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Electro-optic Behaviour of a Nematic Liquid Crystal Mixture

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Abstract: *The optical properties of nematic liquid crystal mixture along with their electrical capacitance and dissipation constant were measured as a function of applied bias voltage and frequency. A bias field dependence of dielectric permittivity of the sample has been evaluated for various frequencies. Contrast ratio has also been evaluated and plotted against frequency and bias voltage. These parameters are crucial for understanding and optimising the performance of modal liquid crystal device.*

Keywords: bias voltage, contrast ratio, nematic liquid crystal, optical property

1. INTRODUCTION

With the emergence of liquid crystal based display technology, further research interest has been generated to study the use of liquid crystals for other optical applications. Two such applications are optical switching and optical storage.[1–5] Optical switching allows us to manipulate the direction of polarisation of the liquid crystal, thereby rotating the optic axis to a desired angle, using an external electric field. Liquid crystals with large polarisation are able to exhibit a linear response in switching for very small electric fields. However, in optical storage, the direction of polarisation can vary across the area of a flat cell of liquid crystal.

The switching between on and off states of nematic liquid crystal pixels can be controlled with the well-known electro-optic effect. Switching between the "on" and "off" states is achieved by changing the molecular orientations from a field aligned to a surface aligned arrangement.

The detection of particular character by the eye and hence its legibility depends on the luminance and chrominance of the character compared to its background. If these parameters of picture elements are same as those of the back ground, the pixel is indistinguishable from the back ground. In the case of liquid crystal display, the more popular metric is contrast ratio (CR). By definition, CR is always more than or equal to one and more CR means better visibility.

The measurement of optical transmittance with variation of temperature is a well-known technique for detecting different phase transitions in thermotropic liquid crystals. The optical transmittance has been reported by a large number of works[6–10] for nematic as well as cholesteric samples. But the liquid crystals are the samples in which orientation of the molecules also vary with the application of electric field. The change in the orientation of dipoles also affects optical transmittance. Recently, our group has published an electro-optical study of guest-host ferroelectric liquid crystal, nanoparticles and dye doped nematic liquid crystal. Also, J. Hemine et al. reported electro optic and dynamic study for a ferroelectric liquid crystal.[11–14] To study the variation of optical transmittance and relaxation frequency with the change in bias voltage, measurement has been made on a commercial nematic mixture E-24. This mixture has been chosen for two reasons; first, this sample has a broad nematic range and second, the nematic range lies within the room temperature.

2. EXPERIMENTAL

Phase transition temperature of nematic liquid crystal mixture E-24 is $C \xleftrightarrow{-5°C} N \xleftrightarrow{54°C} I$. For the dielectric measurement impedance gain/phase analyser of Hewlett-Packard (HP 4194A) has been used. The real and imaginary parts of the permittivity of the sample have been obtained from the formulae published in the authors' previously published paper.[6]

The experimental arrangement for CR measurement has been described.[11] CR is the ratio of the greater luminescence (L_{max}), i.e., luminescence of character or background, to the lesser luminescence (L_{min}).

$$CR = L_{max}/L_{min}$$

3. RESULTS AND DISCUSSION

Variation of optical transmittance with natural log of frequency for different bias voltage has been shown in Figure 1. Optical transmittance has been taken in arbitrary unit for convenience. Below the 4V bias voltage, there is no variation in optical transmittance irrespective of frequency. The value of optical transmittance shows a dip and it falls sharply with frequency as the bias voltage is increased above 4V. The critical frequency at which the optical transmittance starts decreasing has been plotted with respect to the bias voltage and shown in

Figure 2. Between 7.5 to 8.0V, this frequency becomes almost constant. This can be explained from the fact that we are using a cell containing sample under plainer alignment and the bias voltage has the tendency to align the liquid crystal molecules perpendicular to the plates of the sample holder. Hence, when the bias voltage is small, the field applied on the molecular dipoles is small and the value of optical transmittance is nearly linear as in the case when no voltage is applied. But as soon the voltage is about 4V, the value of electric field and hence the rotating force on the molecular dipoles of nematic liquid crystal increases. There is tendency for these dipoles to be aligned perpendicular to the plates and with the increase of bias voltage, the critical frequency of applied field decreases and after 8V, it remains almost constant.

