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Transient photoconductivity, dielectric anisotropy and elastic constants properties of 4-n-hexyl-4'-cyanobiphenyl (6CB) nematic liquid crystal

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The elastic constants, dielectric anisotropy and transient photoconductivity properties of 4-n-hexyl-4'-cyanobiphenyl (6CB) nematic liquid crystal have been investigated. The structure of the LC changes from positive to negative dielectric anisotropy at a critical frequency value, f_c. The f_c values at dark and laser illumination were found to be 630.50 kHz and 653.94 kHz, respectively. The laser illumination increases critical frequency value of the LC. The splay K_{11} and bend K_{33} values at dark and laser illumination were determined and these values decrease with frequency and laser illumination. The dielectrical relaxation of the LC indicates a non-Debye type relaxation behavior. The application of the laser significantly alters the shape of the transient photoconductivity. The mobility values at dark and laser illumination were found to be 0.196×10^{-6} cm^2/V.s and 0.134×10^{-6} cm^2/V.s, respectively. The mobility of the charge carriers decreases with laser illumination. The transient photoconductivity of the LC increases with laser illumination.

Keywords: Liquid crystals, dielectric anisotropy, elastic constants

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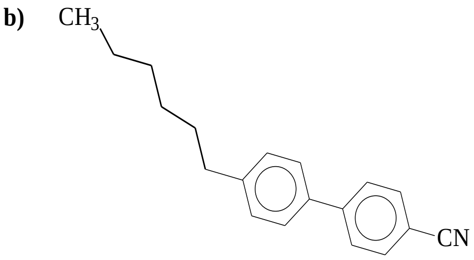
1. Introduction

4-n-hexyl-4'-cyanobiphenyl (6CB) is one of the best known liquid crystalline substances. 6CB, as well as other members of the nCB homologous series, is important from the point of view of applications due to the possession of a strong dipole moment, good chemical stability and a convenient temperature range of the nematic phase [1]. Dielectric relaxation spectroscopy has proven to be powerful technique to obtain the valuable information about the molecular properties of nematic liquid crystals. The relationship between static dielectric permittivity and molecular properties of liquid crystals has long been an objective of dielectric studies [2-4]. The anisotropic dielectric properties of liquid crystals play an important role in determining the electro-optical response of liquid crystal devices. Dielectric anisotropy ($\Delta\varepsilon$) and elastic constants (splay (K_{11}), twist (K_{22}) and bend (K_{33})) are important for physical properties of liquid crystals. Elastic constants correspond to the three basic distortions of nematic liquid crystals. Determination of these parameters is important as these constants control switching characteristics. Many experimental results on dielectric properties of 6CB are available in the literature [1,5-6]. However, no detailed investigation of laser illumination on dielectric anisotropy and elastic constants has been reported. It is well-known that elastic constants can be obtained from three experiments which are planar (K_{11}), twisted planar (K_{22}) and homeotropic cell (K_{33}). But, K_{11} and K_{22} values can be simultaneously obtained from capacitance-voltage method [7-11]. In this paper, we investigated the dielectrical anisotropy, elastic constants and transient photoconductivity properties of 6CB liquid crystal.

2. Experimental

Before the construction of the cell, Indium tin oxide (ITO) covered glass substrates were spin coated with polyvinyl alcohol (PVA) at 2000 rpm and they were cured at 50 ^{o}C for 2 hours. The thickness of the coating is 100 nm and these coating layers were exposed to surface treatment of unidirectional rubbing with velvet in order to obtain preliminary molecular orientation. The ultimate form of the constructed cell is planar with 2 degree rubbing tilt. Measurement cell was made up of two glass slides separated by Mylar sheets having 14.1 μm thickness assembled for parallel alignment. This cell was filled in capillary action with the 4-n-hexyl-4'-cyanobiphenyl (6CB) [12]. The chemical structure of the 6CB is shown in Fig. 1. The final cell gap is 14.2 μm. Experimental set-up is shown in Fig. 2. The capacitance-voltage measurements were performed by HIOKI 3532-50 LCR meter and KEITHLEY 2400 sourcemeter at room temperature.



