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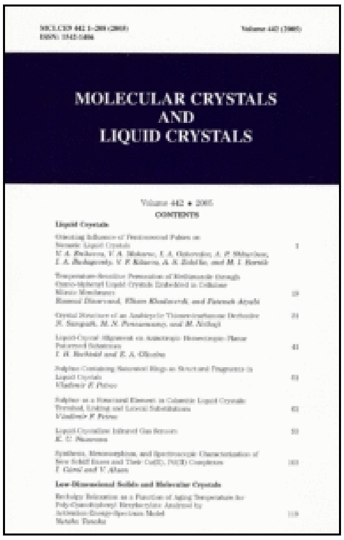

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Wide Viewing Angle and Fast Responding TN LCD

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WIDE VIEWING ANGLE AND FAST RESPONDING TN LCD

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A new type of TN display device has been fabricated by sandwiching a dual frequency addressable nematic liquid crystal material between two unrubbed polyimide coated glass plates. Between crossed polarizers, the bright state is observed by applying a high frequency electric field, while the dark state by applying a low frequency electric field of similar strength. This dual frequency addressed rubbing free device shows very wide and highly symmetric viewing angle characteristics, with contrast ratio comparable to that of a rubbed TN device, and with very fast response time.

Addressing the device in a "dual frequency dual amplitude pulsed mode" leads to only a small increase (∼1.5 times) in power consumption in comparison with the conventional single frequency addressed device.

Keywords: fast responding; TN LCD; wide viewing angle

INTRODUCTION

The major drawbacks of the conventional twisted nematic (TN) display are (i) a limited and asymmetric viewing angle, with contrast inversion in certain directions, and (ii) a comparatively slow response time. Further, the rubbing method usually employed for the alignment of the molecules during the fabrication of this cell generates dust particles and electrostatic charges, which result in a reduction in the production yield.

Several methods have been proposed for the enhancement of the viewing angle. They are achieved by an addition of an external retardation film [1–3], the use of the in-plane switching mode [4–6], the multidomain mode [7,8], and the amorphous (rubbing free) mode [9,10]. To get faster response

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*Corresponding author. E-mail: clcr@vsnl.com the methods adopted are the use of thin cells [11], the in-plane switching mode [4–6], the π-cell [12] and dual frequency addressing [13–15].

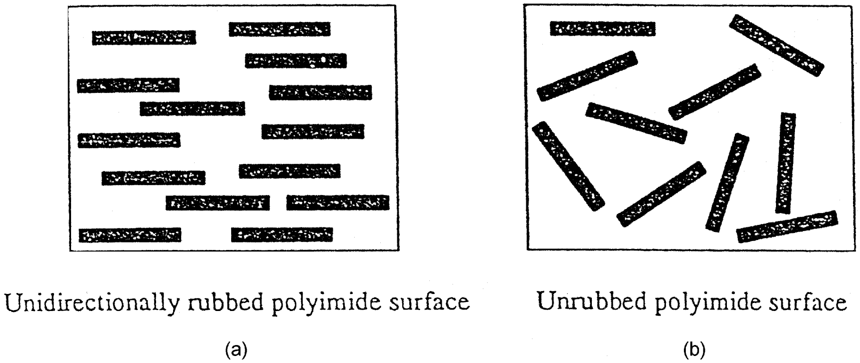
We describe here a new type of TN display with a novel addressing system which shows wide and highly symmetric viewing angle characteristics with contrast ratio comparable to that of the conventional rubbed TN device and very fast response time. Throughout this paper we discuss the device addressed in the *normally white* mode.

THE AMORPHOUS TN CELL

Figure 1(a) illustrates the arrangement of the molecules when the polyimide coated surface is rubbed unidirectionally. The molecules lie parallel to the substrate plane and are oriented unidirectionally in the plane. On the other hand, as shown in Figure 1(b) if the surface is unrubbed, the molecules lie parallel to the substrate plane but randomly oriented in the plane. As indicated earlier, the viewing angle is limited and unsymmetrical in the conventional rubbed TN device, whereas it is wide and highly symmetric in the amorphous (unrubbed) TN display [9,10].

MATERIAL EMPLOYED

The material used in the present device was a dual frequency addressable nematic. The material has a dielectric anisotropy $\Delta\varepsilon$ which changes sign at a cross-over frequency f_c, $\Delta\varepsilon > 0$ for $f < f_c$ and $\Delta\varepsilon < 0$ for $f > f_c$ as shown schematically in Figure 2. It is well established that in such materials the



(a)

(b)

FIGURE 1 Schematic representation of the arrangement of the molecules (a) lying parallel to the substrate plane on a unidirectionally rubbed surface (b) lying parallel to the unrubbed surface but oriented randomly in the substrate plane.

