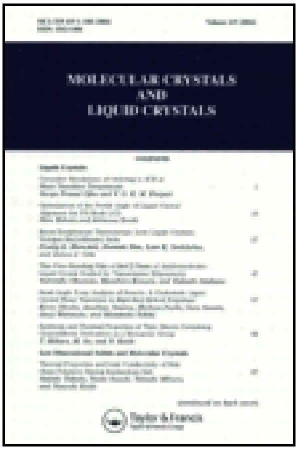

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Frequency Dependence of Light Transmittance in a PDLC

F. Bloisi [a] , C. Ruocchio [a] & L. Vicari [a]
[a] Istituto Nazionale per la Fisica della Materia Dipartimento di Scienze, Fisiche Università di Napoli "Federico II" Piazzale V. Tecchio, 80 I, 80125, Napoli, Italy

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FREQUENCY DEPENDENCE OF LIGHT TRANSMITTANCE IN A PDLC.

F. BLOISI, C. RUOCCHIO, L. VICARI
Istituto Nazionale per la Fisica della Materia
Dipartimento di Scienze Fisiche
Università di Napoli "Federico II"
Piazzale V.Tecchio, 80
I 80125 Napoli (Italy)

Abstract

Polymer Dispersed Liquid Crystal (PDLC) is a dispersion of liquid crystal microdroplets in a polymeric binder. Droplets are randomly oriented anisotropic spheres and, if their size is close to visible light wavelength, produce a strong light scattering so that the sample is translucent. Light scattering, due to the refractive index mismatch between liquid crystal droplets and surrounding polymer, can be controlled by changing the effective refractive index of the droplets: this can be easily obtained applying an external, low frequency, electric field.

In recent papers we have presented detailed experimental and theoretical studies of the behavior of a PDLC sample when a light beam impinges on it. Here we study the dependence of the PDLC light transmittance on the frequency of the applied external electric field. To this aim we use a mathematical model assuming the liquid crystal dielectric permittivities $\epsilon_{\|}$ and $\epsilon_{\perp}$ to be the most important parameters for the applied field frequency dependence of light transmittance. Theoretical results show a sudden decrease of the transmitted intensity increasing the frequency of the applied voltage. We present also preliminary experimental results confirming this behavior.

1 Introduction

Polymer dispersed liquid crystals (PDLCs) are composite materials made of a dispersion of liquid crystal droplets in a polymeric matrix[1]–[6]. If the liquid crystal is in the nematic phase the droplets appear as randomly oriented spheres of an highly anisotropic optical material. Therefore light impinging on a PDLC film is almost entirely scattered. Application of an electric field in a direction orthogonal to the film surfaces aligns the liquid crystal molecules inside the droplets so that all droplets behave as uniaxial media aligned to the applied field. If the polymer refractive index is equal to the ordinary refractive index of the liquid crystal the scattering for normally impinging light is reduced to zero, so that the sample becomes transparent[7].

Interest in such materials arises from both a basic and an applied point of view. Many authors have dealt with the problem of liquid crystal molecular director distribution[8]-[10] and its consequences on the light scattering in PDLC[11]-[17]. In previous papers[18]-[20] we introduced a mathematical model of the molecular behavior of the sample in order to compute the sample light transmission ratio. In this paper we use this model to examine the dependence of the light transmission ratio on the frequency of the applied external field.

Our theory is developed on the basis of the Palffy-Muhoray[21] approach to the optical description of liquid crystals droplets in PDLC and on the Anomalous Diffraction Approach (ADA) scattering theory[22].

Experimental measurements have been performed in order to verify theoretical forecasts of the model. A second set of experimental measurements has been carried out to verify that the waveform can be totally neglected.

2 The model

In the framework of a previously introduced model[21, 15] the PDLC state can be described by means of three order parameters: the molecular local order parameter, S, the droplet order parameter S_d, and the sample order parameter, S_s.

The local order parameter, i.e. the usual scalar order parameter

$$S = \left\langle P_2(\hat{\mathbf{n}} \cdot \hat{\mathbf{l}}) \right\rangle \tag{1}$$

where P_2 is the second order Legendre polynomial, $\hat{\mathbf{l}}$ is the molecular axis, $\hat{\mathbf{n}}$ is the nematic director, is a function of the temperature, and is assumed to be unaffected by droplet configuration and the external electric field.