6CB

Fig. 1 The chemical structure of the 6CB LC

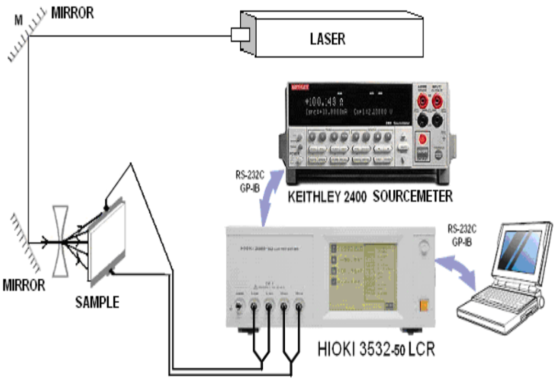


Fig. 2 Experimental setup for measurements

3. Results and discussion

3.1. Determination of dielectric anisotropy and elastic constant values of 6CB liquid crystal

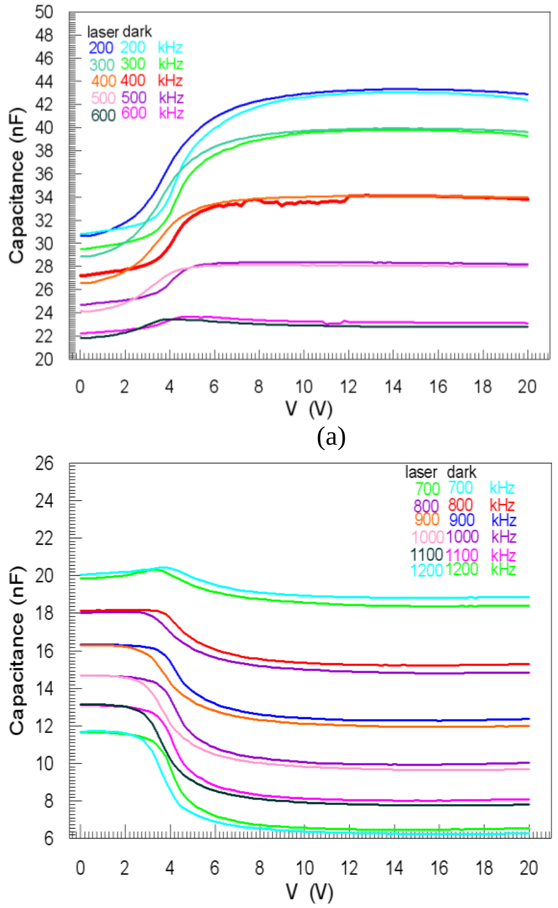
Fig. 3a shows the plots of the capacitance-voltage (C-V) for Δε>0 at dark and laser illumination. The capacitance values increases from the initial value $C_{\perp}$ to the final value $C_{\|}$. At lower voltages, the capacitance does not almost change with voltage and it increases with increasing voltage and reaches a saturation. As seen in Fig.3a, the C-V plots show a threshold voltage. This voltage shifts to lower voltages by laser illumination. This suggests that laser illumination facilities the molecular reorientation. Threshold voltage is described as [8],

$$V_{th} = \pi \left(\frac{K_{11}}{\varepsilon_o \Delta\varepsilon} \right)^{1/2} \qquad (1)$$

where ε_o is the dielectric constant of the vacuum, K_{11} is the splay constant and Δε is the dielectric anisotropy given by

$$\Delta\varepsilon = \varepsilon_{\|} - \varepsilon_{\perp} \qquad (2)$$

where $\varepsilon_{\|}$ is the dielectric constant in the direction parallel to the director and $\varepsilon_{\perp}$ is the dielectric constant in perpendicular to the director. Materials with Δε>0 are called p-type, in which their molecules align with the director parallel to the electric field, whereas in n-type materials with Δε<0, they align perpendicular to the electric field [13]. Fig. 3b shows C-V plots of the LC for Δε<0 at dark and laser illumination. As seen in Fig. 3b, the C-V plots indicate inverse trend according to at up to 600 kHz curves.



