Bistable device using anchoring transition of nematic liquid crystals

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The authors have demonstrated a novel bistable memory device writable by a laser beam. The device utilizes the hysteresis of a temperature-driven discontinuous anchoring transition (orientation change) in a dye-doped nematic liquid crystal. The laser light irradiation switches the stable orientation from homeotropic to planar in a liquid crystal on perfluoropolymer surface. The thickness of recorded lines comes down to as low as ~20 μm. The recorded images were kept at least for a day, i.e., memory effect. We also showed that the temperature range of the hysteresis was lowered down to room temperature using a binary mixture system. © *2009 American Institute of Physics*. [DOI: 10.1063/1.3202781]

Liquid crystals (LCs) director can be aligned parallel (planar or homogeneous alignment) or perpendicular (homeotropic alignment) to substrate surfaces by means of several techniques. One of the most commonly used is coating polymers such as polyimide. This technique is widely used for commercial LC display devices and is very stable and reliable. However, the spontaneous anchoring transition in some combinations of polymer surfaces and LC molecules are reported and explained on the basis of interplay between them.[1–6] It is sometimes possible to control or trigger the orientational change by external stimuli such as temperature,[7,8] electric field,[9] and light.[10,11] Among them, photoinduced orientational change was induced by geometrical change in surface azobenzene molecules, by which homeotropic to planar[10] or in-plane molecular rotation[11] occurs. In our previous article,[12] we have reported temperature-driven anchoring transitions of LCs on a commercially available polymer surface, i.e., a discontinuous planar to homeotropic transition with a large hysteresis region, where both orientations are stable (bistable). In this letter, we demonstrate a memory device using the bistability. Planar regions can be formed by a laser beam in a uniformly homeotropic region and the regions are stable for a long time exhibiting a memory effect.

The nematic LC 4′-butyl-4-heptyl-bicyclohexyl-4-carbonitrile (CCN-47) was obtained from Merck Japan Ltd., and used without any further purification. The LC exhibits the following phase transitions: Cr 25.6 °C SmA 28.2 °C N 57.3 °C I, and possesses a large negative dielectric anisotropy ($\Delta\varepsilon = -5.7$ at 30 °C).[13,14] The laser dye coumarin 153 (C153) was purchased from Lambda physics. Perfluoropolymer poly [perfluoro(4-vinyloxy-1-butene)], known as CYTOP (from Asahi Glass Co., Ltd), was spin coated onto glass substrates and was cured for 30 min at 100 °C. Empty cells were fabricated by using two such glass substrates which were rubbed antiparallel to each other. Polymer beads were used for spacers to make 5 ± 0.3 μm thick cells. Then the LC CCN-47 doped with C153 (0.5 wt %) was introduced into the empty cells using capillary action in the isotropic phase.

Let us first show the anchoring transition and explain the concept of the bistable device using light-induced orientation change. Figure 1(a) shows the variation in transmitted intensity under crossed polarizers as a function of temperature. The measurement was made using a 545 nm light through a rubbed cell where the rubbing direction makes 45° to the polarizers. With decreasing temperature from the isotropic phase, the transmittance due to birefringence appeared because of planar alignment. With further decreasing tempera-

