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Uniform Alignment of Liquid Crystalline Cubic Blue Phase II via Rubbing Treatment

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The uniform alignment of liquid crystalline cubic blue phase II (BPII) has been achieved using a conventional surface rubbing treatment. Through comparison of thick and thin cells of assembled rubbed glass, which were covered with commercially available polyimide (PI), we confirmed that rubbed surfaces play an important role in the fabrication of monodomain PBII. These well-aligned cubic BPII materials can be promising for photonics devices.

Keywords Liquid crystal; blue phase; rubbing; alignment

1. Introduction

Liquid crystalline cubic blue phases (BPs) have attracted attention in the field of photonics due to their self-assembled periodic structure [1]. Cubic BPs have a unique three-dimensional structure that is characterized by double-twisted cylinders and disclination [2]. Cubic BPs can be classified into two types: a body-centered-cubic BP (BPI) and a simple cubic BP (BPII), which are numbered as a function of increasing temperature between the chiral nematic (N*) and isotropic phase [3–5].

The uniform alignment of liquid crystal (LC) molecules is a key issue in manufacturing liquid crystal displays (LCDs). In general, rubbed polyimide (PI)films are used in LCDs to induce homogeneous alignment of LC molecules [6]. Cubic BPs exhibit a poly-crystalline structure with fairly small platelet domains between the two glass substrates, without any special treatment. However, high and constant reflection intensity originating from a specific plane of the cubic BP structures is favorable in order to obtain a high performance photonic device, such as a mirror-less liquid crystalline BP laser [7,8]. Thus, the preparation of a monodomain BP is indispensable from an application point-of-view. However, it is known that orientation control of BPs is difficult to achieve, because, unlike as in nematic liquid crystals, the director in a BP is not uniform [9].

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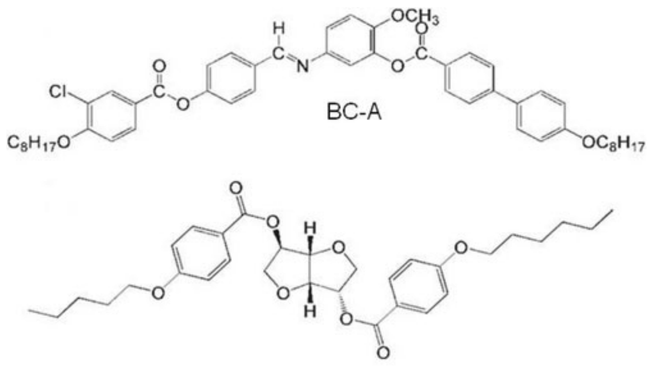

Figure 1. Chemical structures of BC-A and the chiral dopant used in this work.

In this work, we succeeded in preparing uniformly aligned BPII for use in a mirrorless liquid crystalline BP laser, employing a conventional surface rubbing treatment. It is interesting to note that BPII exhibited a tendency to easily realize uniform alignment via this rubbing protocol. Through comparison of thick and thin cells of assembled rubbed glass, which were covered with commercially available PI, we confirmed that the rubbed surfaces play an important role in the fabrication of a monodomain PBII.

2. Experimental

2.1 Materials

We prepared a host nematic (N) mixture consisting of a rod-like nematogen (80 wt%) and a bent-core molecule A (BC-A, 20 wt%). The BC-A molecules possess N phase, and it is known that the temperature range of cubic BPs tends to widen when mixed with bent-core molecules [10,11]. The employed rod-like nematogen (MLC-7026-000, Merck Co.) is a commercially available multicomponent mixture. By blending the chiral dopant (ISO–$(6OBA)_2$) with the host N mixture, a host N* mixture was prepared. Three kinds of chiral mixtures were prepared: CM-1, CM-2, and CM-3, being chiral mixtures that were blended with 6.2 wt%, 6.5 wt%, and 7 wt% of the chiral dopant, respectively. The chemical structures of a BC-A molecule and the chiral dopant used in this work are depicted in Fig. 1.