(a)

(b)

Fig. 3 Capacitance-voltage plots of the 6CB LC at dark and laser illumination a) Δε>0 b)Δε<0

This suggests that the structure changes from the positive type to negative type. The dielectric anisotropy values dependence frequency at dark and laser illumination is shown in Fig. 4. As seen in Fig.4, structure of the LC changes from positive to negative dielectric anisotropy at a critical frequency value, f_c. The f_c values at dark and laser illumination were determined from the Fig. 4 and were found to be 630.50 kHz and 653.94 kHz, respectively. The obtained f_c values suggest that the laser illumination increases the critical frequency. Δε values decreases with laser illumination as laser-molecule interaction occurs in a easer behavior in the exchange of carrier charges.

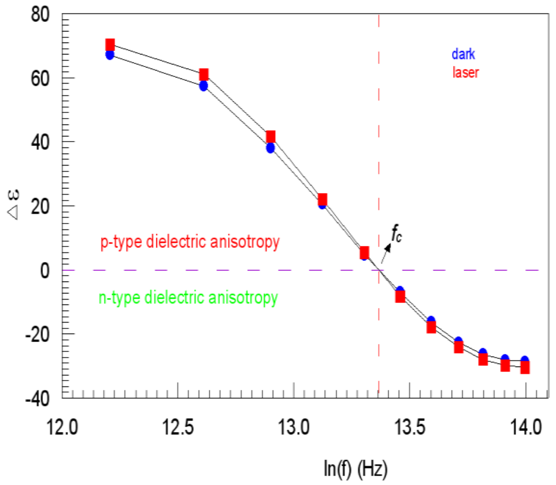


Fig. 4 Variation of dielectric anisotropy values with frequency at dark and laser illumination

The splay K_{11} values at dark and laser illumination were determined and are shown in Fig. 5. The K_{11} values decrease with frequency and laser illumination.

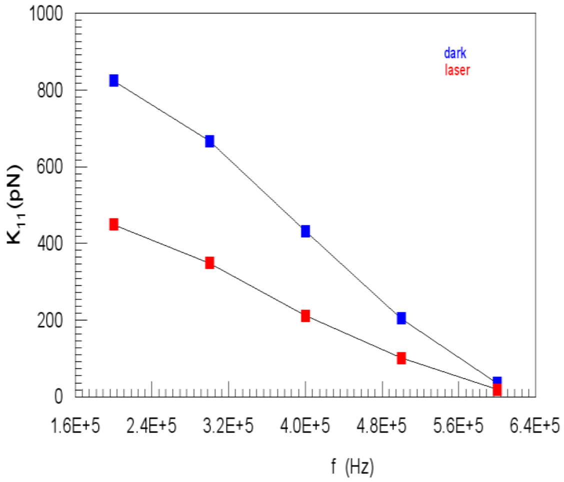


Fig. 5 Variation of K_{11} values with frequency at dark and laser illumination

This suggests that the laser illumination decreases distortions on LC. Fig. 6 shows impedance plots of the LC at dark and laser illumination.

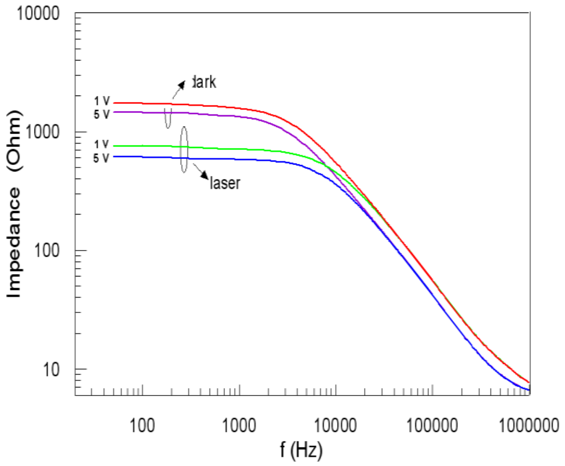


Fig. 6 Impedance-voltage plots of the 6CB LC at dark and laser illumination

The impedance value is constant up to a certain voltage and afterwards, rapidly decreases and tends to constant. The impedance values decrease with laser illumination at lower frequencies. This suggests that the laser illumination changes molecular reorientation, i.e, laser illumination increases the conductance of the LC. The rapid decrease in the impedance is due to changing molecular reorientation. The plots of conductance vs lnf are shown in Fig.7. The plots show two regions, which are dependent and independent regions on frequency. At lower frequencies, the conductance does not almost change with frequency, whereas changes with laser illumination and applied voltage. The first region corresponds to direct current conductivity. The conductivity increases with laser illumination due to molecular reorientation. This suggests that the molecular reorientation of LC and motion of carrier charges are facilitated by laser illumination. But, at higher voltages, the conductance does not change with laser illumination.

