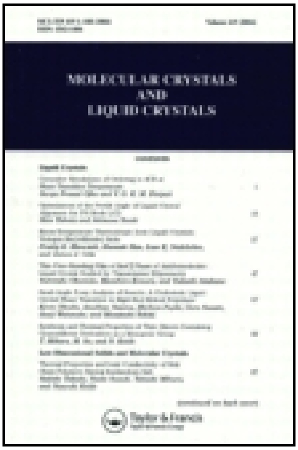

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Dependence of the Electrically Controlled Birefringence on Applied Frequency in a Nematic Liquid Crystal

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Dependence of the Electrically Controlled Birefringence on Applied Frequency in a Nematic Liquid Crystal

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Detailed studies on the dependence of the ECB effect on the applied frequency have been made in a nematic liquid crystal MBBA. It is found experimentally that, when the applied voltage is just above the threshold voltage, there are strong dependences of both the delay time and the mean deformation angle of the molecular director subjected to a constant voltage setup on the applied frequency. Those applied frequency dependences of the ECB effect can be interpreted in terms of the dielectric alignment in an electrically conducting nematic liquid crystal. We have measured the capacitance of the deformed liquid crystal cell varying the applied frequency. The experimental results are compared with the Gruler and Cheung theoretical prediction, and good agreements are obtained between them when the applied voltage is just above the threshold voltage.

I INTRODUCTION

So far, dependences of the various electro-optic effects on the applied frequency have been studied extensively on a nematic liquid crystal under AC excitation. It is known that the frequency dependence of the electrically controlled birefringence (ECB) effect is almost identical in the range from low frequency to the molecular dispersion frequency, and that all the field effects such as the ECB effect have this property.[1,2]

We have made detailed studies on the dependences of the ECB effect on the applied frequency in a homeotropically aligned nematic liquid crystal.

This paper has been presented (I-12P) at the 8th International Liquid Crystal Conference, Kyoto, 1980.

II EXPERIMENTAL

The nematic liquid crystal used was *p*-methoxybenzylidene-*p*-n-butylaniline (MBBA). The cell was made with two nesa-coated glass plates and mylar spacers with 50 μm thickness. The homeotropic orientation was obtained by coating the inner surfaces of the plates with a very thin layer of lecithine.

A collimated 6328 Å laser beam was incident normally to the cell placed between the crossed polarizer and analyzer. The driving AC voltage was applied to the cell with the frequency range from 10 Hz to 30 kHz, and the transmitted light was detected by a photo-diode.

The capacitance of the cell was measured using the wide band bridge type TR–10 (Ando Electric Co.). The electric conductivity of the cell varied from $\sigma_{\parallel} = 1.1 \times 10^{-8}$ $[S/m]$ for purified sample to $\sigma_{\parallel} = 1.2 \times 10^{-6}$ $[S/m]$ by adding tetramethylammonium bromide or tetrabutylammonium chloride as a dopant.

III RESULTS AND DISCUSSION

Figure 1 illustrates the typical transient behavior of the transmitted light intensity. As a characteristic response time, the delay time (τ_{delay}) is defined as the interval between the voltage onset time and the time when the optical transmission is 10% of the first maximum. Figure 2 shows plots of the delay time versus the applied frequency for two voltages of 3.9 [V] and 4.0 [V]. We observe that, when the applied voltage is just above the threshold voltage, there is a strong dependence of the delay time on the applied frequency. When the applied voltage is much higher than the threshold voltage, the delay time is nearly constant and independent of the applied frequency.

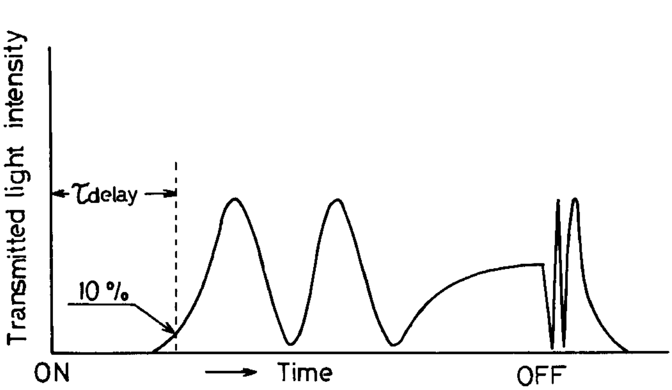

FIGURE 1 Transient behaviour of the transmitted light intensity.

