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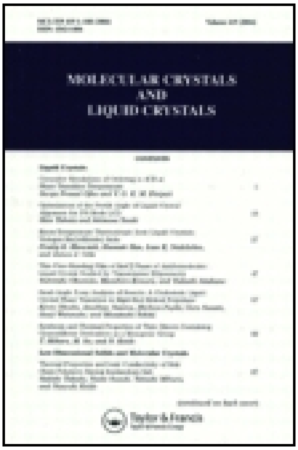

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Physical Properties of the Ferroelectric Phase in Some Fast-Switching Chiral Epoxy Compounds and Lactic Ethers

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Physical Properties of the Ferroelectric Phase in Some Fast-Switching Chiral Epoxy Compounds and Lactic Ethers

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Two classes of liquid crystals of good chemical stability are discussed, which are characterized by high response speed. The epoxy compound have a fairly high spontaneous polarization, 30 nC cm^{-2}, whereas the lactic ethers show the somewhat lower values of 10 and 14 nC cm^{-2}. Tilt angle, polarization, and viscosity measurements are presented. The dynamic field-response is discussed in some detail.

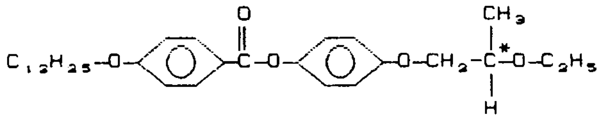
Keywords: smectic, chiral, ferroelectric, tilt, polarization, viscosity

We have made tilt angle, polarization, and viscosity measurements on the compounds of Figure 1, which have been synthesized by Walba *et al.*[1] The polarization is measured by studying the polarization reversal current due to an applied square wave voltage in thin cells filled with the ferroelectric liquid crystal in the bookshelf geometry.[2] The tilt angle is determined by measuring the angle (dynamically) between the extinction positions between crossed polarizers for the same form of applied voltage and geometry.

EXPERIMENTAL

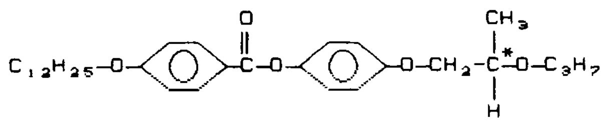
We have used 2 μm thick samples with 17 mm^2 active electrode area. The electrodes are coated with 1000 Å of orthogonally evaporated SiO. The samples have been sheared to get good bookshelf orientation and are temperature-controlled in a slightly modified Mettler

Lactic ether C_2C_{12}:



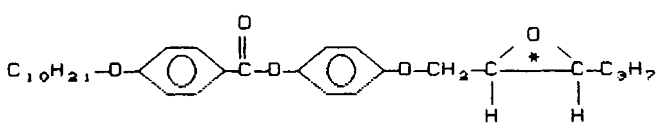
33° 44.5°
X → A → isotropic
27° ↖ C* ↙ 34°

Lactic ether C_3C_{12}:



37° 42°
X → A → isotropic
↖ C* ↙ 35°

Epoxy:



73° 78° 80° 95°
X → C* → A? → N* → isotropic
↖ Sm_2 ↙ (57°)

Fig. 1. Ferroelectric compounds used

FIGURE 1 Ferroelectric compounds used. These materials are available from Display Tech, Inc. P.O. Box 7246, Boulder, CO 80306, USA.

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hot-stage. The amplitude of the applied square-wave voltage has been 10 V for the epoxy sample and 12.4 V for the lactic ethers, and the frequency has been 400–1000 Hz. The current response has been recorded with a Tektronix 7854 oscilloscope. See Ref. 3 for the setup of polarization measurement.

A SIMPLE MODEL FOR THE POLARIZATION REVERSAL CURRENT

The usual way to measure the polarization is to integrate the polarization reversal current after subtraction of current contributions from other effects. A simple model of the polarization reversal mechanism (described in detail in Ref. 4) enables us to get

a. better and more easily obtained values of the ferroelectric polarization
b. values of some other physical parameters
c. better understanding of the physical process
d. a good starting point for making more detailed theoretical models

In our simple model we make the following assumptions and restrictions:

We restrict the model to the low voltage range, below inelastic changes in the samples.