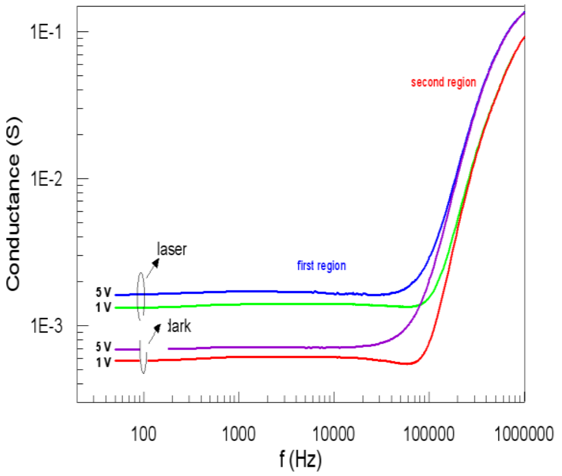


Fig. 7 Conductance-voltage plots of the 6CB LC at dark and laser illumination

The exact relationship between the cell capacitance and the voltage V applied across the cell is expressed as [9-11],

$$\frac{C-C_{\perp}}{C_{\perp}} = \gamma - \frac{2\gamma}{\pi}\frac{V_{th}}{V}(1+\gamma\sin^{2}\varphi_{m})^{1/2}$$

$$X\int_{0}^{\varphi_m}\left[\frac{(1+\chi\sin^{2}\varphi)(1-\sin^{2}\varphi)}{(1+\gamma\sin^{2}\varphi))(\sin^{2}\varphi_{m}-\sin^{2}\varphi}\right]^{1/2}\cos\varphi d\varphi \tag{3}$$

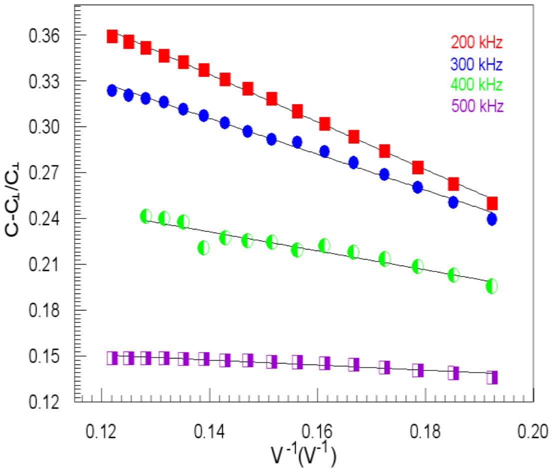
where $\chi = K_{33}/K_{11} - 1$, $\gamma = \varepsilon_{\parallel}/\varepsilon_{\perp} - 1$, φ is the tilt angle between the director n and the cell walls and φ_m is the tilt angle at the centre of the cell. Eq.3 for voltages much higher than the threshold voltages can be rewritten as

$$\frac{C(V)-C_{\perp}}{C_{\perp}} = \gamma - \frac{2\gamma}{\pi}\frac{V_{th}}{V}(1+\gamma)^{1/2} x \int_{0}^{\pi/2}\left(\frac{1+\chi\sin^{2}\varphi}{1+\gamma\sin^{2}\varphi}\right)\cos\varphi d\varphi \tag{4}$$

