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THE GUEST-HOST INTERACTION IN LIQUID CRYSTALS :

1. A New Fast Dichroic Shutter

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ABSTRACT. A new fast optical shutter, based on the guest-host interaction, that uses a 2 mm optical path length, has been demonstrated. Using a suitable pleochroic dye as guest in a cyanobiphenyl nematic host it has been shown that the shutter can be turned on and off in a few milliseconds. The electro-optic cell uses transverse electric fields, and field strength, frequency and temperature studies have been made. It has been shown that both increases and decreases in transient light levels may be obtained by changing the polarisation state of the incident light.

Since the early work of Heilmeier and Zanoni (1) there has been considerable interest in the guest-host interaction, in which the cooperative ordering of a nematic host is used to align suitable pleochroic host dye molecules in an external electric field, because of its potential use in colour switching. It has been shown that the host dye may be either dichroic (2) or fluorescent (3) and recent work (4,5) has discussed in detail several series of suitable dichroic and pleochroic dyes that give potentially better contrast ratios than previously available. Hitherto devices based on the guest-host effect have been limited to rise and decay times of $\sim$ 100-200 m sec. unless the device is extremely thin (6). Such thin devices ($\sim$ 5 μm electrode separation) are technologically difficult to produce over large surface areas. Recently however using a "thick" guest-host cell (7) we found that a fast electro-optic shutter with rise and decay times of the order of 5 m sec. could be fabricated using either guest pleochroic or fluorescent dyes in a cyanobiphenyl nematic host. It is the purpose of this note to present the preliminary details of this work for the dichroism measurements.

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The apparatus consisted of a 2 mWHeNe laser (λ=632.8nm) that could be polarised either vertically (V) or horizontally (H) by use of a suitable Fresnel rhomb and glass-laser prism polariser. The light from this passed through a 2 mm optical path length rectangular glass cell that contained vertical flat gold plated stainless steel electrodes. In this configuration the applied electric field was horizontal and transverse to the optical light path and the electrode spacing was 1.5 mm. Light transmitted through the cell was then detected via a suitable photomultiplier and recorded on a storage oscilloscope. The pleochroic dye used was thiazole at a concentration of 8×10^{-4} g/g in pentyl cyanobiphenyl (5 CB). The suitability of this dye and its structure have previously been discussed (5). Both samples were a gift from BDH Ltd (Poole, Dorset, U.K.) which is gratefully acknowledged. The glass cell was washed in hot chromic acid and then rinsed thoroughly in deionised distilled water, and finally in acetone. With the dye-liquid crystal solution in the cell the surface alignment was shown to be parallel to the electrodes as for equal incident light intensities the ratio of horizontally (I_H) to vertically (I_V) polarised light was 14 : 1, and these dye molecules have been shown to align readily with their geometric and absorption axis along the cyano-biphenyl director axis. It is believed that this homogeneous texture arises from minute surface scratches (or rubbing) produced on introducing the electrode assembly into the glass cell. In later measurements we have produced the same effect using a rubbed polyvinyl-alcohol film (5). In this note, measurements will be given in intensity units as these are the ultimately important units in the assessment of device capability. Further it is not certain that the ordering at the centre of the cell will be the same as that at the surfaces and thus absorption parameters would be impossible to calculate. Pulsed electric fields of durations $\sim$ 200 ms and voltages between 0 and 800 V for frequencies from DC to 10 KHz were applied to the samples.

Depending on the polarisation of the incident light it is possible to produce an increase (for I_V) or a decrease (I_H) in light level over the ambient on application of the pulsed fields and this will be discussed below. With the highly absorbing samples used herein, for no applied field, the ratio of transmitted to incident intensity was typically $\sim 10^{-3}$ and the results will be given for increases in light level (i.e. I_V). In figure 1(a) the field dependence of ΔI_V has been given relative to the field free transmit-