2.2 Cell Fabrication

Two different types of sandwiched cells with different cell gaps were prepared, which were all subjected to the surface rubbing treatment: (1) a thin cell with a cell gap of 10 μm (Cell-A) and (2) a thick cell with a cell gap of 20 μm (Cell-B). The cells that underwent the rubbing treatment were fabricated as follows: commercially available PI (SE-7492, Nissan Chem.) was spin-coated on the slides, which were then cured at 180°C for 20 min. Next, rubbing was performed with a commercial rubbing machine with a moderate rubbing strength and using velvet. Subsequently, two slides were assembled assuring an antiparallel rubbing direction between each other. Then, the prepared chiral mixtures (CM-1, CM-2,

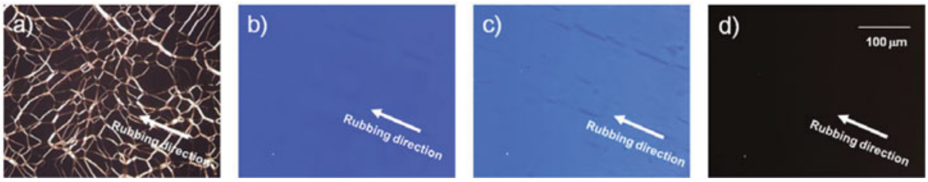

Figure 2. Typical POM images of CM-3 upon heating. A N*-phase (a), characterized by an oily streak texture, progressed into a mono-colored uniform phase (b and c). Finally, the uniform phase changed to the isotropic phase (d). The arrows indicate the rubbing direction.

and CM-3) were injected in an isotropic phase into the prepared sandwiched cells. Once the chiral mixture cooled down to a N* state, cubic BPs in two different cells were observed during the heating process.

3. Results and Discussion

Figure 2 shows a sequence of typical polarizing optical microscopy (POM) images, revealing the textures of CM-3. For POM observations, CM-3 was injected into Cell-A. When subjected to a heating rate of 0.1°C min^{-1}, the N* phase (Fig. 2a), which is characterized by an oily streak texture, progressed into a blue mono-colored uniform phase (Fig. 2b and c). Finally, the uniform phase changed to the isotropic liquid phase (Fig. 2d).

To determine the mono-colored uniform phase between the N* phase and the isotropic liquid phase upon heating, the temperature dependence of the Bragg reflection caused by CM-3 in Cell-A was investigated. Figure 3 depicts typical reflectance profiles of the uniform phase upon heating. The uniform phase exhibited a single peak with a sharp and high reflectance profile. The inset of Fig. 3 shows the extracted peak wavelengths as a function of the temperature. As shown by the figure, the Bragg reflection wavelength shifted to higher wavelengths with increasing temperatures. This trend is explained by the

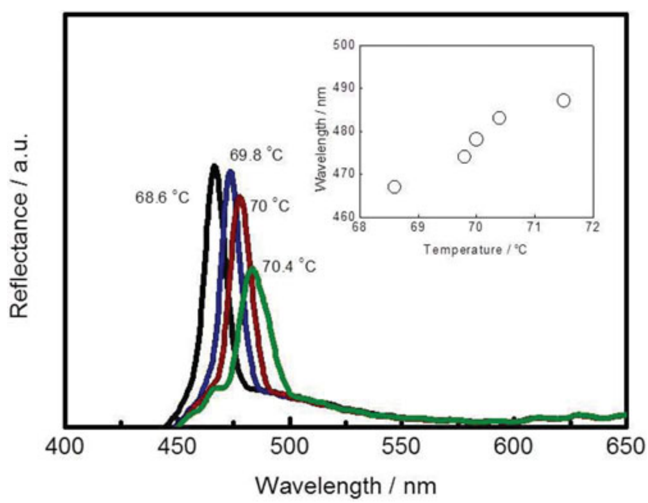

Figure 3. Typical reflectance profiles of the well-aligned uniform phase upon heating. The inset shows the peak wavelengths as a function of the temperature.

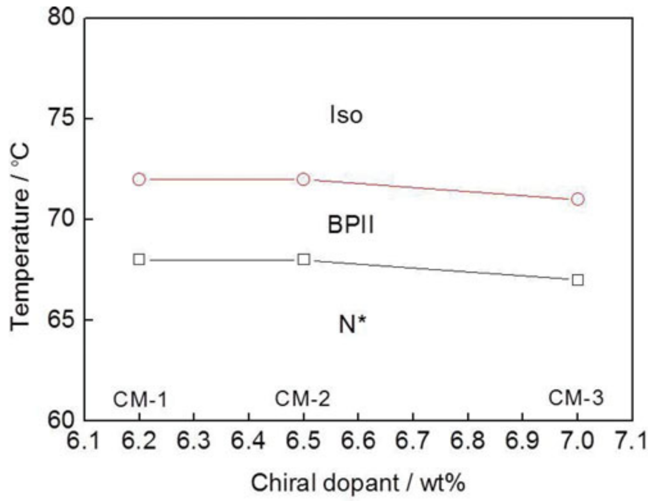

Figure 4. The temperature range of three types of chiral mixtures.

