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Electro-optic and dielectric investigations of a perfluorinated compound showing orthoconic antiferroelectric liquid crystal

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ABSTRACT

We observed microsecond order response ranging from 100 to 600 μs with respect to temperature for a single component fluorinated rigid core antiferroelectric liquid crystals having highly tilted phases. In the antiferroelectric region, we observed V-shaped electro-optic switching in a 4 *μm* indium tin oxide coated homogeneously aligned cell having P_S, ranging from 100 to 200 nC/cm^2. Dielectric studies have revealed an interesting phase that exists during heating in the temperature region between 74 °C and 84 °C. From dielectric results studied we calculated activation energies associated with different relaxation modes using Arrhenius law.

1. Introduction

In recent times, advanced research on the antiferrolectric liquid crystals (AFLCs, both single component and multicomponent) having highly tilted phases reveals a new dimension in the liquid crystal display device applications. High tilted OAFLCs (orthoconic antiferroelectric liquid crystals) are very important because of its director tilt, $\theta = \pm 45^\circ$ that is helpful to solve the static dark state problem. Since the tilts of the molecules in adjacent layers of antiferroelectric smectic C phase (SmC_A^*) are oppositely directed so their net polarization [1–8] becomes close to zero. In antiferroelectric SmC_A^* phase, two relaxation modes can be expected; one with a lower frequency region in the order of a few Hz and the other with a higher frequency region. Although several research groups significantly explained the existence of such phases and its behavior including us [1,2,9–11], but still we need to study its behavior for getting further inside to elucidate the dynamics appropriately. We have assumed here both the observed relaxations as the in-phase and the anti-phase fluctuation phenomena in our dielectric study based on what we already discussed in our earlier publications [9–11]. Although it is hardly observable any kind of Goldstone relaxation may happen to appear a Goldstone-like mode near 1 kHz, but it arises due to residual helical super-structure.

It was already reported by several research groups including us that the perfect dark state problem which already existed in AFLCs instead for having several advantages such as tristate switching capability, easy dc compensation, microsecond response, hemispherical viewing angle (in-plane switching geometry), intrinsic log gray-scale capability and no ghost effect, can be removed by using OAFLC having tilt angle at approximately 45° [1–8]. Because of this the importance of research in high tilted AFLC has made a significant advancement in recent times. Besides the pre-transitional effect, and thus dynamic light leakage, is minimized or even rendered completely absent by using high tilted OAFLC molecules.

Several sub-phases such as SmC_α^*, SmC_β^*, SmC_γ^* show complex electro-optical signature having polarization between antiferroelectric and ferroelectric phases and those are classified according to the number of layers and their orientation in a unit cell [12]. The appearance of several sub-phases may occur due to the emergence of the Devil's staircase [12]. Several research groups showed the behavior of SmC_β^* phase in the different kind of appearance depending on its conformal geometry and the surface anchoring energy provided by the cell geometry [12–16].

In the present work we have studied the electro-optical properties and the dielectric spectroscopy of a single component, high tilted AFLC. Spontaneous polarization of the sample has also been measured and the electro-optical behavior has been studied.

2. Experimental procedure

The investigated high tilted AFLC sample was newly synthesized by R Dabrowski et al. [17,18] by using partly fluorinated compounds of a common formula as given below in Fig. 1.

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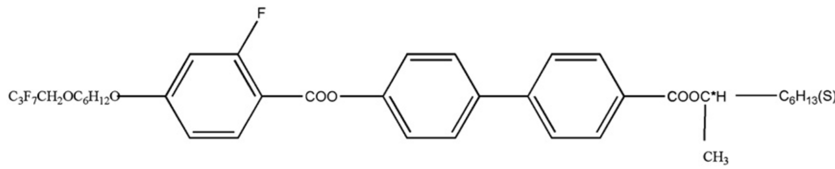

Fig. 1. Chemical formula of the studied high tilted AFLC.

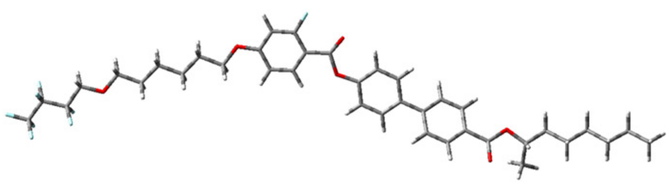

Fig. 2. Optimized energy configuration of the AFLC molecule using Gaussian 98 (b3lyp/3-21 g).

The phase sequence of the sample is given as below [17,18]:

Cr < 44.8 SmC_A^*75.9 SmC^*105.7 SmA 107.1 Iso

The indium tin oxide (ITO) coated planar aligned EHC glass cells with thickness of 4 μm were used for electro-optic study and cells of 10 μm thickness were used for dielectric study. The effective area of the cell was 16 mm^2. The detailed procedure of the cell preparation is as similar to our earlier paper [10,11]. Dielectric data was recorded using a HP 4192A Impedance Analyzer and controlled by the computer in the frequency range from 10 Hz to 13 MHz with different temperatures. The measured dielectric spectra were fitted with the Cole–Cole [19] fit function as given below:

$$\varepsilon'' = \frac{\sigma_0}{\varepsilon_0}\cdot\frac{1}{\omega^s} + \sum_{k=1}^{N} \mathrm{Im}\left\{\frac{\Delta\varepsilon_k}{[1+(i\omega\tau_k)^{\alpha_k}]}\right\} \quad (1)$$

