Explanation of the Anomalous Photoinduced Current Transients in Nematic Liquid Crystals

In a recent Letter, Sugimura, Sonomura, Naito, and Okuda[1] (SNNO) reported their experimental observations of anomalous photoinduced current transients in nematic liquid crystals (NLC). They found two peak currents with opposite signs. As a function of time, the first peak is a Dirac-function-like pulse and the second one is an exponentially decreasing function (Fig. 1 of Ref. 1). The magnitudes of both current peaks increase linearly with the intensity of the illuminated light. The critical behavior of the first peak in the vicinity of the nematic-isotropic phase-transition temperature T_c corresponds to that of the specific heat associated with an orientation order parameter (Fig. 4 of Ref. 1). One important result of SSNO's observations is that the direction of the anomalous current depends upon the sign of the dielectric anisotropy $\Delta\epsilon$ of the NLC under investigation. SSNO propose that the pyroelectric effect in NLC is responsible for the photoinduced anomalous current transients. However, we feel that their observations may be interpreted as the photovoltaic effect arising from the nonlinear polarization of the NLC under incident light.

In a previous article[2] we have already shown that with normally incident light on a homogeneously aligned NLC cell, there will be no second-harmonic generation but a dc emf U will be generated which is proportional to the intensity I_0 of the incident beam. With Eqs. (3.10), (4.16), (6.11), and (6.12) of Ref. 2 one can show that

$$U \propto S_2 I_0 , \tag{1}$$

where S_2 is the orientation order parameter, and that

$$U \propto \Delta\epsilon I_0 . \tag{2}$$

If we assume that the photoinduced current I_p observed by SSNO is the result of the photovoltaic emf U given by Eqs. (1) and (2), then the above-mentioned characteristics of the anomalous current transients are well explained.

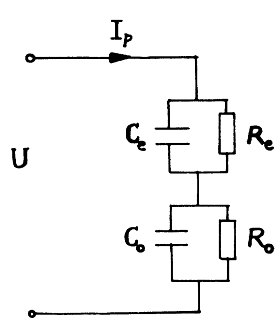

FIG. 1. Equivalent circuit of a NLC cell allowing for an electrical double layer.

In their measurement, SSNO apply a dc voltage across the NLC cell. In that case, experiments[3] demonstrate that field-induced ion drift to the electrodes takes place. The maximum field strength occurs near the electrodes where electrical double layers are formed. The equivalent circuit of the NLC is shown in Fig. 1, where R_e and C_e are the resistance and the capacitance of the double layer near the electrodes, respectively, and R_0 and C_0 are that of the bulk of the NLC.[4] R_e is small in comparison with R_0 and C_e is large in comparison with C_0. In the calculation, we may simplify the incident light pulse by a Dirac function $I_0\delta(t/\tau_0)$ (where τ_0 is the duration of the pulse) and at the same time we may neglect C_0. With Eq. (1), the photoinduced current transient I_p in the equivalent circuit is then given by

$$I_p = \frac{U}{R_0}\left[\delta\left(\frac{t}{\tau_0}\right) - \frac{\tau_0}{R_0 C_e}\exp\left(-\frac{t}{\tau}\right)\right], \tag{3}$$

where $\tau = R_0 R_e C_e/(R_0 + R_e)$ and U is the magnitude of the photovoltaic emf. Clearly, Eq. (3) explains the two peak currents observed by SSNO both in sign and in shape.

In short, we have shown that the anomalous photoinduced current transients in NLC are caused by the photovoltaic effect of the nonlinear polarization together with the dc field-induced ion drift to electrodes, i.e., the electric-double-layer effect. Certainly more detailed study on this subject still remains to be done, e.g., the dependence of R_e and R_0 on the applied dc field.

Ou-Yang Zhong-can and Sen Liu
Chinese Center for Advanced Science and Technology
World Laboratory
P.O. Box 8730
Beijing 100080, China
and
Institute for Theoretical Physics
Academia Sinica
P.O. Box. 2735
Beijing 100080, China

Xie Yu-zhang[a]
Physics Department
Tsinghua University
Beijing 100084, China

Received 25 October 1989
PACS numbers: 61.30.−v, 72.40.+w

[a]Formerly Yü-chang Hsieh.

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