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New electromechanical effect in chiral smectic C* liquid crystals

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Résumé. — Un nouvel effet électromécanique a été trouvé dans des cristaux liquides S_C^* orientés planairement, sous l'influence d'un champ électrique alternatif appliqué. En plus du phénomène électrooptique bien connu, des vibrations mécaniques ont été observées dans la direction parallèle aux couches smectiques et perpendiculaire au champ électrique.

Abstract. — A new electromechanical effect has been found in planar oriented S_C^* liquid crystals under the influence of an applied alternating electric field. Apart from the well-known electrooptical effects a mechanical vibration has been observed in a direction parallel to the smectic layers and perpendicular to the electric field.

In recent years there has been increasing interest in ferroelectric liquid crystals, mainly due to the delicate electrooptical effects [1-5] caused by the possible linear coupling between spontaneous polarization and electric field.

One of the first experimental evidences of the existence of spontaneous polarization lying in the smectic layers was given by Pieranski *et al.* [6]. In their experiment a homeotropic S_C^* sample was used and a shear velocity parallel to the layers induced a non-zero average polarization in a direction perpendicular to the layer normal and the shear.

In the present letter we report about a new electromechanical effect detected in S_C^* systems which can be interpreted as the inverse effect of the one published in [6].

In our experiment the planar oriented S_C^* sample has been placed between two glass plates, smectic layers being perpendicular to the glasses (see Fig. 1).

The lower plate (1) has been fixed while the upper one (2) was allowed to move against a spring. An alternating electric field **E** has been applied to the sample perpendicular to the glasses, inducing the well-known electrooptical effects such as switching [1, 2] or helix unwinding [3-5]. Apart from those it has been observed that under the influence of the field a mechanical vibration **u** of the upper plate occurred in a direction parallel to the smectic layers and perpendicular to the electric field.

The mechanical vibration of the upper plate has been detected by a ceramic pick-up sensitive to the displacement. After amplifying the signal of the pick-up it has been found that the frequency of the mechanical vibration of the sample is the same as that of the applied electric field. The observed amplitude of the vibration was proportional to the electric field. The above described electromechanical effect has been detected in the S_C^* phase of various liquid crystal compounds

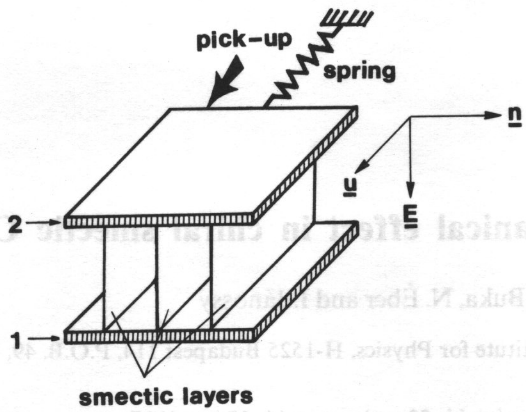

Fig. 1. — Experimental set-up. 1 and 2 are the lower and upper glass plates of the sandwich cell filled with an S_C^* material. The orthogonal vectors **n**, **E** and **u** indicate the direction of the helical axis, the applied electric field and the displacement of the upper plate respectively.

and mixtures for different sample thicknesses between 5 and 70 μm, independently of the fact whether the sample was unwound or not.

The measurement presented here was carried out on a liquid crystal binary mixture FK 4 [7] with a following phase sequence :

$$\text{Is} \xrightarrow{67\,^\circ\text{C}} \text{Ch} \xrightarrow{63\,^\circ\text{C}} S_A \xrightarrow{29\,^\circ\text{C}} S_C^* \xrightarrow{16\,^\circ\text{C}} S_I^*$$

The pitch in the S_C^* phase was about 5 μm and an unwound sample of 10 μm thick was used. The mechanical natural frequency of the set-up (liquid crystal, upper plate and spring) depends on the quality of the alignment and was found in the range of 300-600 Hz. The applied voltage U_{eff} was kept at 5 V throughout the experiment, while its frequency was changed.

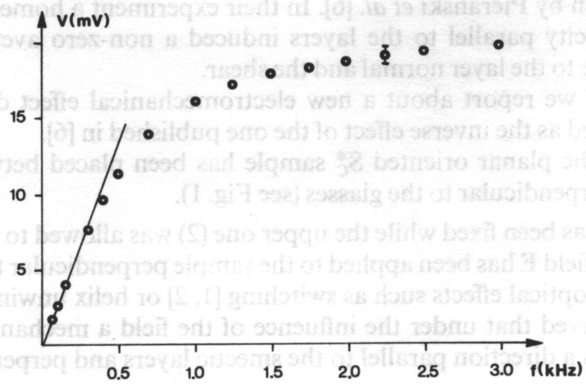

Fig. 2. — The frequency dependence of the pick-up signal at $U_{\text{eff}} = 5$ V.

In figure 2 there is plotted the frequency dependence of the electric signal of the pick-up which is proportional to the amplitude of the vibration.

Important features of the experimental data are, that :

1. — there is no static effect, i.e. a d.c. voltage does not induce any displacement,

2. — the amplitude of vibration is proportional to the frequency up to a few hundred Hz. At higher frequencies a deviation from linearity occurs, but no resonance around the natural frequency was detected.

The measurement was carried out up to $f = 5\,000$ Hz. An estimate of the absolute value of the displacement can be given taking into account the technical characteristics of the ceramic pick-up. For the above binary mixture at $T = 27$ °C, $f = 1\,000$ Hz, $U_{\text{eff}} = 25$ V and $d = 10$ μm one can get for the vibrational amplitude of the upper plate a value about 2 μm.

The above presented electromechanical effect is similar in its appearance to the phenomenon of piezoelectricity in solid state physics. However there are important differences which do not allow to use an interpretation given for the piezoeffect in crystals.

First, the frequency dependence of the effect implies that in case of a low frequency harmonic electric field $E = E_0 \, e^{i\omega t}$ the vibrational amplitude is proportional to $\mathrm{d}E/\mathrm{d}t = i\omega E$ rather than to E.

The second difference arises from the smectic structure. The displacement was found perpendicular to the helical axis. Since there is no long range positional ordering within a smectic C layer, it can be regarded as a two-dimensional liquid. Consequently, interpreting a translational motion inside the smectic C layers a continuum theory of fluids should be used in which the viscous behaviour of the substance plays an important role rather than the elastic properties do which is the case in crystals.

The existing theories of the S_C^* phase [8-10] cannot give an account of the observed electromechanical effect. Its interpretation needs a continuum theory which is capable to handle irreversible phenomena, e.g. viscous flow, in the presence of an electromagnetic field. Such a continuum theory is under development for the chiral smectic C* liquid crystals [11, 12].

We think that due to the chirality and biaxiality of the S_C^* phase there exists a new cross-effect, a hidden cross-coupling between dielectric relaxation and viscous flow. It results in a force, exerted on the sample, which is proportional to $\mathrm{d}E/\mathrm{d}t$. A model discussing the theoretical interpretation of the electromechanical effect in more detail will be presented in a forthcoming paper [13].

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