The dielectric strength ($\Delta\varepsilon_k$), the relaxation time (τ_k), the dc conduction parameter (σ_0), the exponent α are empirical fit parameters that define about the distribution of the relaxation peaks for each individual process k involved in the dielectric relaxation. All four

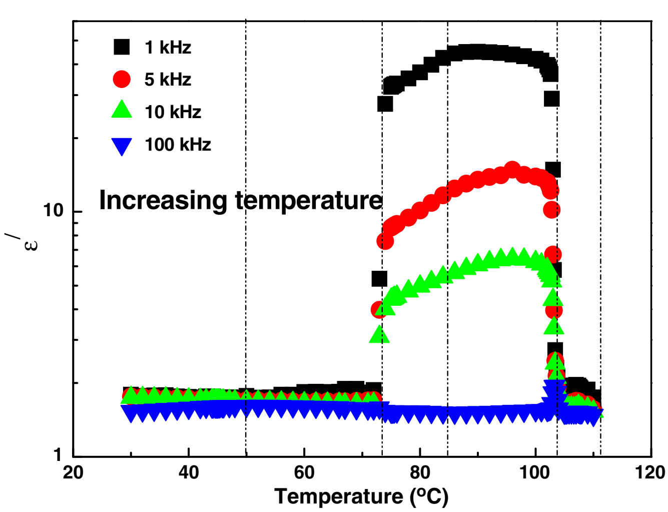

Fig. 3. Variation of real component of dielectric permittivity (ε/) with temperature at different frequencies. The vertical lines denote the transition point of several phases such as Cr<50 SmC_A^* 74 SmC^* 103 SmA 101 Iso. The line at 85 °C may be associated with a transition from higher order SmC^* to lower order SmC^* phase.

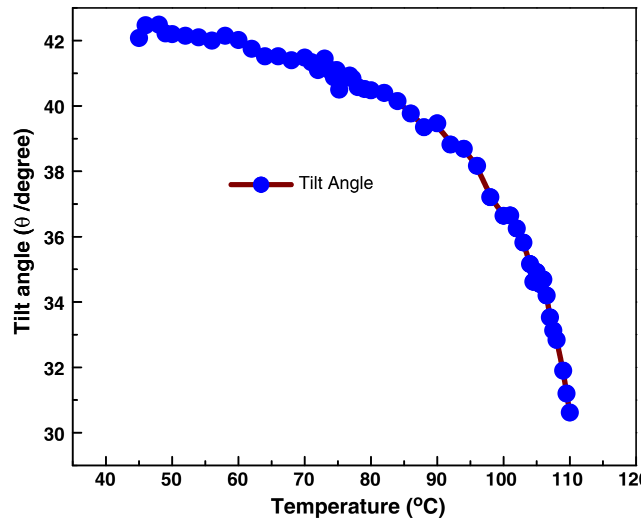

Fig. 4. Variation of tilt angle (θ) with temperature.

parameters were extracted after suitably fitting with Cole–Cole function (1) [19].

The real (ε/) and imaginary (ε//) components of dielectric function can be extracted as given below:

$$\varepsilon' = \varepsilon_\infty + \sum_{k=1}^{N} \frac{\Delta\varepsilon_k[1+(2\pi f\tau_k)^{\alpha_k}\cos(\alpha_k\pi/2)]}{[1+(2\pi f\tau_k)^{2\alpha_k}+2(2\pi f\tau_k)^{\alpha_k}\cos(\alpha_k\pi/2)]} \quad (2)$$

$$\varepsilon'' = \frac{\sigma_0}{(2\pi f)^S} + \sum_{k=1}^{N} \frac{\Delta\varepsilon_k(2\pi f\tau_k)^{\alpha_k}\sin(\alpha_k\pi/2)}{[1+(2\pi f\tau_k)^{2\alpha_k}+2(2\pi f\tau_k)^{\alpha_k}\cos(\alpha_k\pi/2)]} \quad (3)$$

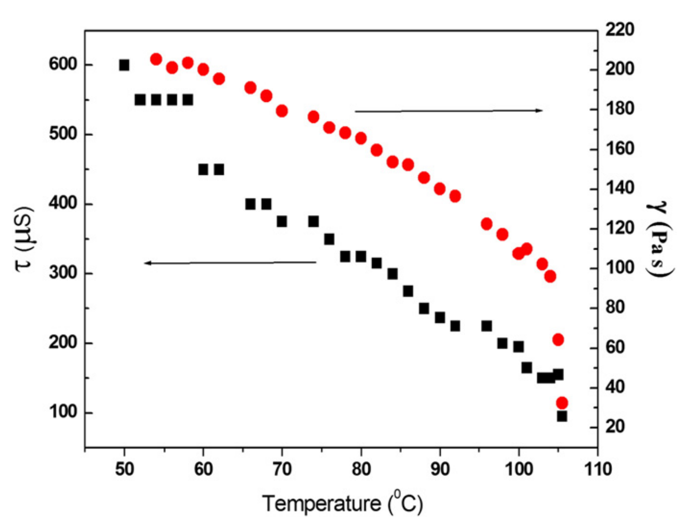

Fig. 5. Variation of response time (τ) and rotational viscosity (γ) with temperature.