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A Novel Alignment Layer for Bistable Surface by Using Electrospun PVCi Microfibers

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We propose a novel forming method for the bistable surface for the nematic LC with the poly (vinyl cinnamate) (PVCi) fibers, the fibers were spun by using the ES and were carried out the photo-alignment treatment by the UV irradiation. In this method, each stable state in the bistable states for the LC orientation might be realized. Because lots of fibers were stacked not only the substrate surface but also in the bulk of the LC cell, and then the anchoring force for the LC alignment was affected in three dimensions.

Keywords LC alignment; electro-spinning; bistable surface; PVCi fiber

1. Introduction

In recent years, bistable LCD has been developed in order to achieve the low power consumption display [1, 2]. In this paper, we propose a novel forming method for the bistable surface with the nematic LC by using poly (vinyl cinnamate) (PVCi) [3, 4] fibers. The electrospinning (ES) method [5–26] is known as one of the spinning technique which is fabricated very fine polymer fibers under the high electric field. Recently, this method has been noticed because the technique can be relatively easily produced the fine fibers which have the micro to nano order in diameter. The basic ES implement is composed by a high voltage power supply, a capillary, a material tank, and a collector as shown in Fig. 1. The material was prepared for spraying: first, the material was diluted in an appropriate solvent, next, it was put into a material tank (syringe) connected with a thin capillary which diameter was less than 1 mm. The ES method has some attracted attentions because it can be spun fine fibers without any thermal process and many materials can select. Furthermore, spun fibers can be almost aligned in one direction on the collector wheel with high-speed rotation [27]. The application to the LC devices, for instance, a CPDLC mode which can apply to as a privacy window by using the cellulose fibers has been proposed [28]. The purposes of this paper are performed to determine the condition of forming the layer consisted of

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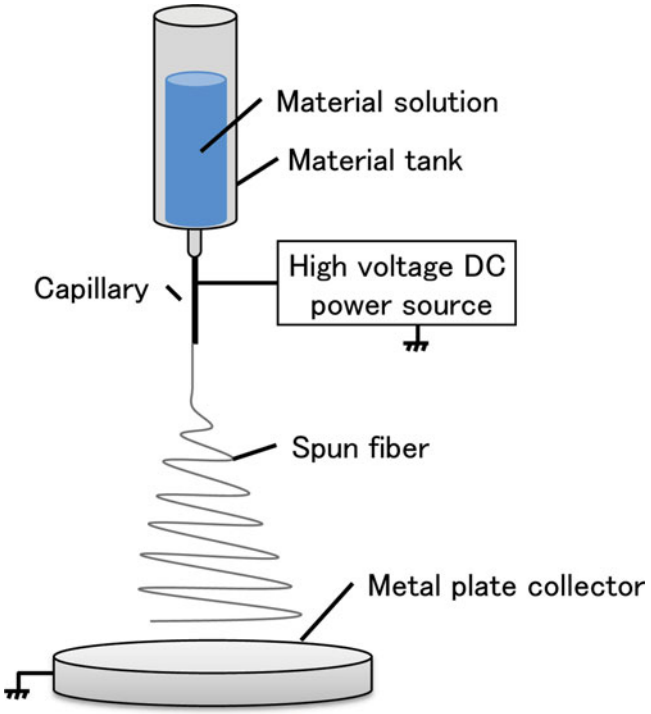

Figure 1. Electrospinning method.

uniaxis PVCi fibers by the ES treatment and the proffer of a novel technique for forming the bistable layer consisted of PVCi fibers by applying the photo-alignment technique.