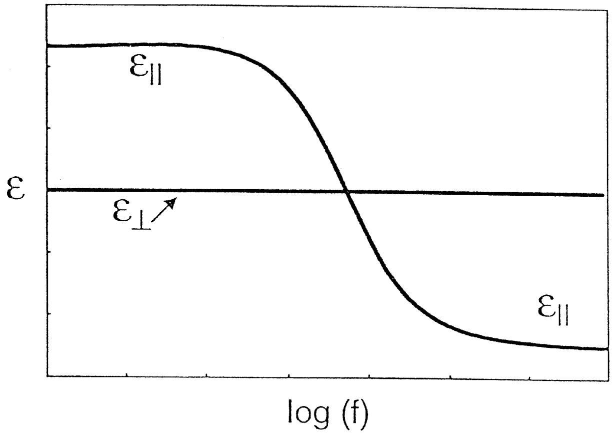


FIGURE 2 Frequency (f) dependence of the dielectric constant along ($\varepsilon_{\|}$) and perpendicular ($\varepsilon_{\perp}$) to the director in a dual frequency addressable nematic material. Note that the dielectric anisotropy $\Delta\varepsilon(=\varepsilon_{\|}-\varepsilon_{\perp})$ changes sign at the crossover frequency f_c.

response time is much faster that for the conventional single frequency TN device and also there is a greater multiplexing ratio [14]. Commercially available dual frequency addressable ROLIC 2F-3333 together with a chiral dopant ROLIC CM209F was used in our experiments. The concentration of the dopant was adjusted to give 90° twist in the 8 µm thick cell.

EXPERIMENTAL ARRANGEMENT

Dual frequency addressing was achieved by switching the frequency between low frequency $f_{low} = 1\,kHz$ ($\Delta\varepsilon > 0$) and $f_{high} = 20\,kHz$ ($\Delta\varepsilon < 0$) using an arbitrary waveform generator (Stanford Research Systems DS 345) in conjunction with a power amplifier (FLC Electronics). Response time measurements were carried out using a polarizing microscope (Leitz, DMRXP) and a photodiode connected to a digital oscilloscope (Tektronix TDS420A) to determine the transmitted optical power. Viewing cone analysis was performed using a Display Measuring System (Autronics Melchers). The schematic diagram of the experimental set up is shown in Figure 3.

SWITCHING CHARACTERISTICS

A typical electrooptic response curve is shown in Figure 4. The regions marked f_{low} and f_{high}, represent respectively the periods when the device

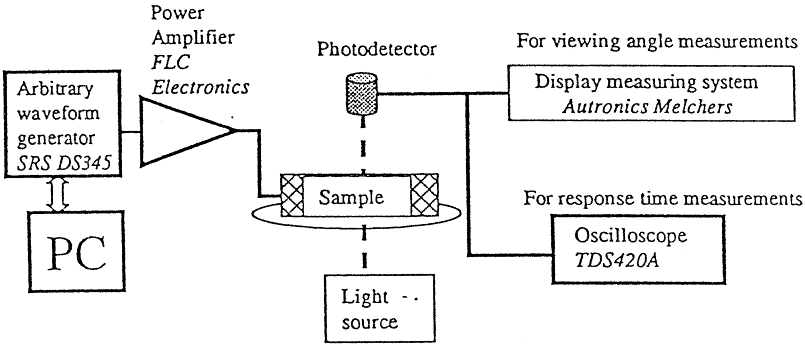


FIGURE 3 Schematic diagram of the experimental arrangement used in the present studies.

switches from the dark to the bright state. The time required for this switching τ_{10-90} is 550 µs, which is about 200 times faster than that for single frequency addressing (Fig. 5(a) and (b)). In contrast, the time required to switch from the bright to the dark state for the dual frequency device remains the same as for the conventional TN device.

