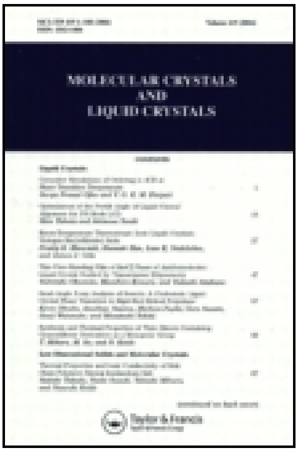

Molecular Crystals and Liquid Crystals Science and Technology. Section A. Molecular Crystals and Liquid Crystals

Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gmcl19

Photocurrent in a Nematic Liquid Crystal

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Version of record first published: 23 Sep 2006.

To cite this article: Nobuhiro Jinno, Akihiko Sugimura, Shuichi Murakami, Hiroyoshi Naito, Masahiro Imai & Ou-Yang Zhong-can (1995): Photocurrent in a Nematic Liquid Crystal, Molecular Crystals and Liquid Crystals Science and Technology. Section A. Molecular Crystals and Liquid Crystals, 263:1, 491-498

To link to this article: http://dx.doi.org/10.1080/10587259508033608

Mol. Cryst. Liq. Cryst. 1995, Vol. 263, pp. 491–498
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PHOTOCURRENT IN A NEMATIC LIQUID CRYSTAL

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Abstract The photocurrent transients induced by illuminating a nematic liquid crystal sample with a light pulse under dc voltage application are investigated. Three types of current peaks are normally observed in the photoinduced current transient. The anomalous photoinduced current transient, which does not originate from the transport of electronic carriers in the bulk, occurs in a time range of microseconds or less only in the nematic phase. In the similar time range, other two types of current peaks appear both in the nematic and isotropic phases. The occurrence of these current peaks, which is likely to be due to the generation and recombination process of electron-hole pairs, and the ionic carrier transport in the bulk induced by the light excitation, are studied experimentally and discussed briefly.

INTRODUCTION

Photoinduced effects in nematic liquid crystals (NLC) are important in the fields of both basic material science and device application. There are some reports of such photoinduced effects.[1–4] Recently the anomalous photoinduced current transient (APCT) in the nematic phase has been experimentally observed by illuminating with a xenon flash lamp and applying a dc voltage,[1] and its mechanism has been elucidated theoretically on the basis of the nonlinear optical Pockel's effect induced by Freedericksz transition.[2] However, the photoconductivity of NLC has not fully been examined yet. In this paper, we report the experimental results of the transient currents in an NLC cell by a light pulse excitation.

EXPERIMENT

The material used was pentyl cyanobiphenyl (5CB). The nematic liquid crystal material was introduced between two pieces of glass with transparent In_2O_3 electrode on the surface. Both surfaces having polyimide thin layers (100nm thickness) were rubbed to obtain the homogeneous alignment. The area of the cell was typically 2 cm^2. The thickness of the cell was d=6.8 μm. The nematic-isotropic phase transition temperature T_c of 5CB is 308 K. The cell was illuminated by a xenon flash lamp (energy 15 μJ, duration 10 μs) and a depolarized nitrogen pulsed laser (energy 4 mJ, duration 6 ns), which is collimated with the area of 2 cm^2. Stabilized dc voltage was applied to the cell. Provisions were made for maintaining the cell at constant temperatures in the nematic and isotropic ranges. Transient current was observed through a series load resistor and by means of a digital storage oscilloscope. The electric signals measured was downloaded to a microcomputer for storage and analysis.

RESULTS AND DISCUSSION

Transient Photocurrent in a Millisecond Time Range

Figure 1 shows the photoinduced transient current shapes occurring in a millisecond time range for the various dc voltages from −30 V to −5 V at 318 K. The photoinduced currents, whose polarity is the same as that of the conduction current in the NLC cell, have peaks in about 1 ms, dependent of the applied voltage. These current peaks are due to the drift of the impurity ions in the NLC bulk. Applied voltage dependence of reciprocal peak time $1/t_p$ at 318 K is shown in Figure 2. From Figure 2 the drift mobility of ionic carriers at 318 K is estimated to be μ=1.4$\times$ 10^{-5} cm^2/Vs from $1/t_p \simeq \mu V/d^2$.