Therefore, it can be concluded that after 8V, the alignment due to the surface effect is completely vanished and the molecules are aligned in the direction of the field due to the bias voltage. This is also supported by the fact that the value of the optical transmittance is minimum at the highest value of the bias voltages. Another important observation is that after 65.0 kHz of applied frequency, at least for the bias voltages of 4, 5 and 6V, the optical transmittance again increases to its maximum value.

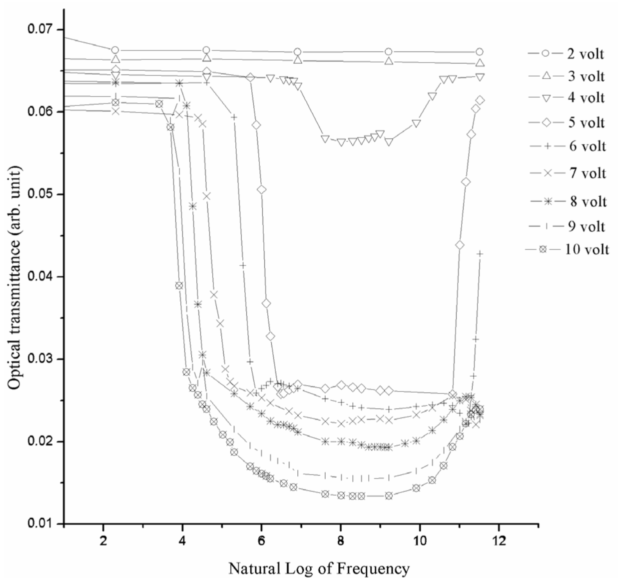

Figure 1: Variation of optical transmittance with natural log of frequency for different bias voltage.

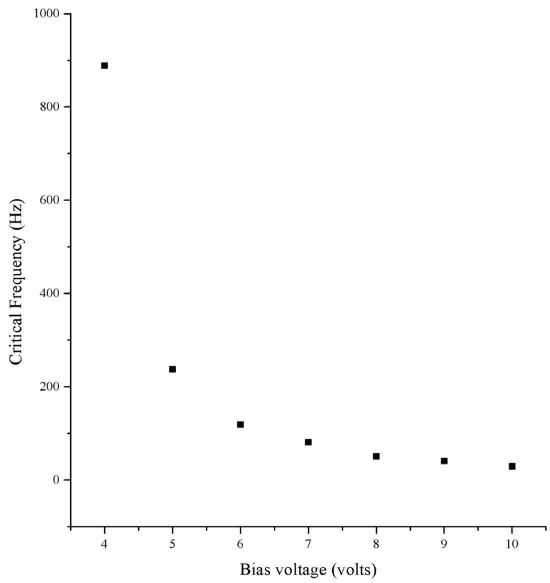

Figure 2: Variation of critical frequency with different bias voltage.

The difference of maximum value and the minimum value of optical transmittance with the variation of frequency for a given value of bias voltage, define as ΔI (I_{max}–I_{min}), has been examined and is shown in Figure 3. It may be seen that for lower bias voltages, up to 3V, there is hardly any noticeable change. However, beyond 3V, the ΔI value increases sharply till about 5V, after which there is not much variation in ΔI values. This may be explained from the fact that the change in the optical transmittance is due to orientation of liquid crystal molecules in the direction of electric field arises from the bias voltage. This occurs only after 3V and beyond the bias voltage of 5V, the molecules orientate sufficiently, explaining why further increase in voltage does not significantly affect the value of ΔI_{max}.

