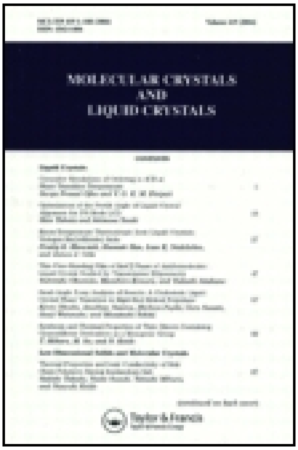
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Transmission of Liquid Crystals in the near Infrared*

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INTRODUCTION

The dynamic scattering mode (DSM) in nematic liquid crystals of negative dielectric anisotropy has been the subject of extensive fundamental and applied research, but almost all of these experiments have been performed in the visible spectral domain. In this wavelength range, when an increasing voltage (dc or low frequency ac) exceeding a threshold below 10 V is applied to a nematic thin layer held between two transparent electrodes, the incident light is scattered due to electrohydrodynamic instabilities, and the cell transmission decreases rapidly towards a low value (a few percent); this latter then remains constant, even if the applied voltage is high (80 V, for example).

Little attention has been given to the transmission of such cells in the infrared range. Fray *et al.*[1] have determined for various applied voltages the light intensity scattered by a nematic of negative dielectric anisotropy in the infrared (about $\lambda = 10\ \mu m$); their results show three different regions attributed to the size of the scattering domains compared with the incident wavelength. Kawachi *et al.*[2] have recently mentioned the possibility of

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using nematic liquid crystals like MBBA as optical waveguide materials at 1.3 and 1.5 μm.

In this paper we report experiments on the transmission in the near infrared range (up to 2.5 μm) for nematic liquid crystals of negative dielectric anisotropy and for increasing applied voltages corresponding to the usual dynamic scattering mode.

EXPERIMENTAL

The experimental set-up is conventional. The sample is held between two conducting glass plates separated by mylar spacers (thickness about 10 μm). The initial orientation of the liquid crystal is homogeneous or homeotropic; the first is achieved by rubbing the electrodes, the second by deposition of a very thin film of surfactant HTAB (hexadecyltrimethylammonium bromide). The liquid crystal used in many of our experiments is ZLI 1735 (from E. Merck) which is nematic in the temperature range −10 to 79°C, and has a dielectric anisotropy $\varepsilon_a = -0.5$. However, the effects reported below have also been observed with other negative nematics, in particular with MBBA, provided that the electrical conductivity of the liquid crystal is sufficient (for this purpose a small quantity of tetrabutylammonium chloride is added to the nematic). The cell temperature is kept constant, but can be varied between 7 and 70°C. The transmission spectra for various applied ac voltages (50Hz) have been determined, in the spectral range from 0.4 to 2.5 μm, using a Beckmann spectrophotometer or a monochromator and a pyroelectric detector. The incident light beam is always perpendicular to the glass plates containing the liquid crystal.

RESULTS

Typical transmission spectra obtained at 20°C with the spectrophotometer for ZLI 1735 (thickness 13 μm) in a homogeneous alignment and for various applied voltages (50 Hz) are reproduced in Figure 1. The variation of the ratio I_v/I_o (I_v and I_o being respectively the transmitted light intensities with and without applied voltages V) with the light wavelength λ is plotted in Figure 2 for the same values of the voltage.

It appears that:

i) at an applied voltage of 7.5 V, which corresponds approximately to the threshold of instabilities, the cell transmission varies little around a value of about 50% in the wavelength range studied (0.4 to 2.5 μm);

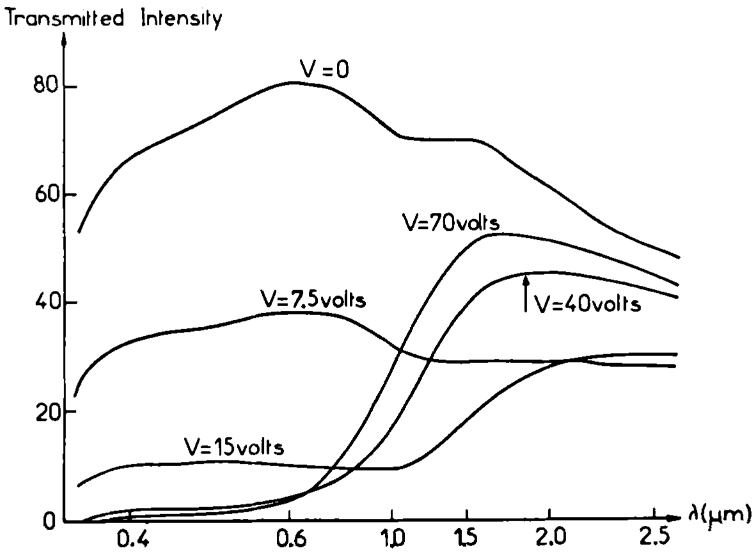

FIGURE 1 Transmission spectra obtained with the Beckmann spectrophotometer for ZLI 1735 at 20°C.

