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STRONG ELECTROACOUSTIC EFFECT IN FERROELECTRIC LIQUID CRYSTAL CELLS

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A strong electroacoustic effect of a ferroelectric liquid crystal cell was observed with a 1 MV/m electric square field in the frequency range from 3 kHz to 30 kHz. The sound emitted can be heared with the naked ear and easily detected with a simple microphone. The electroacoustic effect vanishes in the chiral S_A-phase.

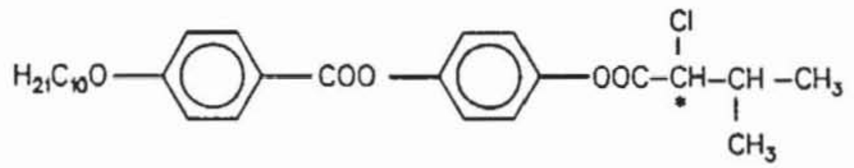
INTRODUCTION

In surface stabilized geometries liquid crystals with chiral smectic C^* phases exhibit a fast electrooptic effect[1)] caused by their ferroelectric properties[2,3)]. Due to their ferroelectric behaviour, electromechanic effects like piezoelectricity, flexoelectricity or electrostriction are expected[4,5)]. Because the liquid-like mechanical behaviour of low molecular mass liquid crystals seems to be unsuitable for a study of electromechanical effects at equilibrium conditions, recent investigations of electromechanical effects focus on FLC-polymers and FLC-elastomers[5-7)]. As will be presented in this letter, low molecular mass FLC's in thin surface stabilized cell also show a remarkable electromechanic effect, if the frequency of the activating field is in the range of high sonic or ultrasonic frequencies.

EXPERIMENTAL

The compound 4-(S)-(+)-2-[chloro-3-methyl-butyryloxy]phenyl-4-(decyloxy)-benzoate[8)] (1) is used in this study and exhibits a monotropic S_C^* phase within the phase sequence: cryst. · (S_C^*) · 45 °C · S_A · 64 °C · isotr.

At 40°C the director tilt angle is 14 degrees, the spontaneous polarization ≈ 40 nC cm^{-2}, the internal rotational viscosity ≈ 50 mPa s^{-1} and the splay elastic constant $1.5 \cdot 10^{-11}$ N m^{-2} [9].



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The compound is filled in a commercially available 4μm cell (E. H. C. Co. Ltd., Tokyo) with transparent Ito electrodes and parallel rubbed polyimide layers which leads to a planar orientation of the LC phases. The exact thickness of the cell used was determined to 3.85 μm by the interference spectrum of the empty cell with application of the corrections given by Yang[10] considering the optical influence of the polyimide and Ito layers.

The cell is placed on a home made hot stage in a polarizing microscope and connected to the voltage supply (HP 8116A pulse/function generator and Krohn Hite KH-7500 broadband amplifier). The hot stage consists of a single hot-plate which can be rotated around two axes, parallel and perpendicular to the optical axis of the microscope.

A well oriented S_C^*-phase is obtained after slowly cooling down from the isotropic phase. At 40 °C the original chevron structure of the cell is transformed into a bookshelf structure by applying a high amplitude (≈ 15 MV m^{-1}) and low frequency (≈ 200 Hz) electric square field[9]. Subsequently the amplitude of the applied field is decreased to 1 MV m^{-1} and the frequency increased from 3 to 30 kHz. The sound emitted from the cell can be heared with the naked ear, if the frequency of the applied field is below the cut-off frequency of the human ear.

The acoustic response is recorded after amplification (Tektronix AM 502) with a digitzing memory oscilloscope (Hewlett-Packard 54 200A) by a simple microphone placed next to the cell and perpendicular to the substrate normal. For eliminating low frequency statistical noise, 64 frames of the signal are averaged.

RESULTS AND DISCUSSION

At 40 °C and application of an electric square field of 1 MV m^{-1} amplitude the macroscopically observable electrooptic effect of the cell almost vanishes between a frequency of 1 to 2 kHz. In this frequency range fluctuations within the texture can be observed between crossed polars. At higher frequencies these visible fluctuations decrease and a sound can be

