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Light on dark laser addressed smectic liquid crystal projection displays†

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Two techniques for producing dense uniform bulk scattering in cells containing smectic A liquid crystals have been examined for use in a large area liquid crystal projection display. Textures obtained using both thermal pulses and by dynamic scattering in the smectic A phase were evaluated for their uniformity and scattering density. The conditions required for optimum scattering are described in terms of the electrical characteristics of the scattering pulses used, the effects of different surface alignment treatments and of the nematic bandwidth of the materials employed. The two techniques are compared with respect to their suitability for large area, high information content, white on black, laser addressed liquid crystal light valves.

1. Introduction

Large area laser addressed liquid crystal light valve displays have been demonstrated in a variety of formats in recent years [1]. In many of these, scattering areas are written onto a clear non-scattering liquid crystal cell using local heating from a focused laser. Projection through the cell in a schlieren optical system produces black images against a white background [2]. In order to reverse the contrast of the light valve to enable its use in projection overlay displays, whilst making efficient use of the available light, it is necessary to induce the entire active area of the liquid crystal cell into a densely scattering spherulitic focal conic texture, which provides the uniform black background off-state. Clear lines are then written by laser heating when a small electric field is applied across the liquid crystal cell.

Two known techniques [3, 4] for producing the scattering off-state are evaluated to establish the optimum cell and material parameters for display operation. In the first of these a large current pulse was applied through one of the inner transparent electrodes of indium-tin oxide in the cell for several tens of milliseconds. The intense local heating which this produced and the subsequent rapid cooling from the isotropic phase gave rise to scattering spherulitic focal conic texture in the smectic A phase. In the second case the liquid crystal was doped with hydroxy methyl ammonium bromide (HMAB) and a large low frequency AC square wave was applied to the cell. The ensuing electrohydrodynamic instabilities also induced a densely scattering texture.

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2. Experimental

(*a*) *Thermal scattering*

Test cells were mounted in a thermostated enclosure which allowed their temperature to be controlled to +/− 0·05°C across the active area. The current for the pulse heater was provided by a 10 mF capacitor bank with a mosfet power switch. This was charged up to a voltage V and then discharged across the heater plate resistance ($R = 10\,\Omega$) of the cell for a short time period (T ms). The capacitor bank was large enough to ensure that V remained almost constant throughout the pulse time. In between scattering pulses, cells were rendered homeotropic by a two second burst of high voltage, high frequency field (100 V 1 kHz AC square wave). Collimated light from a He–Ne laser was used in conjunction with a silicon photodiode and schlieren stop [5] to measure the contrast ratio of the scattering textures produced. The photodiode output was coupled to a storage oscilloscope and a digital voltmeter to enable cell transmission to be recorded throughout the pulse duration. The contrast ratio (CR) was defined as the ratio of cell transmission in the homeotropic state (T_H) to that when in the scattering state (T_S).

$$\mathrm{CR} = T_H/T_S.$$

The results were collected for cells with two types of surface alignment; one had a chrome complex ($C_{17}H_{35}CO_2Cr_2Cl_4OH$) spin coated as a monolayer from a 0·3 per cent by weight solution in methanol, to promote homeotropic orientation and the other had a vacuum deposited SiO layer (300 Å thickness) evaporated at a 90° angle to the substrate, to promote a random planar alignment [6]. The contrast ratios were determined for a range of pulse power densities (P_D) by varying the capacitor voltage (V) whilst keeping the pulse width constant at 30 ms duration,

$$P_D = V^2/AR.$$

where A is the area of the resistive heater. The time taken for the liquid crystal to cool from the isotropic phase transmission (100 per cent) to 50 per cent transmission was recorded with the storage oscilloscope. Results were repeated for both cell types over a range of bias temperatures below the S_A–N transition.

(*b*) *Dynamic scattering*

The cells were mounted as above and connected to a high voltage AC field burst generator. Cells which had been doped with either 0·005 or 0·02 per cent by weight of HMAB were prepared and scattered using low frequency (50 Hz, 100 Hz and 200 Hz) high voltage field pulses. The percentage of the cell area filled with scattering texture in both cell types, after the burst of AC, was recorded at a range of bias temperatures. Both cells had chrome complex surface alignment since cells manufactured with SiO layers and filled with identical mixtures could not be scattered. In between scattering field bursts the cells were cleared by applying a large, high frequency electric field (100 V 1 kHz AC square wave).