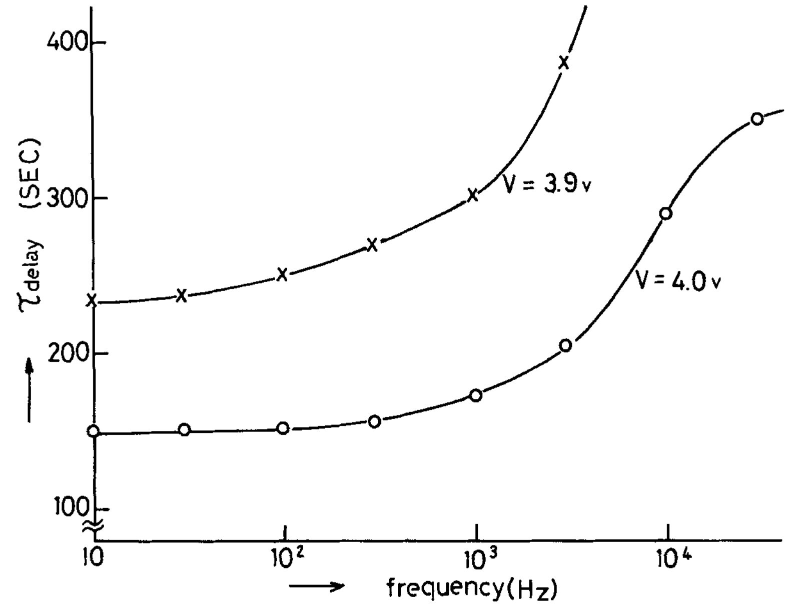

FIGURE 2 Plots of τ_{delay} versus frequency at 25°C (cell thickness; 50μm).

We have obtained the mean deformation angle of the molecular director subjected to a constant voltage setup, from the data of the transient decay characteristics of the optical transmission shown in Figure 1.[3] The mean deformation angle ($\bar{\theta}$) is then determined using the following relationship:

$$\bar{\theta} = \sin^{-1}\left[\left\{\left(\frac{n_0}{R/d + n_0}\right)^2 - 1\right\} \Big/ \left\{\left(\frac{n_0}{n_e}\right)^2 - 1\right\}\right]^{1/2} \tag{1}$$

in which R is retardation:

$$R = d[n_e(V) - n_0] = N \cdot \lambda \tag{2}$$

where $n_e(V)$ is the effective extraordinary refractive index for the applied voltage V, n_e the extraordinary refractive index, n_0 the ordinary refractive index, d the cell thickness, N the number of peaks in the transient decay of the transmission light intensity, λ the laser wave length (6328 Å). Figure 3 is plots of the mean deformation angle versus the applied frequency for the same two voltages as in Figure 2. It is observed that the mean deformation angle decreases with the increase of the applied frequency.

It is deduced from the above experimental results that the ECB effect depends in general on the applied frequency. Those dependences of the ECB effect on the applied frequency can be interpreted by a model of Gruler and

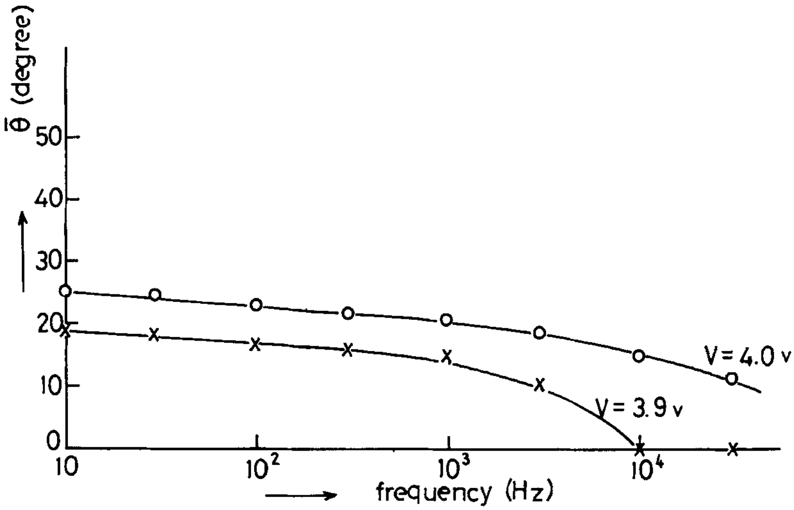

FIGURE 3 Plots of $\bar{\theta}$ versus frequency at 25°C (cell thickness; 50μm).

