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THE GUEST-HOST INTERACTION IN LIQUID CRYSTALS :

2. A New Fast Fluorescent Shutter

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ABSTRACT. A new fast optical shutter, based on the guest-host interaction using a fluorescent dye, has been demonstrated. Using acridine orange as guest in a cyanobiphenyl nematic host it has been shown that the shutter can be turned on or off in a few milliseconds. The electro-optic cell, which has a 2mm optical path length, uses transverse electric fields and both field strength and frequency dependence 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 or emergent light.

It was shown recently, by using the guest-host interaction (1) with a pleochroic guest dye in a cyanobiphenyl host and a 2mm optical path length, that a fast dichroic shutter could demonstrated (2). Rise and decay times of the order of 5ms were recorded and it was shown that, by changing the polarisation state of the incident light, an increase or decrease in light level could be obtained. It is the purpose of this note to show how similar fast transient electrooptical effects may be demonstrated using a fluorescent dye, with the added advantage of the broad wavelength emission of the dye molecule. Such dyes are well known commercially as image brighteners and ordering of fluorescent dyes under continuous electric fields in a nematic host was demonstrated by Sackmann and Rehm (3) in 1970.

The apparatus consisted of a 10mW HeCd laser (λ = 441.6nm) that could be attenuated using neutral density filters and polarised either vertically (V) or horizontally (H) by use of a suitable Fresnel rhomb and a glan-laser prism polariser. The light from this passed through a 2mm optical path length rectangular glass cell that

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contained vertical flat gold plated stainless steel electrodes. The electrode spacing was 1.1mm and the electric field was horizontal and transverse to the optical light path. Light transmitted from the cell passed via another glan-laser polariser and an optical cut-off filter (Barr & Stroud type OG 550) to a detecting photomultiplier and the signal was then recorded on a storage oscilloscope. The fluorescent dye used was acridine orange (AO) at a concentration of 2x10^{-4} g/g in pentyl cyanobiphenyl (5 CB). The 5CB was a gift from BDH Ltd (Poole, Dorset, U.K.) which is gratefully acknowledged. The cell preparation was as previously described and the surface alignment was verified as being homogeneous parallel to the electrodes (2). Herein measurements will be given in intensity units as these are the important units in assesment of device capability, and without knowing the orientation at the centre of the cell it would be impossible to calculate the absorption parameters. The pulsed electric fields varied in frequency between DC and 10KHz, in voltage between 0 and 800V and were applied for durations of ∿200ms.

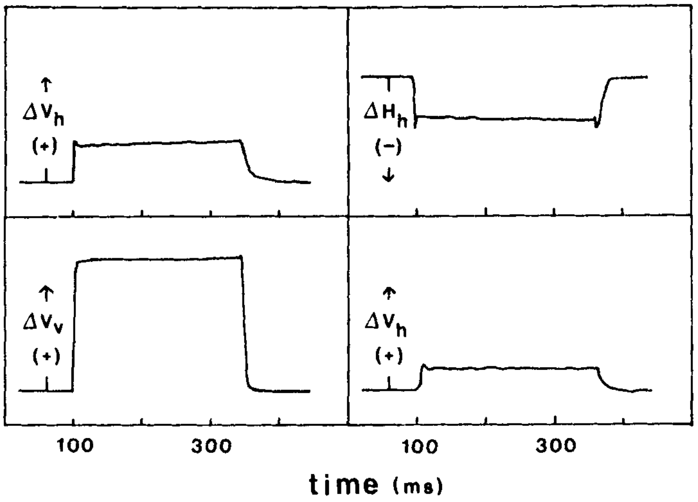

FIGURE 1. Transient changes in the polarised components of fluorescence for AO-5CB. The optical responses are normalised to the same zero field intensity and the applied field was a 250ms D.C. pulse with E = 3.7kV. cm^{-1}.

Fluorescence is a two step process involving absorption at a given wavelength and reemission at a longer wavelength, and is associated with electronic transitions which relative to the dye molecular geometry, are directional in space. Thus changes in orientation of the dye molecule change the absorption and subsequent emission intensities and depending on the polarisation of the incident and transmitted light and the sample thickness or concentration it is possible to produce an increase or decrease in light level (4). With the dye AO and for absorption of blue light and emission above 550 nm, both the absorption and transmission moments lie in the plane of the molecue, and if the dye is ordered by the liquid crystal via the guest-host interaction, application of an electric field will produce changes (Δ) in the fluorescent light level. This can be seen to be the case in Figure 1 for the AO-5 CB system, where V and H refer to the incident light and v and h refer to the fluorescent light polarisation states. Detection of the fluorescent components was at zero angle (i.e. in the direction of the incident beam) and the cutoff filter ensured no blue light was transmitted to the photomultiplier. These changes show that AO is infact ordered by 5CB, that it is possible to produce both positive and negative changes in light level, and that when using pulsed fields the transient effects are relatively fast. Further if the incident light is polarised at the magic angle of 54°45' no absorption and hence no fluorescence changes are recorded, as was also the case for the purely dichroic dye (2).

