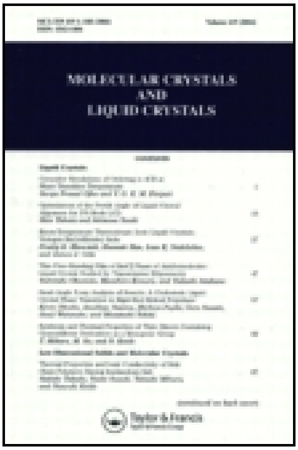

Molecular Crystals and Liquid Crystals Science and Technology. Section A. Molecular Crystals and Liquid Crystals

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

# POLARIZATION MEASUREMENT IN NEMATIC LIQUID CRYSTAL BASED ON THE PYROELECTRIC RESPONSE TO LASER IRRADIATION

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Version of record first published: 24 Sep 2006

*Mol. Cryst. and Liq. Cryst.*, 2001, Vol. 366, pp. 283-293
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# Polarization Measurement in Nematic Liquid Crystal Based on the Pyroelectric Response to Laser Irradiation

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The polarization measurement of a nematic liquid crystal has been performed by a pyroelectric technique using short pulse of a Nd:YAG laser to create temperature increment. The temperature increment has been evaluated independently by monitoring temperature dependent birefringence for a He-Ne laser beam. The sign and absolute magnitude of surface polarization have been evaluated for both the planar and homeotropic orientation of the nematic liquid crystal at a solid substrate. The flexoelectric polarization in a hybrid cells has also been measured using the same pyroelectric technique. The value of the sum of the flexoelectric coefficients ($e_1$+$e_3$) for 5CB is negative and about −13pC/m at room temperature.

*Keywords:* surface polarization; flexoelectric polarization; 5CB; pyroelectric polarization

## INTRODUCTION

The nematic liquid crystal has no macroscopic polarization because of the absence of a polar axis. However, the symmetry breaking at the interface such as with solid substrate can cause the surface polarization [1-3]. On the other hand, macroscopic polarization may also be induced even in the bulk of the nematic liquid crystal by a splay or bend distortions, which is so called a flexoelectric polarization. In a hybrid aligned cell, flexoelectric polarization is conspicuous which is planar at one and homeotropic at opposite interface. In the hybrid cell, polarization contains three contributions, one from the bulk and the others from the planar and hometropic interfaces, respectively.

Althogh a lot of studies on the surface and flexoelectric polarizations have been carried out for many years, the quantitative data are very scarce and depend on methods of measurement [4,5]. The signs of polarization also have never been measured. It is difficult to separate the contributions to the macroscopic polarization from the surfaces and the bulk.

The pyroelectric technique has been used for investigation of crystalline ferroelectrics [6]. The advantage of the pyroelectric technique is a possibility to determine the sign and absolute value of the macroscopic polarization without application of an external field. Therefore, the response has no influence caused by the screening of the external field. Especially, the pyroelectric technique using short pulse irradiation has a high sensitivity for investigation of a spatial distribution of the polarization along the polar axis. It makes possible to separate the contributions to the macroscopic polarization from the surfaces and the bulk. It is also useful technique for investigation of the surface polarization in the nematic liquid crystal.

In this study, we evaluate the sign, the absolute magnitude and the temperature dependence of the surface and flexoelectric polarizations in a nematic liquid crystal 5CB (4-pentyl-4'-cyanobiphenyl) using pyroelectric technique with a short pulse laser. The sign, absolute values and temperature dependence of the surface and flexoelectric polarization was manifested for both planar and homeotropic orientations. The flexoelectric polarization was investigated using hybrid alignd cell.

## EXPELIMENT

In ferroelectrics, pyroelectric coefficient is defined as $\gamma_0=dP_S/dT$ where $P_S$ is spontaneous polarization $T$ is temperature. In a more general case, instead of the spontaneous polarization, we may consider any macroscopic polarization $P^*$ and introduce a macroscopic pyroelectric coefficient

$$\gamma=dP^*/dT.$$

Integrating the pyroelectric coefficient starting from a certain temperature $T_i$ further above the N-I transition, we can calculate the temperature dependence of $P^*$ in the nematic phase and know contribution only from nematic ordering.

$$P^*(T)=\int_{T_i}^{T}\gamma(T)dT$$

In order to measure $\gamma(T)$ we have to change temperature of a nematic layer by a small amount $\Delta T$ in the area $A$, and record a pyroelectric response $V_p$ across the load resistor $R_L$ shunted by capacitance $C$. Illuminating by a short laser pulse, the pyroelectric response reach $A\gamma\Delta T/C$ and decay with a $R_LC$ time constant.

$$V_p=\frac{A\gamma\Delta T}{C}\exp\left(-\frac{t}{R_LC}\right)$$

In the experiments we used sandwich cells consisting of two parallel glass plates covered with ITO conductive layers and separated from each other by teflon spacers. The front and rear ITO electrodes are different in its absorption at infrared light. For the measurements of $\gamma(T)$ in the surface layer (front interface), a strong gradient of temperature increment $\Delta T(z)$ along the cell normal has to be provided in order to isolate the contribution from the opposite side (rear interface).