The droplet order parameter

$$S_d = \left\langle P_2(\hat{\mathbf{N}}_d \cdot \hat{\mathbf{n}}) \right\rangle_{droplet} \tag{2}$$

where $\hat{\mathbf{N}}_d$ is the droplet director (i.e. the mean value of $\hat{\mathbf{n}}$ inside each droplet) and the average is taken over each droplet, describes the droplet configuration and allows us to compute the droplet ordinary and extraordinary refractive indices.

The arrangement of the liquid crystal molecules inside each droplet depends on many parameters (e.g. the droplet radius, the alignment at the droplet surface, the liquid crystal elastic constants), however it has been calculated[23] that the bipolar configuration (molecules are strongly aligned to the droplet director $\hat{\mathbf{N}}_d$, with two disclination at the "poles" of the droplet) is energetically preferred in case of tangential anchoring. This configuration is commonly used since it gives high contrast and low driving voltages. In a previous paper[15] we have shown that, for such configuration the droplet refractive indices are

$$n_{do} = \frac{2}{\pi} n_o \, F\left(\frac{\pi}{2}\,,\, \frac{1}{n_e}\sqrt{\frac{2}{3}(n_e^2 - n_o^2)(1 - S_d)}\right) \tag{3a}$$

$$n_{de} = \frac{n_o\, n_e}{\sqrt{\frac{2}{3}(n_o^2 - n_e^2)S_d + \frac{1}{3}(n_o^2 + 2n_e^2)}} \tag{3b}$$

where $F(\theta, m)$ is the complete elliptic integral of the first kind, n_o and n_e are the liquid crystal refractive indices. Let us note that $S_d = 1$ means that the nematic directors of all molecules are aligned to the droplet director, so that, as expected, $n_{de}\,|_{S_d=1} = n_e$ and $n_{do}\,|_{S_d=1} = n_o$. For the bipolar configuration we assume $S_d = 0.7$.

Finally the sample order parameter, describing the droplet reorientation due to the external field, is defined as

$$S_s = \left\langle P_2(\hat{\mathbf{E}} \cdot \hat{\mathbf{N}}_d)\right\rangle_{sample} \tag{4}$$

where $\hat{\mathbf{E}}$ is the direction of the applied electric field and the average is taken over the whole sample. To compute S_s we use the implicit relations[15]:

$$\begin{aligned} S_f &= \frac{1}{4} + \frac{3}{16}\frac{e_a^2 + 1}{e_a^2} + \frac{3}{32}\frac{(3e_a^2 + 1)(e_a^2 + 1)}{e_a^3} \ln\left|\frac{e_a + 1}{e_a - 1}\right| \\ e_a(S_f) &= E\sqrt{\frac{3\,\epsilon_p\, v_{lc}}{\varepsilon_{lc} + 2\varepsilon_p - v_{lc}(\varepsilon_{lc} - \varepsilon_p)}\frac{\varepsilon_{\|} - \varepsilon_{\perp}}{K_d}} \\ \varepsilon_{lc}(S_f) &= \varepsilon_{\perp} + \frac{1}{3}(1 + 2SS_dS_f)(\varepsilon_{\|} - \varepsilon_{\perp}) \end{aligned} \tag{5}$$

where $e_a(S_f)$ is the reduced electric field, v_{lc} is the volume fraction of liquid crystal in the sample, $\varepsilon_{\|}$ and $\varepsilon_{\perp}$ are the liquid crystal dielectric permittivities, ε_p is the polymer dielectric permittivity and K_d is an elastic constant per unit volume taking into account the torque which, after the field is switched-off, produces relaxation of the droplets to their original orientation.