2. Bistable Surface by Electrospun PVCi Microfibers

We propose a novel forming method for the bistable surface for the nematic LC with the PVCi fibers. A lot of fibers were spun and stacked on the glass substrate by using the ES method and the layer was formed. The photo-alignment treatment was carried out to that layer. The schematic image of fundamental principle of the bistable surface formed by the electrospun PVCi fibers that was treated by the photo-alignment technique is shown in Fig. 2. The glass substrate coated with the ITO film was fixed on the side surface of the cylindrical collector made of the aluminum with diameter 7 cm. And, spun PVCi fibers were reeled off and piled up to this collector with high-speed rotation. The fibers were aligned to one direction along the rotation direction of the collector. Then, the polarized UV light was irradiated to that substrate stacked PVCi fivers due to the photo alignment treatment. The polarized direction was along the fiber aligned direction, that is, the side chain of PVCi perpendicular to the fiber direction was remained. Apropos, it is known in general that the LC molecules have a characteristic that their long axes are aligned parallel to the direction of tiny groove structure or filamentous fiber. As a result, it seemed that two alignment forces were induced, the direction that was an along the fiber direction affected by stacked fibers and the other one was a perpendicular to the fiber direction affected by the photo-alignment, for orienting the nematic LC. And, those forces were combined and two orientation easy axes arose. Then, each stable state in the bistable states for the LC orientation might be

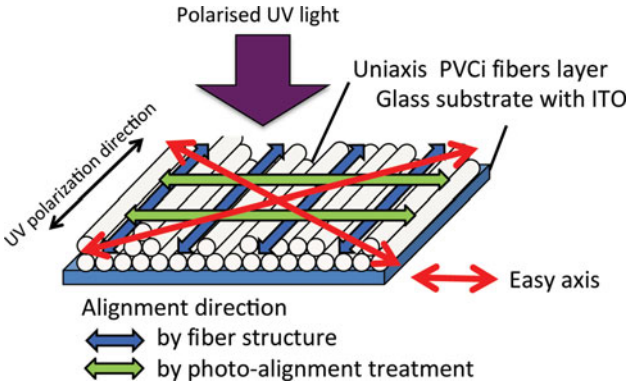

Figure 2. Schematic image of fundamental principle of the bistable surface electrospun PVCi fibers with photo-alignment technique.

realized. Because lots of fibers were stacked not only the substrate surface but also in the bulk of the LC cell, and then, the anchoring force for the LC alignment was affected in three dimensions.

3. Experimental

3.1. Fabrication of Uniaxis PVCi Fiber Layer

Polymer Concentration. The polymer concentration can affect the shape and diameter of fiber in the ES process is known, it is necessary to appropriate concentration depending on the purpose and material. Experiments were carried out as follows. The glass substrate coated with the ITO film was set into the conductive holder was horizontally setup, and a micro syringe with capillary with 110 μm of internal diameter was set to 6 cm in the upper part of the glass substrate as shown Fig. 3(a). And 10 kV of the DC voltage was applied between the holder and capillary for 30 sec. The syringe was full of the PVCi (Polysciences, Inc.) solution and 0.6 kgf/cm^2 of the air pressure was applied in the syringe. As a solvent, the tetraphydrofuran (THF) was used. Here, the concentration of 4 to10 wt% of the PVCi solution was used. The spun fibers were evaluated by the laser microscope.

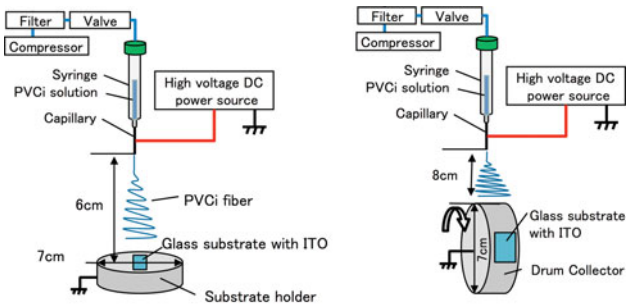

Figure 3. Our ES implements.

Distance Between Capillary Tip and Substrate. The next, the orientation of fibers depend on the distance between substrate and capillary tip using the rotation collector was evaluated. The experimental implement for this experiment is shown in Fig. 3(b). The distance between capillary tip and substrate was varied from 4 to 10 cm, the rotation collector had 7 cm in the diameter and the rotational speed was 1000 rpm. Other conditions of this experimental were same as the experiment mentioned above. The evaluation of the orientation distribution of fibers under each condition was done by using microscope photos with the image analysis software (Fiji [image J 1.47i]).