In figure 2(a) the field dependence of ΔH_v has been given relative to the field free intensity (H_v) and in figure 2(b) tracings of the recorded electric field transients illustrate the time dependence of the effect. The other components ΔH_h (negative) and ΔV_h, ΔV_v (positive) were similarly field dependent but varied in magnitude as can be seen from figure 1. Maximum changes of -0.2 and +0.8 were recorded for $\Delta H_h/\Delta H_h$ and $\Delta V_v/V_v$ respectively. From figure 2 it is clear that both the rise and decay of the fluorescence changes are field dependent and the higher the applied field strength the faster the transient changes. Using a definition for the decay time τ as that time required to decay back to 1/eth of the maximum intensity, then for the maximum applied field $\tau \sim 15$ msec. The rise time is less than 5ms. It is possible as the change in ΔH_v is not completely saturated that at higher field strengths faster changes could be recorded. These transient response times

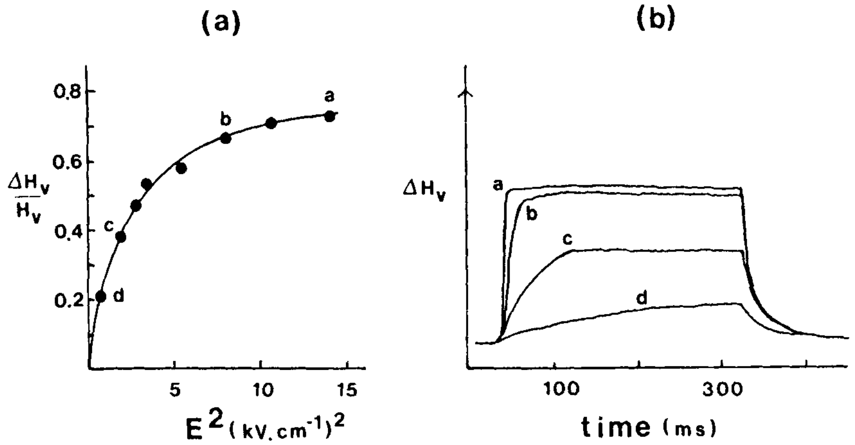

FIGURE 2(a) Field and (b) time dependence of ΔH_v for DC applied fields and a temperature of 23.3℃. In (a) ΔH_v has been normalised with respect to the field free fluorescent intensity, where-as in (b) ΔH_v is in experimental units.

were independent of frequency between DC and 10KHz for equivalent r.m.s field strengths. However as shown for alternating fields, in figure 3(a) the fluorescent light intensity change is composed of a steady component (ΔV_h) and a superimposed signal $\delta(\Delta V_h)$ of double frequency. This double frequency component, recorded for all four possible combinations of V,H,v,h, undergoes a frequency dispersion and is negligible above ∿1kHz, figure 3(b), whilst the steady signal ΔV_h remains constant throughout this frequency range. Thus the same overall change in ΔV_h can be produced, for the equivalent r.m.s. field, above 1 kHz as with DC fields but without the low frequency electrode polarisation and impurity conduction effects that are often detrimental to sample lifetimes. The low frequency measurements reported do however show that the fluorescence cell can be repetitively pulsed and could therefore be commercially useful.

In conclusion, an electro-optic switch turn on and off time of several milliseconds has been demonstrated using the guest-host interaction with a fluorescent dye. Such measurements confirm previous results obtained for a pleochroic thiazole dye. Thus with a 2mm optical path length,

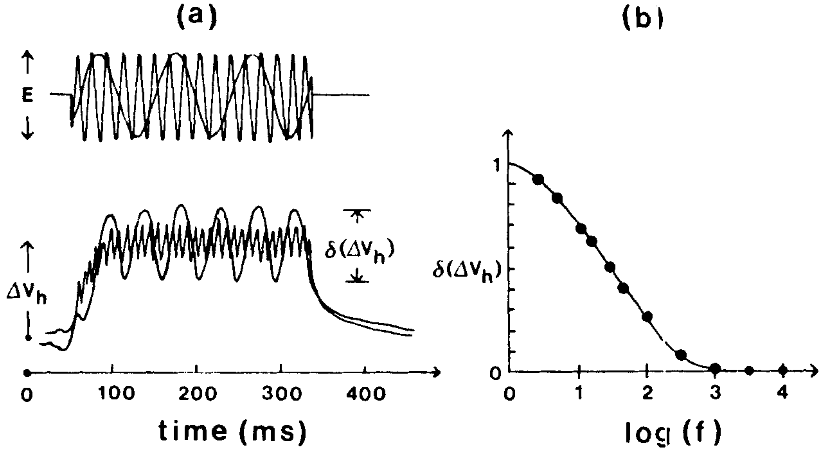

FIGURE 3. (a) The frequency doubled fluorescent signal (ΔV_h) at 10 and 50 Hz where the two signals have been super-imposed for comparison, and the applied field E given for reference. The $E_{rms} = 2.1$ KV.cm^{-1} in both cases. (b) The frequency dispersion of the frequency doubled component, $\delta(\Delta V_h)$.

faster transient response times are recorded than with conventional thin cells (i.e. 20-50μm spacing and $\tau \sim 100$-200ms). The results have been presented for a fixed dye concentration, optical path length, and surface alignment, and future studies will examine how changes in these parameters affect device performance. The contrast ratios recorded with the fluorescent dye were lower than those obtained for the dichroic shutter (2). There are two main reasons for this. Firstly the AO may not have such a high order parameter when the 5CB is aligned as the thiazole used in (2), and secondly as fluorescence is a two step process involving absorption and emission, considerable depolarised scattering of the emitted light within the cell may take place before the light is finally transmitted. The AO was chosen (a) for its solubility in 5CB and (b) because of its geometric shape and highly directional transition moments. Recent preliminary measurements carried out by the author have indicated that dimethylaminonitrostilbene is more highly ordered than the AO used herein, and future work will examine the effect of the fluorescent dye structure on order parameter in the cyanobiphenyls. It is thus anticipated that contrast ratios will be considerably improved, and that with the advantage of the wide viewing angle and brightness associated with fluorescence such fast electro-optic devices may have useful commercial applications.

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