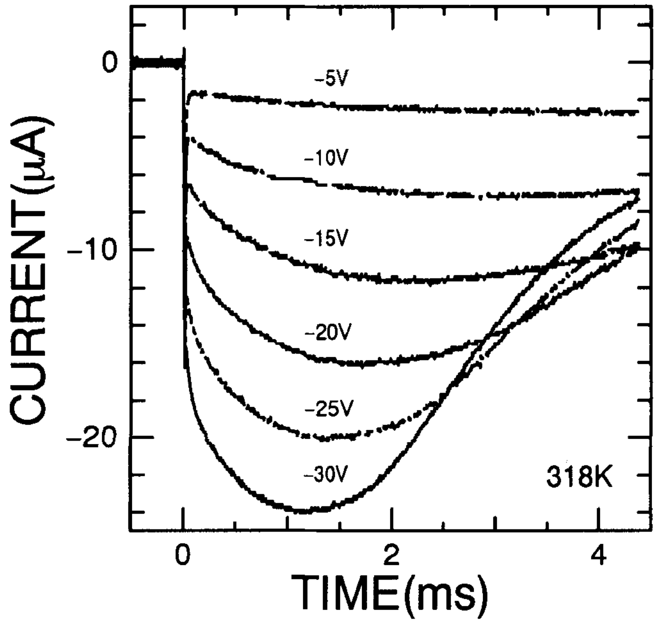

FIGURE 1 Photoinduced transient current shapes for the various dc voltages from −30 V to −5 V at 318 K.

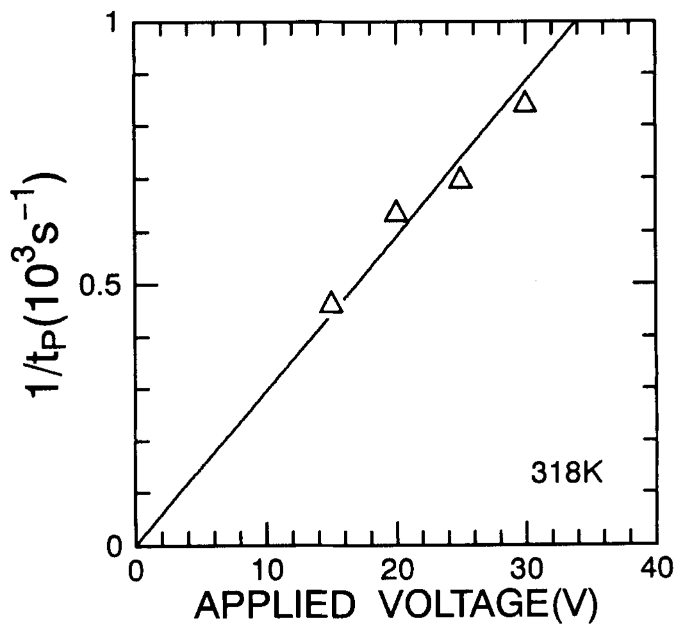

FIGURE 2 Applied voltage dependence of reciprocal peak time $1/t_p$ at 318 K (isotropic phase).

