

Chapter 4. STUDIES ON ELECTRO-OPTIC SWITCHING

- 4.1. Introduction
- 4.2. Experimental setup
- 4.3. Method, Results and Discussion
 - 4.3.1 Nature of response
 - 4.3.2 Grey scale
 - 4.3.3 Bistability
 - 4.3.4 Switching - dependence on field parameters
 - 4.3.5 Decay of switched state
 - 4.3.6 Multiple pulses
 - 4.3.7 Rotational viscosity
- 4.4 Conclusions

STUDIES ON ELECTRO-OPTIC SWITCHING

4.1 INTRODUCTION

An essential requirement of liquid crystals, which find applications in electro-optic devices such as spatial light modulators and displays, is a fast response to an applied signal. Further in multiplexed and large area matrix addressed displays the pixels should retain their switched state till next addressing. This implies that a memory effect or a bistable operation is also a necessary characteristic of these materials.

The stability of the states depends on its decay time after switching process. A critical analysis of the switching characteristics can reveal the process involved in switching. Hence a study of these dynamic characteristics is important from the scientific as well as application points of view.

The definition of the timings involved in the electro-optic switching (optical response) are usually derived from a plot as shown in Fig.4.1.

The electro-optic effect observed is not instantaneous with the application/removal of electric field. The time delay associated with this is termed as

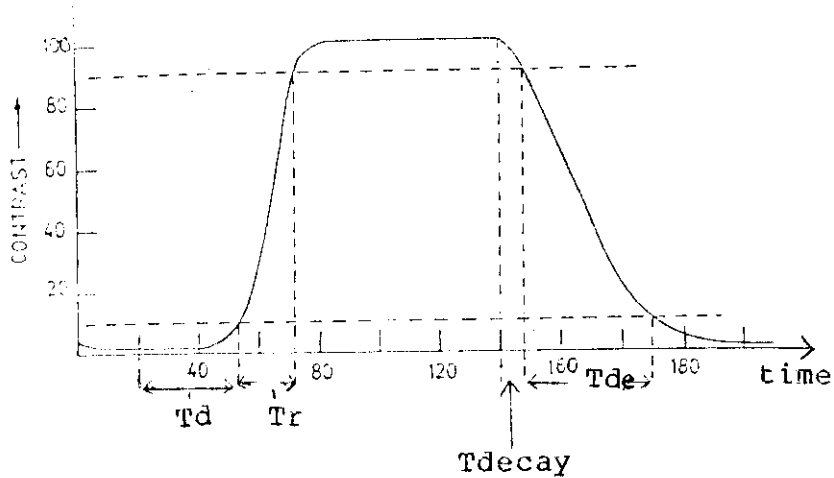


Fig. 4.1 The electro-optic switching times of a FLC

delay time (T_d). It is the time required for a 10% change in transmission (from 0% to 10% during rise or from 100% to 90% during decay). Rise time (T_r) is defined as the time during which the device gets 90% transmission (absorption) from the 10% level and decay time (T_{de}) is the time in which the contrast falls from 90% level to 10% level.

In actual device operations the rise and decay times include the delay time also. Usually the delay time during decay is very small, while it is significant during

rise. Hence actual ON time and OFF time of electro-optic devices are

$$T_{\text{on}} = T_r + T_{\text{do}}$$

$$T_{\text{off}} = T_{\text{de}} + T_{\text{dl}}$$

where T_{do} and T_{dl} are the delay times during rise and decay respectively.

In conventional liquid crystal devices using nematic and cholesteric materials (DSM and TN modes), response times are limited to the order of milliseconds. In these cases the driving force for molecular reorientation is derived from the interaction of the applied field with anisotropy of the dielectric tensor.

In ferroelectric liquid crystals, due to the permanent dipoles associated with their molecules, an applied field can couple with the spontaneous polarisation. This polarisation torque added to the dielectric torque enhances the response time of the device.

The electro-optic response time of a ferroelectric liquid crystal (FLC) device depends on the cell configuration, temperature, strength of spontaneous polarisation and other material constants like tilt (θ), apart from the parameters of the applied field.

Ferroelectric liquid crystals are characterised by an intrinsic helix of the director orientation, with its

axis perpendicular to the smectic layers. In thin samples where thickness is very much less than the helical pitch ($d \ll p$), this helix can be suppressed by means of interaction between the liquid crystal and closely spaced bounding glass plates as in the case of surface stabilised ferroelectric liquid crystals (SSFLC) [45 & 65]. In such configurations high switching speed (submicroseconds) and bistability have been obtained by many workers.

For relatively thicker samples ($d \gg p$), optical switching is usually explained on the basis of the unwinding of the helix of the ferroelectric liquid crystals [66]. Devices based on this phenomena make use of the two switched states corresponding to the fully unwound and fully wound conditions. OBOB, the ferroelectric liquid crystals used in the present study, has a comparatively high rotational viscosity and a low value of pitch. Hence a large energy is required to unwind the helix of this material. For electric fields above the critical unwinding value, the area of ferroelectric domains that get switched depends on the amount of energy transferred to molecules. For low voltages, the helix of the ferroelectric liquid crystals is partially unwound. Hence for a given pulse width, the extent of unwinding and hence the light transmitted through the ferroelectric liquid crystals cell

should be proportional to the voltage of the pulse. This suggests the possibility of voltage controlled optical intensity levels (grey levels) in the material. Under suitable conditions of temperature and sample thickness, for a range of field values, these optical transmission levels can be sustained for a reasonably long duration. The work presented in this chapter is an attempt in this direction with excellent results.