We assume that the director field can everywhere be represented by giving the angle ϕ between the polarization and the normal to the electrodes. Figure 2 displays the geometry of the cell.

The motion of the director is dominated by the viscous torque $\gamma\dot{\phi}$. To get regular mathematical solutions similar to the experimentally obtained curves, we need also an elastic torque, which for simplicity is chosen to be

$$K \cos \phi$$

where K is a cell-dependent effective elastic constant.

The period of the square wave is assumed to be chosen so long that the angle ϕ essentially finds its equilibrium position during each half-period.

We then get the differential equation

$$-PE \sin \phi + K \cos \phi = \gamma \dot{\phi},$$

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where P is the ferroelectric polarization and E is the applied electric field. This is the equation for an over-damped pendulum, with the equilibrium position at $\phi = \phi_0$, where

$$\phi_0 = \arctan (K/PE).$$

The differential equation has the solution

$$\phi = \phi_0 + \arcsin \frac{1}{\cosh(\kappa(t - t_0))},$$

where

$$\kappa = \frac{\sqrt{(PE)^2 + K^2}}{\gamma}$$

and t_0 is the time when ϕ passes $\phi_0 + \pi/2$.

The current contribution from the polarization reversal is easily calculated as

$$I = -AP\,\dot{\phi}\,\sin\phi.$$

Knowledge of the analytical shape of the current enables us to do a quick estimate of the area of the polarization reversal current bump (cf. Figure 3):

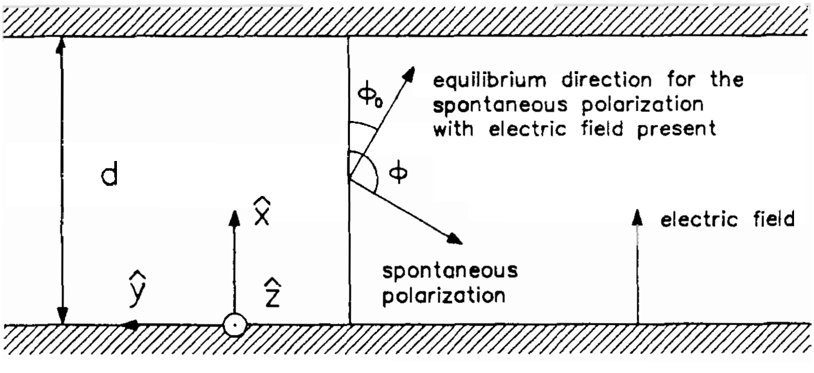

FIGURE 2 Geometry of the cell. The smectic planes are parallel to the plane of the paper.

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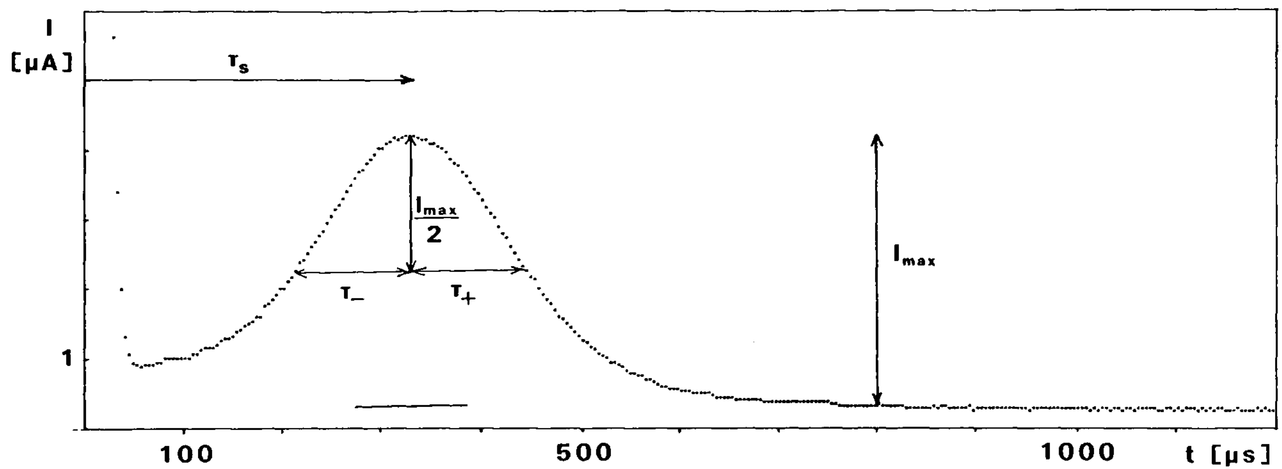


