Laser-driven microflow-induced bistable orientation of a nematic liquid crystal in perfluoropolymer-treated unrubbed cells

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Abstract: We demonstrate laser-driven microflow-induced orientational change (homeotropic to planar) in a dye-doped nematic liquid crystal. The homeotropic to planar director alignment is achieved in *unrubbed* cells in the thermal hysteresis range of a discontinuous anchoring reorientation transition due to the local heating by light absorption in dye-doped sample. Various bistable patterns were recorded in the cell by a programmable laser tweezers. The width of the patterns depend on the scanning speed of the tightly focussed laser beam and the minimum width obtained is $\simeq 0.57\mu$m which is about 35 times smaller than the earlier report in the *rubbed* cells. We show that the motion of the microbeam spot causes local flow as a result the liquid crystal director is aligned along that direction.

OCIS codes: (160.3710) Liquid crystals; (230.3720) Liquid-crystal devices; (350.4855) Optical tweezers or optical manipulation.

References and links

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1. Introduction

In any liquid crystal device, the orientation of liquid crystal molecules is achieved by treating the substrate surfaces, i.e., coating alignment layer, rubbing, etc. Commonly two different types of alignments are used such as planar and homeotropic. In case of planar the director (average orientational direction of the molecules) is parallel to the substrate and aligned along the rubbing direction. The orientation of the director can be changed by applying electric or magnetic field inside the cell. Because the director cannot be switched at the surfaces, these devices are monostable in the sense that the on-state is realized as long as the electric field is applied. It is known that the bistable device, in which two different stable states are memorized can reduce the power consumption considerably. In such liquid crystal devices, two possible orientations can be realized depending on the external stimuli such as electric or magnetic fields [1] or light [2]. There are several reports on the bistable [3–9] and even tristable [10] orientations of nematic liquid crystals. These are achieved mostly by appropriate surface engineering which allows for switching of molecular orientation at the surfaces [11]. The switching can also be driven by temperature [12, 13]. In the recent past we have reported a temperature driven discontinuous anchoring transition of a nematic liquid crystal on perfluoropolymer-treated surfaces [14]. In rubbed cells with dye-doped sample we demonstrated memory and rewritable bistable devices using direct laser writing technique [15,16]. We found when the chiral dopant is added the sample becomes cholesteric and various changes in the texture related to the variation of pitch emerges at the anchoring transition [17]. We also observed that the homeotropic alignment of smectic liquid crystals on the same perfluoropolymer are undisturbed by the external mechanical shock [18]. In the present study we show that using a programmable laser tweezers one can easily record bistable patterns of various shapes in *unrubbed cells*. The recorded line width can be reduced to the optical limit and hence are potential for high density liquid crystal data storage.

2. Experimental Results and Discussion

We used a liquid crystal $4^{'}$-butyl-4-hepty-bicyohexyl-4-carbonitrile (CCN-47) obtained from Merck. It exhibits the following phase transitions: Cr. 25.6 ^{o}C SmA^{o}C N 57.3 ^{o}C I. It has a large transverse dipole moment and possesses negative dielectric anisotropy ($\Delta\varepsilon = -5.7$ at 30 ^{o}C) [19]. The laser dye 4-dicyanomethylene-2-methyl-6(p-dimethylaminostyryl)-4H-pyran

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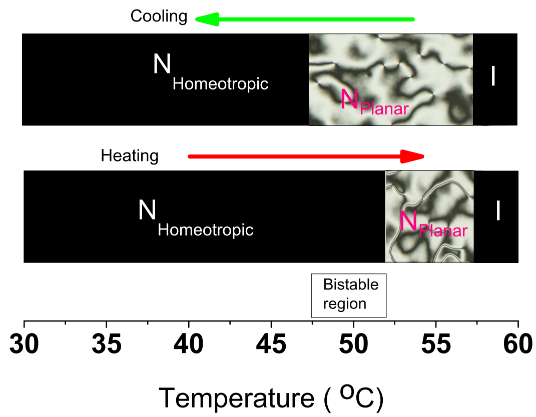

Fig. 1. Representative textures of the sample as observed under optical polarizing microscope in cooling (top) and heating (bottom). The bistable (hysteresis) temperature range is indicated below.

(DCM) was purchased from Exciton and 0.1wt% was mixed with the CCN-47 liquid crystal. An amorphous perfluoropolymer, poly[perfluoro (4-vinyloxy-1-butene)] (CYTOP) obtained from Asahi Glass., Ltd was spin coated onto the ITO coated glass plates. These plates were cured at 100 ^{o}C for about 30 min. Epoxy glue was used to make cells and Mylar spacer of thickness 5 μm was used to maintain the cell thickness. The samples were filled in the cells at the isotropic phase by capillary action. An ITO coated glass plate of thickness 1.2 mm was used as a heater. We used a laser tweezers setup that was built around an inverted microscope (Nikon Eclipse, TE2000-U) with an argon laser operating at 514 nm as a light source and a pair of acousto-optic deflectors driven by a computerized system (Aresis, TWEEZ 70) for trap manipulation. The experiments were performed using a 60X high numerical aperture water immersion objective.

