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Light scattering properties induced by memory effects in a nematic liquid crystal cell without rubbing

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A memory effect of molecular orientation observed in a nematic liquid crystal cell without rubbing is investigated by using a pairing of plane and parallel electrode structures. The liquid crystal cell gives an opaque state by heating it up to an isotropic phase and cooling down to a nematic phase with an external field applied; strong light scattering properties can be obtained. The opaque state is stable for a long period of time at room temperature. However, once the liquid crystal cell is heated up to an isotropic phase and cooled down in the absence of an external field, the opaque state can be cleared and the cell returns to its transparent initial state. The light scattering properties and microscopic textures of the liquid crystal cell are investigated for various experimental conditions.

1. Introduction

Some kinds of memory effect by use of an external field in a nematic liquid crystal cell without surface treatment, such as rubbing, have been reported previously [1–3]. Recently, a memory effect of uniform molecular orientation was observed by using a nematic liquid crystal cell with a patterned electrode structure without rubbing treatment [4]. Once the liquid crystal cell is heated up to an isotropic phase and cooled down to a nematic phase (HC-treatment) with an AC electric field, molecular orientations are memorized on the surface of the substrate along the lateral component of the non-uniform electric field produced by the patterned electrode structure. These memory effects induced by the external field may be expected to apply to a new type of nematic liquid crystal device or to a new molecular orientation method.

In this paper, a liquid crystal cell with a pair of plane and parallel electrode structures (such as is found in usual liquid crystal display devices) is prepared by using a PVA alignment layer without rubbing surface treatment, and its memory effects on molecular orientation are investigated. In this case, the liquid crystal cell gives an opaque state and strong light scattering properties can be obtained. Some relations between the light scattering properties and several conditions of the HC-treatment are investigated, and these strange phenomena are discussed in terms of the memory effects of the molecular orientation on the electrode surface without rubbing.

2. Experimental

ITO coated glasses were used as substrates of the liquid crystal cell, and both surfaces of the substrates were coated with PVA which was not treated by any surface treatment such as rubbing. A Myler spacer with a thickness of 25 μm was sandwiched

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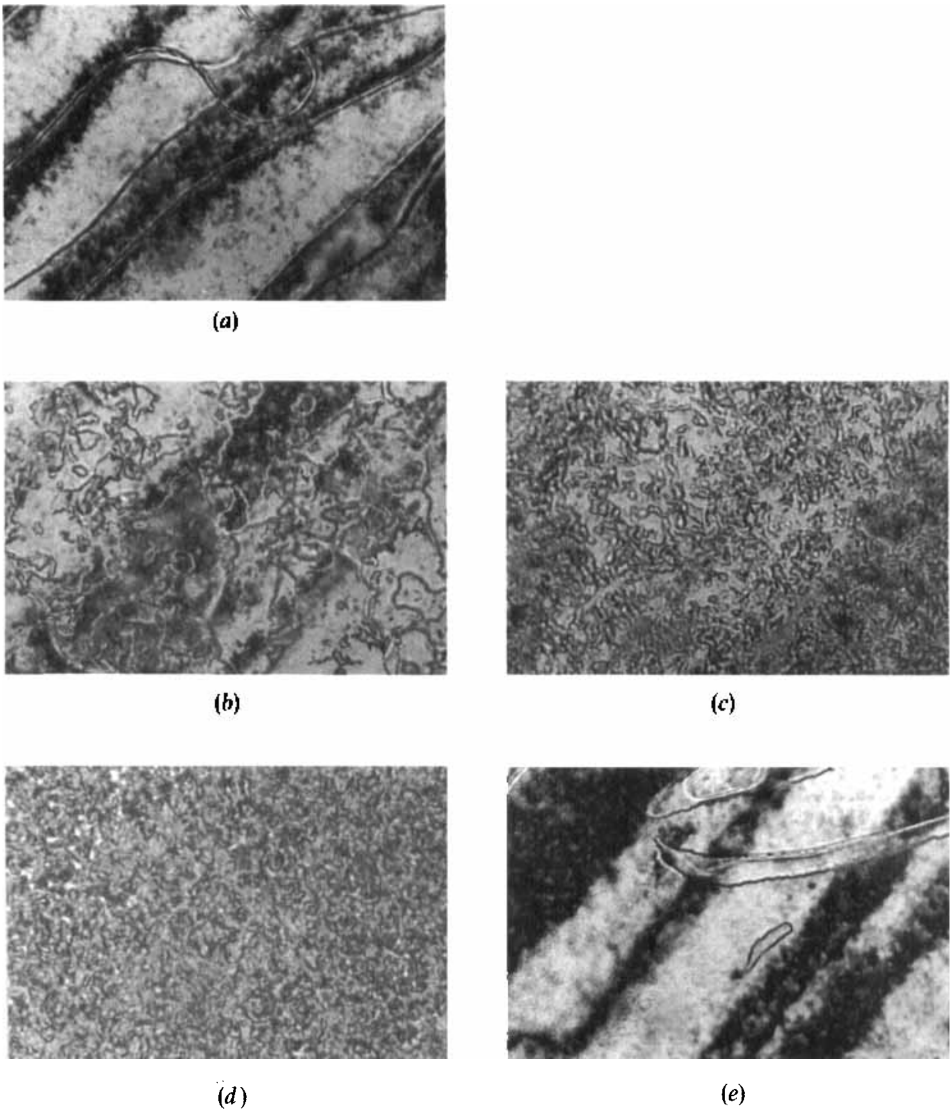
between those two substrates, and a nematic liquid crystal with a positive dielectric anisotropy (K15: BDH) was put into the cell in an isotropic phase.