Assuming that multiple scattering can be neglected, the transmitted light intensity ratio is

$$I_t/I_0 = \exp\left(-\rho_N d_s \sigma_s\right) \tag{6}$$

where ρ_N is the number of droplets per unit volume, d_s is sample thickness, $\sigma_s = \langle\sigma_d\rangle_{sample}$ is the sample average scattering cross section[18]

$$\sigma_s = \tfrac{1}{2}\sigma_G\left(2kR_d\right)^2\left(\tfrac{n_{de}-n_{do}}{n_p}\right)^2 \\ \left[\left(\tfrac{n_p-n_{do}}{n_{de}-n_{do}}\right)^2 - \tfrac{2}{3}\tfrac{n_p-n_{do}}{n_{de}-n_{do}}\left(1-S_s\right) + \tfrac{4}{105}\left(7-10S_s+3\tilde{S}_s\right)\right] \tag{7}$$

where $k = 2\pi/\lambda$ is the wavenumber of the impinging radiation,

$$\tilde{S}_s = \frac{7}{12} + \frac{5}{12}S_s - \frac{35}{32e_a^2}\left[\frac{2}{3} + \frac{(e_a^2-1)^2}{4e_a^2} - \frac{(e_a^2+1)^2(e_a^2-1)}{8e_a^3}\arctan\left(\frac{2e_a}{e_a^2-1}\right)\right] \tag{8}$$

R_d is the droplet radius, $\sigma_G = \pi R_d^2$ is the geometrical droplet cross section, n_p is the polymer refractive index, n_{do} and n_{de} are the ordinary and extraordinary droplet refractive indices.

3 Experiment

The sample (Epon 815 by Shell Chemical Company: 25.8%, MK 107 by Wilmington Chemical Corporation; 7.4%, Capcure 3-800 by Diamond Shamrock & Co.: 30.1%, Bostik B by Bostik 3.4%, E7 by BDH: 33.3%) is obtained sandwiching the PDLC between two conducting (ITO coated) glasses. Mylar spacers ensure that the sample thickness is $d_s = 20\mu m$. The liquid crystal E7 is an eutectic mixture of cyano-polyphenyl compounds widely used for direct drive displays and other applications. After curing in a thermostated oven at $60°C$ for 16 hours the sample is translucent (white). A low power ($5mW$) He-Ne laser beam (Fig.1) at normal incidence, together with a photodiode detector, is used to measure the sample transmission ratio. A chopper and lock–in configuration is used to reduce the noise. A reference beam, obtained by a beam splitter, is sent to a second photodiode detector to check beam power stability. An external electric field is applied by means of a function generator and a voltage amplifier. In Fig.2 we report the experimental data of the transmitted intensity vs. the electric field frequency ν.

The most important parameter influencing the dependence of the sample transmission ratio vs. the external electric field frequency is the liquid crystal dielectric permittivity. A direct comparison with theoretical values cannot be performed since $\varepsilon_{\parallel}(\nu)$ and $\varepsilon_{\perp}(\nu)$ data are not available for liquid crystal E7. However, while working to obtain more information about such material, let us perform a first comparison with the theoretical model using the dielectric permittivities of liquid crystal K24 (octyl-cyanobiphenyl), easily found in literature[24]. Using $\varepsilon_{\parallel}(\nu)$ and $\varepsilon_{\perp}(\nu)$ data

