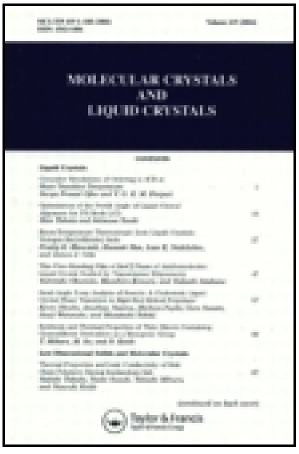

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Electric Field Effect on the Soft and Goldstone Modes in Ferroelectric Liquid Crystals

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ELECTRIC FIELD EFFECT ON THE SOFT AND GOLDSTONE MODES IN FERROELECTRIC LIQUID CRYSTALS

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Abstract The influence of dc electric field on the Goldstone and soft modes in a ferroelectric liquid crystal has been studied with optical method. The complex behaviour of these modes has been observed. The applied electric field not only quenches the Goldstone mode, but also strongly modifies the properties of the soft mode.

INTRODUCTION

Two specific modes caused by fluctuations of the director can be observed in ferroelectric liquid crystals[1]: 1) the soft mode related to changes in the tilt angle value, and 2) the Goldstone mode related to changes in the tilt direction. In the smectic A phase only the first mode appears, whereas in the smectic C^* phase both modes occur. Therefore, the studies of the soft mode in the SmA phase, especially in the vicinity of the phase transition, are relatively easy. In the SmC^* phase the situation is different. At low temperatures, far away from the SmC^* - SmA transition point the amplitude of the soft mode is so small that practically in experiment only the Goldstone mode can be observed. On the other hand, close to the transition point the amplitudes and frequencies of both modes are comparable[2]. Thus, without application of some special procedures, a contribution of both vibrations always reveals in the experiment. To separate the soft mode one often freezes the Goldstone mode applying a dc electric field sufficiently strong to remove the helix (see e.g.[3]). This procedure makes the studies of the soft mode considerably easier. However, the question arises to what extent the procedure, in which one applies a relatively high field, affects the soft mode itself. This problem was investigated by Gouda et al.[4] in the smectic A phase. Here, we present the first results concerning the electric field effect on amplitudes of these modes in both SmC* and A phases.

EXPERIMENTAL

The ferroelectric modes are usually studied with the dielectric methods, i.e. by measurements of the electric permittivity at various frequencies[1-5]. In our experiment the optical method of detection was applied. The method consists in measuring the intensity of light passing through the sample placed between the crossed polarizers. If an ac electric field directed parallel to the smectic layers is applied to the sample then the intensity of light passing through will be described by the following formula:

$$I = I_o \sin^2 2\phi \sin^2 \frac{\delta}{2} , \qquad (1)$$

where I and I_o denote the intensity of transmitted and incident light, respectively. ϕ is the angle between the vibration direction of polarizer and the optic axis plane, whereas δ is the phase difference between ordinary and extraordinary rays after passing the sample. The applied electric field affects the ϕ or δ angle depending on the orientation of the sample and causes the modulation of light intensity. It can be shown that the amplitude of light modulation is proportional to the ferroelectric component of electric permittivity[6]. Thus, the optical detection method provides the same information like the dielectric method, but on the other hand is much more sensitive. The block diagram of the measuring equipment is shown in Figure 1. The measurements of light modulation were performed at various frequencies of the applied field (10 Hz - 100 kHz). The dc and ac voltages were applied in the same direction (parallel to the smectic layers).

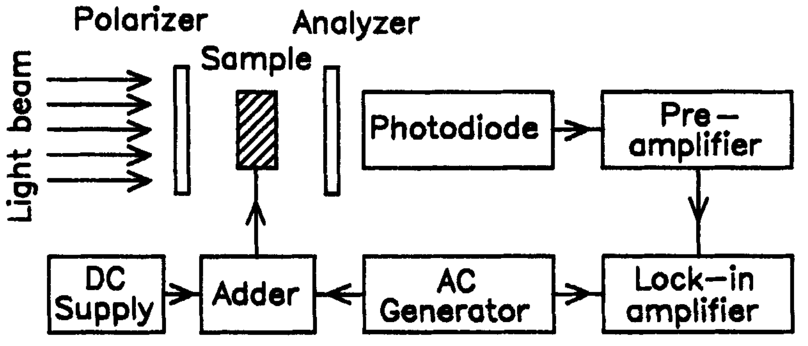

FIGURE 1. Block diagram of the measuring equipment.