Studies have also been conducted on the rise time, the delay time, the decay time and bistable switching characteristics of the ferroelectric liquid crystals in planar configuration. Applications are suggested in spatial light modulators and electro-optic displays. Experiments are repeated with two commercially available ferroelectric liquid crystalss CE3 and CE8 (BDH, UK) and the dynamic characteristics are compared with that of OBOB.

4.2 EXPERIMENTAL SETUP

Experimental setup is shown in Fig.4.2. The sample is mounted on a cell holder kept inside a metallic chamber with optical windows. The cell holder can be tilted on a horizontal and vertical axis perpendicular to the path of the incident beam of light. The cell is illuminated by a 0.95 milli watt unpolarised He-Ne laser of wavelength 632.8 nm through a light attenuator and a polariser. The cell is

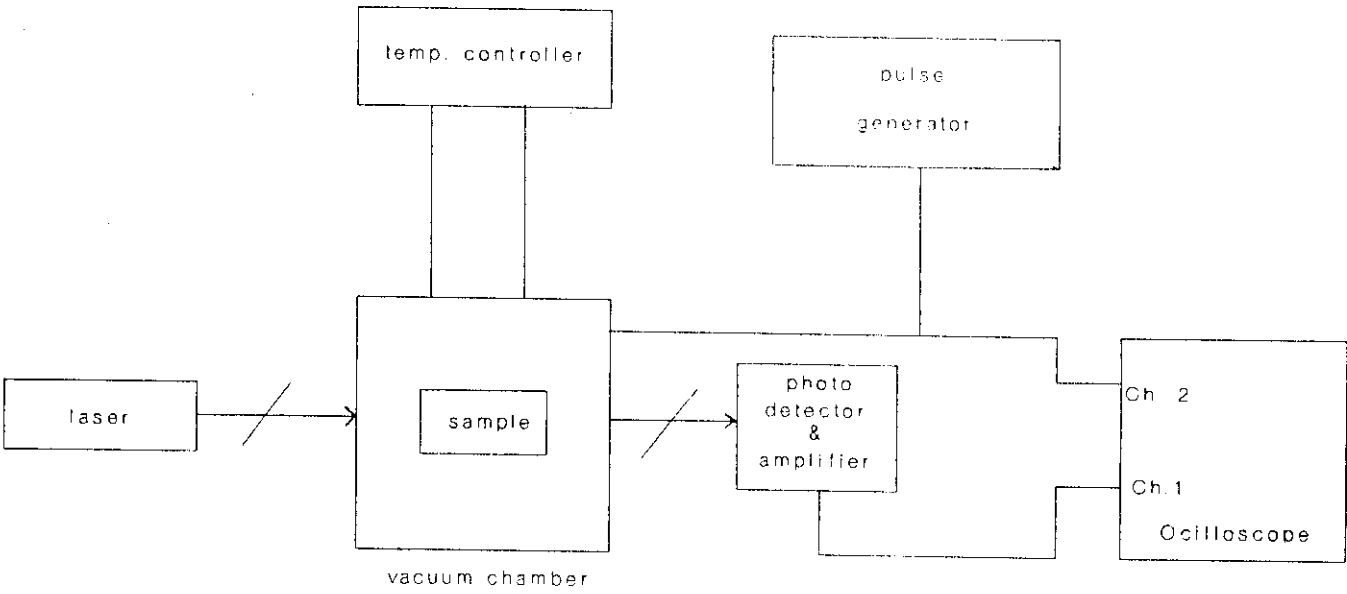


Fig. 4.2 Expt:1 setup for studying the electro-optic switching of OBOB

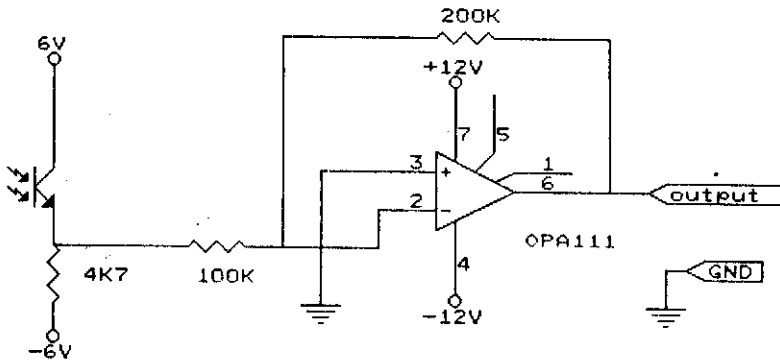


Fig. 4.3 Optical detection unit

mounted so that the laser beam can pass from normal incidence into the preferred viewing quadrant.

The detection unit consists of a photo diode having a uniform response for the light source (Fig.4.3). The current through the series resistance 4.7 K is proportional to the intensity of light falling on the photo transistor. The resulting voltage drop across the resistance is fed to an inverting amplifier constructed around OPA 111 (a low noise DIFET op.amp.). The output of the amplifier is fed to the cathode ray oscillograph.

The pulse generation and amplification unit as well as the microprocessor controlled temperature controller are same as those described in chapter 3. The applied signal and output of the detector are displayed on a digital storage oscilloscope.

The sample of ferroelectric liquid crystals is sandwiched between two conducting glass plates whose resistivity is less than 200 ohms/sq.cm. The glass plates are cleaned and evened out in a plasma discharge and pre-treated with silane and polyvinyl alcohol as suggested by Patel et al.[62]. Alignment of the sample obtained by unidirectional rubbing is improved by applying a slowly varying electric field.

