LINEAR ELECTROMECHANICAL EFFECT IN A POLYMERIC FERROELECTRIC LIQUID CRYSTAL

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Abstract   A linear electromechanical effect was detected in a ferroelectric side chain polymeric liquid crystal. Experimental data on temperature and frequency dependence are presented.
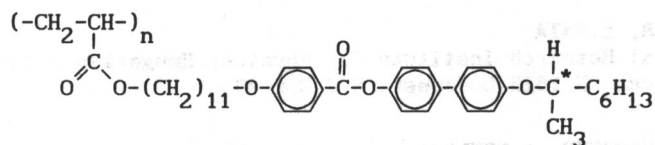
INTRODUCTION

Ferroelectricity is one of the most remarkable features of the chiral smectic C^* (S_C^*) liquid crystals[1]. Due to the presence of spontaneous polarization this phase exhibits a fast electrooptical switching[2] as well as a linear electromechanical effect[3] which has been studied in detail for various monomeric liquid crystals.[4-8]

There exist polymeric liquid crystals which possess S_C^* phase, hence these polymers are ferroelectric too.[9-12] Two of us have synthesized even such polymers which exhibite fast electrooptical switching as well.[13-15]

Recently a linear electromechanical effect, similar to that observed in low molar mass liquid crystals, has also been detected in polymeric S_C^* liquid crystals.[16,17] In this paper we present some experimental data about this phenomenon.

SAMPLE AND EXPERIMENTAL SET-UP

Our measurements were carried out using a polyacrylate side chain polymer with a chemical formula[13,14]

$$(-CH_2-CH-)_n \\ | \\ C \\ O \quad O-(CH_2)_{11}-O-\langle\rangle-\overset{O}{\overset{\|}{C}}-O-\langle\rangle-\langle\rangle-O-\overset{H}{\underset{CH_3}{\overset{|}{\underset{|}{C^*}}}}-C_6H_{13}$$

having M_W=15000 and its polydispersity characterised by M_W/M_N=1.5. Based on polarisation microscopy of 2 μm samples and DSC the phase sequence of this compound has been reported as:

$$I \xrightarrow{151\ ^oC} S_A \xrightarrow{142\ ^oC} S_C^* \xrightarrow{125\ ^oC} S_X \xrightarrow{92\ ^oC} S_B \xrightarrow{50\ ^oC} Glass$$
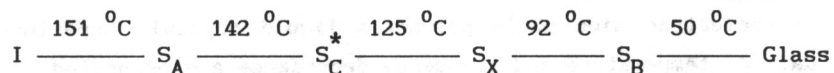
In the S_C^* phase the sample exhibited fast ferroelectric switching, however, in the S_X phase only a switching of electroclinic type could be detected.[14]

In order to determine the electromechanical response of the polymer we used the experimental set-up shown in Figure 1, a similar one as for investigation of monomers.[4,5,7] The polymeric liquid crystal was introduced in its isotropic phase in between two ITO coated glass plates separated by 15 μm thick teflon spacers. The lower glass plate was fixed to a thermostage while the upper one was connected to the membrane of a loudspeaker via a rigid metal rod, hence the upper glass could slide easily on the spacers. Parallelism of the cell was ensured by micropositioning supports. A piezoelectric accelerometer (Brüel&Kjær 4375) was attached to the connecting rod allowing detection of vibrations against the loudspeaker membrane, i.e. in a direction parallel to the glass plates. Using a charge amplifier we obtained an electric signal proportional to the acceleration (1000 mV/ms^{-2} at maximum sensitivity) which was analysed by a lock-in amplifier (Ithaco 3962). The AC voltage from the internal oscillator of the lock-in was applied to the electrodes via a high
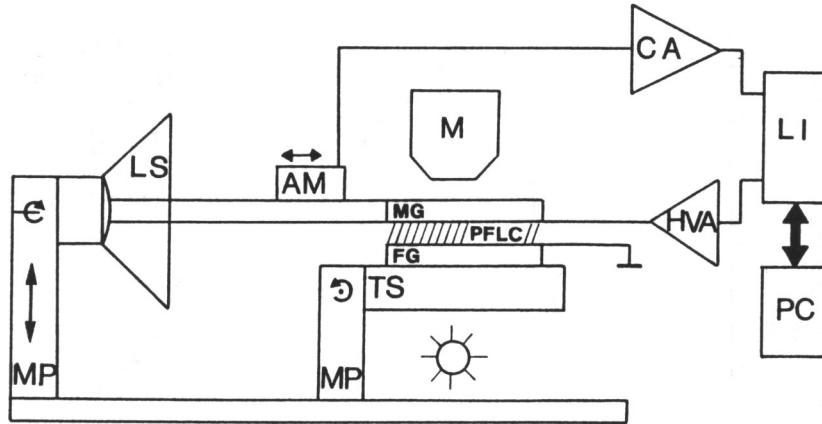
FIGURE 1   Experimental set-up for vibration measurements.
MG: moving glass, FG: fixed glass, MP: micropositioning support,
PFLC: polymeric ferroelectric liquid crystal, TS: thermostage,
M: polarising microscope, LS: loudspeaker, AM: accelerometer,
CA: charge amplifier, HVA: high voltage amplifier, LI: lock-in
amplifier, PC: computer