(*c*) *Mixtures used for scattering measurements*

The smectic mixtures were based on the 4-*n*-alkyl-and 4-*n*-alkyloxy-4′-cyanobiphenyls and were supplied by BDH [7]. The acronyms for these and their transition

temperatures are

Mixture	$T_{S_A N}$/°C	$T_{S_A/NT}$/°C
S_2 + 2 per cent IR DYE	44·9	47·1
BDH 13980 + 2 per cent IR DYE	54·1	55·1
BDH 13977 + 2 per cent IR DYE		60·2

The infrared dye plays no part in the scattering but is required for laser writing in the actual display cells, it has therefore been included in the mixtures to take into account its effect on their transition temperatures.

3. Results and discussions

(*a*) *Thermal scattering*

The initial scattering studies using thermal pulsing were made on a smectic mixture (BDH 13980) which has a narrow 1°C nematic band between the smectic A and isotropic phases. All attempts to scatter these mixtures produced bar patterns in the cells, as shown in figure 1. These patterns were attributed to director flow patterns set up in the nematic phase which on cooling were frozen into the smectic phase. In order to avoid this effect cells were prepared with a smectic mixture (BDH 13977) which had no nematic band. These cells showed no tendency to form bar patterns but instead gave rise to dense, highly uniform scattering textures. The results obtained with this material are shown in figures 2 to 5.

Figures 2 and 3 show the contrast ratios obtained in cells with both the chrome complex and SiO alignment over a range of bias temperatures below the S_A–I transition. The peak contrast ratios obtained for the SiO aligned cells were about two orders of magnitude greater than those of cells with chrome complex alignment. Microscopic examination of the textures produced in chrome complex aligned cells indicated that the weak scattering resulted from homeotropic realignment close

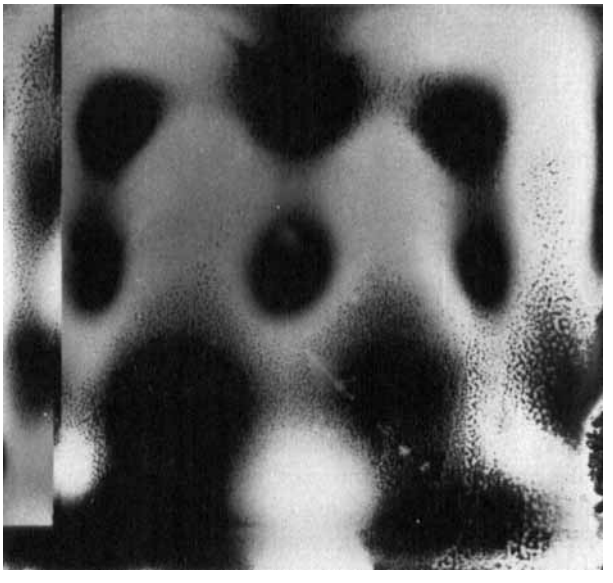

Figure 1. Typical director flow patterns quenched into the smectic phase from thermal pulsing of mixtures with a narrow nematic range.

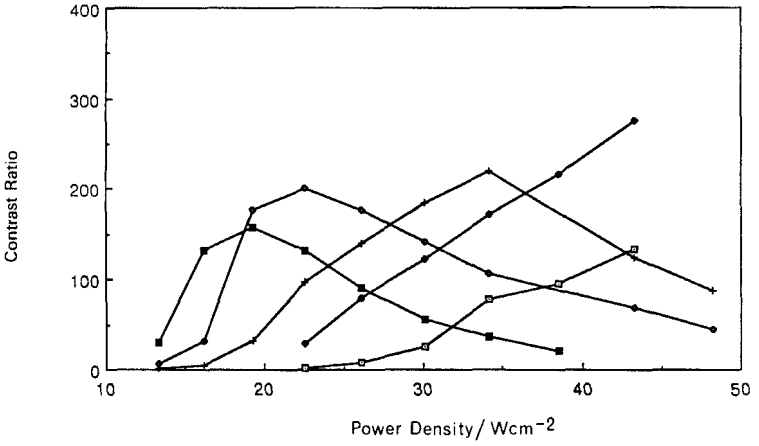

Figure 2. Plot of contrast ratio against thermal pulse power density in cells with chrome complex alignment. ⊡, represents bias-10; ◆, bias-7; +, bias-6; ◇, bias-5; and ■, bias-4.