Rotation Speed of the Collector. The rotation speed of the collector was varied from 1670 to 3300 rpm. The distance between the capillary tip and substrate was 8 cm, and 10 wt% of PVCi solution was used for the ES. Other conditions of this experimental were the same as the above-mentioned one.

3.2. Fabrication of Bistable Layer

The grass substrate (25 × 10 × 1.1 mm) with ITO film was set into the conductive rotation wheel holder as shown in Fig. 3(b). The syringe was full of the PVCi solution and 0.6 kgf/cm^2 of the air pressure was applied in the syringe. As a solvent, the THF was used. Here, the concentration of 4 to 10 wt% of the PVCi solution was used. The rotation speed of the holder was 4920 rpm. And, 10 kV of DC voltage was applied between the holder and capillary for 90 sec. After that, the substrate was baked in 120°C for evaporate solvents. Then, the polarized UV light (1 J/cm^2) was irradiated to that substrate stacked PVCi fivers due to the photo alignment treatment. The polarized direction was along the fiber aligned direction, that is, the side chain of PVCi perpendicular to the fiber direction was remained.

The other hand, the vertical alignment film (SE-1211 4 wt% Nissan Chemi. Ind.) was formed on the surface of another glass substrate by the spin-coat method. Then, the empty cell was assembled by those two substrates. The LC material, 5CB (Merck) was injected into the cell at the isotropic phase, and cooled down to the room temperature.

4. Results and Discussion

4.1. Fabrication of Uniaxis PVCi Fiber Layer

Figure 4(a)–(d) shows photos of PVCi fibers fabricated by the different concentrations of PVCi solution, respectively. These fibers were spun without using the wheel collector. The spindle-shaped fibers were observed when the low concentration of PVCi solution was used as shown in Fig. 4(a)–(c). Additionally, it was observed that the number of spindle-shaped fibers decreased when the PVCi concentration increased. However, it was not observed when 10 wt% of the PVCi solution was used. On the other hand, a tendency to the thick diameter of fiber was spun when the PVCi solution concentration was increased was observed. The viscosity of the solution increased when the concentration increased, then the inside of capillary was easily blocked, that is, the reproducibility of spinning the fibers was reduced. It seems that the optimal concentration of the solution for spinning the fibers such thin and smooth was 10 wt%.

Figure 5(a)–(d) shows the photos of PVCi fibers fabricated by the different distance between capillary tip and substrate using the wheel collector. The angle that was formed by overlapping fibers under the microscope field was evaluated by the histogram analysis, is shown in Fig. 6(a)–(d). In this histogram, the azimuth angle along to the collector rotation

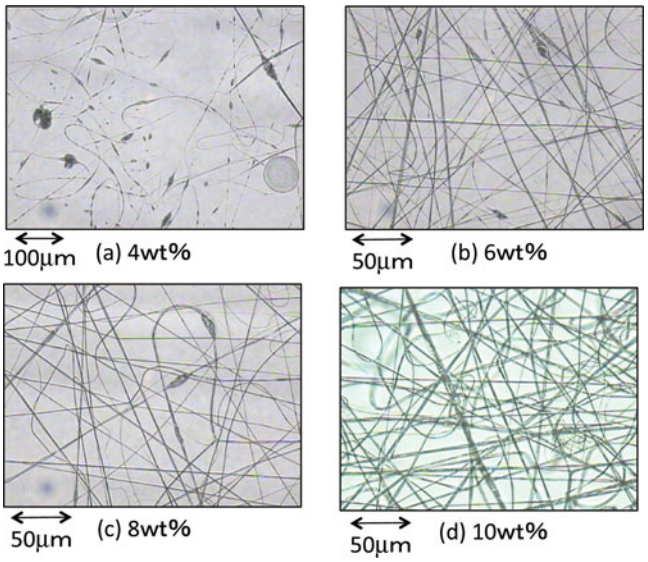

Figure 4. Photos of PVCi fibers fabricated by different PVCi concentrations.

direction was defined as 0 deg. The smoothness on fiber surface was reduced in the samples under the spun conditions which were 6 cm and 4 cm of the distance between capillary tip and substrate. Additionally, a wide peak that was drawn by the envelope curve in the histogram was obtained. Because the flying time of fibers was short, it seemed that the stretching process was not enough for spinning fibers. The other hand, the orientation of