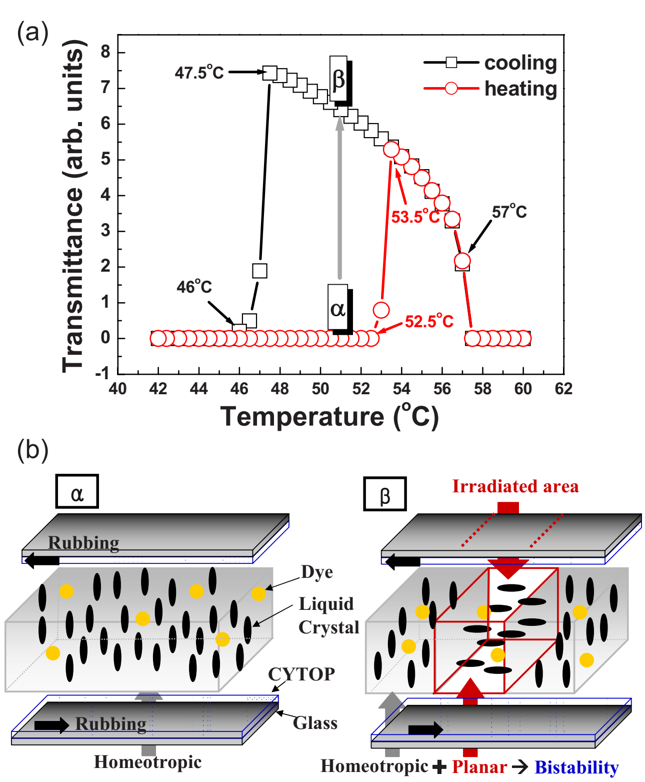

FIG. 1. (Color online) (a) Transmittance intensities of an orientated sample of CCN-47 doped with C153 (0.5 wt %) under crossed polarizers as a function of temperature. (b) Schematic illustration of light-induced anchoring transition and bistability.

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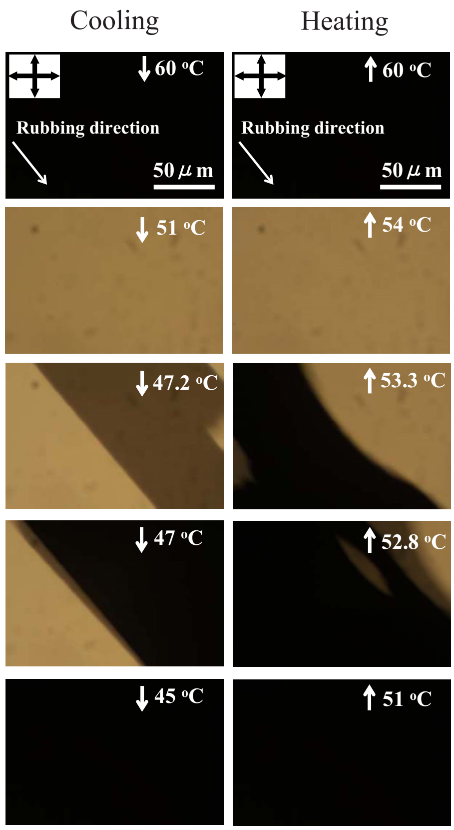

FIG. 2. (Color online) POM images of LC textures showing anchoring transitions in the cooling (left) and heating (right) processes.

ture in the nematic phase the transmittance abruptly decreased to zero at 47.5 °C, indicating a discontinuous change in LC director (anchoring transition) from planar to homeotropic. Upon heating back, the transmittance suddenly increased at 52.5 °C with a large hysteresis of ~5 °C. The presence of the hysteresis region with a considerable width is a key requirement for the bistable device. First we keep our cell at a homeotropic anchoring state (α state), as shown in Fig. 1(b) (left). By irradiating a part of the cell, dye molecules absorb the light energy, resulting in a certain temperature rise within a region of beam size in the cell. If the temperature rise is above the upper anchoring transition temperature, the irradiated part of the sample changes its orientation into planar anchoring (β state). Because of bistability, the planar and homeotropic states coexist stably, as shown in Fig. 1(b) (right).

The process of anchoring transition in the dye-doped CCN-47 is shown in Fig. 2. In our previous paper, we reported the transition process in an unrubbed cell, where planar orientation appeared with schlieren texture. In the present case, planar orientation appears as a uniform bright region because of uniform orientation to the rubbing direction. On cooling (left row) after the transition from the isotropic phase, planar texture was preserved down to 47.5 °C. On further cooling (47.2 °C) a dark domain appeared, propagated, and finally coalesced into one dark domain at 45 °C, indicating a homeotropic orientation. On heating (right row) the transition to the planar from homeotropic anchoring took place. Noticeable observation was that the transition during cooling and heating processes propagated along the rubbing direction, whereas the transition was associated with round domains in unrubbed cells.

