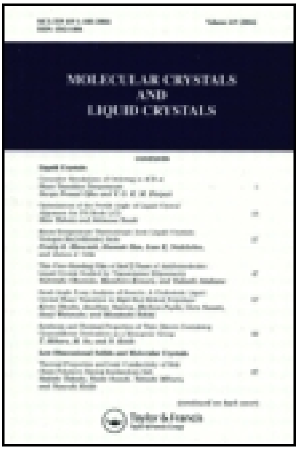

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Influence of Smectic Layer Structure on Electric Field-Induced Migration of SiO_2 Particles

Keizo Nakayama [a], Masanori Ozaki [a] & Katsumi Yoshino [a]
[a] Department of Electronic Engineering, Graduate School of Engineering Osaka University, 2-1 Yamada-Oka, Suita, Osaka, 565-0871, JAPAN

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Influence of Smectic Layer Structure on Electric Field-Induced Migration of SiO_2 Particles

KEIZO NAKAYAMA, MASANORI OZAKI and KATSUMI YOSHINO

Department of Electronic Engineering, Graduate School of Engineering Osaka University, 2–1 Yamada-Oka, Suita, Osaka 565–0871, JAPAN

The migration of SiO_2 particles under the application of an ac electric field has been observed in the various phases. SiO_2 particles in the Iso. and N* phases migrated in a circle. In the SmA and SmC* phases, SiO_2 particles migrated along the smectic layer. This indicates that the smectic layer structure influences the migration of SiO_2 particles. The migration has been examined with a monodomain, a multidomain and a planar cell. The migration was not observed in a homeotropic aligned region. The migration has been found to require the polarity reversal of the applied electric field.

Keywords: smectic layer structure; smectic liquid crystal; anisotropy

INTRODUCTION

Anisotropy is one of the interesting characteristics of liquid crystal. Anisotropy is observed in electrical, optical and mechanical properties which arise from the structure and alignment of the molecules, such as electric conductivity, dielectric constant, refractive index, magnetic susceptibility and viscoelastic constant[1-4].

On the other hand, we have presented the electric-field-induced migration of SiO_2 particles in liquid crystal upon the application of an ac electric field[5]. The characteristics of the migration of SiO_2 particles depend on the phase, and anisotropy was found in the migration of SiO_2 particles.

In this paper, we report the influence of smectic layer structures, such as a multidomain structure, in the migration of SiO_2 particles in detail.

EXPERIMENTAL

The ferroelectric liquid crystal used in this study was CS-1024 (CHISSO Co.), which shows following phase sequence: isotropic (Iso.) – chiral nematic (N*) – smectic A (SmA) – chiral smectic C (SmC*). The achiral liquid crystal used in this study was 4'-(hexyloxy)phenyl-4-octyloxy-benzoate (HOPOOB), which indicates following phase sequence: Iso. – N – SmC. Figure 1 shows the molecular structure of HOPOOB.

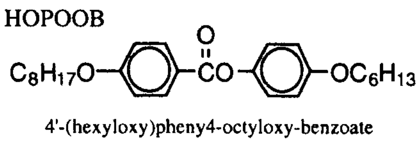

FIGURE 1 The molecular structure of HOPOOB.

A small amount of spherical SiO_2 particles of 1μm in diameter, which was generally used for a spacer, was mixed into the liquid crystal. SiO_2 particles, however, were cohesive with each other in a liquid crystal and show the tendency to form groups of several μm in diameter. The migration of particles was investigated by a polarizing microscope using a charge coupled device camera, and recorded by a video recorder.

The sample was sandwiched between two Indium-Tin-Oxide (ITO) glass plates with 12μm cell gap. For the planar alignment, both surfaces of the substrate were coated with a polyimide and rubbed, and were coated with a silan coupling material for the homeotropic alignment. In the planar alignment cell, smectic layer is perpendicular to the surfaces of substrates, and parallel in the homeotropic alignment cell. Therefore, the direction of applied electric field is parallel to the smectic layer in the planar alignment cell, and perpendicular in the homeotropic cell.