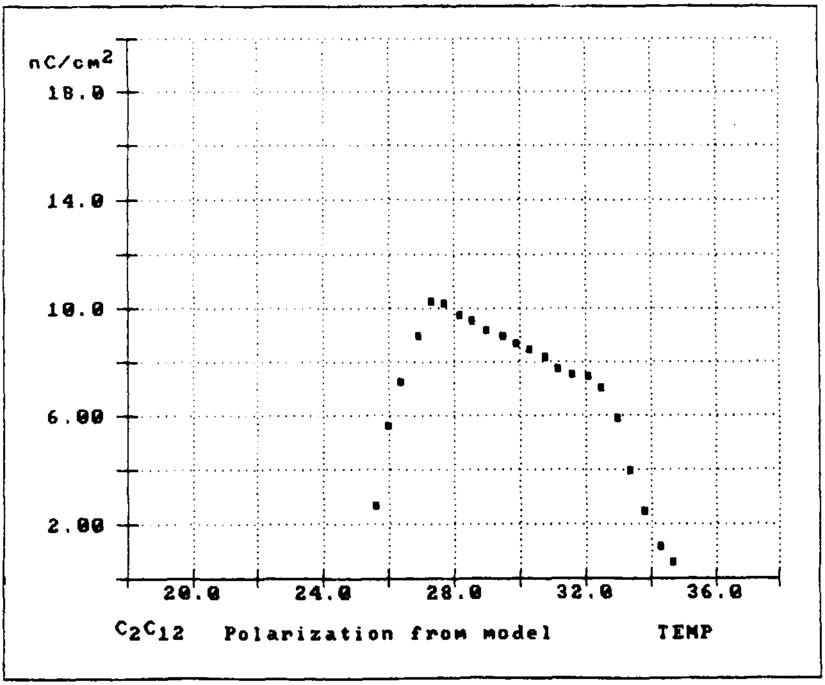
FIGURE 3 A typical measured polarization reversal curve: First comes the fast exponential charging of the capacitor and then the polarization peak on top of an almost constant contribution from ionic conductance. The relation between τ_s and $(\tau_- + \tau_+)$ can be used to estimate the equilibrium angle ϕ_0. This gives the proportionality constant between the spontaneous polarization and $I^*_{max}(\tau_- + \tau_+)$.

The area = (the height of the current bump) times
(the half-value width) times
(a numerical factor)

The numerical factor can easily be calculated from our formulas. It depends weakly on the value of ϕ_0, which in turn is easily estimated from the shape of the curve. The value of polarization obtained in this way seems to be quite insensitive to various types of experimental deviations from the ideal behaviour. We also get good agreement with other measurement methods.

RESULTS

In Figure 4 is shown the spontaneous polarization for the three compounds. For the epoxy compound and for C_2C_{12} the measured, decreasing values at the low-temperature part of the curves are due to partial crystallization in the liquid crystal, giving a smaller active area



(a)

FIGURE 4 Spontaneous polarization evaluated according to the model.

