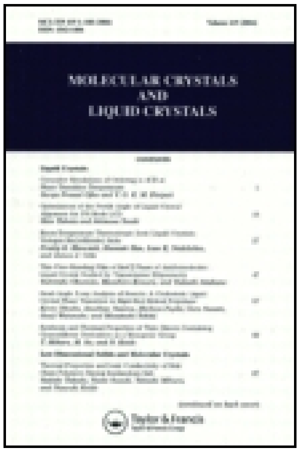

Molecular Crystals and Liquid Crystals Science and Technology. Section A. Molecular Crystals and Liquid Crystals

Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gmcl19

Smectic Layer Rotation by Electric Field in Ferro- and Antiferroelectric Liquid Crystals

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Version of record first published: 04 Oct 2006

To cite this article: Keizo Nakayama, Masanori Ozaki & Katsumi Yoshino (1997): Smectic Layer Rotation by Electric Field in Ferro- and Antiferroelectric Liquid Crystals, Molecular Crystals and Liquid Crystals Science and Technology. Section A. Molecular Crystals and Liquid Crystals, 304:1, 339-343

To link to this article: http://dx.doi.org/10.1080/10587259708046979

Mol. Cryst. Liq. Cryst., 1997, Vol. 304, pp. 339-343
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SMECTIC LAYER ROTATION BY ELECTRIC FIELD IN FERRO- AND ANTIFERROELECTRIC LIQUID CRYSTALS

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Abstract A reversible rotation of smectic layer in ferroelectric and antiferroelectric chiral smectic C phases has been investigated as a function of a waveform of applied voltage pulses and cell geometry. The layer rotation is caused by applying asymmetric voltage pulses and the rotation direction depends on the waveform of pulses and the sign of spontaneous polarization. In addition, the reversible layer rotation in the smectic A phase has been observed by applying asymmetric voltage pulses and interpreted in terms of electroclinic effect. The layer rotation in the chiral smectic C phase of the ferroelectric liquid crystal doped with ionic impurity has been also found by applying DC voltage.

INTRODUCTION

The smectic layer rotation in a plane parallel to the substrates has been investigated in ferroelectric liquid crystal (FLC).[1-3] In these cases, the layer rotation requires the rubbing treatment on the substrate and the layer rotation is irreversible. Moreover, the rotation angle is limited to a tilt angle.

On the other hand, we have reported a reversible layer rotation in the chiral smectic C (SmC*) phase of FLCs and the antiferroelectric SmC* (SmC_A*) phase of antiferroelectric liquid crystals (AFLCs) by applying asymmetric voltage pulses.[4-7] This layer rotation does not require the rubbing treatment and the layer rotates exceeding a tilt angle and even over 180°. In this paper, we present detailed study on the smectic layer rotation in the SmC* and SmC_A* phase by the application of voltage with asymmetric waveform. In addition, we have observed the reversible layer rotation in the smectic A (SmA) phase by applying asymmetric pulses and the layer rotation by applying DC voltage in the SmC* phase of FLC doped with ionic impurity. These phenomena are very interesting from not only practical but also fundamental points of view.

EXPERIMENTAL

FLCs used in this study are mainly R-configuration (hereafter referred to as (R)) of 4'-(1-methoxycarbonyl-1-ethoxy)phenyl-4-[4-(n-octyloxy)phenyl]benzoate (1MC1EPOPB) and mixed liquid crystal CS-1024 (CHISSO Co.). AFLC used in this study is mainly 4-(1-trifluoromethylheptyloxycarbonyl)phenyl-4'-octyloxybiphenyl-4-carboxylate (TFMHPOBC). 1MC1EPOPB indicates following phase sequence:Isotropic (Iso.)–SmA–SmC* and CS-1024 indicates Iso.–chiral nematic–SmA–SmC*. TFMHPOBC indicates Iso.–SmA–SmC_A*.

A sample was sandwiched between two In-Sn oxide (ITO)-coated glass plates. Two surface conditions of substrate were used in this study. One is a non-treated cell in which both surfaces were not treated with any surfactant and the other is a rubbed cell in which surfaces were coated with rubbed polyimide and the rubbing direction of both surfaces was antiparallel. The cell gap was 6μm.

The rotation angle was defined as an angle between layer normal after applying pulses and the initial direction which was obtained in the SmA phase. The positive voltage was applied to the lower electrode. Figure 1 shows asymmetric waveforms mainly used in this study.