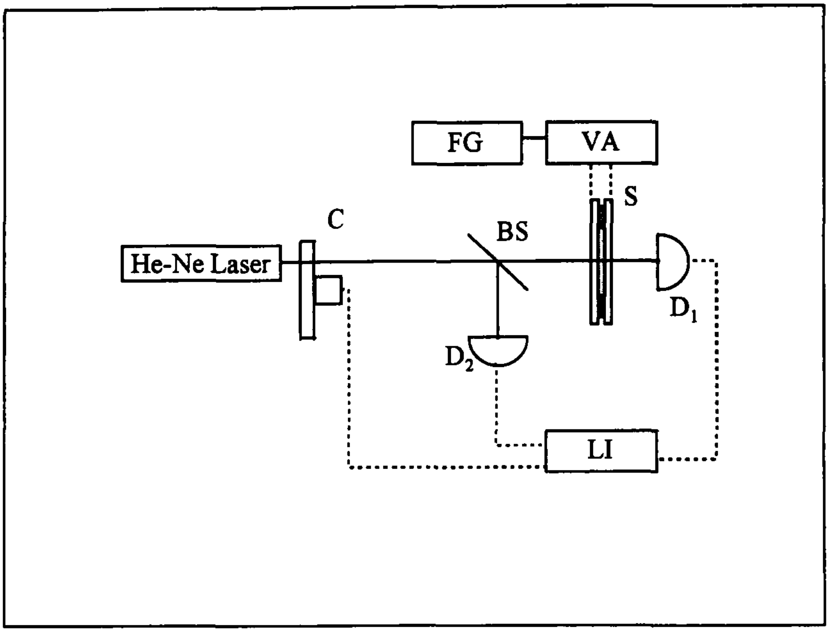

Figure 1: Experimental setup. $He-Ne$: $5mW$ He-Ne laser; C: chopper; BS: beam splitter; S: sample; D_1 and D_2: photodiode detectors; FG: function generator; VA: voltage amplifier; LI: lock-in amplifier.

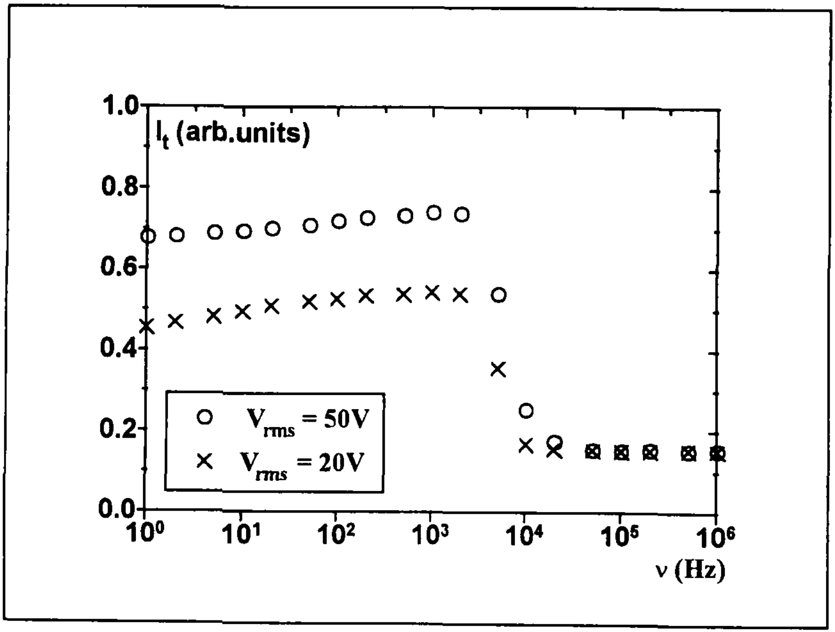

Figure 2: Experimental values of the sample transmitted intensity vs. the frequency of the applied electric field.

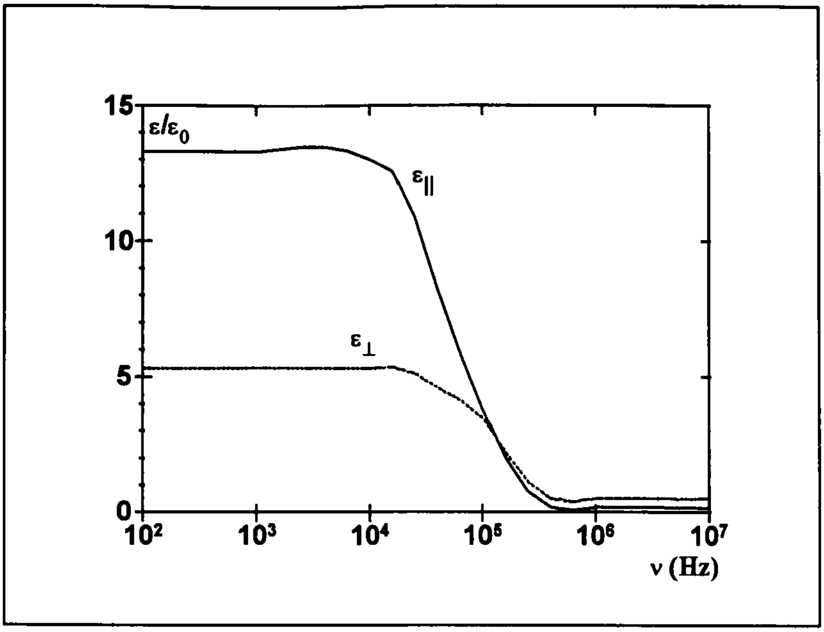

Figure 3: Dielectric permittivities of liquid crystal K24 vs. the frequency of the applied electric field.

