Phase-Only Optical Information Processing

D. J. Potter

Chapter 5
The 16×16 Spatial Light Modulator

Chapter four saw an introduction to the field of optical phase-only correlation. Within the context of phase-only optical information processing, it is the further aim of this project to demonstrate the usefulness of the 16×16 SLM as a binary phase-only optical correlator. This goal can be broken down into two stages, each of which forms the subject of the next two chapters, namely

1. To show the need for, and devise, improved final assembly techniques for devices intended to perform phase modulation (Chapter six).

2. To evaluate the performance of a device with such a low space-bandwidth product in performing phase-only optical correlation and devise a practical filter computation algorithm for this purpose (Chapters seven and eight).

For SLMs in general, there exist many techniques whereby amplitude and/or phase modulation can be effected in practice. Many devices operate using non-binary optical effects, such as the Deformable Mirror Device (DMD) [53], the Hughes LC Light valve [40], the Photo-Emitter Membrane Light Modulator (PEMLIM) [54] and so on. A complete review of these mechanisms is outwith the scope of this thesis, but many excellent review articles are available on the subject, notably [55].

This short chapter serves to introduce the light modulating effects possible by using liquid crystal technology, this being employed in the 16×16 SLM used in this project. Section one briefly reviews the physics of liquid crystals and concisely details the electro-optical effects used in this project. An understanding of the particular drive circuitry of the 16×16 SLM is required in order to appreciate how the device drives the liquid crystal layer. The circuitry is fortunately quite simple, and section two follows the operation of the pixel logic circuitry of this device.

1 Liquid Crystals

Liquid crystals have found widespread application of late with the commercial availability of small, portable LC television sets. Further, all Spatial Light Modulator design projects in the Applied Optics Group of this University to date have used liquid crystals as a light modulating medium overlying a VLSI silicon backplane [56]. A brief introduction to the physics of liquid crystals shall quickly lead to an appreciation of their specific use as a phase-modulating medium in this project. Where it arises, the word `cell' refers to the structure within which the LC is contained and arises from the frequent use of transmissive test cells for the investigation of the optical properties of the material. Of all the literature available on this subject, perhaps the most concise and clear cut approach belongs to Wu [57] to whom the reader is referred for further details.

1.1 Liquid Crystal Mesophases

Liquid crystals are materials which posses many qualities attributable to liquids, together with molecular

ordering properties normally associated with crystals in particular. The molecular ordering of any particular LC is usually temperature related (thermotropic), the particular state of the LC being termed a *mesophase*. LC molecules are generally rod shaped and each molecule has an associated polarisation vector, namely the particular arrangement of atoms within the molecule results in a net dipole moment associated to the molecule as a whole. It is this which causes the spontaneous molecular ordering within the material, and which allows this ordering to be changed upon application of an external electric field.

Liquid crystals are commonly classified into three groupings - nematic, cholesteric and smectic, and of particular interest to this project are the nematic liquid crystals. The local orientation of the LC molecules is described by the *director* $\underline{D}$, which is a time averaged vector function[1]. Nematic LCs are characterised by a director having the same orientation throughout the LC cell, this being a consequence of the particular molecular interactions of the material. As such, nematic LCs are said to posses orientational order but lack any *translational* order within different layers of the cell. Figure 5.1 illustrates what is meant by these terms for each of the three classes of liquid crystals.

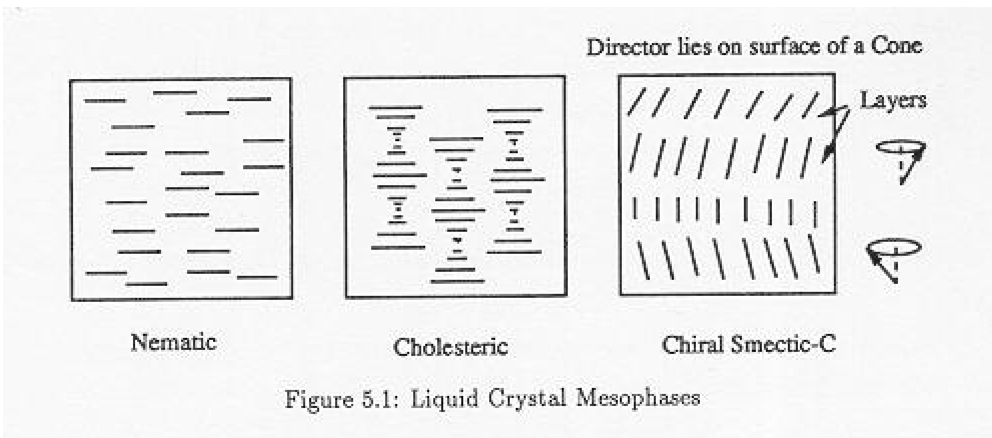

Figure 5.1: Liquid Crystal Mesophases

Cholesteric liquid crystals are similar to the nematic, with the exception that the local molecular interactions do not favour parallel alignment of the directors of neighbouring molecules. Consequently, cholesteric LCs have a helical cell director configuration, the pitch of the helix having the same length generally as a wavelength of visible light. LCs possessing a helical precession of director orientation are said to exhibit *chirality*. Like the nematic LCs, the cholesteric mesophase is therefore characterised by orientational order but a lack of translational order, so that no layer structure may be identified within a cell. These LCs shall not be discussed further as they have so far not been used by researchers within the Applied Optics Group in Edinburgh.