Those temperature increment has accomplished differently for pure 5CB and 5CB doped with 1wt% dye, respectively.

In the first case, we used two kinds of ITO electrodes which have considerably different absorption for the laser beam of wavelength $\lambda$=1064nm. In the second case, we illuminated by the laser beam of wavelength $\lambda$=532nm and the absorption of light by the dye induced gradient of temperature toward the bulk of cells.

We prepared a pair of planar, homeotropic and hybrid cells with thickness 53µm infiltrated pure and dye doped 5CB. For the planar orientation polyimide layer was spun on two glass substrates and rubbed unidirectionally, while for the homeotropic orientation ITO surfaces were cleaned carefully. In the hybrid cell, both planar and homeoropic orientations were combined. For simplicity, we call these cells PP(planar), HH(homeotropic) and HP(hybrid) cells, and add capital D for 5CB doped with dye.

The absorption of the front and rear ITO electrodes for the light of wavelength at $\lambda$=1064nm were 24% and 9% and less than 1% for $\lambda$=532nm in all cells. The method of the measurement of surface and flexoelectric polarization is as follows.

In the case of surface polarization, it is difficult to measure temperature increment at surface layer due to light absorption of ITO electrodes, so that we adopted following method. At first, we illuminated HHD and PPD cells by the light at $\lambda$=532nm. From these results we could calculate temperature increment $\Delta T_0$ at surface layer and then $\gamma(T)$. Next we illuminated the same cells by the light at $\lambda$=1064nm and compared with former results. Since there is no absorption in the bulk for infrared region, we can find temperature increment at surface layer for $\lambda$=1064nm in this way. At last, illuminating HH and PP cells at $\lambda$=1064nm, we could find surface polarization at pure 5CB and solid substrate interface.

In the case of flexoelectric polarization, HPD cell was used but it has two contributions which come from surface and flexoelectric polarizations as mentioned above. For the purpose of distinguishing the flesxoelectric contribution from surface polarization, PPD cell was also used. We illuminated the side of planar interface by the laser light at $\lambda$=532nm because the contribution of the planar interface was weaker than that of the homeotropic interface. After subtracting the contribution of the planar-solid substrate interface (the response of

PPD) from the whole pyroelectric response, we can evaluate the contribution from the bulk, that is, flexoelectric polarization.

For the surface and flexoelectric polarization measurements, we have to find the absolute magnitude of $\Delta T_0$ at the front interface and average value of $<\Delta T>$ over the cell thickness *d*. This has been done as follows. At first, $<\Delta T>$ has been measured by monitoring laser induced birefringence at wavelength $\lambda$=632.8nm of the same cell and in the same geometry as used for pyroelectric measurements. Figure.1 shows the geometry of this "optical thermometer" technique. Next, in case of bulk absorption, we calculate $\Delta T_0$ from the $<\Delta T>$ value measured and known profile of the absorption $\Delta T(z)=\Delta T_0 \exp(-Dz/d)$, where $D$ is optical density of a cell.

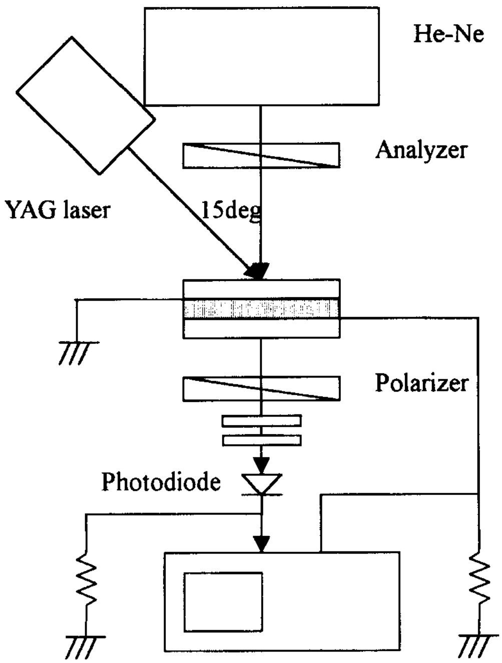


FIGURE.1 The geometry of "optical thermometer"

We used He-Ne laser polarized at 45° to the horizontal plane, an analyzer crossed with the laser beam (-45°) and a photodiode providing time resolution of 1μs. Transmitted light intensity detected by a photodiode oscillates with temperature.

$$I_{dc} = I_0 \sin^2(\Delta\Phi/2)$$
$$\Delta\Phi = (2\pi d/\lambda) < n >$$

The intensity is measured as a d.c. component of the photodiode current. Temperature increment by a pulse of YAG laser is detected as this oscillating curve and a pulse current equal to differential $\Delta I=(dI_{dc}/dT)<\Delta T>$ is measured as an a.c. component of the same photodiode. Therefore comparing d.c. component with a.c. component, we found temperature increment $\Delta T$.