voltage amplifier. During measurements the texture of the sample was
observed by a polarizing microscope.

The glass plates were spincoated by polyimide but only one of
them was rubbed, so in order to obtain a planar orientation the sample
was sheared[18] at the $I-S_A$ phase transition in an applied AC field.

Unfortunately our sample possessed a very broad $I-S_A-S_C^*$ phase
transition, i.e. a coexistence of three phases was detected over a
10 °C temperature interval in the form of domains of different phases.
Within a domain the transitions into the other smectic phases were
sharp, however, in various domains they occurred at different
temperatures within a range of 5-10 °C. This inhomogeneity of the cell
remained even after repeated heating-cooling cycles. Due to this
merging $I-S_A-S_C^*$ phase transitions the sample was only partially
orientated with a lot of focal conics. We could not decide whether
this feature was due to the larger sample thickness or to material
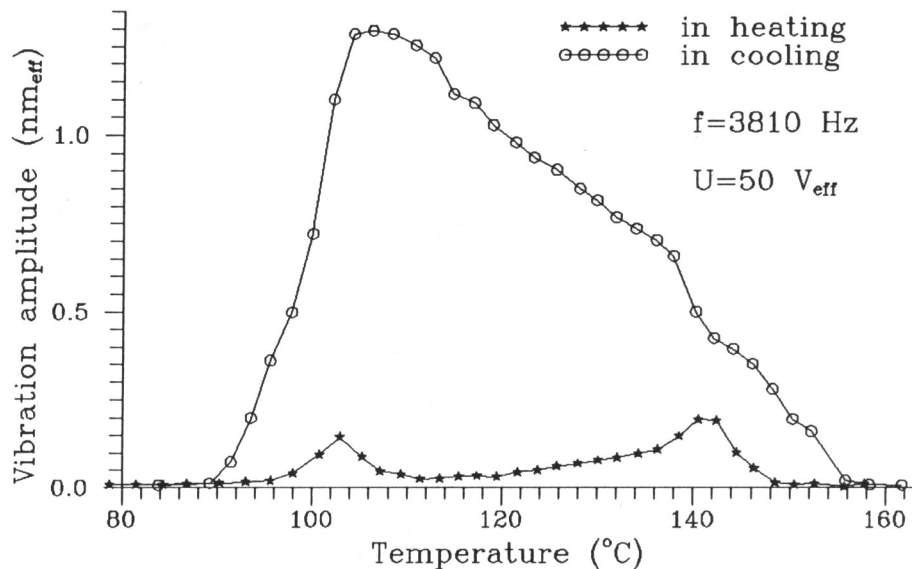degradation.

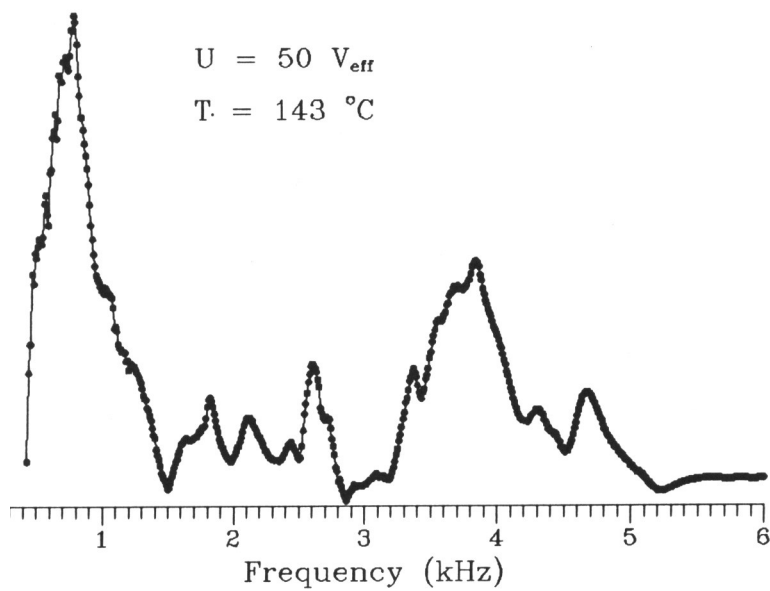FIGURE 2   Temperature dependence of the vibration amplitude.