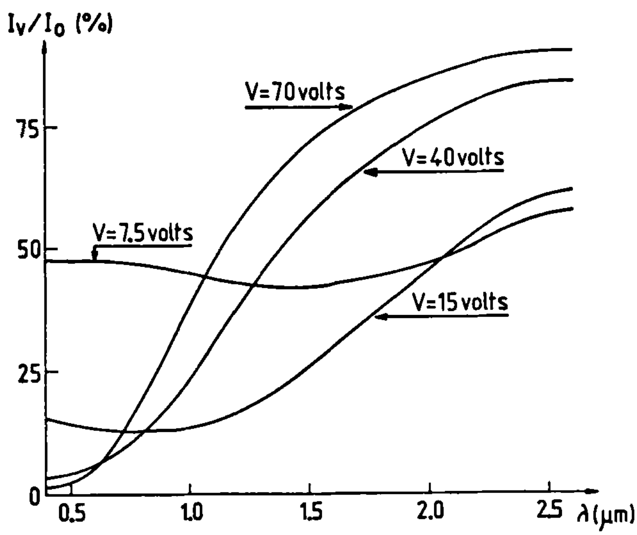

FIGURE 2 Variation of I_v/I_o (I_v = transmitted light intensity with an applied voltage, I_o = transmitted light intensity without voltage) with λ (linear) for ZLI 1735 (13 μm thick and with homogeneous alignment) at 20°C and various voltages.

ii) at higher voltages, the transmission, low (or very low) in the visible spectral range, increases with the voltage in the near infrared from $\lambda = 0.6$ to 0.7 μm; for example at $\lambda = 1.5$ μm it rises from 25% for $V = 15$ V to 70% for $V = 70$ V; this increase is faster as the voltage becomes higher.

These variations under the same conditions are also shown in Figure 3, where the relative transmission of the nematic film is plotted against the applied voltage at various wavelengths. It must be noted that at 2.5 μm and for voltages of 70–80 V, almost all of the incident light is transmitted, and consequently the scattered light intensity is very low.

The behavior of the nematic product in the homeotropic alignment is similar to that in a homogeneous orientation; an increase of the cell transmission in the infrared range appears for high voltages between 0.6 and 0.7 μm.

As indicated above, other nematics were used: for MBBA doped with a low percentage of quaternary ammonium salt, the same phenomenon is observed; the transmitted infrared intensity increases, other variables kept unchanged, with the electrical conductivity of the liquid crystal, i.e., with the quantity of dopant.

A first model put forward to explain the nematic light scattering and its angular variation assumed the liquid crystal to be composed of aligned

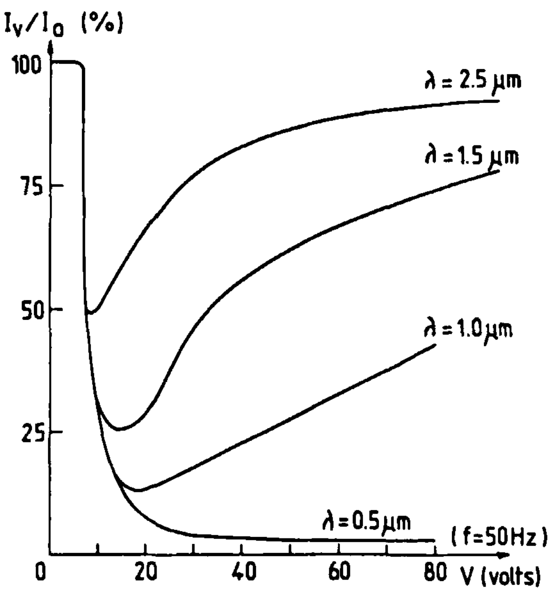

FIGURE 3 Variation of I_v/I_o with voltage for ZLI 1735 (13 μm thick and with homogeneous alignment) at 20°C and various wavelengths.

molecular swarms, their orientations being uncorrelated. Now it is well known[3,4] that light scattering is interpreted in terms of small amplitude orientational fluctuations, the density fluctuations giving a negligible contribution and the light scattering being expected to decrease with increasing wavelength, under our conditions as $1/\lambda^2$.

It does not seem that the influence of an electric field on the importance of orientational fluctuations has been taken into account, probably due to the complexity of the electrohydrodynamic processes which appear in this case, but it can be supposed that these fluctuations are more important at high fields. In Figure 4 we have plotted the relative scattered intensity $I_o - I_v/I_o$ (with the same notations as above) against $1/\lambda^2$ for ZLI 1735 at 20°C and for three values of the voltage. The curves show that over a range, the larger as the voltage is higher, these scattering losses are proportional to $1/\lambda^2$ whereas in the visible spectral domain they depend little on the wavelength and the voltage.