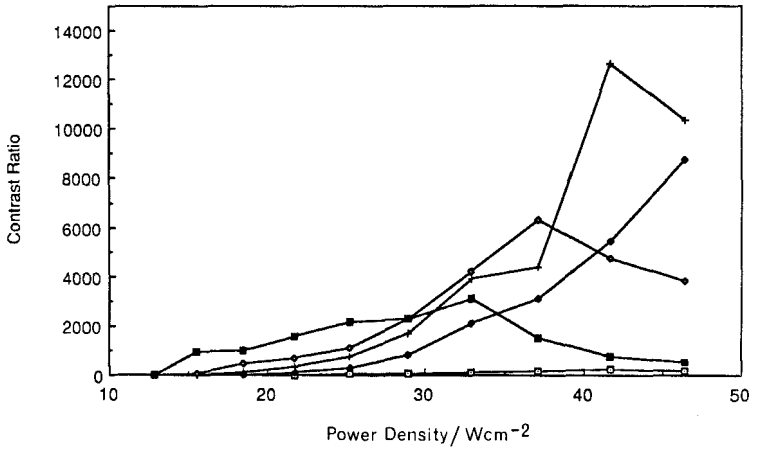

Figure 3. Plot of contrast ratio against thermal pulse power density in cells with SiO alignment. ⊡, represents bias-10; ◆, bias-7; +, bias-6; ◇, bias-5; and ■, bias-4.

to the surfaces. In cells with SiO surface treatment differences in scattering densities were largely attributed to variations in the size of the focal conic domains. These results confirmed our previous observations obtained using laser heating [6].

For both SiO and chrome complex aligned cells, an optimum power density was observed for each bias temperature at which the contrast ratio was greatest. Below this optimum, the contrast ratio decreased since only those regions close to the heater plate were heated into the isotropic phase by the thermal pulse and hence cooled to give a thin scattering texture. Above this optimum, excessive heating gave rise to longer cooling times enabling surface forces to reorient the liquid crystal director. In cells with chrome complex alignment, regions close to the alignment layer cooled to give a homeotropic texture whereas cells with the SiO surface treatment cooled to give weakly scattering focal conic textures. At lower bias temperatures more energy was required to ensure that all the liquid crystal was heated into the isotropic phase. The optimum power density required for maximum scattering density was therefore found

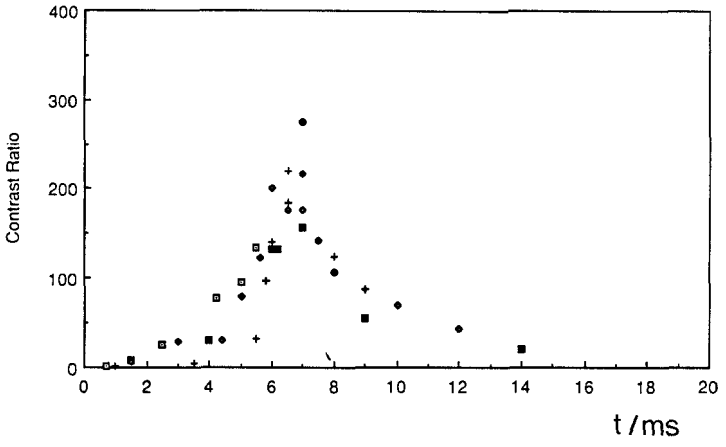

Figure 4. Scatter plot of contrast ratio against the cooling time from isotropic to 50 per cent trans in cells with chrome complex alignment. ⊡, represents bias-10; ◆, bias-7; +, bias-6; ◇, bias-5; and ■, bias-4.

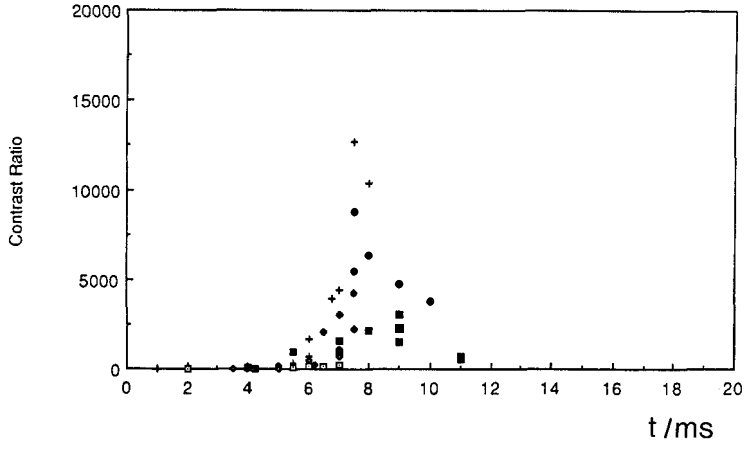

Figure 5. Scatter plot of contrast ratio against cooling time from isotropic to 50 per cent trans in cells with SiO alignment. ⊡, represents bias-10; ◆, bias-7; +, bias-6; ◇, bias-5; and ■, bias-4.