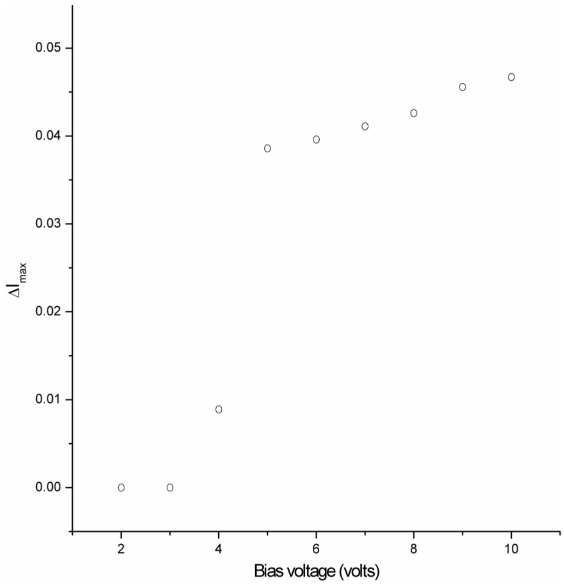

Figure 3: Variation of maximum change in optical transmittance with different bias voltage.

Figure 4 shows the variation of optical transmittance with bias voltage for five different frequencies. For low frequency (0.01 kHz) there is a small decrease in optical transmittance with bias voltage. As the frequency increases (0.1 and 1.0 kHz), a significant and steady decrease in optical transmittance is observed. However, for higher frequencies (10 and 100 kHz), there is an abrupt decrease in the optical transmittance till about 5V of bias voltages, after which the value becomes almost constant. It may be because as bias voltage increases, the alignment of molecules within the sample holder changes from plainer to perpendicular to the plates of sample holder. At low frequencies, liquid crystal molecules (LCM) respond to the applied frequency but at higher frequencies, the LCM are not responding to the applied field, hence optical transmittance decreases.

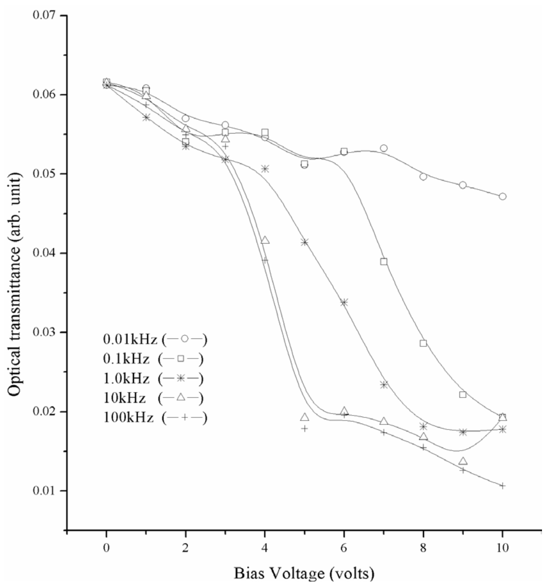

Figure 4: Variation of optical transmittance with voltage at indicated frequencies.

In Figure 5, the dependence of f_r (relaxation frequency) on the biasing voltage is presented. The frequency f_r were determined by the peak values of the plot between ε'' vs frequency presented in the inset of Figure 5. It may be observed that the value of f_r is dependent on the applied voltage, i.e., it increases with the increasing voltage. This type of behaviour has also been reported by Pavel et al. and Roy et al.[16,17] Basically, f_r is the frequency at which maximum absorption of applied electromagnetic field takes place and it increases with increase in applied bias field.