We have also considered the temperature dependence of the scattering. The theoretical relation giving the scattered intensity shows that it is essentially proportional to ε_a^2/K (ε_a dielectric anisotropy, K elastic constant); now both parameters ε_a and K decrease with increasing temperature so that the temperature effects are relatively small. The transmission spectra have been determined for a given voltage at various temperatures, and the

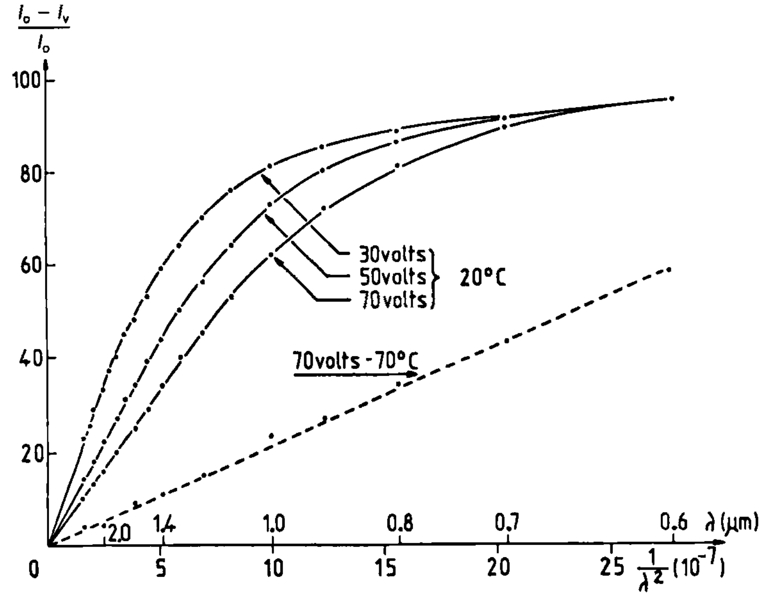

FIGURE 4 Relative scattered intensity $I_o - I_v/I_o$ *vs* $1/\lambda^2$ for ZLI 1735 (13 μm thick and with homogeneous alignment) at 20°C and various voltages.

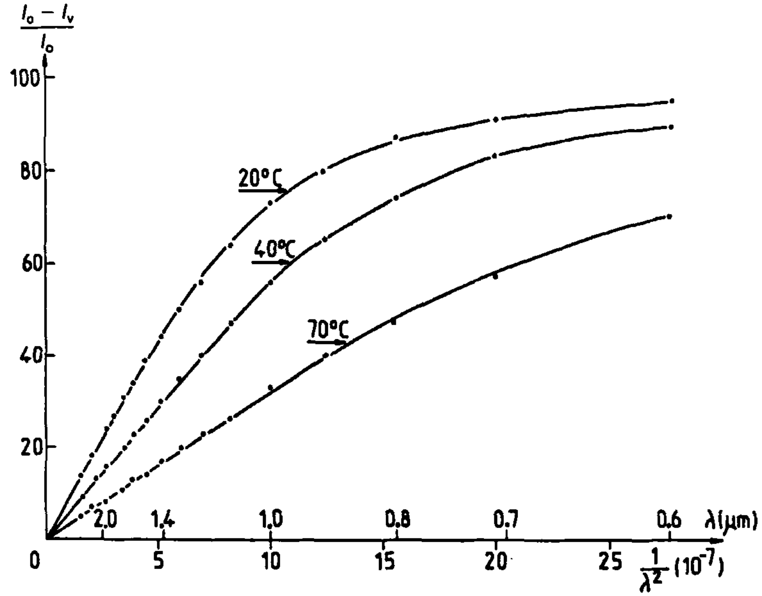

FIGURE 5 Temperature dependence of scattering losses *vs* $1/\lambda^2$ for ZLI 1735 (13 μm thick and with homogeneous alignment) at 50 V and various temperatures.

scattered light intensity is plotted against $1/\lambda^2$ in Figure 5 for three temperatures. It appears that the scattering losses are reduced by a rise in temperature; this variation is particularly important near the nematic-isotropic transition temperature (79°C for ZLI 1735) where the transmission at short wavelengths (0.5 μm, for example) increases drastically as observed by Khoo[5] and ourselves. In our experiments, this effect is shown clearly in Figures 4 (curve in broken line) and 5, for a temperature of 70°C.

The variations in the transmission of the nematic liquid crystal in the near infrared, produced by an applied voltage, can be used in numerous applications such as shutters, modulators, . . . in addition to that mentioned above[2] as an optical waveguide at 1.3 μm particularly interesting in optical communications. It is also possible to have a memory effect by the addition of a cholesteric material to the nematic (for example by addition of 10 wt% of cholesteryl nonanoate to ZLI 1735); this infrared filter can be erased by applying an HF voltage (≈1000 Hz).

Acknowledgments

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