## RESULTS AND DISCUSSION

Figure.2 shows the temperature dependence of the pyroelectric response of HHD and PPD cells. In the isotropic phase, the response is already seen but we are interested in the response from nematic ordering, so we subtract this contribution. From these results it should be noted that the sign of the polarization *Ps* is different for the planar and homeotropic alignments.

In order to consider the absolute sign of *Ps*, let me explain the relationship between signs of *Ps* and pyroelectric response using the scheme shown in Fig.3. In Fig.3, the sign of Ps is defined as positive when it points from a substrate to a liquid crystal along *z* axis. Assuming that at the ground electrode, for example, *Ps* points to the left ($Ps$<0) as shown in the figure, negative image charge should be collected at the grounded electrode (A). On illuminating the grounded electrode (A) by laser light to heat up, the absolute value of Ps decreases as the polar order decreases, and the negative image charge on the grounded electrode is released. As a result, the current flows from the ground through the liquid crystal to a register $R_L$, and the positive voltage appears across $R_L$.

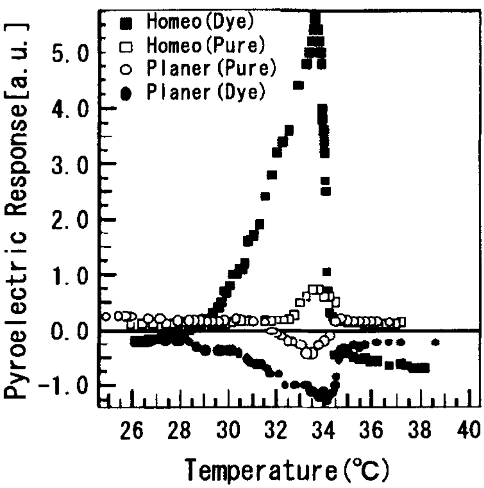


FIGURE.2 Pyroelectric response for homeotropic and planar cells.

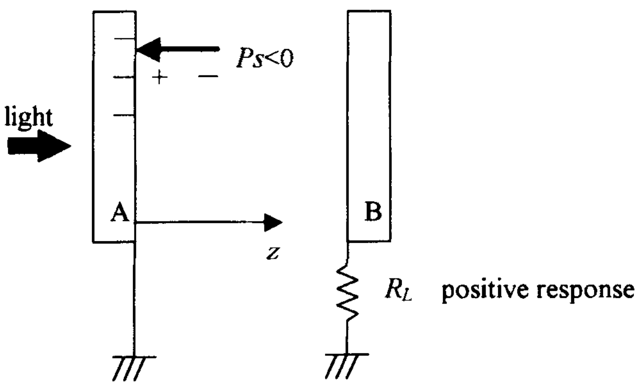


FIGURE.3 Schematic explanation of the relationship between signs of Ps and pyroelectric response.

Consequently, the positive pyroelectric response corresponds to the negative Ps which points from the liquid crystal to the substrate. According to the results shown in Fig.2, surface polarization directs from liquid crystal to solid substrate in case of homeotropic, and opposite in planar case.

The absolute values of surface polarizations for both orientations are shown in Fig.4(a),(b).

The effect of the cell thickness on the pyroelectric response in a dye-dope planar cell has been investigated. The same measurement was carried out at wavelength $\lambda$=532nm of PPD cell with varying its thickness. The condition of the cell was almost same except for polyimide layer for planar alignment. These results are shown in Fig.5. Comparing 50μm-thick cell having a different polyimide with above result, pyroelectric response of planar orientation seems to have no serious relation with the type of polyimide. In additon, the response in 70μm and 100μm cells were not so much different from that in 50μm cell. It confirms that the cell thickness 50μm were large enough to provide a complete absorption of light at $\lambda$=532nm.

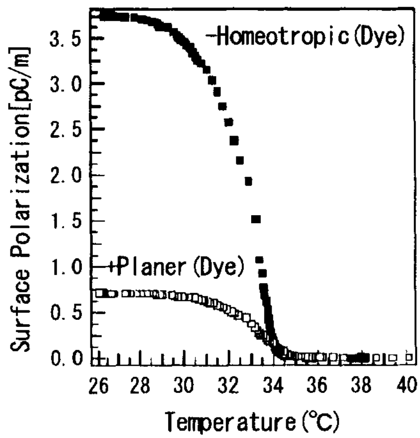


FIGURE.4 (a) Temperature dependence of surface polarization in both HHD and PPD cells.