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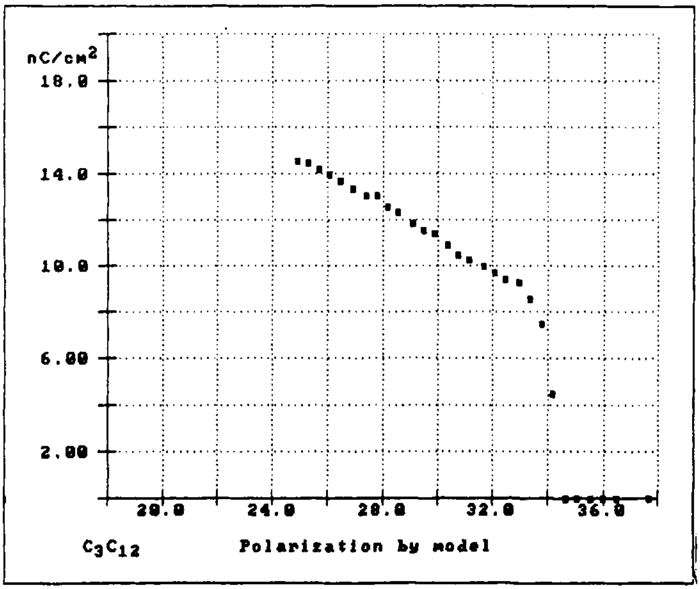
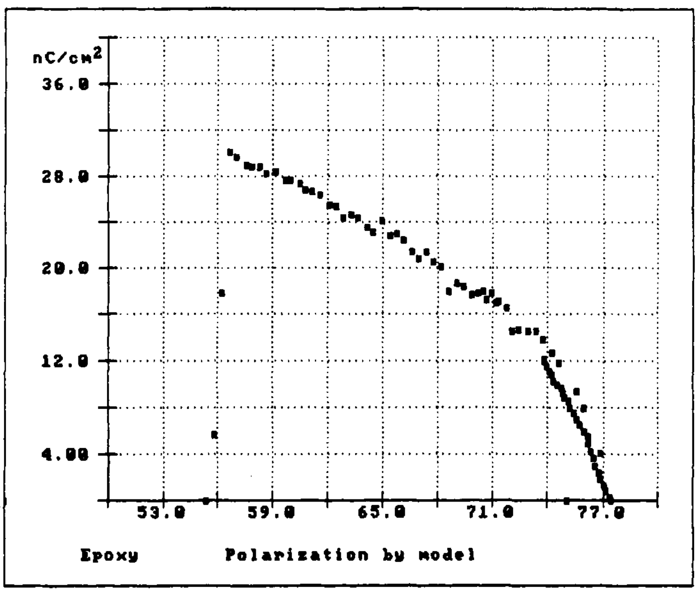


(b)



(c)

FIGURE 4 (*Continued*)