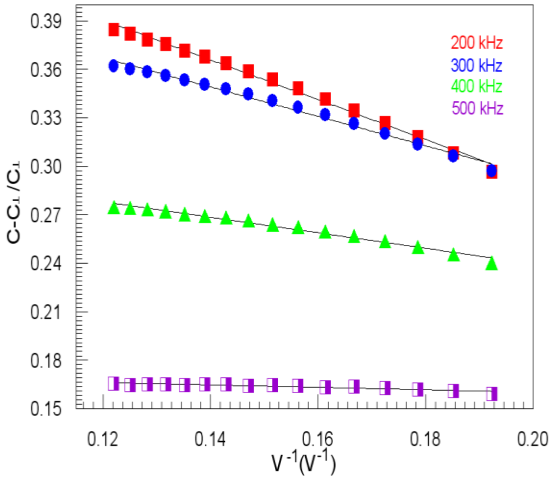
and simplified form of Eq. 3 can be described as,

$$\frac{C(V)-C_{\perp}}{C_{\perp}} = \gamma - \alpha V^{-1} \tag{5}$$

The plot of $C(V)-C_{\perp}/C_{\perp}$ vs V^{-1} gives a straight line and thus, γ and α values can be determined from the intercept and slope of this figure. Figs.8(a-b) show plots of $C(V)-C_{\perp}/C_{\perp}$ vs V^{-1} at dark and laser illumination.



(a)



(b)

Fig. 8 Plots of C-C⊥/ C⊥ vs. V^{-1} of the 6CB LC a)dark b)laser illumination

From the slopes of figures, the K_{33} value was determined using $\chi = K_{33}/K_{11} - 1$ relation. The variation of K_{33} values with frequency is shown in Fig. 9. The blend elastic constants of LC sample decrease with frequency of applied voltage. The laser illumination changes bend elastic constants and these values decrease with laser illumination.

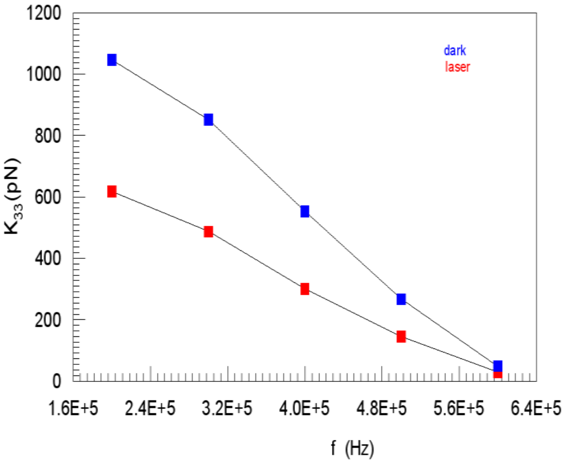


Fig. 9 Variation of K_{33} values with frequency at dark and laser illumination

3.2 Analysis of dielectrical relaxation in the 6CB LC by Cole-Cole model

The complex dielectric constant of the LC is defined as [14],

$$\varepsilon^{*}(\omega) = \varepsilon_{1} + i\varepsilon_{2} \tag{6}$$

where ε_1 and ε_2 are the real and imaginary part of the dielectric constant, respectively. The Cole-Cole plots of the LC at dark and laser illumination are shown in Figs.10 a(-b). Figures show a semicircle and centre of the semicircles lies below the ε_1 axis. This suggests that a distribution of relaxation time takes place in 6CB LC. An empirical relation for complex dielectric constant suggested by Cole-Cole is described as [15-17],

$$\varepsilon^*(\omega) = \varepsilon_\infty + \frac{\varepsilon_0 - \varepsilon_\infty}{1 + (i\omega\tau)^{1-\alpha}} \qquad (7)$$

where $\varepsilon^*(\omega)$ is the complex dielectric constant, ε_0 is the limiting low-frequency dielectric constant and ε_∞ the limiting high-frequency dielectric constant, τ is the average relaxation time, ω is the average angular frequency, α is the distribution parameter. The Cole-Cole plots for 6CB LC suggest a non-Debye type relaxation behavior. This behavior is probably due to the dipolar rotation around the long molecular axis. The diameter of Cole-Cole plots increases with applied voltage, whereas laser illumination decreases. It is evaluated that the relaxation process of the LC is associated with the reorientation of molecules.