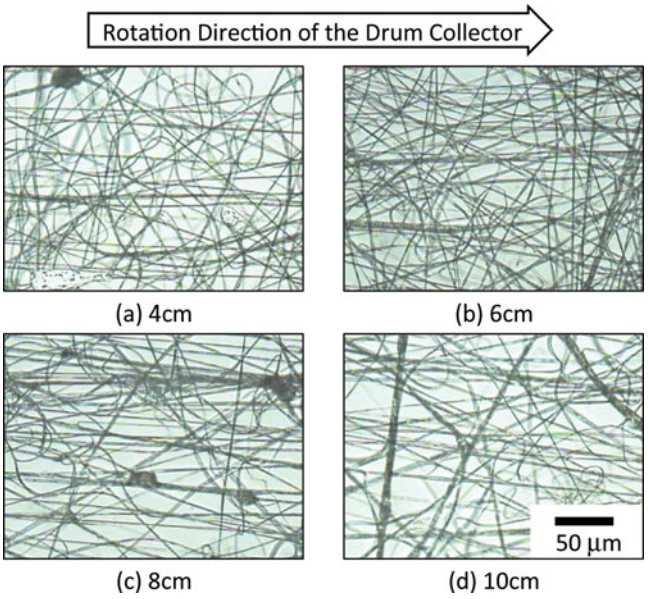

Figure 5. Photos of PVCi fibers fabricated by the wheel collector depend on the distance between capillary tip and substrate.

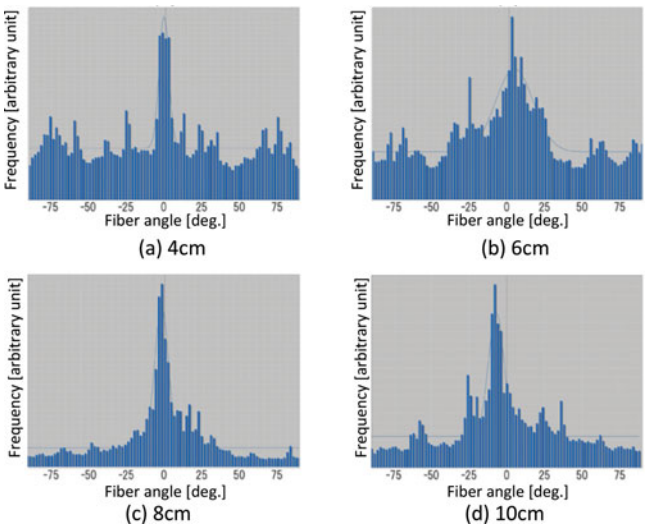

Figure 6. Histograms of the fiber angles.

fibers was passable, however, the interval of fibers in the fiber layer was coarse under the condition of the long interelectrode distance. Because, it was considered that spinning fibers were easily stacked on the other part from the collector due to the long interelectrode distance, and the collection rate was reduced. A good smoothness of the fiber surface by the visual observation and a good orientation property for fibers were obtained under the condition by 8 cm of the distance. Therefore, it was concluded that this condition was the optimal condition by our implement.

Figure 7(a)–(d) shows the photos of PVCi fibers which were fabricated by the wheel collector by the different rotating speed. It was observed that the orientation of fibers could

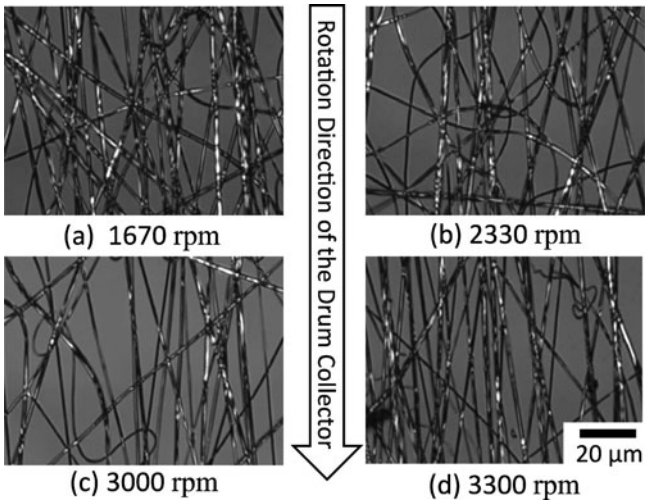

Figure 7. Photos of PVCi fibers which were fabricated by the wheel collector at rotating different speeds.