RESULTS AND DISCUSSION

Monodomain Cell

Figure 2 shows typical traces of the moved particle in the N* and SmA phase of CS-1024 in a rubbing cell. The black points in these figures indicate the positions of moved particle with a certain interval; (a):100msec and (b):1sec. The applied voltage was a rectangular wave with ±100V amplitude and 60Hz frequency. In the Iso. and N* phases, particles migrated in a circular pattern. Figure 2 (a) shows the trace of moved particle in the N * phase. The velocities, rotation directions and radius of each moving particle were not equal.

On the contrary, particles migrated linearly in the SmA and SmC* phase as shown in Fig. 2 (b). All particles migrate along the smectic layer, that is, perpendicular to the rubbing direction in this cell. As a result, a smectic layer structure influences the migration of SiO_2 particle.

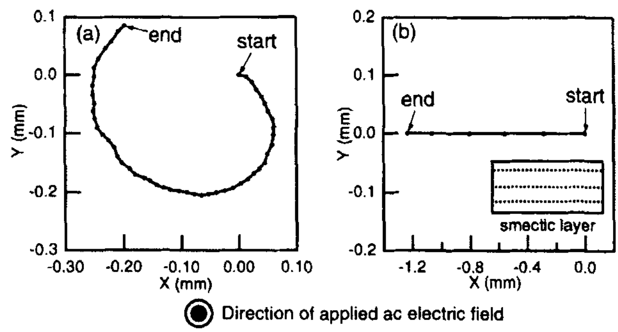

FIGURE 2 The traces of the particle. (a) In the N* phase. (b) In the SmA phase.

When the voltage pulses including asymmetric components are applied continuously to a ferroelectric liquid crystal cell, a smectic layer structure throughout the sample cell rotates around the axis perpendicular to the surface of the substrates[6]. In other words, the smectic layer structure, whose layer normal is not parallel to the rubbing axis, is obtained by applying asymmetric voltage pulses. In the case of CS-1024, the smectic layer structure rotated by several degrees even with a rubbing cell.

We also studied the migration in the cell with layer rotation. After the layer rotation, particles migrated linearly along a newly realigned smectic layer. This result indicates that the direction of the linear migration depends not on the rubbing direction but on the layer structure.

Multidomain Cell

The material with the Iso. – N – SmC phase sequence shows the degeneracy of two smectic layer structures in the SmC phase following the N phase[7]. In the N phase, the molecular director is parallel to the rubbing direction. With decreasing temperature to the SmC phase, the molecules tilt away from the normal of the smectic layer formed in the SmC phase. However, the strong anchoring on the rubbed surfaces keeps the molecular director parallel to the rubbing direction at the N – SmC phase transition. Consequently, the smectic layer normal should tilt by the tilt angle $+\theta$ and $-\theta$ with respect to the rubbing direction. Therefore, the HOPOOB cell whose surfaces were rubbed in the unidirection, shows two types of domains as shown in Fig. 3.

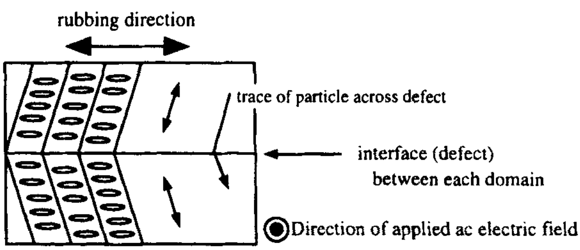

FIGURE 3 The migration of SiO_2 particles in a multidomain cell.

In this cell, the migration of SiO_2 particles was also investigated. When a rectangular voltage (±60V, 150Hz) was applied to the cell, the particles moved in the same manner as the CS-1024. HOPOOB does not show ferroelectricity and the dielectric anisotropy is negative, so that the molecules does not switch even under ac electric field. Accordingly, this result indicates that not only ferroelectricity but also the molecular switching is not required for the particle migration.