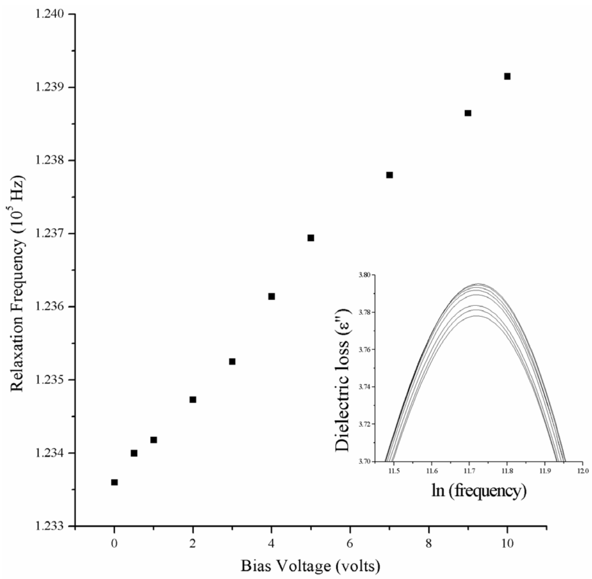

Figure 5: Variation of relaxation frequency with bias voltage.

Figure 6 and 7 present the plots of CR against bias voltage and natural log of frequency respectively. The CR value increases with increase in bias voltage after 3V. At lower frequencies, i.e., between 100 Hz and 1 kHz, the CR increases slowly but for at higher frequency values, i.e., between 10 kHz and 100 kHz, it shows a sharp increase as shown in Figure 6. The CR value increases slowly with frequency up to nearly 22 Hz for different bias voltage (Figure 7) and beyond that, the CR increases sharply and reaches maximum which is different for different bias voltages. After 20 kHz, the contrast ratio starts decreasing.

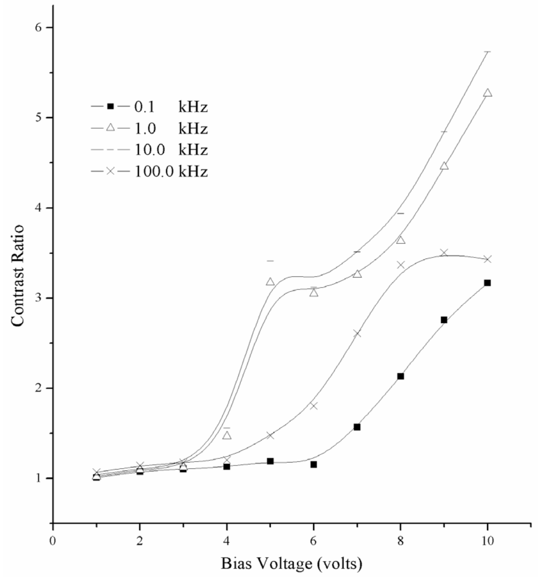

Figure 6: Variation of contrast ratio with bias voltage.

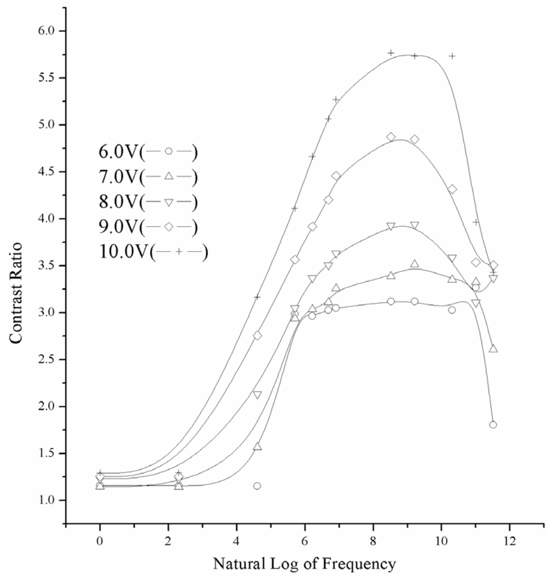

Figure 7: Variation of contrast ratio with natural log of frequency for different bias voltages.

4. CONCLUSION

The variation of optical transmittance with bias voltage and frequency has been investigated experimentally. It has been observed that the optical transmittance decreases with increase in bias voltage, and it also varies with different frequencies. The value of relaxation frequency is dependent on the applied voltage, showing increases with increase in applied bias voltage. In this study, important parameters have been generated which can be made useful for new applications and devices relevant to the liquid crystal technology.

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