RESULTS AND DISCUSSION

When an AC voltage was applied onto the sample in the S_C^* phase, a mechanical vibration of the upper plate occurred just as in case of low molar mass S_C^* liquid crystals[3]. The direction of the displacement was parallel to the glass plates. In case of sine-wave excitation the waveform of the acceleration signal is typically a slightly distorted sine-wave of the same frequency, where the higher harmonic distortion is more pronounced at higher voltages and lower frequencies. This means that the linear electromechanical effect does exist in the investigated polymeric S_C^* liquid crystal. Since we were interested in this linear phenomenon we measured only the linear component of the acceleration by the lock-in amplifier.

In Figure 2 we present the temperature dependence of the vibration amplitude. Despite of the poor orientation, the vibration amplitudes are of similar order of magnitude as in S_C^* phase of low
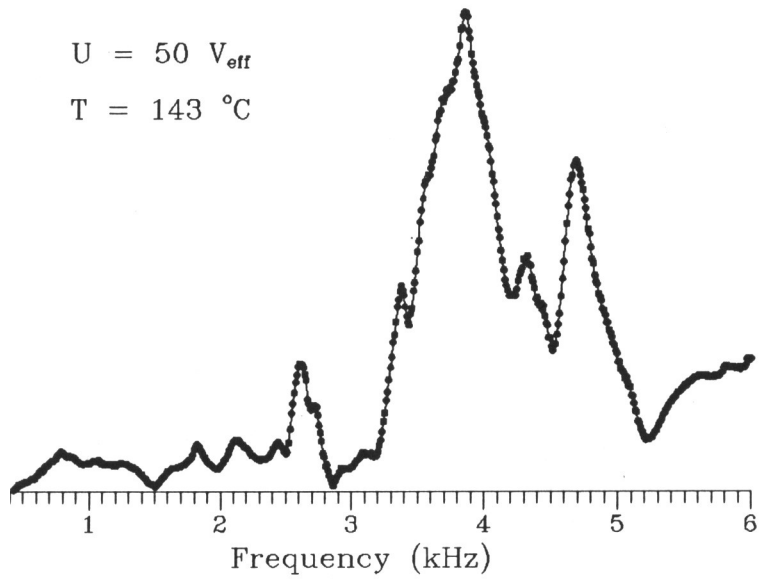
Frequency dependence of the acceleration in S_C^* phase.

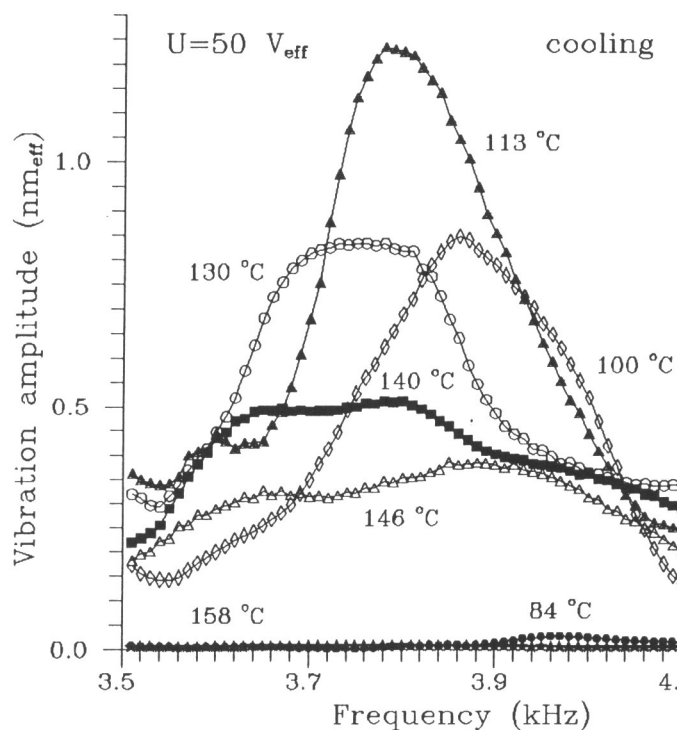Frequency dependence of the displacement in S_C^* phase.

FIGURE 5   Frequency dependence of the vibration amplitudes at some temperatures during cooling.

molar mass compounds[7] and are about three orders of magnitude larger then those reported recently for an another ferroelectric polymer[16]. Figure 2 illustrates that this electromechanical effect is existing even in the lower temperature S_X phase of the same compound, moreover, it may be stronger in S_X than in S_C^*.

