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A TECHNIQUE FOR LOCAL MEASURING THE PYROELECTRIC COEFFICIENT

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Abstract The technique described in the paper is a version of the well known Chynoweth method for the dynamic measurements of the pyroelectric coefficient. It is based on the detection of the repolarization current caused by heat pulses applied to a sample.

1. OPTICAL EQUIPMENT

A single-mode He-Ne laser (wavelength λ = 632.8 nm, power P = 8 mW) was used as a source of heat pulses. Mechanical choppers, provided two modulation frequencies, 201 and 905 Hz. When investigating liquid crystals (LC) transparent in the visible spectral range, an anthraquinone dye dissolved in LC was used as an absorber of radiation. The absorption maximum of the dye is near 594 nm. The concentration of the dye was less than 3% wt to provide the optical density of the order of 1 for samples of any thickness. A laser operating in the continious regime in the visible range allows the local measuring the pyroelectric response to be carried out. An optical scheme of the set-up is shown in Fig.1. A laser (1) beam is focused by a microscope (5) onto a sample (13) placed in a thermostate (14). The thermostate is located on an object table (15) of the microscope equipped with two microscrews with digital recording of their displacement. The accuracy of the

X,Y-scales is 1 μm and the size of the focused laser spot at the sample is about 10 μm.

A glass cube (21) directs a part of the beam to a photo-detector (4) for light intensity control. The other photo-detector (18) is placed just under the thermostate to measure the transmitted light intensity. In both cases silicon sun battery elements with preamplifiers (3,19) were used.

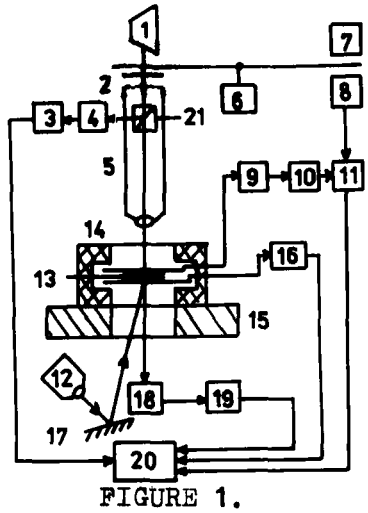

FIGURE 1.

A polarizing microscope focusing the laser radiation allows the visual observation of textures of liquid crystals in situ, and the control of the position of a laser spot in the texture. A shield (2) is used for safety reasons. The texture observations are performed in transmission regime. A lamp (12) and movable mirror (17) provide irradiation of a sample with white light.

A pre-amplifier (9), a selective amplifier (10) and phase-sensitive detector (11) were used for detecting the pyrovoltage. In the reference channel a light chopper (6), light emitting diode (7) and a photo-diode (8) were installed. All sighals including that from a temperature control circuit (16) were processed with a computer (20).

2. A CELL AND A THERMOSTATE

A liquid crystal cell is a flat capillary formed with two glass plates covered with SnO_2.

Wedge form cells were used when the thickness de-

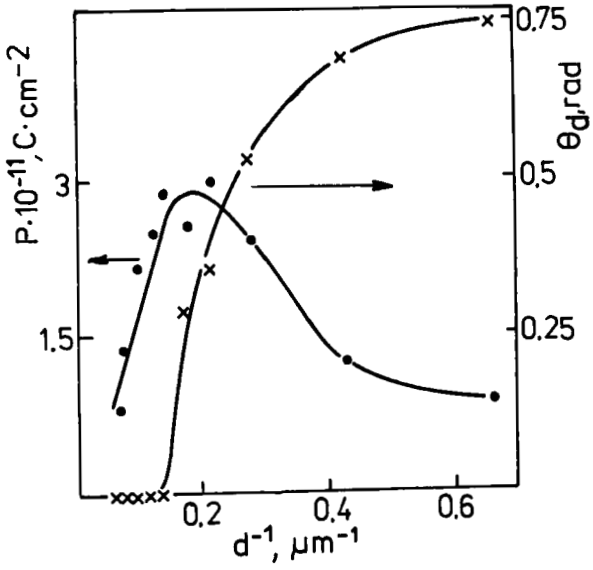

FIGURE 2.

pendence of the pyro-electric voltage was to be measured. The wedge angle was also measured interferometrically. As usual, the angle was 10^{-3} rad, 1% uniform throughout a sample. In order to reduce the electric capacity of a cell the top electrode was made in the form of strip 300-600 μm wide. The very edge of the wedge was not covered with coating to avoid shortages.