It should be noted that SiO_2 particles migrate along the smectic layer as shown in Fig. 3. In other words, SiO_2 particles in each domain migrate in the different direction.

Moreover, the interface between each domain, i.e., the defect influenced the migration of SiO_2 particles. When the moving SiO_2 particles reached the defect of domains, some particles stopped migrating and reversed the direction, and others went across a defect and into the next domain as shown in Fig. 3.

Homeotropic Cell

The behavior of SiO_2 particles in a homeotropic Cell (HC) was also investigated. With increasing the amplitude of the applied ac electric field, a HC in part became the planar alignment since the dielectric anisotropy is negative. Under the intermediate field, there coexist planar and homeotropic alignment regions in the cell. In the region of planar alignment, the migration of SiO_2 particles was observed, while any particles in the homeotropic alignment region did not migrate. As a result, it is considered that particles does not move in the homeotropic alignment region.

Since surfaces of HC were not rubbed, the planar alignment induced by the field made a multi domain structure, such as a focalconic domain. Even in this region, particles migrated along smectic layer. If the smectic layer curves in the domain, the particles move along the curved layer.

Frequency Dependence

Figure 4 shows the number of moved particles as a function of the frequency of applied ac electric field using the planar cell of CS-1024. The amplitude was ±100V.

In this figure, particles migrated only in the limited range of frequency. When the dc voltage of 100V was applied, the migration of particles was not observed. This indicates that the polarity reversal of applied field is required for the migration of SiO_2 particles.

In the case of high frequencies (several hundred Hz), particles also cannot migrate. It is considered that the response time of the particles in CS-1024 to the polarity reversal of applied field is longer than several msec.

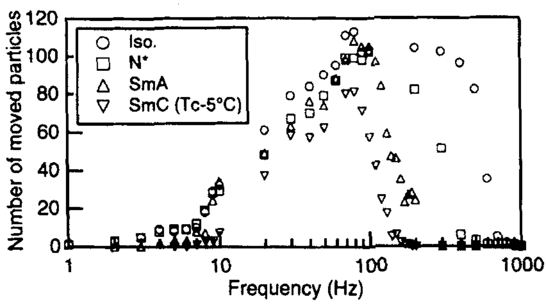

FIGURE 4 The frequency dependence of the number of moved particles.

Temperature Dependence

Figure 5 shows the temperature dependence of the threshold voltage, above which particles can migrate by the application of a rectangular wave. The sample used in this experiment was CS-1024 and the surfaces were rubbed for the planar alignment. The threshold voltage increased with decreasing temperature. In the SmC* phase, the threshold voltage dramatically changes with temperature.

There are clear discontinuous points of the threshold voltage at the Iso–N* and N*–SmA phase transition. This discontinuity is considered to arise from the first-order transition of the viscoelastic constant at Iso–N and N–SmA phase transition.

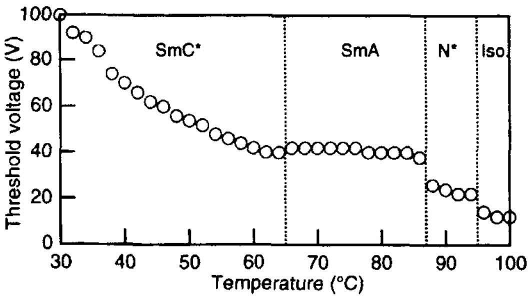

FIGURE 5 The temperature dependence of the threshold voltage.

CONCLUSION

The migration of SiO_2 particles under the application of an ac electric field was observed in the various phases. SiO_2 particles in the Iso. and N* phases migrated in a circle. In the SmA and SmC* phases, in which the liquid crystal molecules form a smectic layer structure, SiO_2 particles migrate along the smectic layer. In HC, only particle in the planar alignment region induced by application of ac electric field migrated. Moreover, the migration was not observed under the application of a dc electric field.

Acknowledgments

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