Cheung[4] that the deformed nematic liquid crystal can be described by a series of electric elements, each of which contains a capacitance parallel to a resistance (Figure 4). They have pointed out that the dielectric alignment of the molecular director in *an electrically conducting* nematic liquid crystal depends on the frequency due to the frequency dependence of the non-uniform local electric field strength.

Since the dielectric alignment can be detected by measuring the capacitance of the liquid crystal cell, they have derived the theoretical equation for the variation of the capacitance with the applied AC voltage. The theoretical equation for the homeotropic aligned sample is as follows:

$$\frac{C - C_0}{C_0} = \frac{2(\varepsilon_\perp - \varepsilon_\parallel)/\varepsilon_\parallel}{k + 1 + a}\left(\frac{V}{V_0} - 1\right) + 0\left(\frac{V}{V_0} - 1\right)^2 + \cdots \tag{3}$$

here

$$k = (k_\parallel - k_{33})/k_{33} \tag{4}$$

$$a = \left[\frac{\sigma_\perp - \sigma_\parallel}{\sigma_\parallel} + \left(\frac{\omega}{\omega_0}\right)^2 \frac{\varepsilon_\perp - \varepsilon_\parallel}{\varepsilon_\parallel}\right] \cdot \left[1 + \left(\frac{\omega}{\omega_0}\right)^2\right]^{-1} \tag{5}$$

$$\omega_0 = \sigma_\parallel(\varepsilon_0 \cdot \varepsilon_\parallel)^{-1} \tag{6}$$

$$V_0 = \pi[k_{33}/(\varepsilon_0 \cdot \Delta\varepsilon)]^{1/2} \tag{7}$$

where C is the capacitance of the deformed liquid crystal cell, C_0 the capacitance of the undeformed liquid crystal cell, ω the angular frequency $(2\pi f)$,

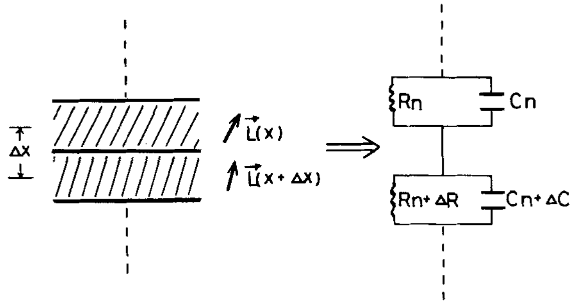

FIGURE 4 Illustrates how the deformed nematic liquid crystal can be described by a series of electric element. Each element contains a capacitance parallel to a resistance.

k the elastic constant, σ the electric conductivity, ε the dielectric constant. For the vanishing electric conductivity ($\sigma \to 0$), the theoretical equation is in agreement with that of non-conducting nematic liquid crystal and the dielectric alignment is independent of the applied frequency.

We have measured the capacitance subjected to a constant AC voltage to detect the dielectric alignment of the conducting nematic liquid crystal ($10^{-8} < \sigma < 10^{-6}[S/m]$), and confirmed the Gruler and Cheung theoretical prediction. Figure 5 shows plots of $(C - C_0)/C_0 \times 100\%$ versus the applied frequency for the applied voltage V = 4.5 [V], where C_0 is the capacitance of the undeformed cell and is measured by applying much lower AC voltage than the threshold voltage, and C is the capacitance of the deformed cell. It is observed that the capacitance of the deformed cell decreases dispersively