The homogeneous orientation of liquid crystals was achieved by rubbing a layer of polyvinylketal after its polymerization. The homeotropic orientation was provided by layers of chromium distearylchloride.

A thermostate included a copper block with a heater and tubular channels for cooling samples with nitrogen vapour from Dewar vessel. Two identical sample holders were used, one with a real sample and the other with a model sample for temperature control. The temperature gradient between the two holders did not exceed 0.1°C for the rate of the temperature change less than 0.5 grad/min. The accuracy of the absolute and relative temperature measurements was 0.1 and 0.05°C, respectively.

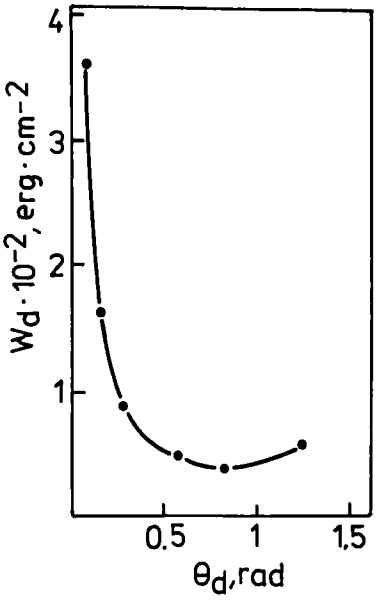

FIGURE 3.

3. THE MEASUREMENT OF A PYRO-RESPONSE

We need a relationship between the pyroelectric voltage induced across cell electrodes by a modulated light beam and the pyroelectric coefficient of matter. In our case light is absorbed in a thin layer of liquid crystal (less than 10 μm) due to the dye dissolved. The absorbed thermal energy goes out of a liquid crystal into adjacent thick glass plates. The thermal properties of liquid crystals and glasses are approximately the same. It may be proved by the calculation of the thermal diffusion coefficient $D_T = 2K/c\rho$ where ρ, K, c are density, thermal conductivity and heat capacity of substance ($D_T = 12.04 \cdot 10^{-4}$ and $17.9 \cdot 10^{-4}$ cm$^2 \cdot$s^{-1} for glass and benzene, respectively). We use sine-modulated irradiation, thus for the absorbed heat we have

$$Q(t) = Q\,(1 - \cos \omega t), \qquad (1)$$

where angular frequency is usually equal to $\omega = 1256$ s^{-1}. For this frequency a characteristic length of heat diffusion in glass is $L_T = \sqrt{D_T/\omega} \approx 12$ μm and it has to exceed a half of the thickness of the layer in the case of the non-uniform distribution of the pyro-electric coefficient across cell thickness. For thin absorbing layers we can use a solution of the set of equations

which describes a response of the pyro-electric layer being in contact with thick glass substrate[1]. The presence of the second substrate is accounted for by a factor 1/2 for the increase in temperature and, as a result, for the pyroelectric voltage:

$$U_{(T)} = \frac{Q_o \langle \gamma \rangle \sqrt{\omega / D_T} \cos \omega T}{\sqrt{2} \cdot c \cdot \rho \cdot C \sqrt{\omega^2 + (1/R_o C_o)^2}} . \qquad (2)$$

Here R_o and C_o are resistance and capacity of the input circuit of a pre-amplifier, the impedance of a cell being included. C is capacity of a cell kept in formula (2) in explicit way to account for the change in thickness of the wedge-form cells.

We neglect the in-plane heat diffusion. Special tests with a defocused laser beam have shown an independence of the signal of the geometry of a spot, thus one can use uni-dimensional model for calculation of the temperature increase.

