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Electro-optical features of antiferroelectric liquid crystal material (S)-(+)-4-(1-methylheptyloxycarbonyl) phenyl 4′-(6-octanoyloxyhex-1-oxy) biphenyl-4-carboxylate in its ferro and antiferroelectric phases

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ABSTRACT

A detailed investigation of the electro-optical switching parameters of an antiferroelectric liquid crystal (S)-(+)-4-(1-methylheptyloxycarbonyl) phenyl 4′-(6-octanoyloxyhex-1-oxy) biphenyl-4-carboxylate (abbreviated as S-7H6Bi) has been carried out. S-7H6Bi has paraelectric (SmA*) and ferroelectric (SmC*) phases in addition to antiferroelectric (SmC$^*_A$) phase. Switching parameters viz. spontaneous polarization and switching time were determined by polarization reversal method. The spontaneous polarization (P_s) is found to be highly temperature dependent and decreases with temperature. The maximum value of P_s is found to be ~90 nC/cm^2 whereas the switching time (t_s) is found to be of the order 1–2 ms. The temperature dependent torsional viscosity (γ_t) is of the order 10 Pa sec. It increases with decrease in temperature.

1. Introduction

A new class of tilted chiral smectic liquid crystals known as antiferroelectric liquid crystal (AFLC) was first reported in 1981 [1] and later confirmed by Chandani et al. in 1989 [2,3]. AFLCs became an attractive alternative of ferroelectric liquid crystals (FLCs) in high resolution display applications. Like FLCs, in AFLCs also, the molecules are arranged in layers but tilt in an opposite sense in alternating layers. The details of presently accepted structures of the ferroelectric and antiferroelectric phases have been described earlier [3–5]. Generally the ferroelectric phase is referred to as the ‘synclinic phase’ and the antiferroelectric phase as ‘anticlinic phase’ because of identical and opposing azimuthal orientations of the molecules in adjacent layers, respectively.

The electro-optic effect in AFLCs is based on the fact that the optic axis can be switched between three mutually orthogonal directions corresponding to the direction of applied electric field. Among three, one is the anticlinic state at zero field and two other are the field induced synclinic states. The effective optic axis in the anticlinic state is along the smetic layer normal between the two crossed polarizer and hence results in the dark state. On applying sufficient high voltages (more than threshold voltage Vth), the anticlinic structure become unstable and one of the sublattice switches over smectic cone forming a synclinic state, which yield a bright state. On reversing the direction of field, an opposite effect is seen. The second sublattice switches to the opposite synclinic state, which also yields a bright state (see Fig. 1). In this way AFLC show tristable switching.

Besides fast switching and wide viewing angle, AFLCs have many other excellent electro-optical properties like tri-state switching, easy DC compensation and gray scale capability [6,7]. Despite of these outstanding properties, the commercial production of AFLCs yet not started.

The two major problems are responsible for no commercial application of AFLCDs. The first one is the huge losses of contrast, which is commonly related to a leakage transmission in the absence of applied electric field, called pretransitional effect [8,9]. Second one is poor optical homogeny in off state caused by existence of microscopic defects and existence of two preferred orientations of normal to the smectic layer, which differ by few degrees from each other. Recently D’have et al. proposed a straightforward and elegant solution of the problem of low contrast in AFLCDs. They propose AFLC with cone angle $\theta = 45^\circ$, known as Orthoconic antiferroelectric liquid crystals (OAFLCs), which is about 10-15° higher than cone angle of typical AFLCs

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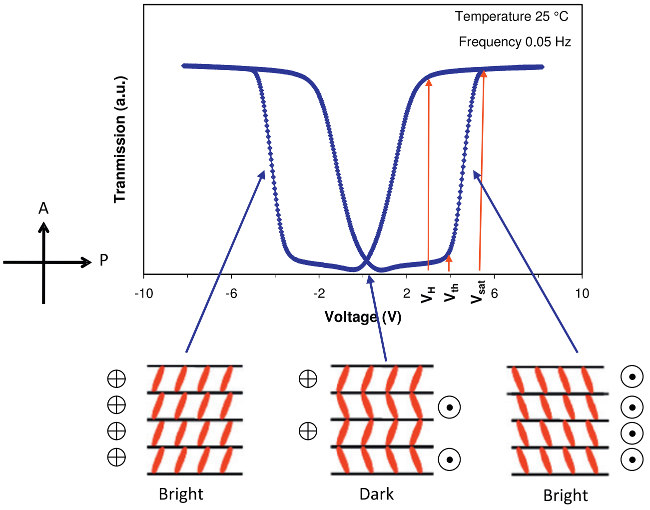
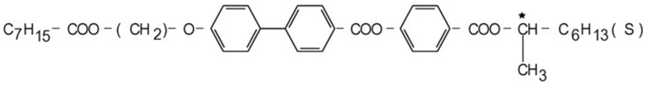


Fig. 1. Working principle of AFLCD showing tri-stable switching response for W132A [7]. When positive or negative cycle of alternating voltage is applied, antiferroelectric state (centre at 0 volt) switches to either of the two ferroelectric states (sides). Vth is the threshold voltage at which intensity starts to increase sharply, Vsat is the voltage at which intensity saturates to its maximum value and V_H is the minimum voltage up to which maximum value of the intensity is hold in the reverse cycle. + and . in circles show directions of the polarization vector (of the smectic layers) opposite to each other but normal to the plane of the paper.

[10,11]. Recently, Piecek et al. [12] have studied the dielectric and electro-optical properties of an OAFLC.