We have investigated the frequency dependence of the vibration amplitudes as well. It can be seen in Figure 3 that the acceleration versus frequency plot exhibits several maxima in the 0.5 – 6 kHz range, a behaviour similar to that of monomers[7]. The calculated displacement is plotted in Figure 4 illustrating that larger displacements are tipically obtained from lower frequency vibrations.

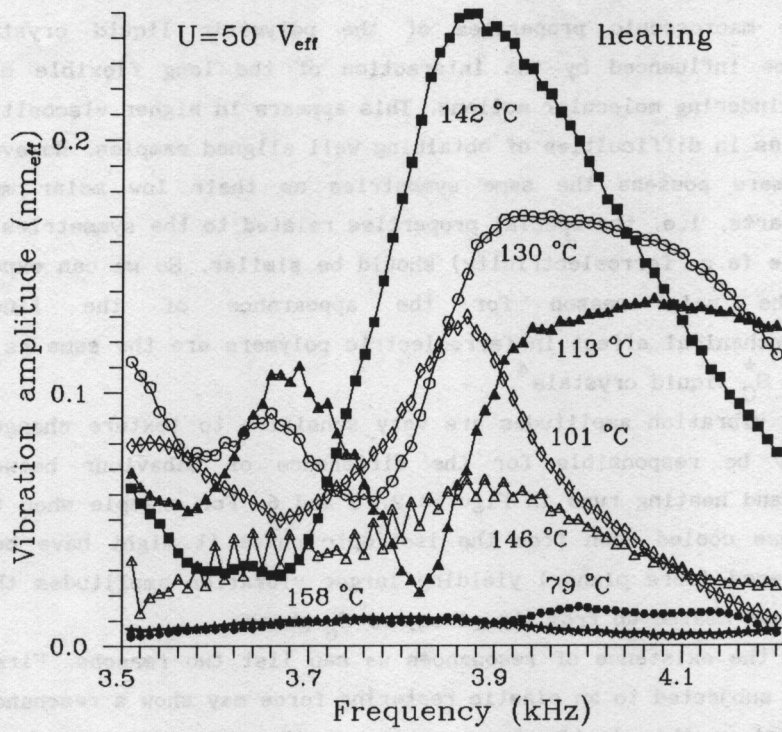In order to obtain information on the temperature dependence we

FIGURE 6   Frequency dependence of the vibration amplitudes at some temperatures during heating.

mapped the spectrum around the most pronounced resonance peak (3.81 kHz) at various temperatures by changing the frequency of excitation in 10 Hz increments while the amplitude of the applied voltage (U=50 V$_{rms}$) was held constant. Some typical spectra are plotted in Figures 5 and 6 for cooling and heating the sample respectively.

The figures show that the behaviour of the sample is definitely different in heating or in cooling. This concerns the vibration amplitudes at a given frequency as well as the value of the resonance frequencies. The shift of the resonance frequency with temperature is more pronounced in the heating cycle which explains the appearance of the double peak in the temperature dependence of the vibration

amplitude in Figure 2.

The macroscopic properties of the polymeric liquid crystals should be influenced by the interaction of the long flexible main chains hindering molecular motions. This appears in higher viscosities as well as in difficulties of obtaining well aligned samples. However, S_C^* polymers possess the same symmetries as their low molar mass counterparts, i.e. the special properties related to the symmetries of the phase (e.g. ferroelectricity) should be similar. So we can expect that the main reason for the appearance of the linear electromechanical effect in ferroelectric polymers are the same as in ordinary S_C^* liquid crystals[4].

The vibration amplitudes are very sensitive to texture changes. This may be responsible for the difference of behaviour between cooling and heating runs in Figures 2, 5 and 6. For example when the sample was cooled down from the isotropic phase it might have been more ordered (more planar) yielding larger vibration amplitudes than when it was heated up from the glassy or S_B phase.

For the existence of resonances we can list two reasons. First, any mass subjected to an elastic restoring force may show a resonance. In our set-up the elastic force acting on the upper glass plate is either due to the displacement of the loudspeaker membrane which behaves like a spring or it is the elastic surface force exerted by the liquid crystal due to deformation of smectic layers in the focal conics caused by the shear.

Secondly, as it has been shown recently,[19] zig-zag defects of the chevron texture can cause resonances as well. Owing to these simultaneously acting mechanisms our cell is part of a mechanical system having several eigenfrequencies which may correspond to the complicated spectrum in Figure 3. Unfortunately our data are not enough to separate the various mechanisms.

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