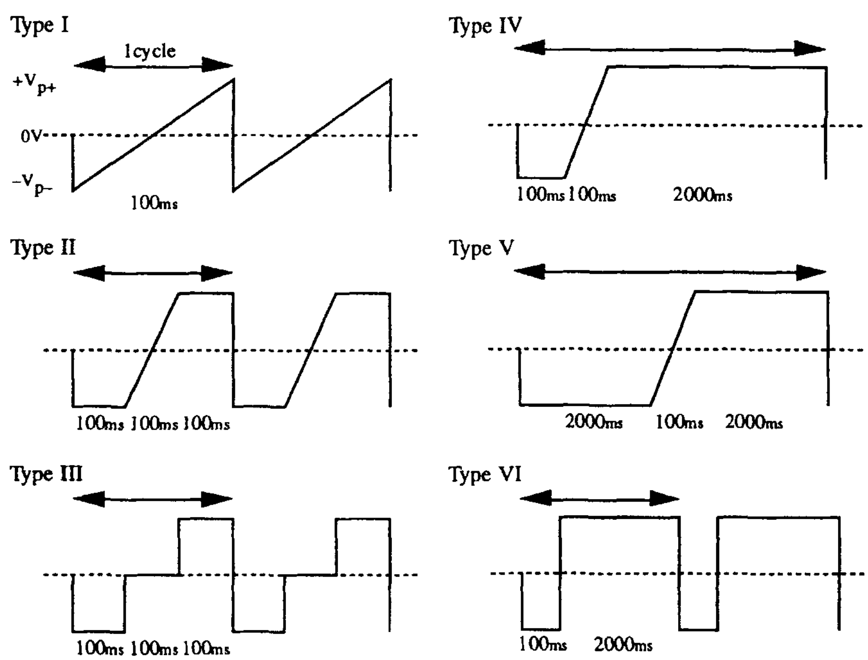

FIGURE 1　Applied voltage pulses used in this study.

RESULTS AND DISCUSSION

Layer Rotation in SmC* of FLCs

Figure 2 shows the rotation angle of (R)1MC1EPOPB by the application of Type I and Type II waveforms of Vp± = 60V in a rubbed cell. Type I which is normal sawtooth waveform can induce the layer rotation although the rotation rate for Type II is slightly larger than that for Type I. This suggests that the constant voltage segments in Type II waveform is not essential for the layer rotation. The important factor determining the layer rotation is the difference in the way of polarity reversal of applied voltage. Namely, the voltage changes slopingly from negative to positive, while it changes stepwise from positive to negative. In deed, the layer rotation is observed by applying Type III waveform of Vp± = 60V which have 0V pause segment instead of the ramp voltage.

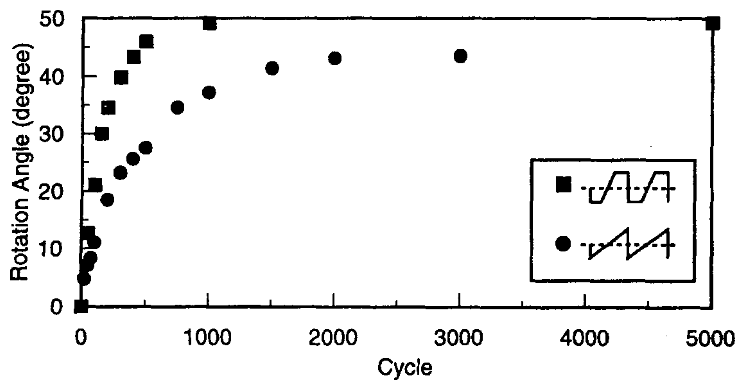

FIGURE 2 The rotation angle of (R)1MC1EPOPB by applying Type I (●) and Type II of Vp± = 60V (■). The positive direction is defined as clockwise rotation.

In Fig. 2, a saturation in the rotation angle is observed. A saturation angle depends on the waveform of applying pulses. The saturation might be caused by the anchoring effect of surface. This is supported by following result. There is no saturation in a non-treated cell which has no unidirectional anchoring characteristic of surfaces. In such cell, the layer rotates over 180°.

To clarify if there is a threshold voltage, the voltage dependence of the layer rotation have been investigated in a non-treated cell. As is evident from Fig. 3 the layer rotation was not observed when Type II waveform of Vp± = 10V was applied for 10000 cycles. However, when Vp± = 20V, the smectic layer rotated by 3.9° at 1000 cycles (at total of 11000 cycles). This result indicates that the threshold voltage exists in the layer rotation of FLCs.

Another notable characteristic is that the rotation direction is determined the waveform of pulses and the sign of spontaneous polarization. This indicates that the direction of the layer rotation is controllable on purpose by a choice of the waveform of pulses and that it is possible to make a new optical device using this layer rotation.