Transient Photocurrent in a Microsecond Time Range

In a time range of microseconds, photoinduced transient current with peaks is observed by illuminating the NLC sample with a xenon flash lamp. Figure 3 shows the photoinduced current shapes for various applied voltages from −30 V to −1.5 V at 298 K (nematic phase). The photoinduced current shapes at 318 K (isotropic phase) are also shown in Figure 4 for various applied voltages from −30 V to −1.5 V. In the nematic phase as shown in Figure 3, photoinduced currents have two kinds of current peaks in a time range of about 10 μs. One (PEAK1) is the current peak flowing in the opposite direction of the conduction current above the threshold voltage for the Fréedericksz transition. The other current peak (PEAK2) has the same polarity as that of the conduction current, and is observed under the condition of applied voltages below the threshold voltage and in the isotropic phase as shown in Figure 4. It is evident from Figures 3 and 4 that the occurrence time of PEAK1 is independent of the applied dc voltages and PEAK1 is not observed in the isotropic phase. The reason for this is that the APCT does not originate in the carrier drift. In the isotropic phase in which the dielectric anisotropy of an NLC disappears, the APCT does not appear.[2] From these experimental results the occurrence of PEAK1 does originate from the APCT due to the nonlinear optical Pockel's effect induced by the Fréedericksz transition.[2] On the other hand, since the PEAK2 is observed both in the nematic and isotropic phase, the occurrence of PEAK2 is not due to the electro-optical effects of the NLC, but likely originates from the generation and recombination process of the photoinduced electron-hole pairs in the NLC bulk with high resistivity more than 10^{10} Ωcm. Figure 5 shows applied voltage dependences of the peak current for various temperatures. As reported in the literature,[1] the APCT increases with increasing temperature up to the phase transition temperature from the nematic to isotropic phase, and with increasing applied voltage in the nematic phase. As shown in Figure 5, the PEAK1 shows the same temperature and applied voltage dependences as those of the APCT. The peak current of the PEAK2 increases with increasing applied voltage and temperature both in the nematic and isotropic phase. Since the generation efficiency and the drift velocity of photoinduced carriers are enhanced by the applied voltage and temperature, the PEAK2 is most likely caused by the generation and recombination of the photoinduced electron-hole pairs. Although it is possible that local heating of the NLC layer by the light absorption in the In_2O_3 layer, we do not discuss here the effect of this heating on the transient current.

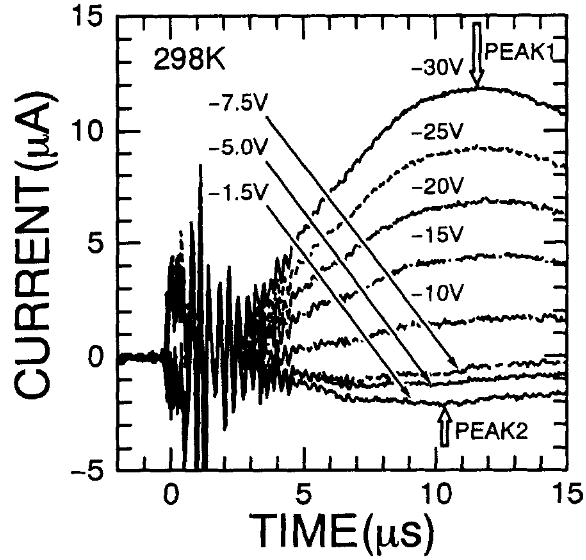

FIGURE 3 Photoinduced current shapes for various applied voltages from −30 V to −1.5 V at 298 K (nematic phase).

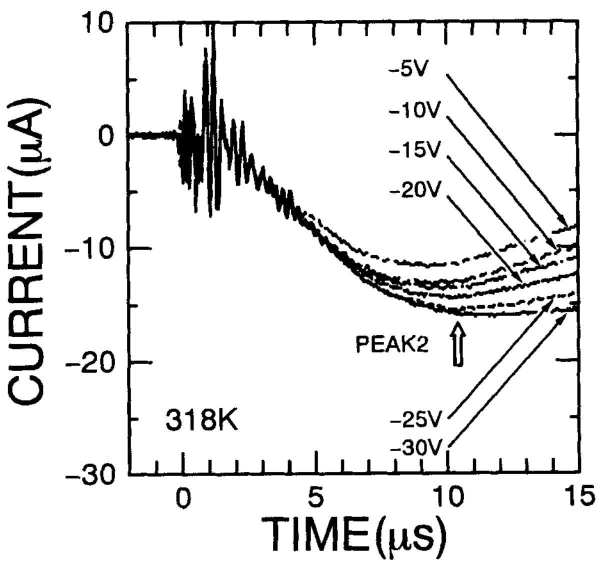

FIGURE 4 Photoinduced current shapes for various applied voltages from −30 V to −1.5 V at 318 K (isotropic phase).