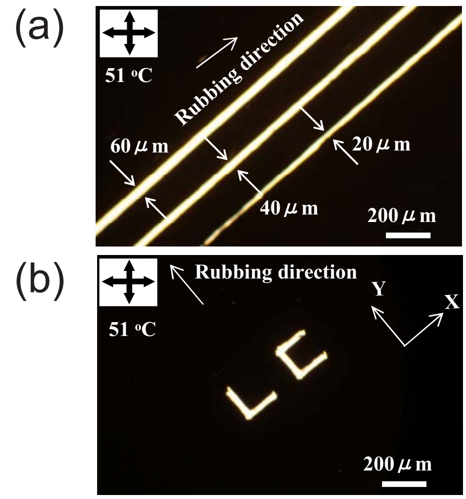

FIG. 3. (Color online) (a) POM image of recorded line patterns. (b) POM image of recorded LC pattern.

Now we describe the performance of recording by laser light. We employed a laser diode, LQC405-360C (a product of Newport), whose wavelength (405 nm) well matches the absorption peak of the dye (C153) used. The laser power before hitting the sample was set to 1.2 kW/mm^2 by neutral density filters. The beam was focused on the sample cell using a lens of a focal length of $f=2.5$ cm. The sample cell was laterally transferred by a computer-controlled *XY* stage. Before irradiation, the cell was cooled down to room temperature from isotropic state in order to obtain complete homeotropic alignment, then heated up to 51 °C, which is in the bistable region, as shown in Fig. 1(a). Parallel lines were recorded along the rubbing direction using a single scan with different speeds, 0.2, 0.5, and 0.8 mm/s. Polarizing optical microscopic (POM) images of the recorded lines are shown in Fig. 3(a), where the rubbing direction makes about 45° with respect to the polarizers. The generated line widths were about 60, 40, and 20 μm depending on the scanning speed, 0.2, 0.5, and 0.8 mm/s, respectively. Thinner uniform line less than 20 μm was hard to obtain maybe due to the intrinsic shape of Gaussian beam and/or heat dissipation of LC. We confirmed that both (bistable) anchoring states remained unchanged at least for a day. Figure 3(b) shows an example of recorded image of tiny characters "LC" observed under a polarizing optical microscope.

It is necessary to decrease the temperature range of the hysteresis to room temperature in order to make the device practical. For that purpose, we prepared binary mixtures of CCN-47 and *p*-cyanophenyl *p*-*n*-heptylbenzoate (CP7B). CP7B shows the nematic-isotropic transition at 55.6 °C, so that we can expect a lower anchoring transition temperature by mixing with CP7B. We confirmed that the binary mixtures exhibit the first order anchoring transition with hysteresis (between triangular and circular symbols) up to the concentration less than 37.2 wt % of CP7B, as shown in Fig. 4. We found that the anchoring transition temperature as well as the clearing temperature (square symbols) decreases with increasing CP7B amount. About 35 wt % of CP7B, we can bring the anchoring transition range down to room temperature. This result indicates the possibility of bistable devices at ambient temperature.

In conclusion, we reported memory and display devices utilizing bistability associated with anchoring transition of

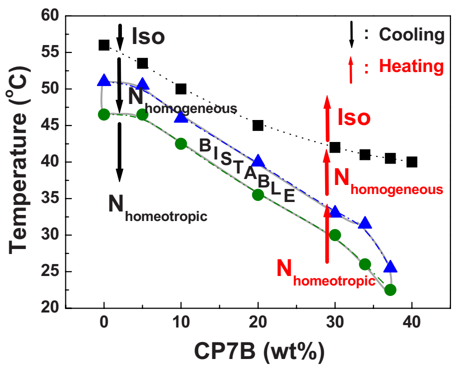

FIG. 4. (Color online) Transition temperatures as a function of the concentration of CP7B in the CCN-47/CP7B binary mixture system. Iso and N stand for isotropic and nematic phases, respectively. The area between triangular and circular symbols represents bistable regime, i.e., both planar and homeotropic alignments are stable.

LC materials on perfluoropolymer-coated substrates. We demonstrated the laser-light-driven recording on the cell. The bistable temperature region was brought down to room temperature using a binary mixture for room-temperature devices.

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[14]We found that the phase transition temperatures and anchoring transition temperatures in our previous paper (Ref. 12) were not correct. This is due to the mistake of temperature calibration.