The liquid crystal cell was heated up once to the isotropic phase and cooled down to the nematic phase (HC-treatment) with an AC voltage (V_{HC}) or a DC magnetic field (B_{HC}) application. The transmission light intensity properties and microscopic textures of the liquid crystal cell in the opaque state were investigated for various conditions of the HC-treatment.

3. Results and discussion

Figure 1 (*a–e*) shows transmission images of the liquid crystal cell observed using a polarizing microscope with crossed polarizers for various voltage levels of V_{HC} during



(*a*)

(*b*) (*c*)

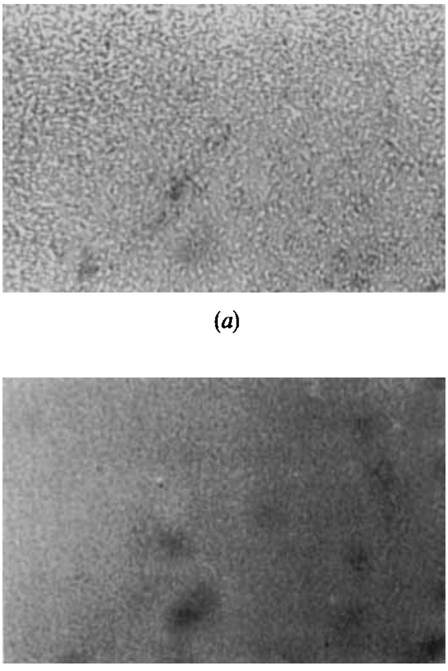
(*d*) (*e*)

Figure 1. Transmission images of the liquid crystal cell (*a*) before HC-treatment; and with the voltage levels (V_{HC}) during the HC-treatment of (*b*) 50 V; (*c*) 100 V; (*d*) 150 V and (*e*) 0 V.

the HC-treatment. Figure 1 (*a*) shows a transmission image of the cell before HC-treatment. It is seen that there are only a few disclination lines and some stripes which may be induced by the flow of the liquid crystal in the fabrication process, and the liquid crystal cell is transparent in the initial state. Figure 1 (*b–d*) shows some images of the liquid crystal cell after the HC-treatment with the voltage levels of 50 V, 100 V and 150 V, respectively. When a relatively low voltage is applied during the HC-treatment, many fine disclination lines appear, as shown in figure 1 (*b*). In this case, the liquid crystal cell gives an opaque state and light scattering properties can be obtained. The density of the disclination lines increases as the voltage level of V_{HC} increases, as shown in figure 1 (*c*) and (*d*), and stronger light scattering effects can be obtained.

The opaque state is stable for a long period of time at room temperature. However, once the liquid crystal cell is heated up to an isotropic phase without voltage, the cell returns to the initial transparent state, as shown in figure 1 (*e*). It is seen that the stripes and a few disclination lines appear again as may be observed in figure 1 (*a*). These memorizing and clearing processes can be repeated many times.

Memory effects of uniform molecular orientation on a PVA surface without rubbing have been reported by using a patterned electrode structure [4]. Such memory effects may be caused by the reorientation of the adsorbed liquid crystal molecules on the surface. Adsorbed liquid crystal molecules may be detached by the heating process to an isotropic phase, and then the molecules are adsorbed again on a surface along the lateral component of the nonuniform electric field produced by the patterned electrode structure during the cooling down process to a nematic phase [4]. However, since the plane and parallel electrode structure is used in this work, the electric field has only



(*a*)

(*b*)

Figure 2. Transmission images of the liquid crystal cell for various applied voltage levels (V_{LC}) of (*a*) 10 V and (*b*) 50 V after the HC-treatment with $V_{HC} = 150$ V.

normal components. Then, the director of the liquid crystal molecules cannot be determined by the electric field in the re-adsorbing process; that is, the molecules are memorized on the surface with randomly distributed directions. Consequently, many fine disclination lines may appear after the HC-treatment.

In the case of the liquid crystal cell with a rubbed PVA surface, no such light scattering properties can be observed, even though the other cell parameters and treatment conditions are exactly the same. If only half of the PVA surface is treated by rubbing, only that half area of the cell forms the opaque state after the HC-treatment.