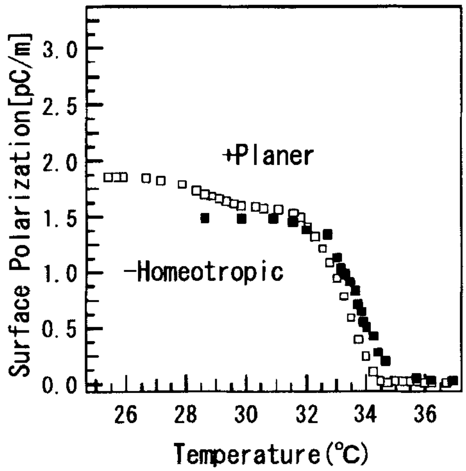


FIGURE.4 (b) Temperature dependence of surface polarization for pure 5CB solid substrate interface.

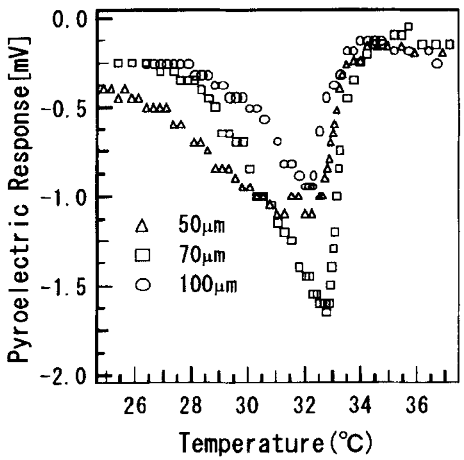


FIGURE.5 Pyroelectric response for planar cell of various cell thickness.

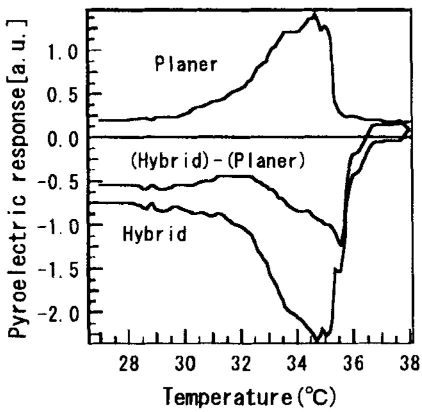


FIGURE.6 Pyroelectric responses from hybrid aligned cell (HPD).

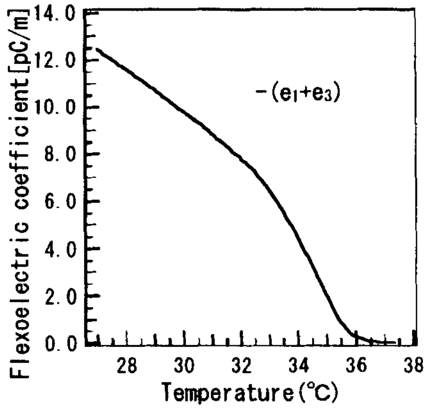


FIGURE.7 Temperature dependence of flexoelectric coefficient

In order to evaluate the flexoelectric polarization, HPD cell was illuminated by laser light from the planar side of the cell. The pyroelectric response of HPD cell is shown in Fig.6. As mentioned above the response from the hybrid cell has two contributions. One is from the bulk, that is flexoelectric polarization, and the other is from interface. Therefore to know flexoelectric polarization we have to subtract the contribution of interface from the total response. The result of calculated flexoelectric coefficient is shown in Fig.7. The direction of flexoelectric polarization is from homeotropic to planar interfaces.

## CONCLUSION

In conclusion, we developed a novel technique for measurements of the absolute sign and magnitude of the surface polarization. This technique combined measurements of the laser induced pyroelectric response with monitoring temperature increment. The directions of surface polarizations were different for the planar and homeotropic alignments, from liquid crystal to solid substrate in homeotropic surface. Flexoelectric polarization pointed from homeotropic to planar interfaces.

## *References*

[1] R.B. Meyer and P.S. Pershan, *Sol. State. Comms.* **13**, 989 (1973).
[2] A. Derzhanski, A. Petrov and M. Mitov, *J. Phys. (Paris)* **39**, 273 (1978).
[3] J.D. Parson, *Phys. Rev. Lett.* **41**, 877 (1978).
[4] O.D. Lavrentovich, V.G. Nazarenko, V.V. Sergan and G. Durand, *Phys. Rev. A* **45**, 6969 (1992).
[5] A.G. Petrov and A. Derzhanski, *Mol. Cryst. Liq. Cryst. Lett.* **41**, 41 (1977).
[6] L.M. Blinov, and V.G. Chigrinov, *Electrooptic Effects* in *Liquid Crystal Materials* (Springer Verlag, New York, 1993).