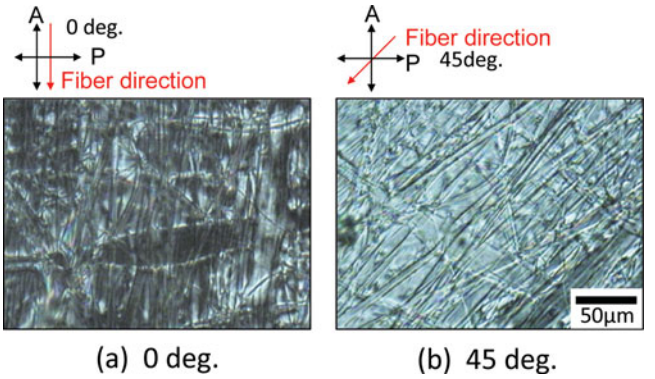

Figure 8. Photos of sample LC cells without the photo-alignment treatment.

be improved as the rotation speed was faster. It was expected that the fiber in the spinning process might be cut due to the high speed reeling. However, this phenomenon was not observed.

4.2. Fabrication of Bistable Layer

Figure 8(a)–(b) shows photos of LC cells without the photo-alignment treatment. The observation was done under the polarization microscope with the closed-Nicol condition. It was confirmed that LC directors were aligned along the fiber because a dark state for the optical extinction was observed when the direction of fiber orientation and the polarization direction in the polarizer were parallel. And, the bright state for the optical interference was observed under the condition in the 45 deg. of angle between the fiber direction and the polarization direction. Therefore, it was confirmed that the injected nematic LCs were aligned along the fiber direction. The reason why uneven areas were observed for the LC alignment in those cells was the uniform orientation of fibers was not obtained on the substrate, unfortunately.

Next, the photos of similar sample LC cells that were carried out the photo-alignment treatment were shown in Fig. 9(a)–(c). The observation was done under the polarization microscope with the closed-Nicol condition. The bistable orientations, i.e., two easy axes, were observed in the cell. In Fig. 9(a), the fiber orientation direction in the cell was set in +12 deg. from the axis of the polarizer, the optical extinction state was observed in the part

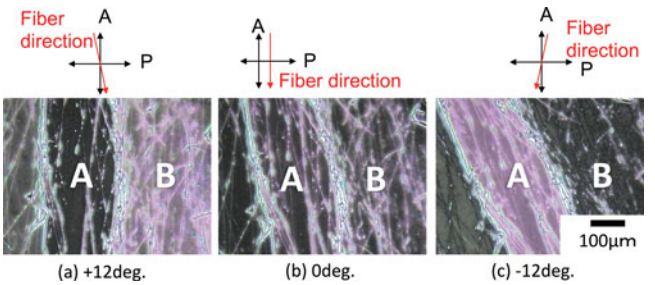

Figure 9. Photos of sample LC cells with the photo-alignment treatment.

B. The other hand, when the fiber orientation direction in the cell was set in −12 deg., the optical extinction state was observed in the part A as shown in Fig. 9(c). In this experiment, the bistable characteristic was obtained only in a part of area where fiber orientation was comparatively uniform. Therefore, the improvement of the fiber orientation property and the spin the thin diameter of fibers are important for this method.

5. Conclusion

We proposed a novel forming method for the bistable surface for the nematic LC with the PVCi fibers, the fibers were spun by using the ES method and were carried out the photo-alignment treatment. In this method, each stable state in the bistable states for the LC orientation might be realized. And, it was confirmed that the LC directors were oriented along grooves formed by the many stacked fibers. Furthermore, in the case of using the LC cell treated by the photo-alignment treatment, the two orientation easy axes were observed in a portion of the cell.

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