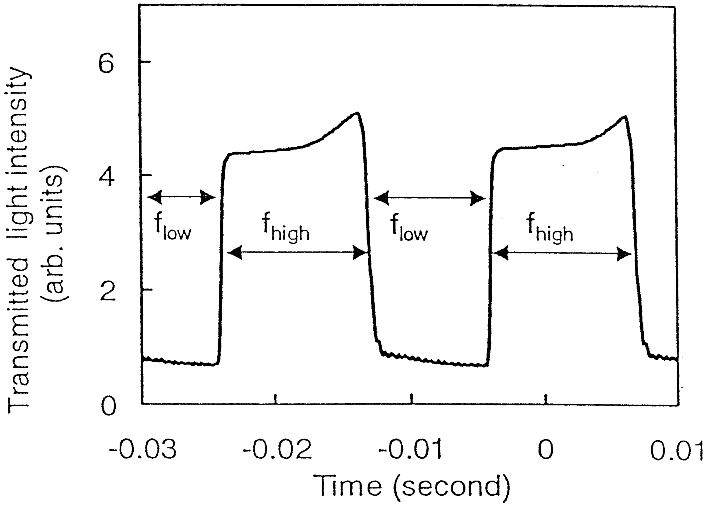


FIGURE 4 A typical electrooptic response curve in the dual frequency addressed nematic used in the present experiments. The regions marked f_{low} and f_{high} represent the periods when the applied voltage is of low and high frequencies respectively (applied voltage: 60 V, f_{low}: 1 kHz, f_{high}: 20 kHz).

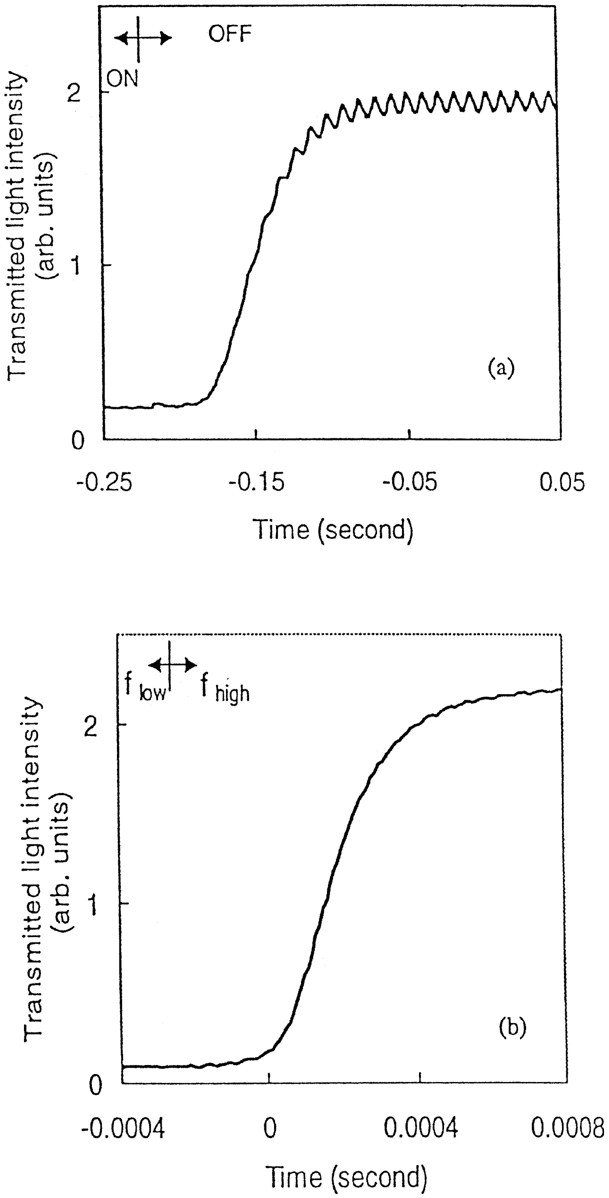


FIGURE 5 Response of the device on changing from the dark to the bright state for (a) a single frequency device (the τ_{10-90} response time is 110 ms) and (b) a dual frequency device (the τ_{10-90} response time is 0.55 ms). The latter shows a 200 times faster response.

VIEWING ANGLE PERFORMANCE

In the conventional TN device, the polyimide coated surfaces are rubbed to give the material a 90° twist of the director on going from one boundary of the cell to the other. As a consequence, the viewing angle of the device is limited and unsymmetrical and in fact there is a contrast inversion in the vertical down direction (Fig. 6).

In the so-called amorphous TN cell, the substrates are unrubbed and molecules are lie parallel to the substrates and randomly oriented in the plane of the substrate (Fig. 1(b)). The nematic material is doped with a chiral compound, the concentration of the dopant adjusted to give a 90° twist in the cell. The viewing angle is wide and symmetrical and there is no contrast inversion in any direction (Fig. 7). We have adopted the amorphous mode to enhance the viewing angle of our device [9,10].