shown in Fig.3 within the previously described model we have evaluated the sample transmitted ratio as a function of the frequency of the applied electric field (Fig.4). The two curves are obtained for two different values of the electric field intensity. The values of the other parameters used in the model are taken from our sample: $n_p = 1.54$, $n_e = 1.73$, $n_o = 1.51$, $\varepsilon_p = 5\varepsilon_0$, $d_s = 20\mu m$, $v_{lc} = 0.6$, $\rho_N = 0.143\ 10^{18}m^{-3}$, $S_{|T=25.5°C} = 0.611$, $Rd = 1\mu m$, $K_{d|T=25.5°C} = 5.97Nm^{-2}$, $\lambda = 632.8nm$. A comparison with Fig.2 shows that the general behavior of $I_t\left(\nu\right)$ is the same for both experimental and computed data.

Another interesting question is the related to the applied field waveform. If the electric field is applied as a square wave, we should perform a Fourier analysis of the signal making the model more complex. Therefore we have experimentally investigated how the transmitted ratio intensity is affected by the applied signal waveform. In Fig.5 we compare light transmitted ratio obtained applying a square, sinusoidal or triangular waveform to the same sample, in the same operating conditions ($\nu = 1kHz$). As can be seen the waveform is unimportant as long as the root mean square value of the amplitude is the same. As a consequence there is no practical interest in taking into account signal waveform into our model.

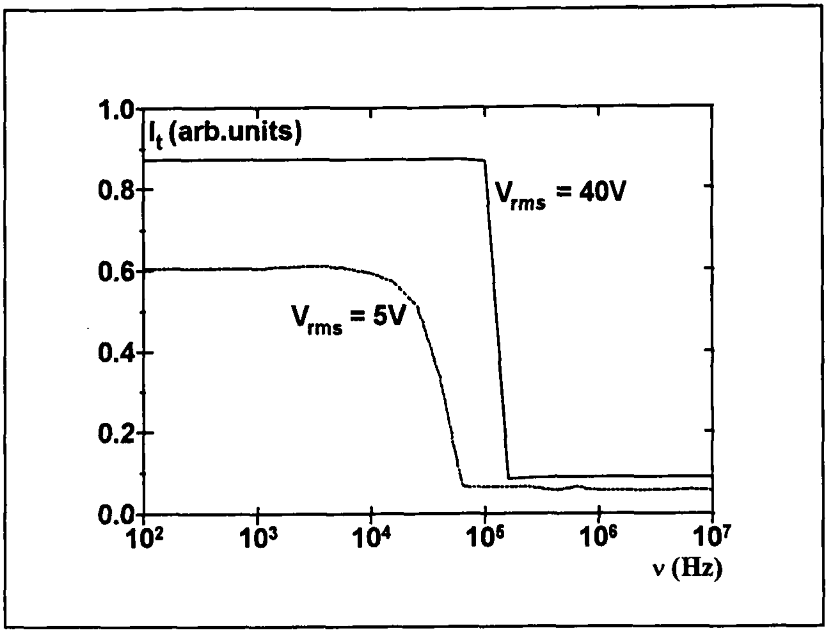

Figure 4: Theoretical values of the sample transmitted intensity vs. the frequency of the applied electric field obtained using the model described. The dielectric permittivities are those given in previous figure.