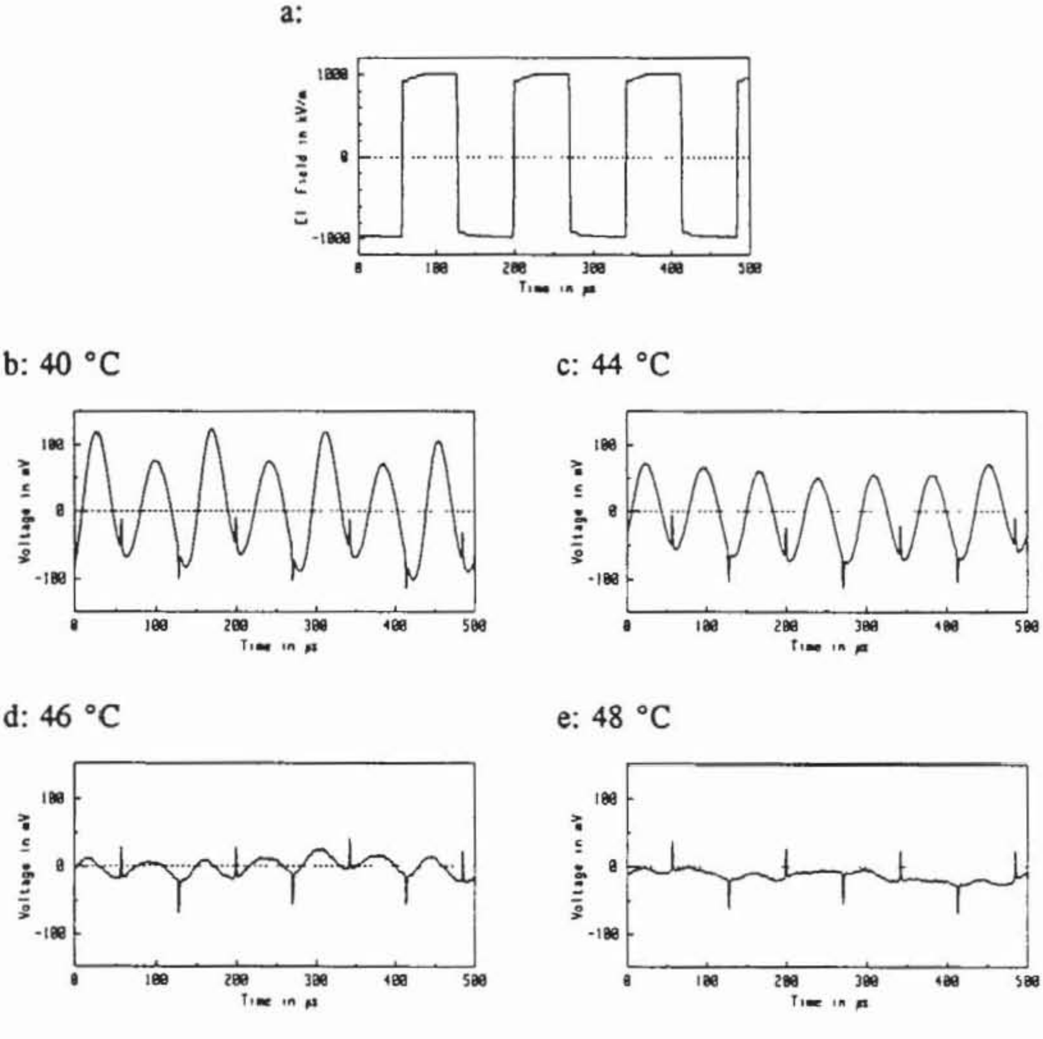

FIGURE 1 Applied electric field (a) and acoustic responses, plotted as amplified microphone voltage vs. time, at different temperatures; b: 40 °C, c: 44 °C, d: 46 °C and e: 48 °C. The spikes on the response curves are due to the electromagnetic induction from the electrode connectors and serve as markers for the field reversal.

heard. The acoustic effect disappears, if the temperature is increased above the $S_C^* \rightarrow S_A$ phase transition temperature or if the monotropic S_C^* phase crystallizes, and it also vanishes, if an empty cell or load resistance is used. These observations lead to the conclusion, that the electroacoustic effect is correlated with the S_C^* phase.

Fig. 1 depicts the acoustic response of the cell plotted as amplified microphone voltage vs. time for a 7 kHz square field (Fig. 1a) with 1 MV m^{-1} amplitude. At 40 °C (Fig. 1b) the acoustic response essentially consists of vibrations in the fundamental and second harmonic frequency. The amplitude decreases slightly, if the temperature is raised to 44 °C (Fig. 1c), very close to the $S_C^* \rightarrow S_A$ phase transition. The amplitude of the electroacoustic effect breaks down rapidly after passing the phase transition at 46 °C (Fig. 1d) and is scarcely detectable at 48 °C (Fig. 1e). The spikes on the response curves are due to the electromagnetic induction from the electrode connectors to the unshielded microphone wires.