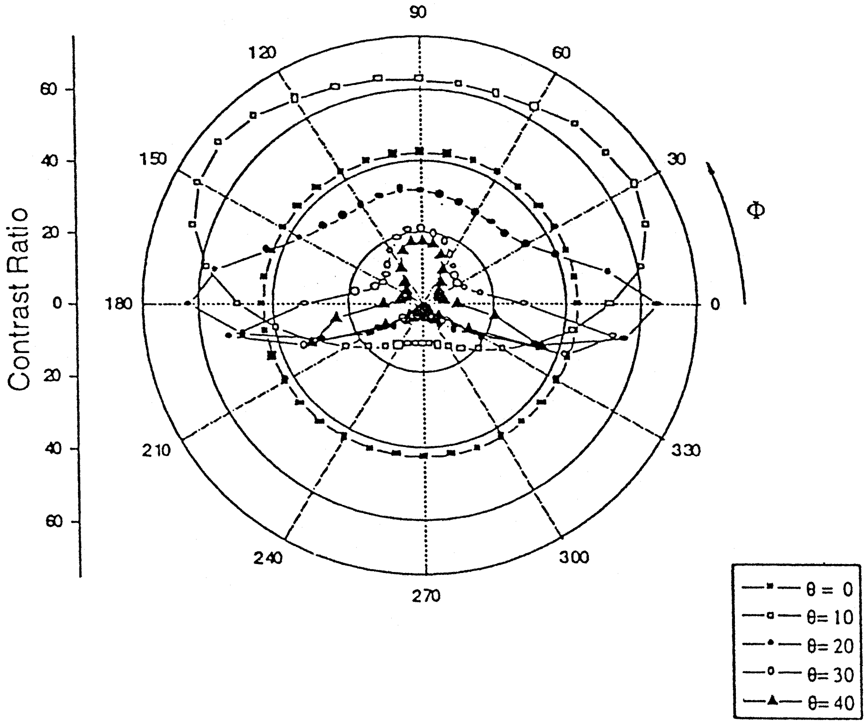


FIGURE 6 Polar plot of the contrast ratio for a single frequency device with its limited and asymmetric viewing angle characteristics. This device shows a contrast inversion along the vertical down direction. (Here the symbols ϕ and θ stand for the azimuthal and polar angles respectively).

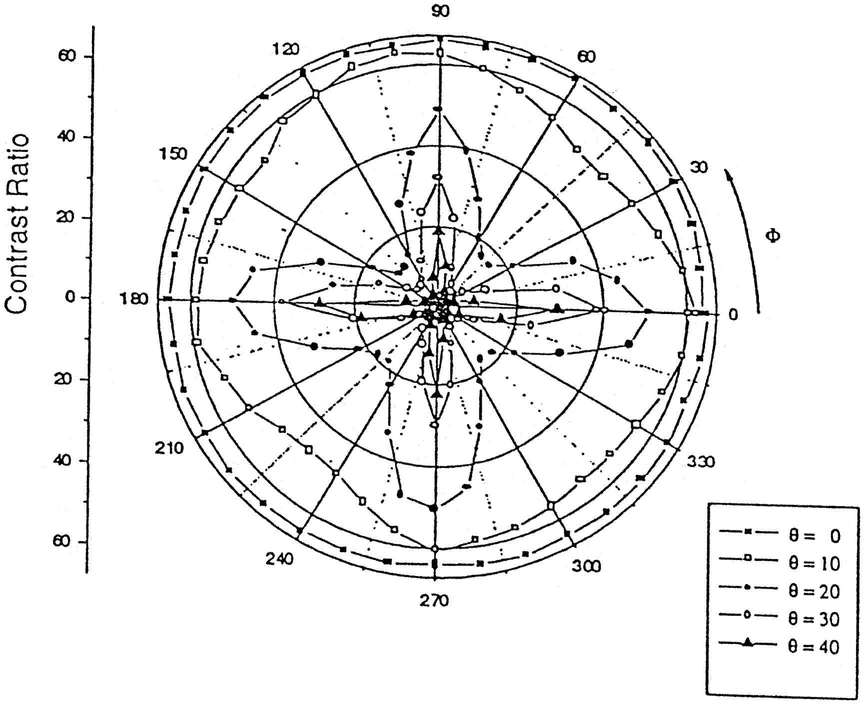


FIGURE 7 Polar plot of the contrast ratio for the dual frequency addressed unrubbed device exhibiting wide and symmetric viewing angle characteristics. There is no contrast inversion along any direction. (Here the symbols ϕ and θ stand for the azimuthal and polar angles respectively).