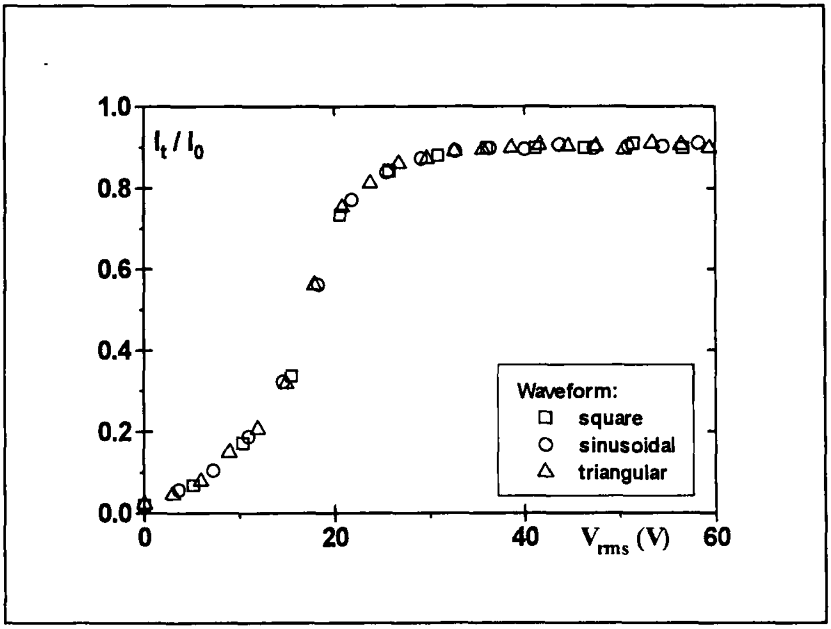

Figure 5: Experimental values of the sample light transmitted ratio vs. the applied voltage for square, sinusoidal and triangular waveforms. The frequency is $\nu = 1kHz$ in all cases.

References

1. P. S. Drzaic, J. Appl. Phys., 60, 2142 (1986).
2. P. S. Drzaic, Liq. Cryst., 3, 1543 (1988).
3. B. G. Wu, J. L. West and J. W. Doane, J. Appl. Phys., 62, 3925 (1987).
4. A. Fuh and O. Caporaletti, J. Appl. Phys., 66, 5278 (1989).
5. S. C. Jain and D. K. Rout, J. Appl. Phys, 70, 6988 (1991).
6. I. C. Khoo and F. Simoni, Physics of Liquid Crystalline Materials (Gordon & Breach, New York, 1992).
7. J. W. Doane, N. A. Vaz, B. G. Wu and S. Zumer, Appl. Phys. Lett. 48, 269 (1986).
8. P. G. de Gennes and J. Prost, The Physics of Liquid Crystals (Clarendon, Oxford, 1993).
9. W. H. de Jeu, Physical properties of liquid crystalline materials (Gordon & Breach, New York,1979).
10. M. J. Stephen and J. P. Straley, Rev. Mod. Phys. 46, 617 (1974).
11. S. Zumer and J. W. Doane, Phys. Rev. A, 34, 3373, (1986).
12. S. Zumer, A. Golemme and J. W. Doane, J. Opt. Soc. Am. A, 6, 403 (1989).
13. P. Palffy-Muhoray, M. A. Lee and J. L. West, Mol. Cryst. Liq. Cryst., 179, 445 (1990).
14. F. Basile, F. Bloisi, L. Vicari and F. Simoni, Mol. Cryst. Liq. Cryst., 251, 271 (1994).
15. F. Basile, F. Bloisi, L. Vicari and F.S imoni, Phys. Rev. E, 48, 432 (1993).
16. F. Bloisi, C. Ruocchio, P. Terrecuso and L. Vicari, Liq. Cryst., 20, 377 (1996).
17. J. B. Whitehead Jr., S. Zumer and J. V. Doane, J. Appl. Phys., 73, 1057 (1992).
18. F. Bloisi, P. Terrecuso, L. Vicari and F. Simoni, Mol. Cryst. Liq. Cryst., 266, 229 (1995).

19. F. Bloisi, C. Ruocchio, P. Terrecuso and L. Vicari, Opt. Lett., 21, 95 (1996)

20. F. Bloisi, C. Ruocchio, P. Terrecuso and L. Vicari, Opt. Commun., 123, 449 (1996).

21 J. R. Kelly and P. Palffy-Muhoray, Mol. Cryst. Liq. Cryst., 243, 11 (1994).

22 S. Zumer, Phys. Rev. A, 37, 4006 (1988).

23. E. Dubois-Violette and O. Parodi, J. Phys. (Paris) Colloq., 30, C4-57 (1969).

24. D. K. Rout and S. C. Jain, Mol. Cryst. Liq. Cryst., 210, 75 (1992).