4.3 METHOD, RESULTS AND DISCUSSION.

Experiments are conducted mainly using samples of OBOB with a thickness of 15 microns. Electro-optical effects are observed in the SmC* phase of the sample for various temperatures, pulse widths and for different voltages. The transmitted intensities of the light are recorded by applying preset pulses preceded by probe pulse in order to avoid voltage- transmission hysteresis. While measuring time constants, care was taken to keep the length of the cable to a minimum so as to avoid the stray capacitance.

4.3.1 Nature of response

Experiments on dynamic characteristics and bistability are conducted with samples kept in open circuit and short circuit conditions after applying a pulse voltage. The samples of OBOB showed ferroelectric behaviour in the SmC* state (72° C to 65° C) during cooling cycle. The response of the ferroelectric liquid crystals depends both on time duration (pulse width) and magnitude (pulse height) of the applied electric pulse. However there is a threshold voltage U_{th} for each pulse width, below which there is no electro-optic effect. The electro-optic response for a

square wave has a general shape as shown in Fig.4.4. This shows two different stages. As the pulse height or width is increased it switches faster and the point of inflection disappears. At higher temperatures, for pulses of even lower height and duration faster and more linear switching takes place.

Here the electro-optic effects take place in two stages. In the first stage molecules well inside the sample undergo a reorientation without the motion of the molecules

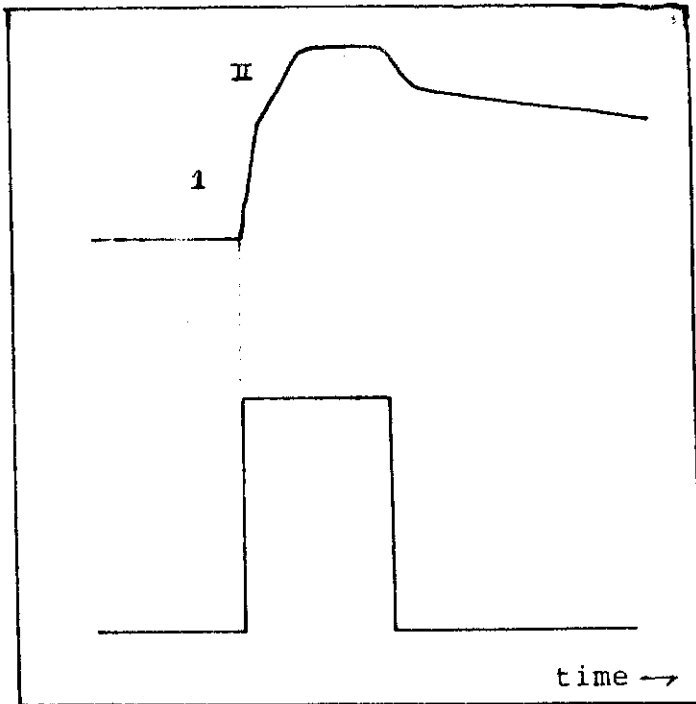


Fig. 4.4 General shape of response curve for a square pulse applied to OBOB

at the surfaces and hence the domain walls do not move. This is due to the strong interaction of the molecules with the rubbed glass electrodes. In the second stage the molecules at the surface also reorient producing switching. This explains the appearance of the point of inflection. At higher fields these two processes take place simultaneously with the disappearance of the step.

4.3.2 Grey scale capability

In this section the main aim is to investigate the existence of well defined intermediate transmission levels for various pulse width-voltage combinations of the applied voltage as well as to examine the possibilities of bistability in the material.

At the higher temperature region (72°C , 74°C) of the SmC^* phase, for pulses of moderate pulse widths and voltages, permanent switching is obtained. For voltages below the threshold value no switching is observed. Thus only these two states are possible at these temperatures.

In the super cooled low temperature region (65°C to 70°C), for pulses of 100 ms, 80 ms and 30 ms duration and for high amplitudes ($U > 40 \text{ V}$), the sample switches to the maximum transmission state (L_{max}). The material retains the switched state for a long time (for seconds) even after

the field is removed. When amplitude of the pulse is reduced the duration for which the material retains the switched state (L_{max}) gradually decreases. On further reduction of pulse-height the switching curve shown in Fig.4.5 is obtained. Here, after initially getting switched to 100% transmission state a relaxation follows and a lower level (L_r) is reached. (The value of light transmission, 750 ms after the applied voltage across the cell is reduced to zero, is taken as L_r). This switched level depends on the height and width of the applied pulse and remains in the

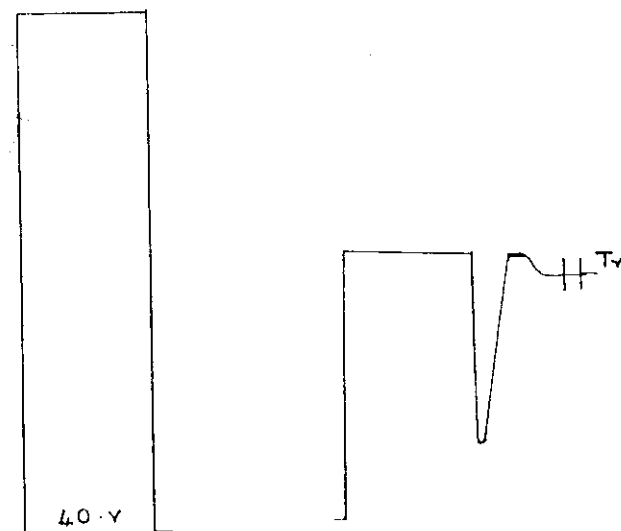


Fig. 4.5 Relaxation of fully switched state of OBOB to intermediate transmission level for comparatively low pulse heights.

