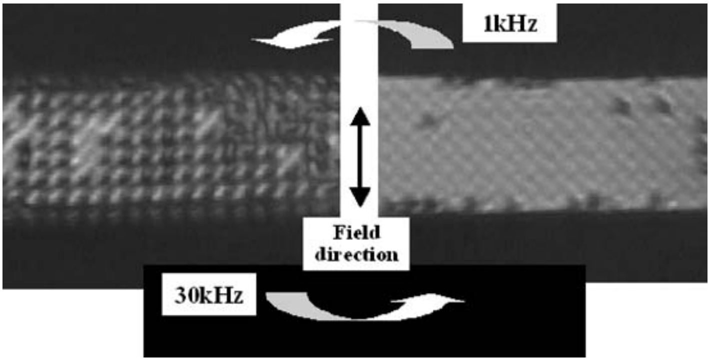

FIGURE 4 Switching between bistable states with a pair of electrodes.

extended the switched area and finally it arrived at the point that the most of the patterned area switched as Figure 4 or middle images of Figure 5. The non-uniformity of the response was supposed to be from the non-uniform distance between electrodes and non-uniform alignment layer

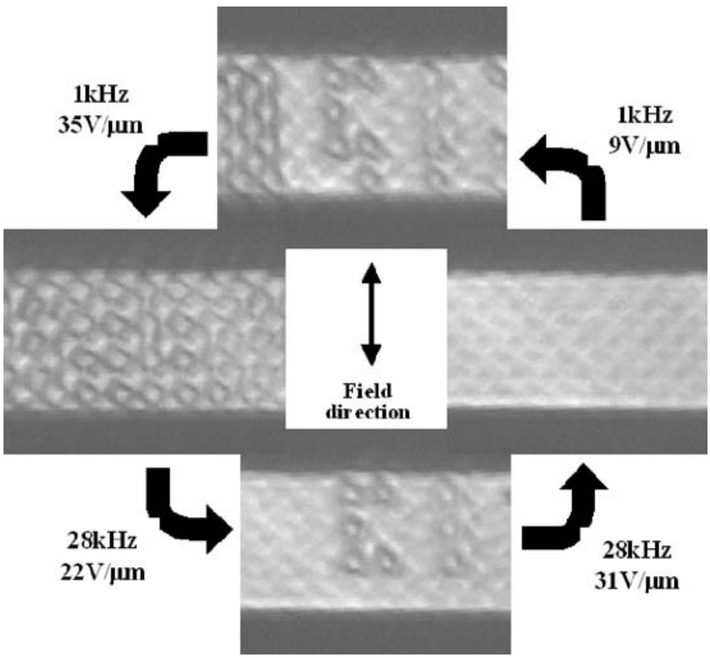

FIGURE 5 Switching behavior of a pattern consisted of $4\,\mu m \times 4\,\mu m$ domains. The scanning density was 30 line/μm.

from the LC flowing effect. If appropriate field strength at high frequency applied, the LC switched to the other orientation, perpendicular direction to the electric field, with the same scenario.

When we checked the switching behaviors with changing unit domain size, the pattern of small domain ($1.5\,\mu m \times 1.5\,\mu m$) showed a little vague switching response, particularly at low frequency. While, the pattern of larger domains of the $2.5\,\mu m \times 2.5\,\mu m$ and $4.0\,\mu m \times 4.0\,\mu m$ showed clear switching, although some parts in the pattern didn't respond at all. The size dependent response was also occurred to the switching using two pairs of electrodes with 5CB for less than $1.0\,\mu m \times 1.0\,\mu m$ unit domain. All the cases, the favor orientation of the macroscopic state was along the LC injection direction. So we think that the LC injection broke surface symmetry and brought non-equivalent free energy between two states.

Orientational switching of this bistability is based on the switching of the surface directors on the boundaries between neighboring domains. It is difficult to distinguish the behavior of the directors on the boundaries in the case of small domains. As the domains size was large enough in Figure 5, we could distinguish the boundary switching. Two images of the far ends in Figure 5 project strong difference of the brightness on the boundaries compared to the inside of domains.

The applied field strength for the most of the area to be switched was about $30\,V/\mu m$. It is much larger than about $5\,V/\mu m$ of the bistable switching using 5CB with two pairs of electrodes [5]. With simple approximations of Rapini-Papoular function for the anchoring energy and large domain size, the threshold field strength was obtained by the minimization of the free energy. The threshold field was expressed as [5]

$$E_{\mathrm{th}} = W_0/2\sqrt{K_{22}\Delta\varepsilon}$$

Here K_{22}: Twist elastic constant, $\Delta\varepsilon$: Dielectric anisotropy,
W_0: Anchoring strength.

Therefore increasing switching field strength means that the increased anchoring strength, decreased twist elastic constant or decreased dielectric anisotropy. Considering the similarity of scanning conditions to the previous, it seems that the difference of the physical parameter affects mainly in the threshold difference [5]. Currently it is not clear what factor enhanced the threshold field strength.

CONCLUSIONS

We could switch freely between two bistable states, which were realized on the frustrated alignment pattern of nematic liquid crystal, with a pair of electrodes, otherwise two pairs of electrodes are necessary to apply in-plane electric field along two different directions. To realize this we used a nematic liquid crystal, which shows the sigh change of the dielectric anisotropy as a function of the electric frequency. Low (1 kHz) or high (30 kHz) frequency field were applied between the electrodes according to the switching direction. However, as the experimental result indicated, the switching threshold field was very high. It is necessary to improve the switching characters.

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