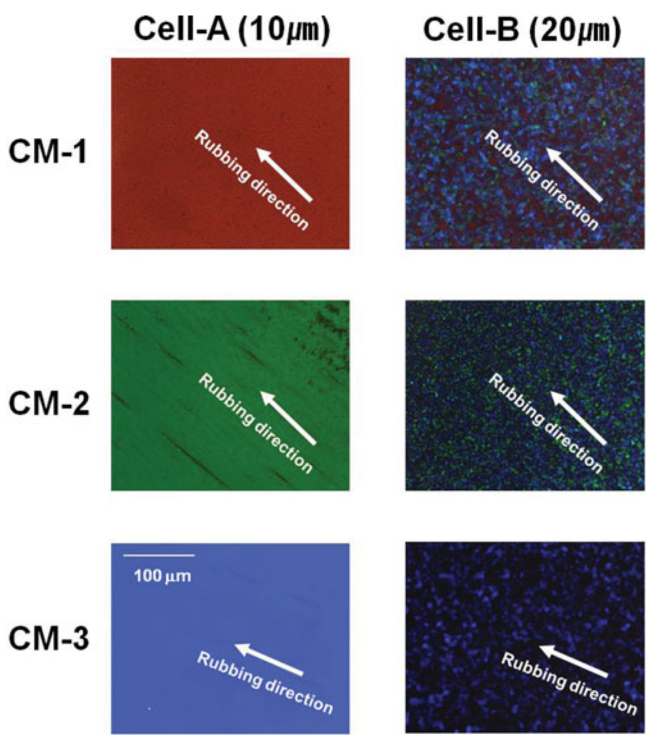

Figure 5. POM images of BPII at the same reduced temperature (1°C above T_{BPII}, the transition temperature from the N* phase to BPII during heating) for the three different chiral mixtures in both Cell-A and Cell-B. The arrows indicate the rubbing direction.

fact that this mono-colored uniform phase is attributed to cubic BPII [5,7,8]. In this regard, the reflections that were collected for the mono-colored uniform phase turned out to be the (100) reflections of the cubic lattice planes of monodomain BPII for a cell subjected to rubbing treatment [7,8].

Based on the POM results and the Bragg reflection observations, the temperature range of BPII in CM-1 was approximately 4°C during the heating process, being larger than that of conventional BPII observed in typical rod-like nematic LCs when blended with a chiral dopant. Similarly, the temperature range of BPII in CM-2 and CM-3 was also determined. The temperature ranges of each type of chiral mixture (CM-1, CM-2, and CM-3 blended with 6.2 wt%, 6.5 wt%, and 7 wt% of chiral dopant, respectively) are shown in Fig. 4.

Figure 5 shows POM images of BPII at the same reduced temperature (1°C above T_{BPII}, the transition temperature from the N* phase to BPII during heating) for the three different chiral mixtures (CM-1, CM-2, and CM-3). The left column shows POM images for Cell-A, while the right column displays the POM images for Cell-B. As illustrated in Fig. 5, uniform BPII showing a single color was only realized in Cell-A. However, non-uniform textures comprised of multi-platelets were observed as the cell gap was increased (Cell-B). These results indicate that rubbed surfaces play an important role in the fabrication of monodomain PBII.

Finally, we succeeded in fabricating a dye-doped cubic BPII with mono-platelet domains using a conventional rubbing treatment on glass surfaces. Using this well-aligned uniform BPII, we were able to drastically reduce the emission threshold energy of the laser action. Details on this process are described elsewhere [7].

4. Summary

We confirmed that uniformly aligned BPII can be readily realized via a rubbing treatment. This is because the BPII possesses a simple cubic structure, while BPI exhibits a body-centered cubic structure. These well-aligned cubic BPII materials can be promising candidates for use in photonics devices, such as mirror-less laser media.

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