In our case the temperature and thickness dependencies of pyro-voltage was measured which were normalized to the intensity of the absorbed light measured independently. The condition $\omega \gg 1/R_o C_o$ is fulfilled as R_o = 100 MΩ and C_o = 100 pF. As a result we have a very simple formula for the calculation of the thickness dependence of the pyroelectric coefficient

$$\langle \gamma \rangle (T,d) = 2C \sqrt{K C \rho \omega} \cdot \frac{U_m(T,d)}{Q(d)} . \qquad (3)$$

After integrating over temperature, according to[2] we have the macroscopic polarization

$$\langle P_f \rangle (T,d) = 2C \sqrt{K C \rho \omega} \cdot \frac{\int U_m(T,d) dT}{Q(d)} . \qquad (4)$$

The absolute calibration of the polarization may be carried out using samples of a well known ferroelectric liquid crystal.

All the signals from the set-up (pyro-response, intensities of coming and transmitted light, voltage from a thermocouple and x,y positions of the laser spot) were processed by a minicomputer "Iskra 226".

4. THE FLEXO-POLARIZATION OF A NEMATIC HYBRID CELL

The technique described was applied to the measurements of the flexoelectric polarization in a hybrid cell filled with nematic 4-pentyl-4'-cyanobiphenyl (5CB). From these data the angular dependence of the anchoring energy was determined for the nematic director at the homeotropic boundary of the cell. For this purpose the temperature dependencies of the pyrocoefficient were measured in the wedge-form cell. Fig.2 shows the flexo-polarization at 27°C as a function of cell thickness (d) calculated from temperature behaviour of the pyro-signal. As it was expected[2] in thick layers ($d > 6\mu m$) the polarization is proportional to d^{-1} and the deviation of the curve $P_s(d^{-1})$ for thin cells is accounted for by the change of the anchoring angle for the director at the homeotropic boundary. The anchoring angle for the director at the homegeneous interface is assumed to be fixed for higher anchoring energy ($W_{hg} \approx 1$ erg cm^{-2} [3]). Using formula[4]

$$P \propto \frac{\cos 2\theta}{d} \qquad (5)$$

and results of the paper[5] one can calculate the change in the director angle, Fig.2, and the angular dependence of the anchoring energy for the homeotropic interface (W_{ht}), Fig.3.

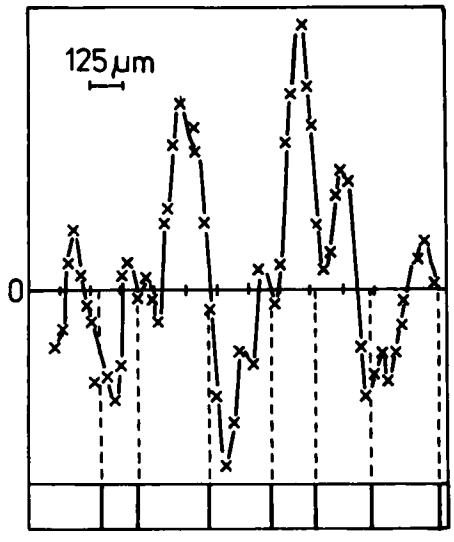

FIGURE 4.

5. SPATIAL DISTRIBUTION OF THE PYROELECTRIC RESPONSE OVER A DOMAIN STRUCTURE OF A SMECTIC C*

We have measured the local pyro-response of a domain texture of a ferroelectric smectic C* liquid crystal (a mixture of pyrimidines with a chiral additive). The amount of the additive was small enough to have a large pitch of the helix (of the order of 100 μm). The same anthraquinone dye (0.5%) was dissolved in the mixture. The substance had the following sequence of phase transitions

$$\text{Cryst} \xleftrightarrow{12^\circ C} C^* \xleftrightarrow{58^\circ C} A \xleftrightarrow{66^\circ C} I.$$

The pyro-response was measured for a sample of 100 μm thickness as a function of a laser spot position. The experimental results are shown in Fig.4. In the same figure a sketch of the zero-field domain strips is shown which corresponds to the sample area studied. When applying the external d.c. field to the sample all the picture is shifted up or down as a function of the field polarity. The amplitude of the spatial dependence of the pyro-response slightly decreases with a field, however the position of the peaks as well as domain strips on a photograph is independent of voltage. The observed pattern disappear simultaneously with domain

strips at the threshold voltage about 50 V.

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