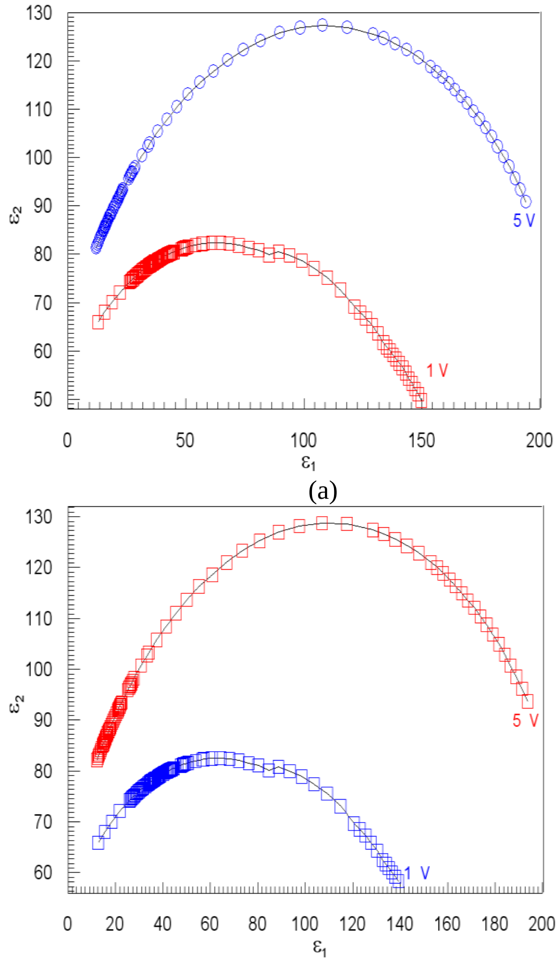


Fig. 10 Plots of Cole-Cole of the 6CB LC at laser illumination a)dark b)laser illumination

3.3. Transient photoconductivity properties of the 6CB LC

Fig. 11 shows transient current curves of the LC at dark and laser illumination. The application of the laser significantly alters the shape of the current. The mobility of charge carrier was determined by the following relation [18]

$$\mu = \frac{d}{tE} \qquad (8)$$

where t is charge carrier the transient time, E is electric field and d is the sample thickness [ ].

The transient time was obtained from the slope of logI-logt curve. The mobility values at dark and laser illumination were calculated using Eq.8 and were found to be $0.196\text{x}10^{-6}$ $\text{cm}^2/\text{V.s}$ and $0.134\text{x}10^{-6}$ $\text{cm}^2/\text{V.s}$, respectively. The mobility value decreases with laser illumination.

The laser illumination increases photoconductivity of the LC.

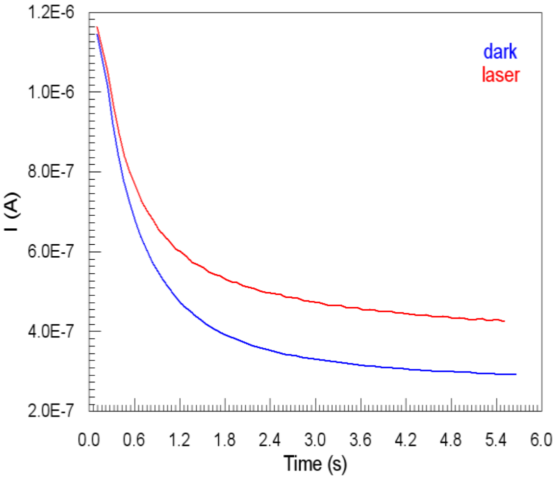


Fig. 11 Transient current plots of 6CB LC at dark and laser illumination

4. Conclusions

The elastic constants, dielectric anisotropy and transient photoconductivity properties of 4-n-hexyl-4’-cyanobiphenyl (6CB) nematic liquid crystal have been investigated. The structure of the LC changes from positive to negative dielectric anisotropy at a critical frequency value, f_c. The laser illumination increases crtical frequency value of the LC. The splay K_{11} and bend K_{33} values at dark and laser illumination were determined and these values decrease with frequency and laser illumination. The dielectrical relaxation of the LC indicates a non-Debye type relaxation behavior. The application of the laser significantly increases the transient photoconductivity of the LC.

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