AFLC materials are rich in mesomorphism. In these materials, competition between the adjacent smectic layers to form anticlinic and synclinic structures causes the appearance of different chiral smectic C subphases, viz. SmC^*_{α}, SmC^*_{β} and SmC^*_{γ} with distinct macroscopic properties in a narrow temperature region in addition to the $\mathrm{SmC}^*_{\mathrm{A}}$ phase [13]. Due to their attractive physical and electro-optical properties, AFLCs are the highly exploited branch of the liquid crystals. In last two decades number of AFLCs (by Dabrowski and others groups) have been synthesized and various efforts have been made to utilize their excellent optical and physical properties [11,14].

In the present work our aim is to study and report the electro-optical properties of a newly synthesized AFLC material ((S) 7H6Bi) having the para, ferro, and antiferroelectric phases in temperature range 100–51 °C [14], however the thermodynamical and dielectric results of the material are reported earlier [15]. The molecular structure of the material is given below.



The phase sequence and transition temperature obtained from the Differential Scanning Calorimetry (DSC) thermograph [15] at the extrapolated hypothetical scanning rate of 0 K/min [16] both in cooling and heating cycles are given below:

Cr (70.8 °C)→$\mathrm{SmC}^*_{\mathrm{A}}$ (85.6 °C)→SmC* (89.9 °C)→SmA* (97.1 °C)→I. (Heating cycle)

In cooling cycle material shows the super cooling effect (on transition from Sm C^*_A to Cr phase)

I (96.6 °C)→SmA* (89.8 °C)→SmC* (84.3 °C)→$\mathrm{SmC}^*_{\mathrm{A}}$ (30.0 °C)→Cr

Here Cr and I represent crystal and isotropic liquid phases, respectively. SmA*, SmC* and SmC^*_A are paraelectric smectic A, ferroelectric (synclinic) chiral smectic C and antiferroelectric (anticlinic) chiral smectic C phases, respectively. Data in the paranthesis represent transition temperatures.

2. Experimental techniques

To determine the electrical parameters viz. spontaneous polarization (P_s) and switching time (t_s) as a function of temperature, polarization reversal method [17,18] has been used with a square wave of frequency 10 Hz/25 Hz and varying amplitude applied across the series combination of parallel plate capacitor cell filled with material and a standard resistor ($R_{st}=1$ MΩ). Martinot-lagarde et al. [19] and Miyasato et al. [20] used square and triangular waveforms, respectively, to measure spontaneous polarization. However we use the square wave pulse since the main advantage of using a square wave is the measurement of switching time in addition to the measurement of spontaneous polarization. Polarization reversal method is useful only when the switching speed is slow in comparison with the RC time constant of the circuit because for faster switching materials the components of current are difficult to separate.

The used planar aligned parallel plate capacitor cell is made of ITO coated glass plates separated by 5 μm. In order to apply sufficient switching voltage of square wave shape, it is amplified by an amplifier of FLC (model A-400). The applied voltage and voltage across R_{st} (and hence current i) is displayed on digitalizing storage oscilloscope (DSO) from HAMEG (model-HM507), which is interfaced to a computer. The temperature of the sample was controlled with the help of a hot stage (Instec HS-1) with an accuracy of ±0.1 °C. The actual temperature near the sample was determined by measuring the thermo-emf of a copper-constantan thermocouple using a six and half digit multimeter of Aligent (model 34410 A) with the accuracy of ±0.05 °C.

On applying square wave of high enough voltage to unwind the helix and to cause polarization reversal, a resultant current (i) induces in the sample through the C–R combination of the circuit. It is written as the sum of following three current

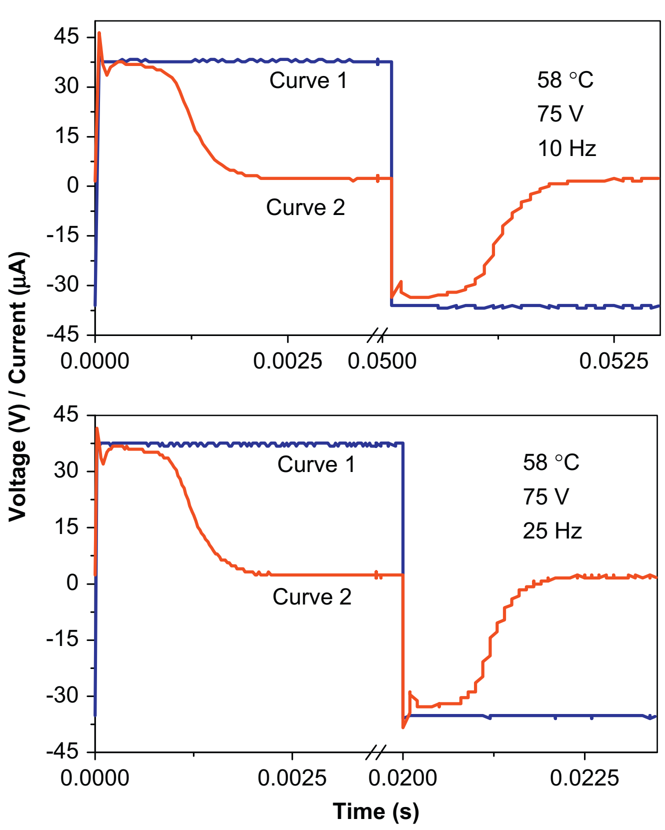


Fig. 2. Input square wave (curve 1) applied at channel 1 and the resultant depolarization current (curve 2) on channel 2 at 10 and 25 Hz.