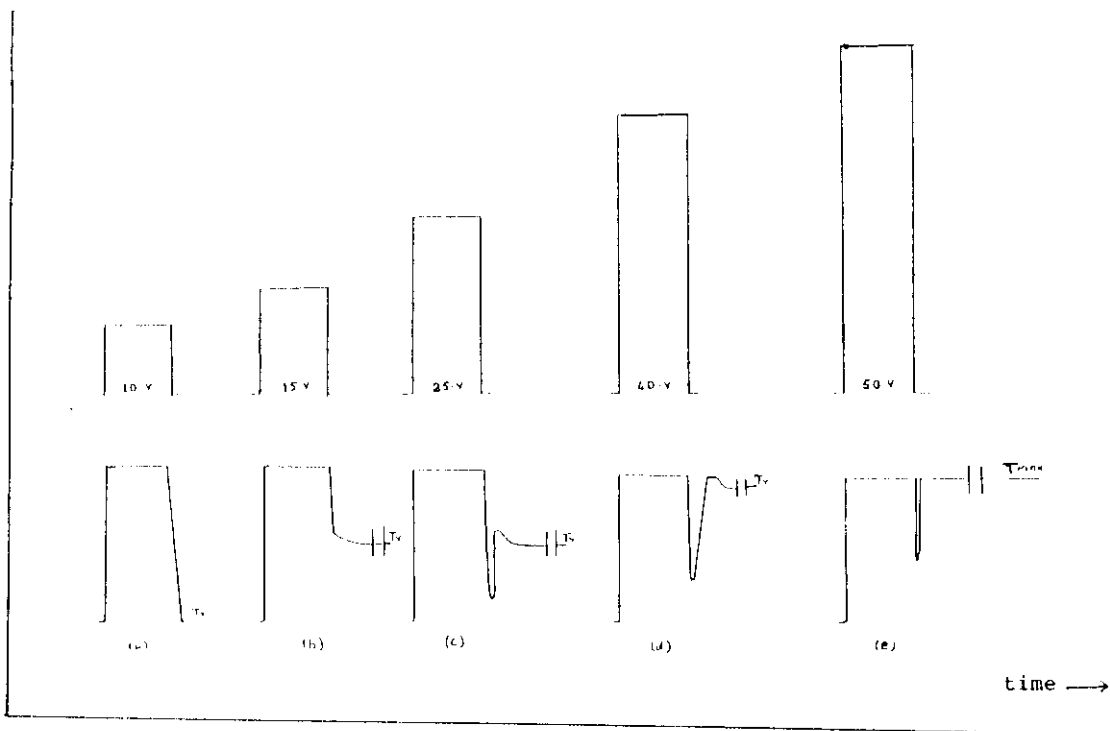


Fig. 4.6 A. Transmission levels for different voltages (pulse width 30 m.s) a: Threshold voltage-b,c,d and e above U_{th} .

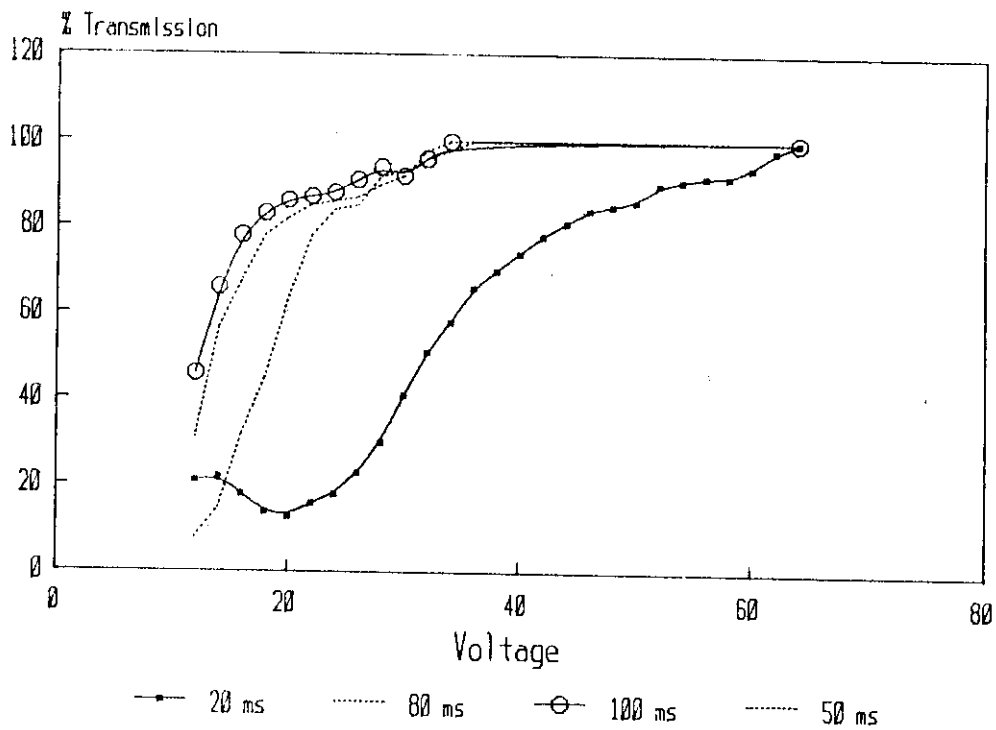


FIGURE 4.6.B-Voltage Vs Transmission Curve, for different pulse widths

state for a long time after the pulse is removed. The response curves for lower voltages are shown in Fig.4.6.(A & B) The voltage range for this partial switching region is very small and is close to the voltage required for full switching.