Figure 2(*a*) and (*b*) shows some transmission images of the opaquely memorized liquid crystal cell observed using microscope for applied voltage levels (V_{LC}) of 10 V and 50 V, respectively, where the liquid crystal has been treated by HC-treatment with 150 V. Many fine disclination lines are observed without voltage, as shown in figure 1 (*d*). When a relatively low voltage is applied, the liquid crystal molecules tend to align perpendicular to the substrate and the disclination lines gradually disappear, as shown in figure 2(*a*) and (*b*). According to this process, the light scattering effects steeply

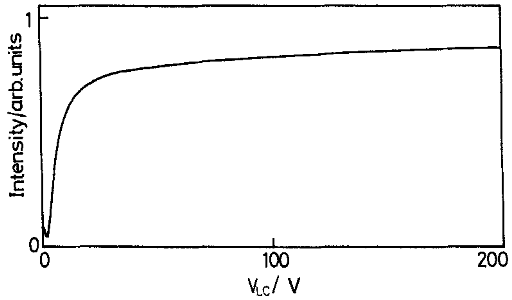


Figure 3. Transmission light intensity versus the applied voltage of the liquid crystal cell after the HC-treatment with $V_{HC} = 150$ V.

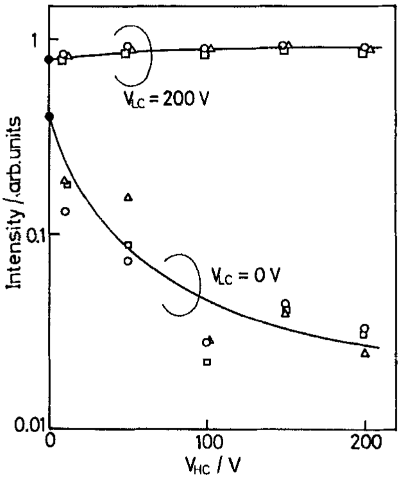


Figure 4. Transmission light intensity properties as a function of V_{HC} with a sufficiently high voltage ($V_{LC} = 200$ V) and no voltage ($V_{LC} = 0$ V) application where V_{HC} is 50 Hz (○), 500 Hz (△) and 5 Hz (□).

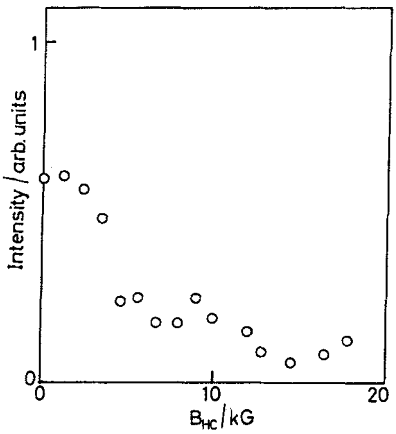


Figure 5. Transmission light intensity as a function of magnetic field intensity (B_{HC}) during the HC-treatment.

decrease, and it is not necessary to apply so high a voltage to change the liquid crystal cell into the transparent state.

Figure 3 shows the transmission light intensity properties of the liquid crystal cell memorized in the opaque state as a function of the applied voltage (V_{LC}), where the cell has been treated by the HC-treatment with 150 V (same as in figure 2). The transmission light intensity at 0 V is very low because of the strong light scattering effects. When a relatively low voltage is applied, the transmission light intensity steeply increases and the liquid crystal cell becomes transparent. These properties correspond to the disappearing process of the disclination lines in figure 2. Low threshold voltage and steep variation in the transmission properties can be obtained. These voltage controlled light scattering properties induced by the surface memory effects may be applied to a new type of light scattering display device with a memory function.

Figure 4 shows the transmission light intensities as a function of V_{HC} applied during the HC-treatment. The transparency with a high voltage application ($V_{LC}=200$ V) is almost independent of V_{HC}. However, it is seen that the transparency without voltage ($V_{LC}=0$ V) decreases as the voltage level of V_{HC} increases; that is, stronger light scattering effects can be obtained with higher voltage application during the HC-treatment. These properties were measured by varying the frequency of the V_{HC} from 50 Hz to 5 kHz, but any significant differences cannot be observed, as shown in figure 4.

When a magnetic field is applied along the direction perpendicular to the surface of the liquid crystal cell during the HC-treatment, strong light scattering properties can also be obtained. Figure 5 shows the transmission light intensities without voltage ($V_{LC}=0$ V) for various intensity levels of the magnetic field (B_{HC}). It is seen that the transparency of the liquid crystal cell decreases as the intensity of the magnetic field during the HC-treatment increases. These properties are similar to that in the case of using the electric field. The opaque state, that is, the random orientation of the liquid crystal molecules may be induced by the aligning force of the applied external field perpendicular to the substrate.

4. Conclusions

Strong light scattering effects can be obtained in a liquid crystal cell with a plane and parallel electrode structure without rubbing treatment. Once the liquid crystal cell is heated up to an isotropic phase and cooled down to a nematic phase with an applied electric or a magnetic field, the liquid crystal cell forms an opaque state.

The opaque state is induced by the creation of many fine disclination lines, and the cleared by heating the liquid crystal cell once up to an isotropic phase without an applied field.

The opaque state is induced by the creation of many fine disclination lines, and the density of these and the light scattering effects increase as the intensity of the external applied field increases.

These properties may be induced by the memory effects of molecular orientation on a surface of PVA-coated electrode without rubbing; that is, the director of the liquid crystal molecules is memorized on a substrate with randomly distributed directions.

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