to increase with decreasing bias temperature. Figures 4 and 5 show the variation of the measured cooling time with contrast ratio for a range of bias temperatures in cells with both SiO and chrome complex alignment. Both cell types showed a sharp peak in their contrast ratios for cooling times of about 7 ms which were measured for pulses at the optimum power density for each bias temperature. Cooling times of less than 7 ms corresponded to low power density pulses and cooling times of greater than 7 ms to high power density pulses.

(*b*) *Dynamic scattering*

The dynamic scattering results shown in figures 6 and 7 indicate the percentage of the cell area induced into the scattering state by a field burst of two seconds at three different frequencies and a range of bias temperatures for the S_2 + 2 per cent IR dye mixture with two concentrations of dynamic scattering dopant (HMAB). In all

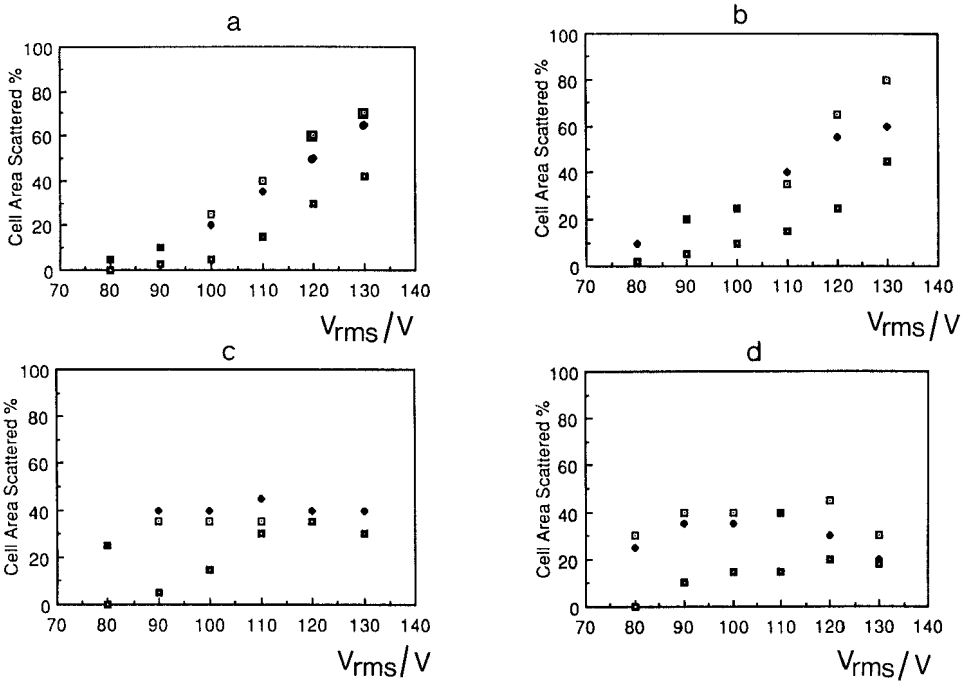

Figure 6. Cell area scattered by a 2 s field pulse in cells with chrome complex alignment and 0·0005 per cent HMAB at bias temperatures of (*a*) 9°C, (*b*) 7°C, (*c*) 5°C, (*d*) 3°C. ⊡, represents a frequency of 10 Hz; ◆, 20 Hz; and ⊡, 50 Hz.