Now, using pulses of comparatively smaller pulse widths (20 ms, 10 ms, 5 ms and 3 ms) starting from a threshold voltage for switching, a linear variation of transmitted light intensity (L_r) with pulse amplitude is obtained (Fig.4.7). In Fig.4.8, the applied voltage has been normalised with respect to the voltage U_0 required to switch the sample to 50% transmission. The shape of the graph remains fairly universal for different pulse widths. This linear dynamic range can be used for obtaining various grey levels.

4.3.3. Bistability.

Below a certain voltage U_{th} , for a chosen pulse width there is no permanent switching. However a small transient electro-optic effect is observed.

Another interesting result in all these cases is that when the sample in its switched state is subjected to a pulse whose amplitude is just below the threshold U_{th} , the stable state (L_{max} and L_r) is switched back to the opaque

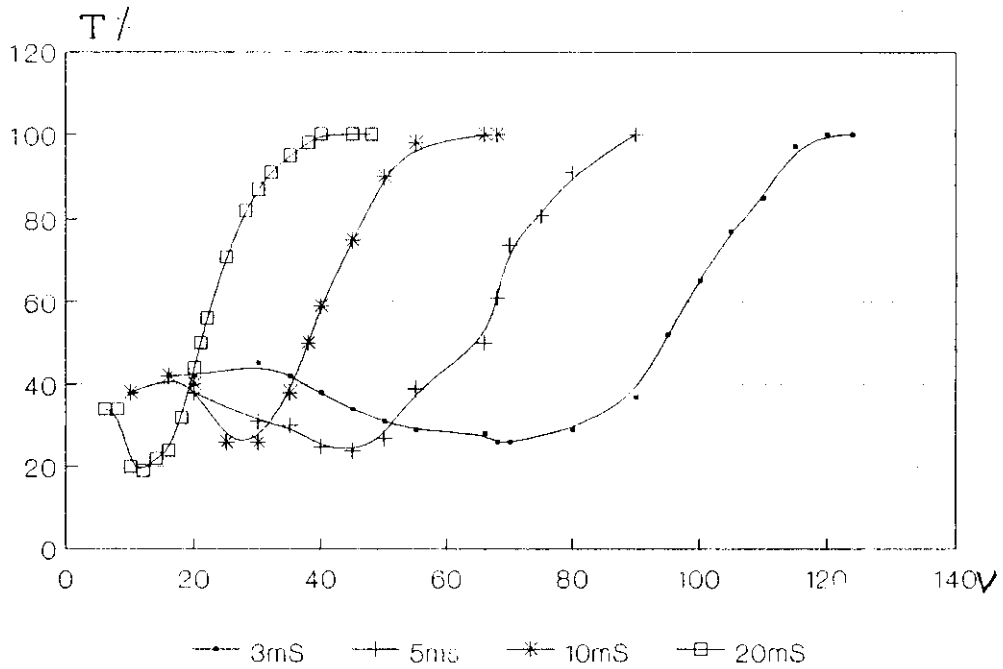


Fig. 4.7 Voltage - Transmission curves for lower pulse widths

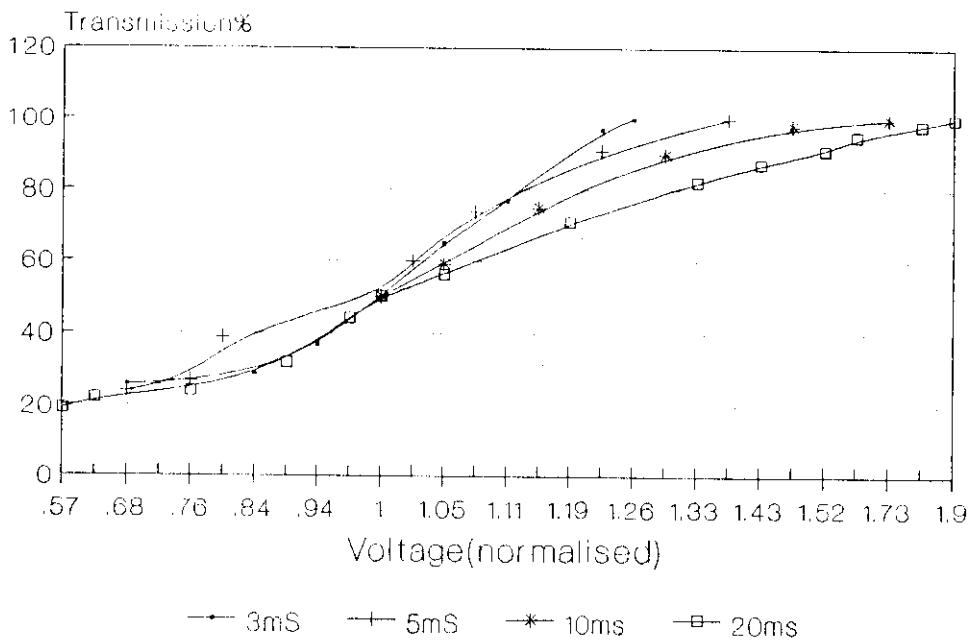


Fig. 4.8 Normalised voltage - Transmission curves for lower pulse widths

state. Hence these pulses can be used as reset pulses. Depending on the pulse width, pulses of 10 to 12 V were used in the present case for resetting the switched state. Thus the ferroelectric liquid crystals can be switched from opaque to high transmission state by a pulse of high amplitude ($U > U_{th}$) and from high transmission state to opaque state by a reset pulse ($U < U_{th}$). Thus bistability is achieved in the material.

In all transmission values observed, the probe pulse is preceded by a reset pulse. The time duration between the pulses is 500 ms. This avoids the hysteresis in voltage-transmission characteristics. A typical reset and probe pulse is as shown in Fig.4.9.