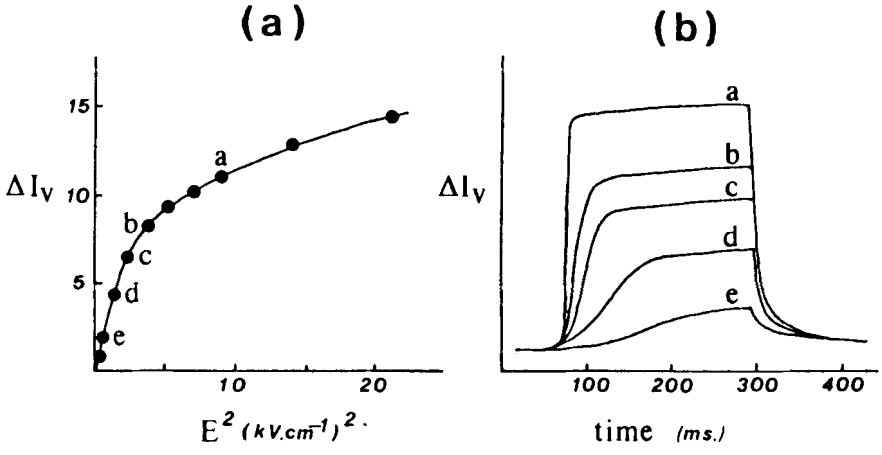

FIGURE 1.(a) Field and (b) Time dependence of ΔI_V for applied field of frequency 3 KHz and a temperature of 25°C. In (a) ΔI_V has been normalised with respect to the field free transmitted intensity, whereas in (b) they are in experimental units.

ted intensity and in figure 1(b) tracings of the recorded electric field transients illustrate the time dependence of the effect.

From figure 1 it is clear that both the rise and decay are field strength dependent and the greater the field strength the faster the transient changes. As the saturation field strength has not been obtained (Fig. 1.a) it is therefore probable that faster changes could be recorded. Using a definition for the decay time τ as that time required to decay back to 1/eth of the maximum transient intensity we find $\tau \sim 5 - 10$ ms. For the same r.m.s. field strength the decay times were frequency independent (between DC and 10 KHz). As the changes ΔI_V are the ratio of the transient transmitted intensity to the ambient light level they are a measure of the contrast ratio. For vertically polarised incident light the molecules are rotated away from an absorpting state on application of the transverse horizontal field and therefore ΔI_V is positive. If however horizontally polarised incident light is used, the light level should decrease from the ambient level towards a maximum absorption and thus ΔI_H is negative. For a truly dichroic phenomenon the magnitudes of both ΔI_H and ΔI_V should change with the plane of polarisation of the incident light becoming zero at the "magic angle" of 54°45' (8), and this can be seen to be the case from figure 2.

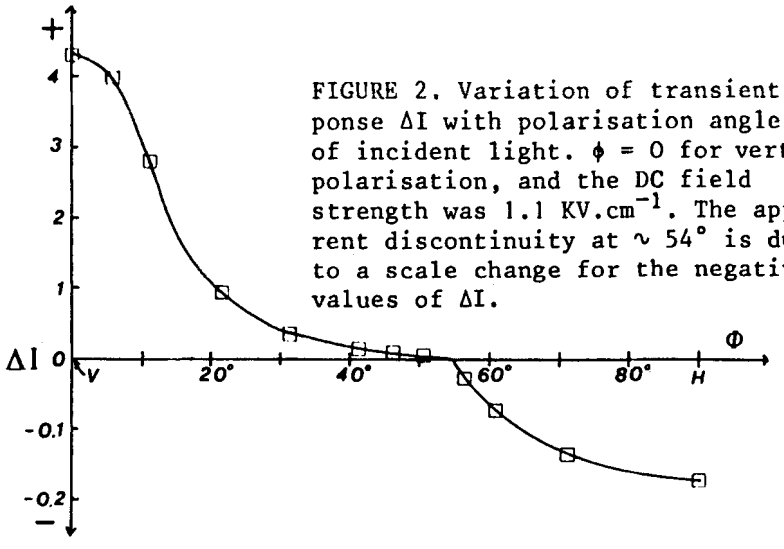

FIGURE 2. Variation of transient response ΔI with polarisation angle ϕ of incident light. ϕ = 0 for vertical polarisation, and the DC field strength was 1.1 KV.cm^{-1}. The apparent discontinuity at ∿ 54° is due to a scale change for the negative values of ΔI.