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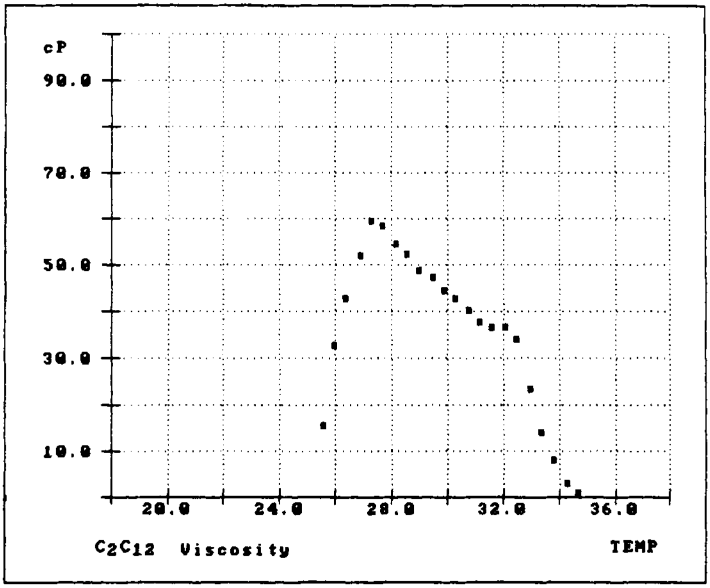
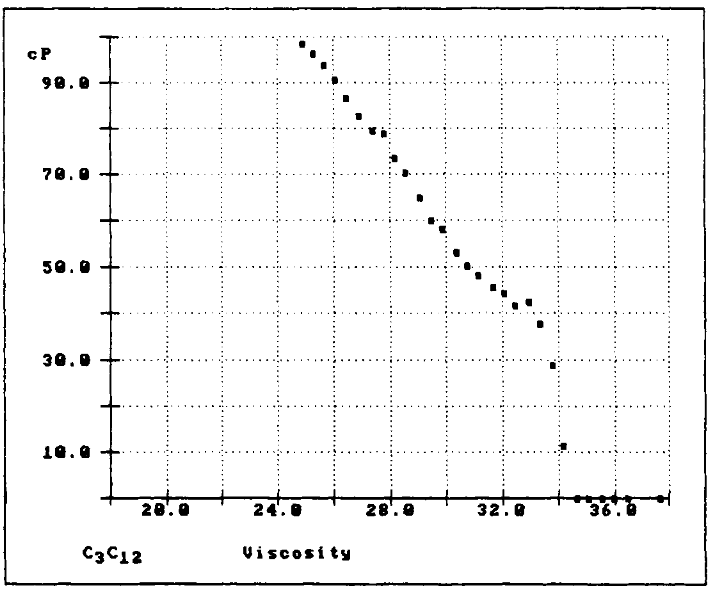
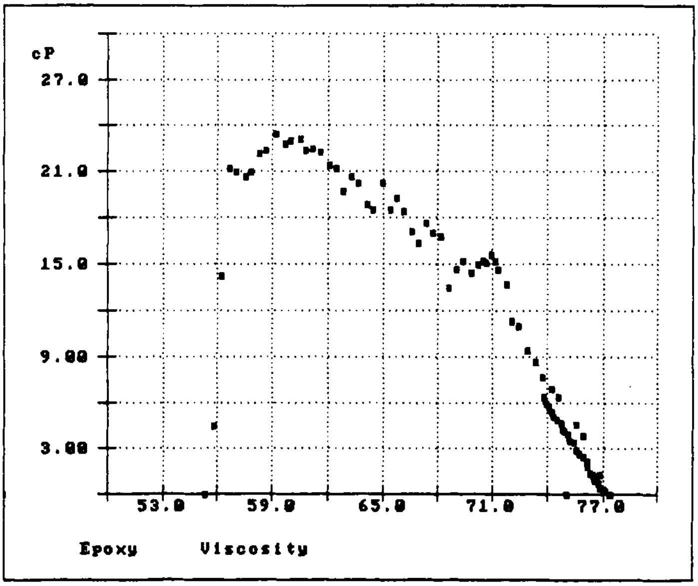


(a)



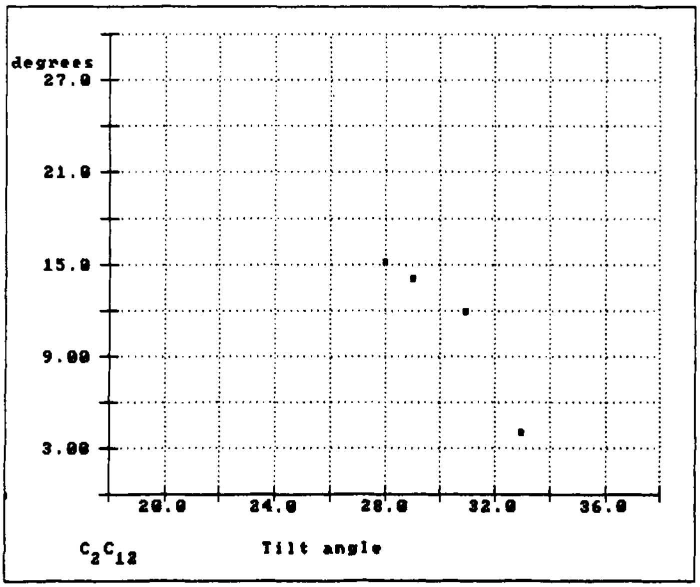
(b)

FIGURE 5 Evaluated vicosity as a function of temperature for the three compounds. To get values in Ns/m^2 multiply with 10^{-3}.