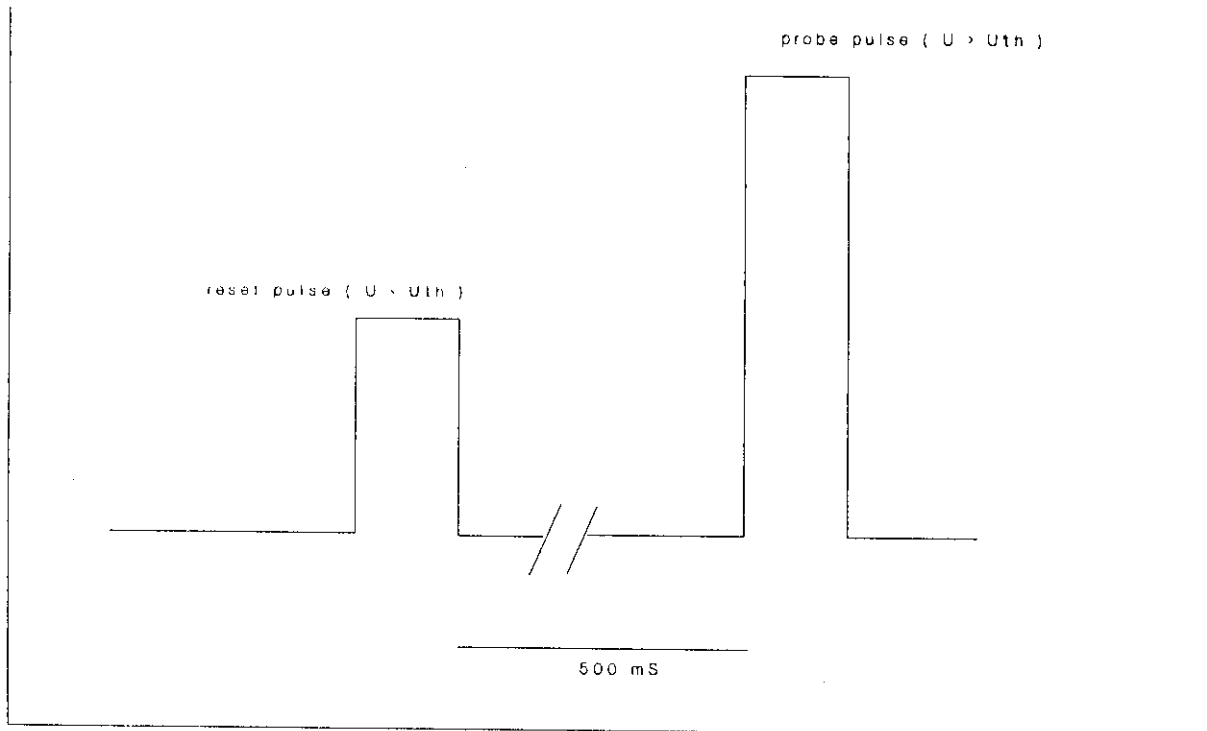


Fig. 4.9 A reset and probe pulse

4.3.4. Pulsewidth - Voltage Relations in Switching.

The relationship between pulse width and voltage is obtained by considering their values corresponding to a particular transmission level. Then the experiment is repeated for different transmission levels. When the reciprocal of pulse width is plotted as a function of the corresponding voltages a linear relationship is observed as seen from Fig.4.10. This suggests that the product of pulse

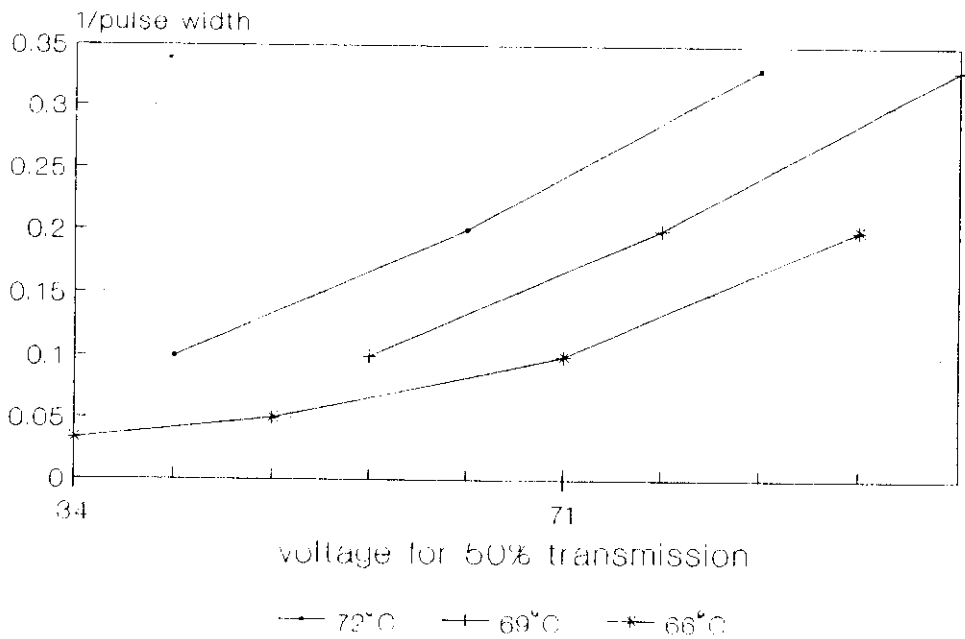


Fig. 4.10 Voltage Vs Pulse width for a given transmission level

width and voltage decides the extent of unwinding induced in the helical structure. However the line does not pass through the origin indicating that such an area law is valid only above a certain voltage.