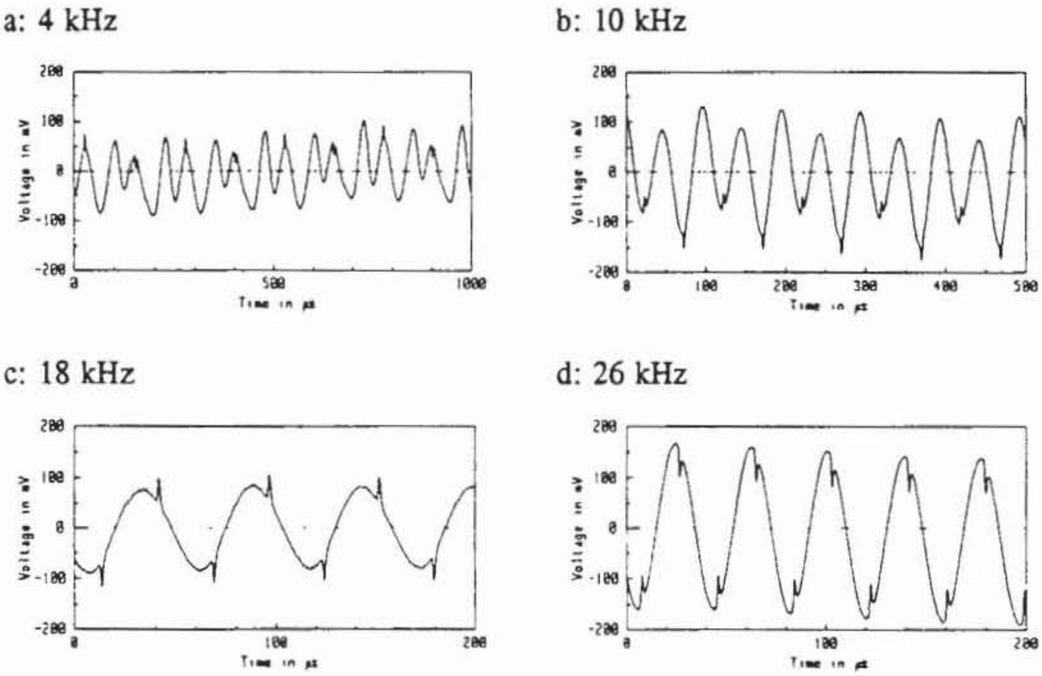

FIGURE 2 Acoustic response to an electric square field with 1 MV m^{-1} amplitude plotted as amplified microphone voltage vs. time at several electric field frequencies and 40 °C; a: 4 kHz, b: 10 kHz, c: 18 kHz and d: 26 kHz.

The frequency behaviour of the acoustic response is rather complex. Some representative response curves to a 1 MV m^{-1} electric square field are depicted in Fig. 2. At an electric field frequency of 4 kHz (Fig. 2a) the response shows a frequency characteristic consisting essentially of the fundamental, second and third harmonic frequency (the electric field period is marked by the distance of the induction spikes, cf. Fig. 1). The contribution of the third harmonic frequency is lost between 5 and 6 kHz and a response curve, as shown in Fig. 2b at 10 kHz electric field frequency, is observed. The second harmonic response vanishes at field frequencies above 12 kHz and the response to the electric square field is almost a sine wave with the fundamental frequency, depicted at 18 kHz frequency of the electric field in Fig. 2c. An electroacoustic effect can still be observed in the ultrasonic frequency range as shown at 26 kHz in Fig. 2d, but the acoustic effect can not be detected anymore above a field frequency of 30 kHz.

The amplitude changes as detected at different frequencies should be regarded as preliminary results, since neither the frequency characteristic of the microphone nor the influence of standing waves and interference due to the surrounding geometry are known. Amplitude maxima are detected at electric field frequencies of 4, 6, 13, 18 and 26 kHz.

It is worth to note, that the acoustic effect can be supressed by applying a small dc-offset field of about 0.2 - 0.3 MV m^{-1}. The response can be damped, if some mechanical pressure is exerted on the upper glass plate of the cell.

An explanation of the electroacoustic effect cannot be provided at the time. The following observations are found:

- The electroacoustic effect arises after the macroscopically observable electrooptic effect breaks down.

- The electroacoustic effect is correlated with the S_C^* phase temperature range. In the chiral S_A phase only a poor or no response is observed.

- The electroacoustic effect leads to a strong nonlinear response with regard to the applied electric square field. The relaxation of contributions with higher harmonic frequencies can be observed at certain field frequencies.

- The electroacoustic effect can be suppressed by small electric dc-offset fields.

An explanation based on the electroclinic effect, which causes a change in the smectic layer thickness, can almost be excluded because of the nonlinearity and the frequency characteristics and because the response almost vanishes in the chiral S_A phase. The correlation with the S_C^* phase, the cut-off frequency at 30 kHz and the suppression of the effect by dc-offset fields[11] point towards a description in relation with the Goldstone mode. But pure Goldstone mode fluctuations occur at constant tilt angle and, therefore, constant smectic layer thickness, and seem not suitable for an explanation of a mechanical effect. Explanations for the effect may be found in reversible changes of the orientational layer structure or reversible domain wall motions.

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