(c)

FIGURE 5 (*Continued*)



(a)

FIGURE 6 Electro-optically measured tilt angles vs. temperature for the three compounds.

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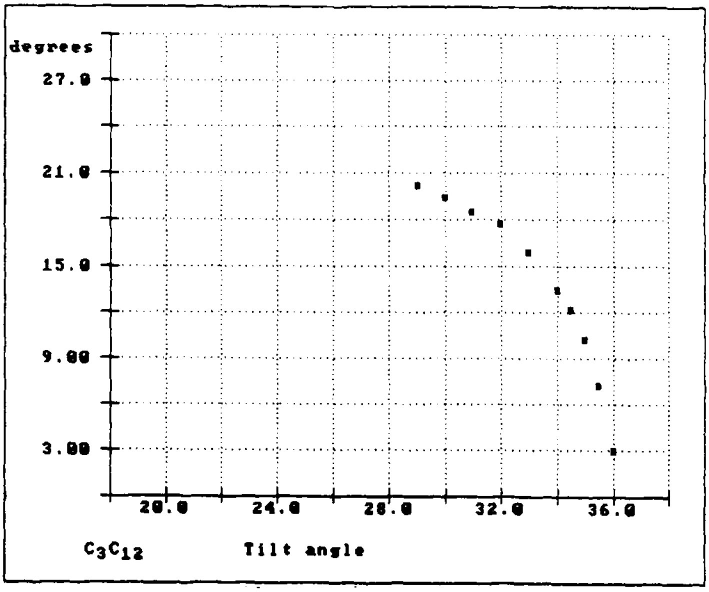
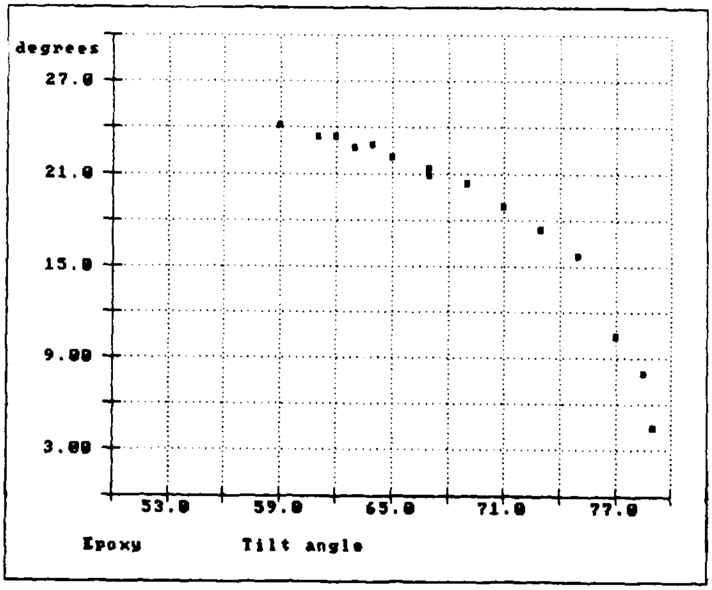


(b)



(c)

FIGURE 6 (*Continued*)

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contributing to the switching current. From the polarization reversal model outlined above also values for the rotational viscosity γ are obtained (Figure 5). The equilibrium angle ϕ_0 should be dependent on cell thickness, but for all the three substances here, values about 10 degrees are typical over most of the temperature interval.

In Figure 6 values for the tilt angle are presented. The electro-optic rise time (measured between the 10% and 90% levels of the optical response between crossed polarizers) for the epoxy sample was around 20 μs in the whole smectic C* range when a square wave voltage of 17 V amplitude was applied. This behaviour might be expected from the very similar temperature dependence (cf. Fig. 4c and 5c) of spontaneous polarization and viscosity.

Acknowledgments

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