The threshold voltage required for switching as well as voltage necessary for getting the specimen switched to any particular transmission level decreases with increase in pulse width. This is due to the fact that by increasing the pulse width more energy is transferred to molecules.

On increasing the temperature the voltage required for any given transmission level decreases considerably. At these temperatures for higher pulse widths (>10 ms) the linear region reduces further and shifts to small pulse amplitudes ($U < 20$ V). For pulses of smaller width and moderate pulse heights, good linear region was obtained. This is due to the lower resistance offered to the dipole moments at higher temperatures as the viscous forces are less at these temperatures.

The mechanism behind the creation and stabilisation of the levels can be explained as follows. During switching the permanent dipoles of the liquid crystal molecules are rotated through a definite angle. During this process a certain amount of charge is transported across the cell thickness. For a certain voltage U , the cell of

capacitance C is loaded with a charge CU within the pulse time. When the cell responds this charge is transported to other side of the electrodes and thus gets compensated. For higher voltages, larger amount of charge will have to be compensated. This makes the molecules rotate through larger angles which results in a higher transmission level.

In addition to the spontaneous polarisation charges, ionic charges also cause switching of the domains. But this effect dies down quickly leaving the spontaneous polarisation effects only. This is why transmission level first goes to maximum and then relaxes to certain definite T_r values. This ionic switching can be avoided at lower voltages which is possible in thin samples.

4.3.5. Decay of switched states.

Since bistable switching depends on the life time of the switched state, decay times were studied by keeping the sample under open and short circuit conditions, just after application of the pulse. The L_{max} state (refer section 4.3.2) reached under pulses of higher amplitudes and of higher pulse widths is retained for very long duration in all cases. But the decay time of the intermediate levels, the dynamic range (L_r) depend on the circuit conditions. The light transmission decreases and comes to a lower level

(20-30%) in 1 to 2 seconds, when the circuit is short circuited. But in open circuit condition (immediately after applying a pulse) the transparent state is retained for a very long time, as shown in Fig.4.11. Similar phenomena is observed by terminating the circuit with a high impedance. The persistence of transparent state even after opening the circuit may be due to the charges stored in the capacitance of the ferroelectric liquid crystals itself. Due to the

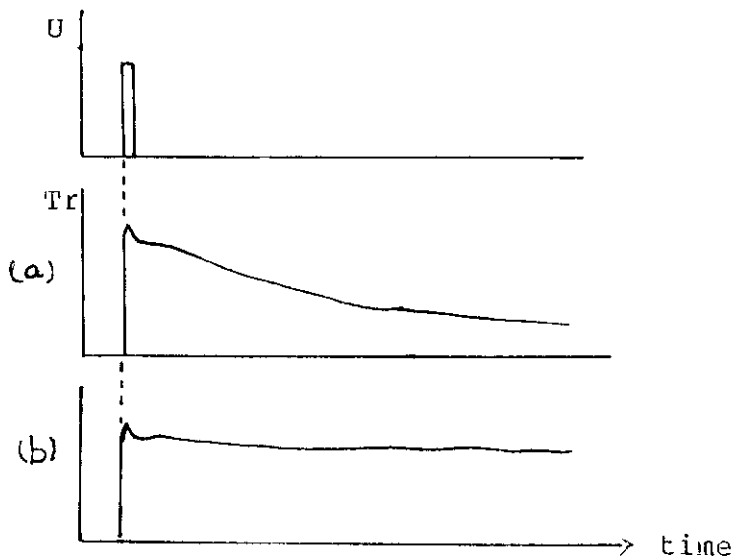


Fig. 4.11 Decay of switched state under (a) short circuited condition (b) open circuited condition

extremely large dielectric constant, the capacitance of the ferroelectric liquid crystals is large compared with the conventional liquid crystals. This results in a long decay time of the state when the circuit is opened or terminated with a large resistance.

4.3.6. Multiple pulses.

A pixel in a matrix addressed display will be subjected to a series of pulses of different voltages and pulse widths in a small interval of time. The main aim of studying the effect of multiple pulses is to examine the presence of cumulative switching under such conditions. In the present case, for voltages higher than the threshold voltage (U_{th}), the resulting state will depend on the previous state. Hence a blanking or reset pulse should be applied before giving the information signals. As explained in the previous section a pulse of voltage almost equal to the threshold value can be used for this purpose. Under this condition an addressing scheme employing an active device like a thin film transistor (TFT) or metal insulator metal (MIM) is highly suitable. As the TFT can open circuit the pixel after application of pulses, the intermediate

level L_r remains stable for a long time.

4.3.7. Rotational viscosity.

The effective ON and OFF times of electro-optic devices are $T_{on} = T_r + T_d$ and $T_{off} = T_{decay} + T_{delay}$ in decay. The rotational viscosity of the ferroelectric liquid crystal can be calculated by measuring T_r separately under increasing pulse voltages.

Such measurements are carried out for the samples of OBOB and the results are plotted in figure 4.12.