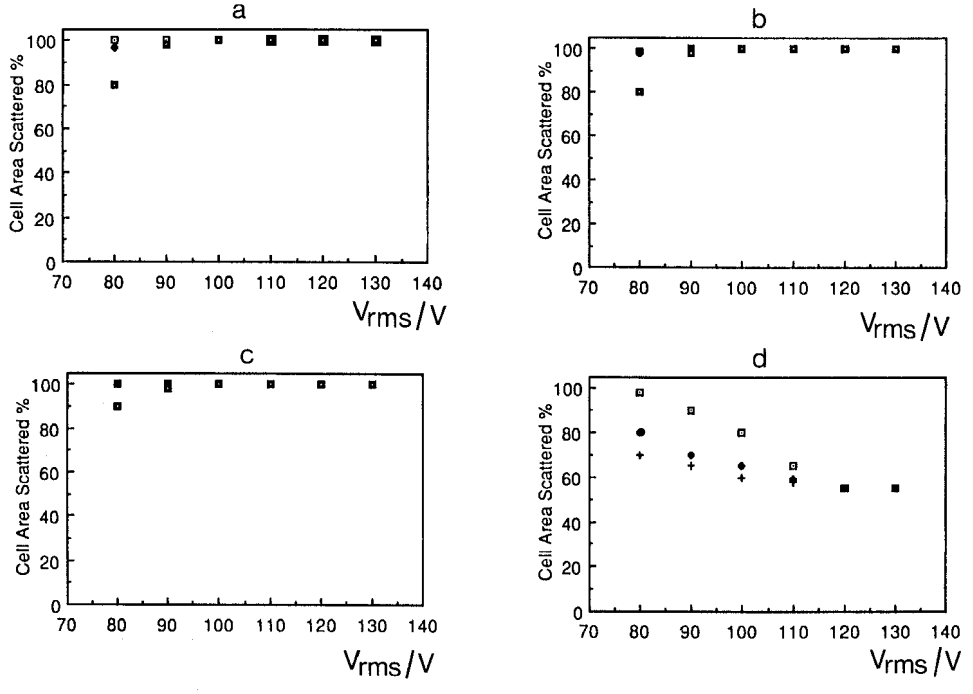

Figure 7. Cell area scattered by a 2 s field pulse in cells with chrome complex alignment and 0·02 per cent HMAB at bias temperatures of (*a*) 9°C, (*b*) 7°C, (*c*) 5°C, (*d*) 3°C. ⊡, represents a frequency of 10 Hz; ◆, 20 Hz; and ⊡, 50 Hz.

cases as the scattering field was increased and threshold voltage (V_{th}) was reached at which scattering was observed in a small number of sites in the cell. Above V_{th} these sites grew and eventually merged to fill the whole of the active area. At a scattering voltage (V_s) above V_{th} the cell was completely scattered within the field burst time. In summary the scattering voltage V_s was found to decrease with increasing bias temperature and dopant concentration and decreasing frequency of the applied field. At high bias temperatures or dopant concentrations electrical heating during the scattering pulse raised the bias temperatures sufficiently for surface forces to cause partial realignment of the liquid crystal which resulted in weakly scattering textures. The contrast ratios produced by dynamic scattering in cells with the 0·02 per cent HMAB mixture were measured for comparison with the results obtained by thermal pulsing. Cells uniformaly scattered 4°C below the S_A–N transition gave rise to contrast ratios as high as 4000 : 1.

4. Conclusions

In a typical schlieren projection display using a 300 W mercury arc lamp, the size of the arc limits the maximum contrast ratio to 200 : 1. Thermal pulsing and dynamic scattering have been shown to produce contrast ratios of 12000 : 1 and 4000 : 1 respectively. Therefore both techniques are well suited for application in high brightness white on black liquid crystal light valves. The general conclusions drawn from a comparison of the two techniques may be summarized as follows:

(1) *Thermal pulsing*
- (*a*) SiO alignment gives higher contrast ratios than chrome complex alignment in all cases.
- (*b*) Removing the nematic phase gives uniform textures.
- (*c*) Maximum contrast ratios are obtained at low bias temperatures with high energy pulses. However, to achieve useful laser writing rates we need to operate at higher bias temperatures. Even at 4°C below the S_A–I transition measured contrast ratios are in excess of 2000 : 1.
- (*d*) At all bias temperatures measured the scattering textures produced showed long term stability.

(2) *Dynamic scattering*
- (*a*) Chrome complex alignment is essential.
- (*b*) A dynamic scattering dopant concentration of around 0·02 per cent HMAB is essential to achieve total coverage of the cell area within the burst time.
- (*c*) Concentrations of dopant above 0·02 per cent give rise to heating problems.

(3) *Comparison of both techniques*
- (*a*) Both thermal pulsing and dynamic scattering can produce textures with contrast ratios well in excess of the 200 : 1 contrast ratio limit of the arc lamp. Thermal pulsing with SiO alignment gives rise to higher contrast ratios than dynamic scattering with chrome alignment.
- (*b*) Thermal pulse scattering calls require very uniform 10 Ω/□ ITO whereas with dynamic scattering cells these parameters are not critical.

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