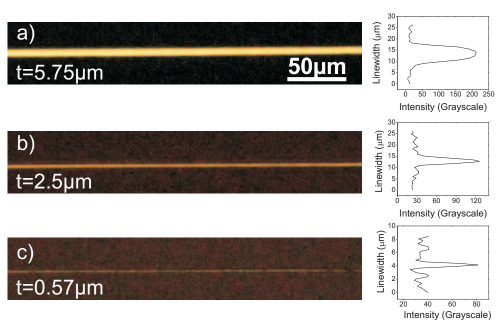

Fig. 2. (a) Recorded lines at various scanning speed of the laser tweezer beam at a temperature 51°C. The scanning speeds are (a)8 μm/s (b)19 μm/s (c)45 μm/s, respectively. The line widths are mentioned in each figures. Laser power 120 mW. Cell thickness $\simeq 5\mu$m. The intensity at each pixel across the bistable line is shown on the right side.

We first show the textures of the sample taken in optical polarizing microscope in heating and cooling in Fig. 1. In case of cooling the sample exhibits planar degenerate texture with many half strength defects in the nematic phase. At 47 °C the texture changes to homeotropic state indicating an anchoring transition. In this case the optical axis is uniform and oriented vertical to

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the substrates [14]. In case of heating the sample remains homeotropic up to the temperature 52 $^{\circ}$C and beyond that it changes to a planar state with characteristic umbilic and wall defects [20]. Thus there is about 5 $^{\circ}$C temperature range of thermal hysteresis in which either planar or homeotropic state can be achieved depending on the heating and cooling. The details of the measurement of transmitted intensity as a function of temperature in rubbed cells and defects in unrubbed cells are reported by us previously [20]. The inclusion of small percentage of DCM dyes does not appreciably change the transition temperatures [15]. Its absorption peak matches with the emission of Argon-ion laser wavelength (514nm) and thus can increase the local temperature by a few degrees and hence can change the orientation.

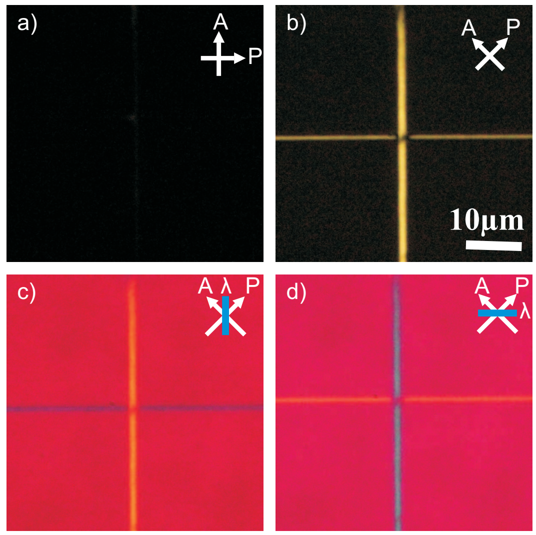

Fig. 3. Two orthogonal recorded lines under polarizing microscope at temperature 51°C (a) the beam scanning direction is parallel to the polarizer/analyser (b) 45° with respect to the polarizer/analyzer (c) with λ-plate and fast axis orientated parallel to the vertical line (d) with λ-plate and fast axis orientated parallel to the horizontal line. Cell thickness 5.2 μm.

In order to write various bistable patterns using programmable laser tweezers we increased the sample temperature from room temperature and held fixed at 51 $^{\circ}$C which is slightly below the anchoring transition temperature (52 $^{\circ}$C). We scanned the beam at various speeds such as 8, 19 and 45 μm/s. The corresponding generated lines are shown in Fig. 2. The intensity at each pixel across the bistable line is shown on the right hand side of Fig. 2. The width was estimated from the full width half maxima (FWHM) of the intensity. We note that the line width decreases with increasing scanning speed and the minimum width achieved is $\simeq$0.57 μm. Assuming the average molecular diameter is about 1nm, the number of molecules that have changed orientation in a cross section perpendicular to the thinnest line (Fig. 2(c)) is about 4×10^6. Previously we have reported about the bistable writing in the hysteresis region of the same sample in rubbed cells using an Argon-ion laser (514nm) and 20X air objective. There we kept the sample on a xy stage and the laser beam was fixed. The writing was done by moving the xy stage and the minimum width obtained was about 20 μm [15]. In the present study we kept the sample fixed and used same laser light through a 60X water immersion objective with large numerical aperture (NA=1.1). The laser was programmed by using an acousto-optic deflector (AOD) for the writing in the focal plane and the minimum width obtained was $\simeq$ 0.57μm. Thus the width of the lines is reduced almost by a factor of 35 compared to the previous report.