All measurements were carried out for 4-octyloxy 4 -[(2 methylbutyloxy) carbonyl] phenylbenzoate having the following phase transition scheme:

$$K32\ (Sc\ 30.5)\ S_A\ 55\ Iso.$$

RESULTS AND DISCUSSION

Fig.2 and 3 present typical dependences of the modulation amplitude of light intensity on a dc voltage at some selected temperatures in the SmA and SmC* phase, respectively. In both phases the modulation amplitude decreases with increasing voltage (with exception of small local maxima at temperatures slightly below the SmC* - SmA transition temperature, Fig.3). The monotonic decrease of the amplitude observed in the SmA phase is in agreement with the results obtained by Gouda et al.[4] with the dielectric method. In the SmC* phase the situation is more complicated, as the optical response consists of two components, both dependent on the strength of electric field. Within the range of small voltages (lower than the critical voltage U_{C1} needed to unwind the helix) the Goldstone mode is decisive, for higher fields

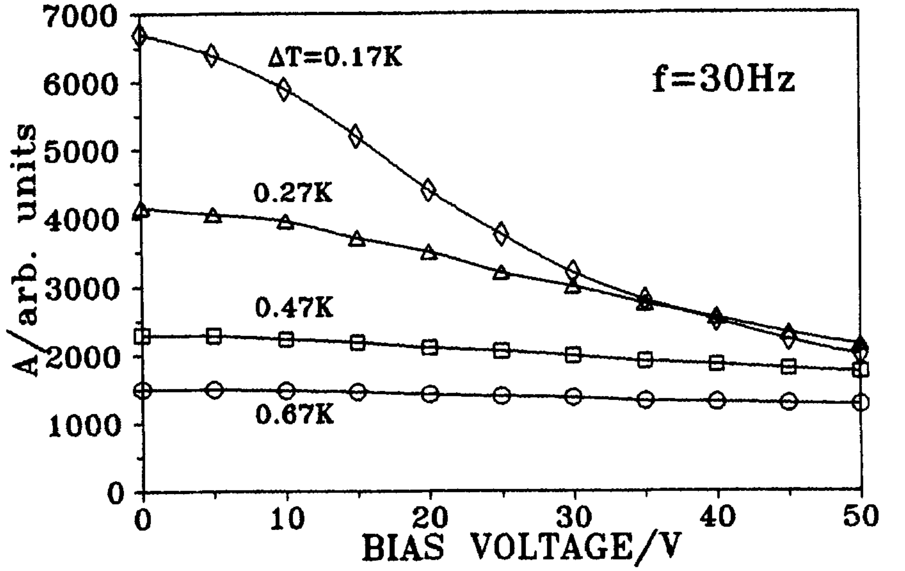

FIGURE 2. Optical response as a function of dc electric field in the SmA phase. Sample thickness 30 μm. Planar orientation.

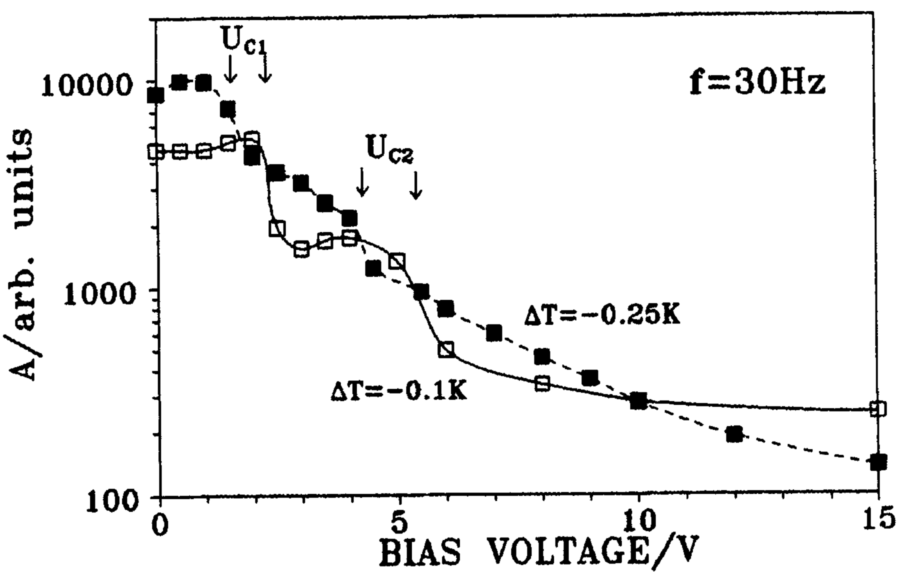

FIGURE 3. Optical response as a function of dc electric field in the SmC* phase. Sample thickness 30 μm. Planar orientation.

the soft mode becomes predominant. The observed decrease in modulation amplitude is mainly, but not exclusively, caused by the suppression of the Goldstone mode; this decrease also occurs within the high field range where the Goldstone mode is no longer present. On the other hand, the dispersion studies[6] show that the Goldstone mode, althouth week, is still detectable at relatively high voltages, exceeding several times the critical voltage U_{C1}. It is comprehensible for voltages within the range $U_{C1} < U < U_{C2}$ (Figure 3) since in this range the sample has a twisted structure[7]. However, the twisted structure cannot explain the presence of the Goldstone mode observed by us in homeotropic samples without helix and in planar samples for $U > U_{C2}$. In these cases, the presence of the Goldstone mode can be explained by the surface layer effect.

The facts presented above show that the Goldstone mode can be removed by electric fields of relatively high intensity exceeding several times the critical field. However, so high fields also distinctly modify the properties of the soft mode. Thus, the application of a dc electric field in studies of the soft mode is not so advantageous as it has been expected and the results obtained in the presence of a dc field should be treated with care.

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