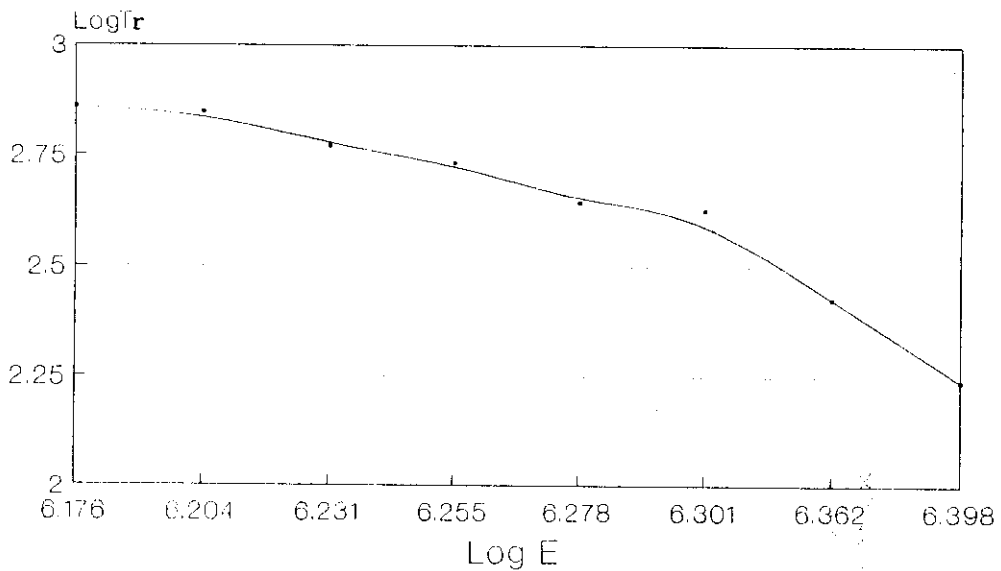


Fig. 4.12 Variation of rise time with voltage of the applied pulse

When pulses of magnitude $U > U_{th}$ are applied, initially both rise time T_r and decay time T_d decrease with increasing pulse voltage (for a given pulse width). T_r shows a $1/E$ dependence for a good range of field. But when the field is further increased T_r does not change appreciably with voltage. Fastest response time (T_d+T_r) of 400 microseconds are observed at 50 Volt pulses and at 100 millisecond pulse width [4.13] with a sample thickness of 15 micrometer. Such speeds are observed at decreased pulse widths also; but for higher voltages.

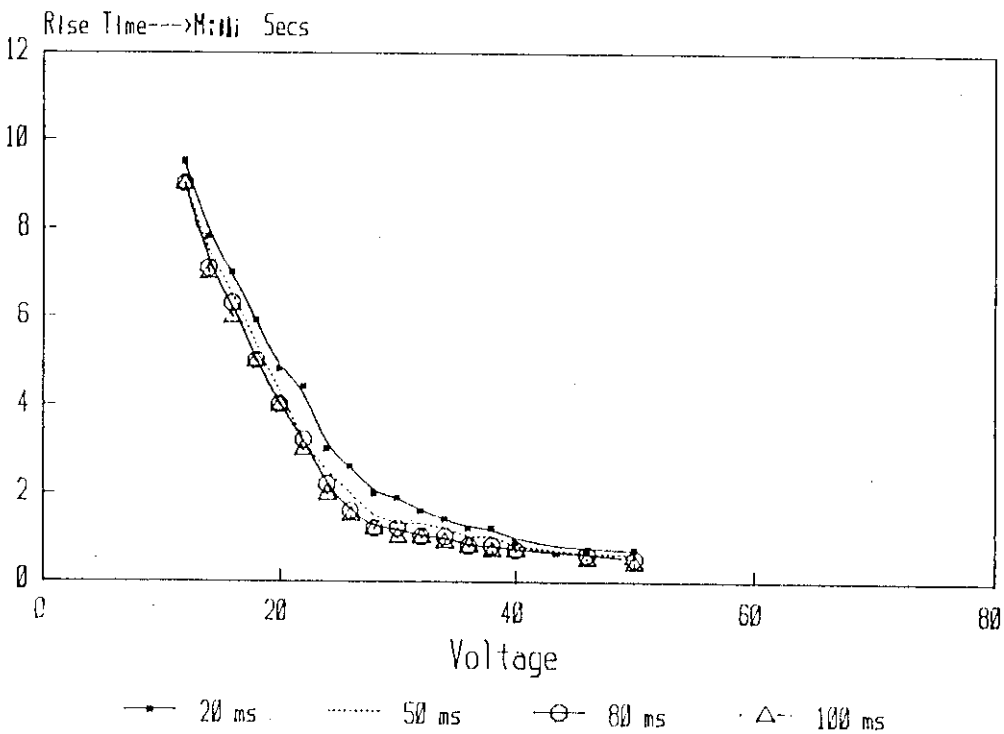


Fig. 4.13 Variation of response time (T_d+T_r) with voltage for pulses of different durations

The electro-optical properties of CE3 and CE8 are also investigated using the same arrangement. For CE3, even pulses of 120 volts do not produce any switching in the SmC* state. Though switching is obtained for CE 8, the response time is 4 to 5 times higher than that for OBOB under similar conditions of cell thickness and applied field.

In chapter 3, section 3.7, the importance of coefficient of rotational viscosity has been established. Its value is calculated from the current curves corresponding to the spontaneous polarisation switching under the reversal of electric field. Coefficient of viscosity can be calculated from the electro-optic characteristics also [64]. It is given by the equation

$$\gamma_{\phi} = 1/1.8 \cdot \text{Ps} \cdot E \cdot T_r$$

Here T_r is the rise time for those field values where it decreases as $1/E$.

The value of rotational viscosity calculated using this equation is of the same order as those calculated from field reversal experiments.

4.4 CONCLUSIONS.

The results of electro-optic switching studies of ferroelectric liquid crystals OBOB show that by aligning the

material in the planar geometry, stable grey levels can be achieved even in thick samples ($d > P_0$) under suitable conditions of temperature and field parameters. The presence of a threshold switching voltage enables this material to be used as pixels in a multiplexed display. Though it requires higher switching voltages and has lower switching speed, (400 microseconds) it can find applications in active matrix displays and light valves.