To understand the director orientation inside the bistable region we created two orthogonal

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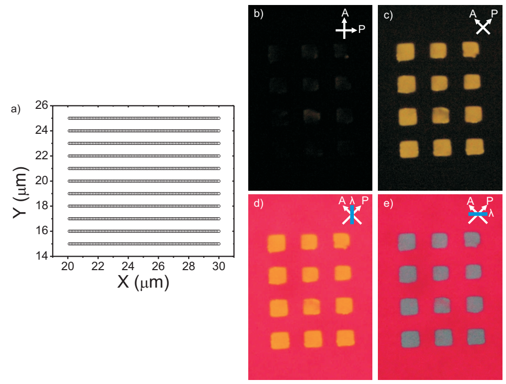

Fig. 4. Square grid patterns prepared at 51°C. (a) Pattern for a square box generated in the computer using Origin Software. Each square box is composed of parallel line of equal width and spacing. (b) the beam scanning direction is parallel to the polarizer/analyser. (c) 45° with respect to the polarizer/analyzer (d) with λ-plate and fast axis orientated parallel to the vertical line (e) with λ-plate and fast axis orientated parallel to the horizontal line. Cell thickness 5.2 μm.

lines in the same cell. In Fig. 3 we show two orthogonal lines which are created at a scanning rate of 11 μm/s. The lines are not seen when they are oriented parallel to the polarizers / analyzer whereas they are observed with good contrast and without any defects when the line direction is changed to 45° with respect to one of the polarizers (Fig. 3 (b)). This suggests that the director is uniformly orientated in both regions (planar and homeotropic). We used a full wave retardation plate (530 nm) i.e., a“red plate” between the sample and the analyzer to find out the director orientation inside two orthogonal lines. Interestingly we found that the two lines show different colors namely yellow and blueish and vice versa depending on the orientation of the fast axis of the red plate. In Fig. 3(c) the yellow line is parallel to the fast axis and the bluish line is perpendicular to it. This means the director is aligned along the direction of the fast axis considering the birefringence of the sample is positive.

For creating various complex bistable patterns we programmed the laser tweezers. A geometrical pattern for making square grid is shown in Fig. 4(a). They are actually made by several lines of equal width and gap. The pattern made by this program as seen under polarizing microscope is also shown in Fig. 4. The spacing between the two neighboring boxes in the x and y directions are equal and is 10 μm and the scanning speed was 10 μm/s. Interestingly we observe that the field of view appears almost dark (Fig. 4(b)) when the polarizers are crossed and the scanning direction is parallel to one of the polarizers but they are bright with good contrast when the scanning direction in the box is 45° with respect to the polarizer or analyzer (Fig. 4(c)). Thus the director orientation inside the boxes are planar whereas it is homeotropic outside the boxes. We further used red-plate to see the director orientation inside the boxes. The textures for two different orientations of the red-plate are shown in Figs. 4(d) and 4(e). This suggests that the molecules change their orientation due to the local heating generated by the absorption of laser light by the DCM dyes and a micro-flow is created along the motion of the beam. Thus the nematic director is aligned along the micro-flow direction. A schematic representation of micro-flow corresponding to the bistable patterns of Fig. 3 is shown in Fig. 5. It may be pointed out that the motion of the beam overwrites any previous orientation of molecules.

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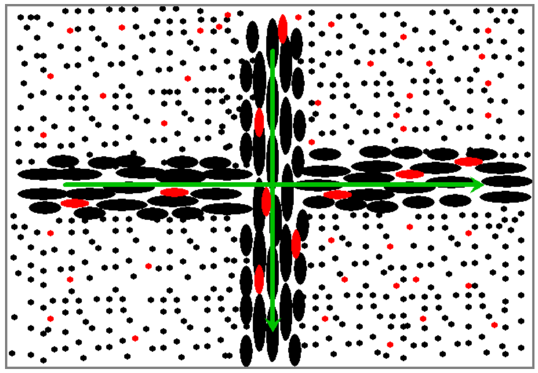

Fig. 5. Schematic representation of the molecular orientation in planar and homeotropic regions (top view). The DCM dye molecules are indicated in red colour. The green arrows indicate the direction of the motion of the beam spot in two orthogonal directions.

3. Conclusion

In conclusion, we have shown that various bistable patterns can be generated easily by using a programmable laser tweezers in the thermal hysteresis region of CCN-47 liquid crystal on perfluoropolymer-treated unrubbed surfaces. The line width decreases with increasing speed and the minimum width obtained is 0.57μm. The orientational transition is induced by local heating generated by a laser in dye-doped samples. The orientation of the director is achieved by a micro-flow in unrubbed cells. Such systems can be used as data storage devices and the storage density can be increased due to the reduction in the line width. Further such patters could also be used as channels for guiding plane polarized light as it sees a larger refractive index (n_e) in the planar region than the homeotropic region (n_o) and thus is useful for “Soft Chip” applications.

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