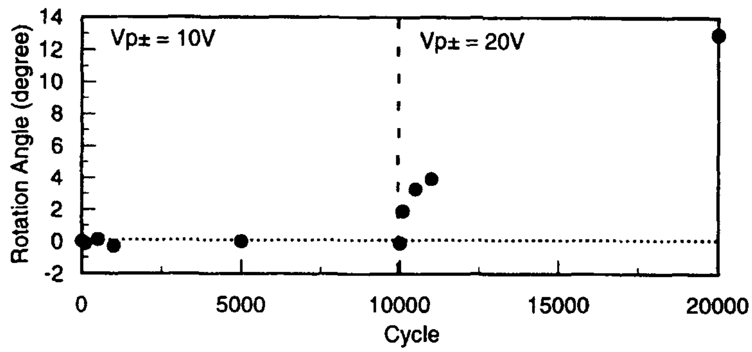

FIGURE 3 The rotation angle of (R)1MC1EPOPB when the Vp± was changed at 10000 cycles. The positive direction is defined as clockwise rotation.

Layer Rotation in SmC_A* of AFLCs

Figure 4 shows the rotation angle of TFMHPOBC in a non-treated cell when various types of waveform of Vp± = 60V were applied. Similarly to FLCs, Type I (sawtooth waveform) causes the layer rotation, though the rotation rate for Type I is smaller than that for Type II. To clarify the effect of the constant voltage segments to the layer rotation, we used waveforms of Type II, IV and V. The rotation rate for Type V is almost the same with that for Type II, although durations of constant voltage segments of opposite polarity in Type V are symmetry and are longer than those in Type II.

On the other hand, the rotation rate for Type IV, in which constant voltage segments with opposite polarities are asymmetric, is larger than those for Type II and V. This suggests that the asymmetry of durations of constant segment with opposite sign promotes the layer rotation. However, TypeVI waveform which does not include the ramp segment can not cause the layer rotation at all. Therefore, the asymmetry of

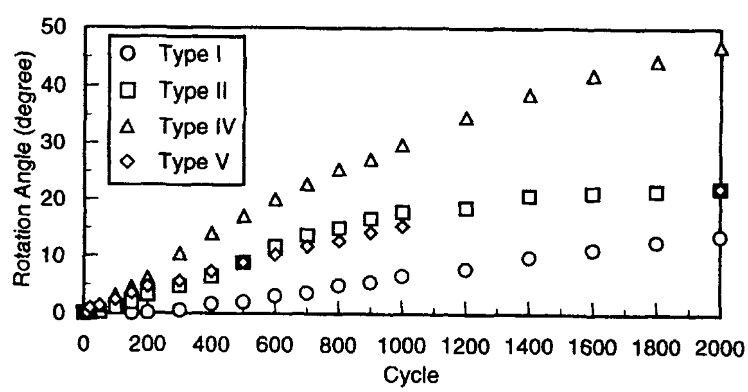

FIGURE 4 The rotation angle of TFMHPOBC. O:Type I, □:Type II, Δ:Type IV, ◇:Type V. The positive direction is defined as counter-clockwise rotation.

the durations of opposite polarity of applied voltage is not indispensable for the layer rotation, but just promotes it.

Similarly to FLCs, the threshold voltage for the layer rotation in AFLCs exists and the rotation direction depends on the waveform of pulses.

Layer Rotation in the SmA of FLC and AFLC[8]

We have also found that the smectic layer rotation was observed even in the SmA phase of TFMHPOBC. The experiment was carried out at 1°C above the phase transition temperature Tc from SmC_A* to SmA phase. The used waveform is Type III and a non-treated cell were used. At Vp± = 80V, the rotation angle saturated at about 29° for 15 minutes.

At this temperature (T–Tc = 1°C), the field induced tilt angle is proportional to the applied voltage up to 160V. This confirms that the field induced phase transition does not occur at this temperature. Therefore, the layer rotation is realized in the SmA phase. In this case, electroclinic effect should play important role. The layer rotation in the SmA phase is common in both AFLC and FLC.

Layer Rotation by DC voltage

The layer rotation does not occur by the application of DC electric field in purified FLC. However, we have found that the smectic layer rotates upon DC field application in FLC whose purity is lowered. In this study, CS-1024 doped with tetracyanoquinodimethane (TCNQ) as ionic impurity was used.

The smectic layer rotated by 40° for 30 minutes by applying DC voltage of +60V. A pure CS-1024 never shows layer rotation by the application of DC voltage. Accompanying with the layer rotation, the violent motion of texture could be observed in a polarizing microscope which might be caused by a flow of impurity.

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