From a device viewpoint the use of alternating fields is generally preferable to DC fields in that electrode polarisation and impurity conduction effects are reduced and sample lifetimes are prolonged. We have examined the performance of the current cell over the frequency range from DC to 10 KHz, Fig. 3. From figure 3(a) it can be seen that the transmitted light intensity is composed of a steady signal (ΔI_V) and a superimposed signal $\delta(\Delta I_V)$ of double frequency. This double frequency component undergoes a frequency dispersion and is negligible above 3 KHz, figure 3b, whilst the steady signal remains constant throughout this frequency range. Thus the same overall change in ΔI can be produced, for an equivalent r.m.s. field, above 3 KHz as with DC fields but without the disadvantages of such fields. The use of very low frequency fields, where $\Delta I = \delta(\Delta I)$, confirms that the cell can be repetitively pulsed and could therefore be commercially useful. Finally the current measurements were carried out at 25(±·2)°C and no significant temperature dependance was measured until within ∿ 1.5°C of the nematic-isotropic transition temperature for 5 CB (i.e. 35.1°C). At this point the relative change in ΔI_V increased rapidly, becoming three times larger for a temperature 0.3°C from the transition, but still within the nematic phase. From a theoretical viewpoint this behaviour is interesting in that the apparent critical temperature corresponds roughly to that given by the Landau - de Gennes phenomenological model for a second order phase transition in 5 CB and this would suggest that significant structural

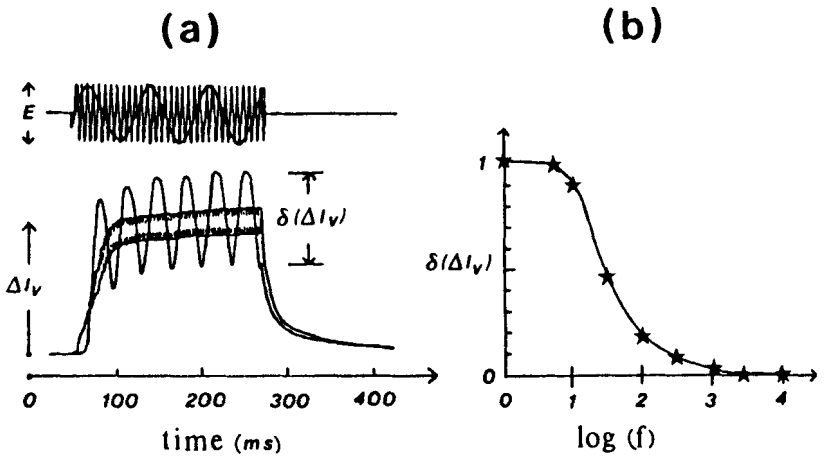

FIGURE 3.(a) The frequency doubled dichroic signal at 10 and 100 Hz where the two signals have been superimposed for comparison, and the applied field E has been given for reference. The E_{rms} = 1.4 kV.cm^{-1} in both cases. (b) The frequency dispersion of the frequency doubled component, $\delta(\Delta I_V)$.

changes are taking place in this restricted temperature range. It is in this range of temperature that the most dramatic changes in order parameter are manifest in the nematic phase (9), and it is presumably the loosening of the ordering that allows larger optical effects to be obtained for a constant applied field. This further suggests that such pleochroic dye probes could be extremely useful for studies of such transitional behaviour.

In conclusion an electro-optic switch with turn on and off times of a few milliseconds has been demonstrated using the guest-host interaction. The results have been presented for a fixed concentration of dye and optical path length and future studies will examine how changes in these parameters and surface alignment affect the device performance. It is also anticipated that such studies will lead to an understanding of the orientational mechanisms responsible for the faster effect in such thick cells. Finally, whilst the applied voltages used in the present cell are higher than those used in conventional thin cell devices the current consumption is very low ($I < 1\mu A$ and $R_{cell} = 2 \times 10^{10}\Omega$) and thus high tension-low current amplifiers of the type currently used in television technology could be used to drive the device between frequencies of 10 Hz and 50 KHz, and make its use feasible.

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