ADDRESSING CONSIDERATIONS

In the conventional TN device the pixel-off state (for a normally-white mode device this corresponds to a change from the dark to the bright state) is obtained by merely switching off the applied voltage. The molecules that are in the homeotropic configuration when the field is on, relax to the equilibrium planar twisted configuration when the field is switched off. Such a relaxation is dominated by surface and viscous forces. Switching from the bright to the dark state is field-driven. Hence, this conventional device consumes power only when the pixel is ON. In contrast, in the dual frequency device both the bright and dark states are field-driven and consequently power is consumed in both states. Further, switching to the bright state involves driving a high frequency capacitative load leading to higher current consumption. Also the device presented here was driven at high

Device	Voltage and frequency applied to get		Measured electrical energy consumption for a complete cycle of 200 ms
	Bright state	Dark state	
Single frequency	No voltage	20 V, 1.3 kHz	0.2 mJ
Dual frequency constant amplitude	60 V, 9 kHz	60 V, 1.3 kHz	12.3 mJ
Dual frequency dual amplitude	60 V, 9 kHz	20 V, 1.3 kHz	10.3 mJ
Dual frequency dual amplitude pulsed	60 V, 9 kHz 1 ms pulse	20 V, 1.3 kHz	0.3 mJ

voltages (60 V) to achieve fast response times. All these factors result in a significant increase in the power consumption of the device. (It may be noted that Schadt *et al.* [16] have remarked on this drawback of dual frequency driven displays). In order to determine the power consumption we measured the current drawn by the device in the conventional single frequency and the dual frequency modes. The conditions under which the tests were carried out and the results are tabulated below.

Notice that the conventional method of addressing a dual frequency device, viz., constant amplitude but switching frequencies to get the two states consumes about 60 times more energy than the usual single (low) frequency addressed device. A slight reduction is seen when the pixel on voltage is reduced to 20 V. However, a significant change is obtained when the bright state is realized using a high frequency pulse (here 1 ms duration). With this mode of addressing the energy consumed is only about 1.5 times that for a conventional TN device. The duration of 1 ms was arrived at by considering the response time and the delay time of the device. As shown in Figure 8, this duration was sufficient to switch the pixel completely from the dark to the bright state.

CONCLUDING REMARKS

We have reported a dual frequency addressed rubbing free device exhibiting very wide and highly symmetric viewing angle characteristics, with contrast ratio comparable to that of the usual rubbed TN device. The device shows a very fast response time and with the new method of addressing has a power consumption level which is comparable to the conventional TN device. These features make it a very suitable candidate for high information content displays including video applications, which at present are dominated by active matrix thin film transistor devices. A problem that

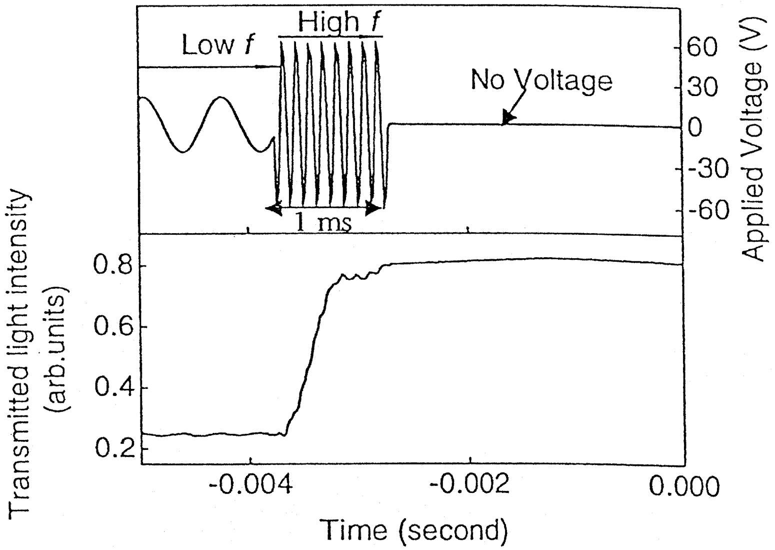


FIGURE 8 Plot to show the principle of dual frequency dual amplitude pulsed mode of addressing the device. Notice that a 1 ms high voltage (60 V) high frequency (9 kHz) pulse is sufficient to switch the device from the dark to the bright state. This results in a drastic reduction in power consumption, which turns out to be only ~1.5 times more than that for a conventional single frequency driving.

remains to be considered is the temperature variation of the cross-over frequency f_c. This can, in principle, be overcome by a suitable choice of compounds (and mixtures) which reduces the temperature variation of f_c so that the low and high frequencies of operation of the device are within practical limits.

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