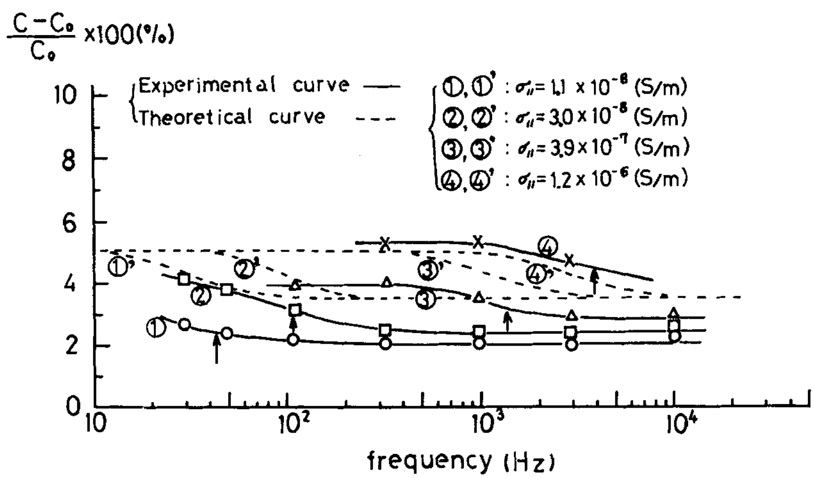

FIGURE 5 Plots of $(C - C_0)/C_0$versus frequency (applied voltage; 4.5 [V]).

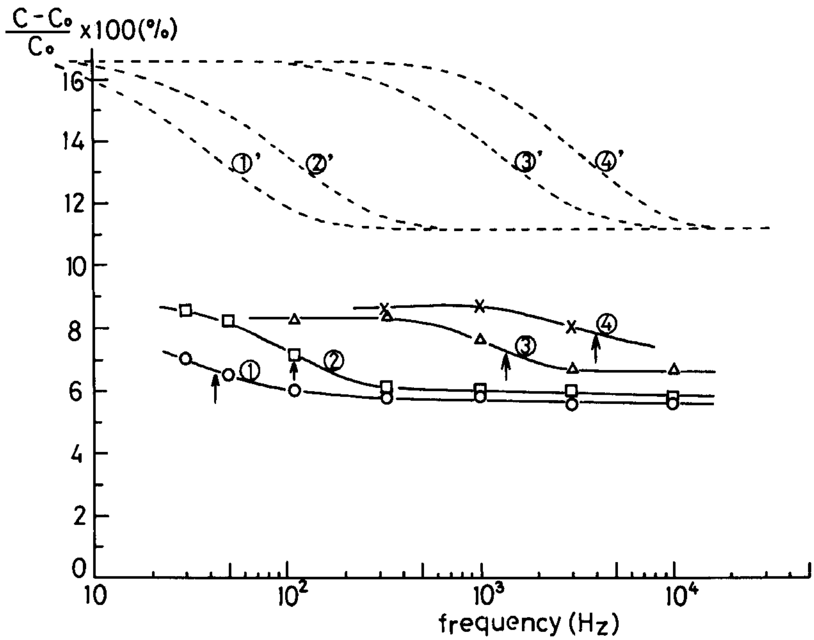

FIGURE 6 Plots of $(C-C_0)/C_0$ versus frequency (applied voltage; 6 [V]).

with the increase of the applied frequency, and this dispersion frequency indicated by the arrow mark increases with the increase of the electric conductivity of the liquid crystal cell. In Figure 5, dotted curves correspond to the theoretical curves and are in agreement with the experimental curves.

Figure 6 shows the same plots as in Figure 5 for the applied voltage V = 6.0 [V] which is much higher than the threshold voltage. In this case, the experimental results disagree with the theoretical values. This is the reason that the theoretical values are obtained by neglecting the second and higher terms of the theoretical equation.[5]

IV CONCLUSION

We have confirmed from the experimental results for the frequency dependence of the deformed cell capacitance that the ECB effect in a nematic liquid crystal depends in general on the applied frequency. Thus, there should be strong frequency dependences of both the delay time and the mean deformation angle which are found experimentally, when the applied voltage is just above the threshold voltage. However, if the applied voltage is much higher than the threshold voltage, both the delay time and the mean deformation angle may be nearly constant and apparently independent of the applied frequency.

Further studies on the frequency dependence of the ECB effect in a nematic liquid crystal should be made for the two frequency ranges, the lower frequency range than the frequency of 10 Hz and the higher frequency range than the frequency of 10 kHz. In the lower frequency range, the electrode polarization effect has to be taken into account. On the other hand, it is necessary to consider the influences of the dielectric heating[6] in the higher frequency range.

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