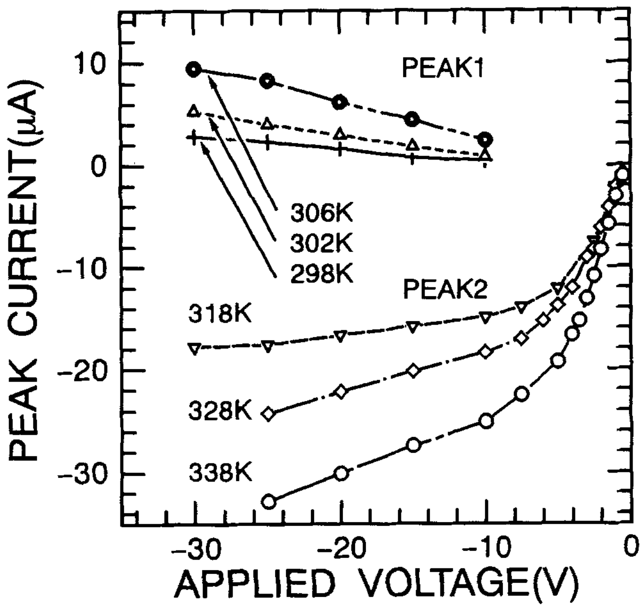

FIGURE 5 Applied voltage dependences of the peak current for various temperatures.

We examine the influence of optical pulse widths on the transient current. By illuminating the sample with a xenon flash lamp with a pulse width of 10 μs for various applied voltages at 298 K, the peak current of the APCT occurs at 11.6 μs after the light illumination. On the other hand, by illuminating the same sample with a N_2 laser with a pulse width of 6 ns for the voltage application of -30 V at 298 K, the transient current peak of the APCT is observed at 250 ns. This transient current shape of the APCT is shown in Figure 6. For this condition, the dark current is several $\mu A/cm^2$, fairly small relative to the photoinduced current. The relationship between the peak time of the APCT and the pulse width is summarized in Table I. It is obvious from Table I that the occurrence of the transient current peak strongly depends on the pulsed width of the light illumination. Although the present experimental results do not give the apparent evidence, the occurrence of the PEAK2 may also be affected by the pulse width of the light illumination. In other words, the measurement of the transient photocurrent of an NLC may give us the detailed information on the generation and recombination process of the photocarriers in the bulk.

TABLE I The relationship between the peak time of the APCT and the pulse width.

light source	pulse width	peak time (298 K)
Xe	10 μs	11.6 μs
N_2	6 ns	250 ns

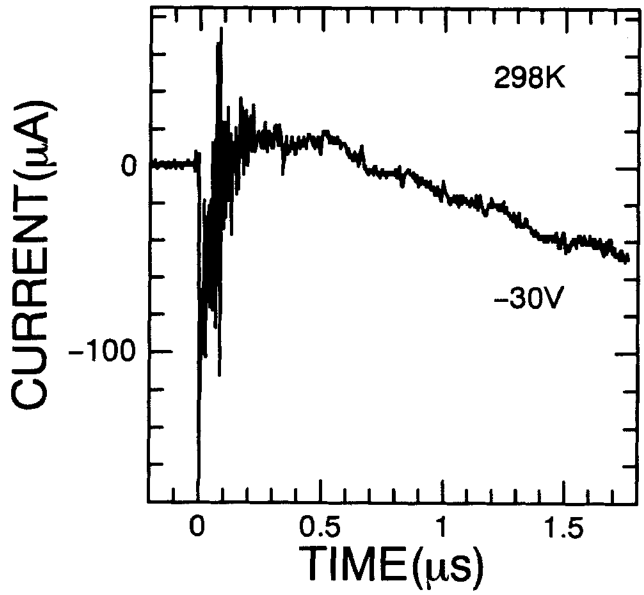

FIGURE 6 Transient current shape by illuminating the sample with a N_2 laser with a pulse width of 6 ns for the voltage application of -30 V at 298 K.

CONCLUSIONS

We studied three types of current peaks which are normally observed in the current transients induced by illuminating a nematic liquid crystal sample with a light pulse under dc voltage application. It is found that in a time range of milliseconds, the current peak is due to the drift of the ionic carriers both in the nematic and isotropic phase, whose drift mobility is estimated to be 1.4×10^{-5}cm^2/Vs at 318 K. The current peak due to the APCT, which does not originate from the transport of electronic carriers in the bulk, occurs in a time range of microseconds or less, dependent on the pulse width of the light illumination only in the nematic phase. In the similar time range, another type of current peak appears both in the nematic and isotropic phases. The occurrence of this current peak is likely to be due to the generation and recombination process of electron-hole pairs. To elucidate this process, progressive experimental and theoretical study is necessary.

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