Finally there are the smectic LCs, which are distinguished as those LCs having both orientational order and translational order. Within this class there exist further subclassifications (S_A-S_K) to specify the nature of the orientational and translational ordering, of which one subclass in particular merits further study. The chiral smectic C mesophase (S_C^*) has a constant molecular orientation within each layer of the LC cell, but this orientation precessess from layer to layer (indeed, this may be said to be the definition of a layer). In fact, the director orientation lies on a helix within the cell. This class of liquid crystal is commonly referred to as `ferroelectric', to which a most informative introduction may be found in [59]. The light modulation mechanism most commonly associated with ferroelectric LCs will be described in the next section.

Alignment of Liquid Crystal Cells

Various optical effects using liquid crystals rely on a particular configuration of the material within the cell. Two common LC cell types are the *homeotropic* and *homogeneous* alignment configurations as shown in figure 5.5.

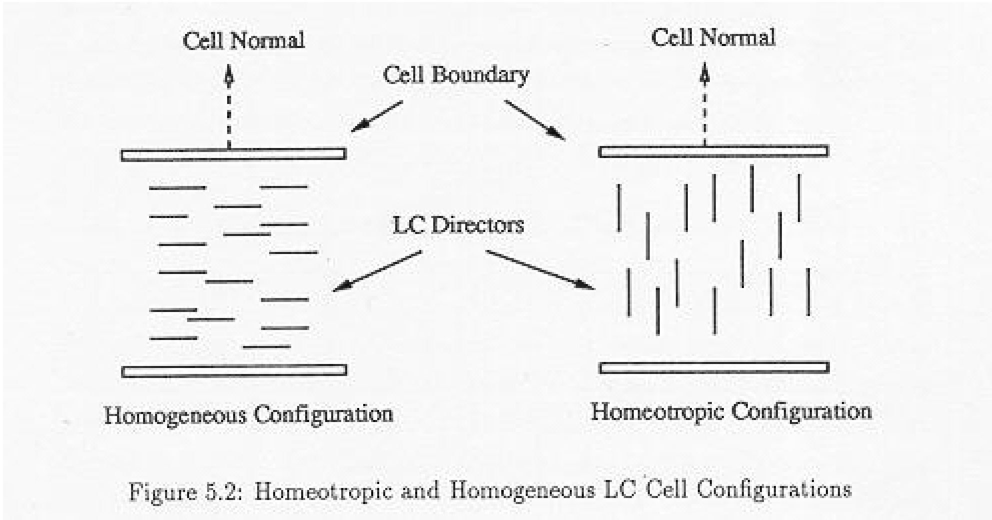

Figure 5.2: Homeotropic and Homogeneous LC Cell Configurations

Homeotropic alignment is characterised by the director lying everywhere perpendicular to the cells walls, and homogeneous alignment by a director which is everywhere parallel to the cell walls. Both states are obtained by suitable treatment of the cell walls. For example, homogeneous alignment can be obtained by arranging for microscopic grooves to cover the wall surface, the grooves aligned along one particular direction. It then becomes energetically favourable for the long axis of the rod shaped LC molecules to align itself with the direction of the micro-grooves. The grooves are commonly formed by evaporation of a crystalline substance at an angle to the cell surface, of which more shall be said in chapter six.

Finally, it is common to *twist* the cell so that the directors at each surface of the cell lie at an angle to one another. This gives rise to the commonly referred to arrangement of a `twisted nematic' cell, where the twist is usually (but not always) 90$^0$. A cell having no twist is usually referred to as having a `parallel' alignment, to distinguish it from the much more common twisted cell arrangements.

1.2 Field Induced Birefringence (FIB)

Nematic liquid crystals posses a dielectric anisotropy, so that the dielectric permittivity ε varies with respect to angle relative to the director orientation. In fact, nematic liquid crystals are uniaxial and birefringent, so that linearly polarised light propagating through the medium experiences two different indices of refraction according to whether the polarisation vector is parallel or perpendicular to the director orientation. The dielectric anisotropy Δε is defined as

$$\Delta\varepsilon = \varepsilon_{||} - \varepsilon_{\perp} \qquad (1)$$

where $\varepsilon_{||}$ is the dielectric permittivity in a direction parallel to the director, etc. The existence of a dielectric anisotropy (and associated birefringence) allows some measure of control over the director orientation through application of an electric field. It is the sign of Δε which determines how the molecules will align themselves in this external electric field: those LCs having $\Delta\varepsilon < 0$ align themselves perpendicular to the field whereas LCs with a positive dielectric anisotropy align themselves parallel to the field. The birefringence associated with nematic LCs is extremely large. If n_e denotes the index of refraction as seen by light polarised such that the electric field vibration is parallel to the director, and n_o the corresponding index for light polarised perpendicular to the director, the birefringence is defined as

$$\Delta n = n_e - n_o \qquad (2)$$

The LC commonly used within this Group, BDH E7, has Δn=0.225 for example, and it is the magnitude of this figure combined with the ability to re-orient the director within the cell which lies at the heart of several important nematic LC light modulation mechanisms.

Perhaps the most straightforward electro-optical effect utilising nematic LCs is that known as `Field Induced Birefringence'. This effect has the distinct advantage that either amplitude or phase modulation can be achieved

by suitable orientation of a polariser-analyser pair as shall now be described.

A layer of nematic LC, with positive dielectric anisotropy, lies in the homogeneous configuration so that the director lies everywhere parallel to the cell walls. Application of an electric field across the cell (usually via transparent electrodes of indium-tin oxide) causes the molecules to attempt to align with the field, the effect being greater in the centre of the cell and increasing with field strength. (The molecules at the cell boundaries being held with greater strength due to strong molecular interactions with the surface). The illustration of figure 5.3 shows both the director orientation throughout the cell in the case of no field and an applied electric field. In fact, a constant DC field causes electro-chemical separation of the substances contained within the liquid crystal, and an AC field applied at kHz rate is used instead. Thus the molecules react to the rms cell voltage [x].

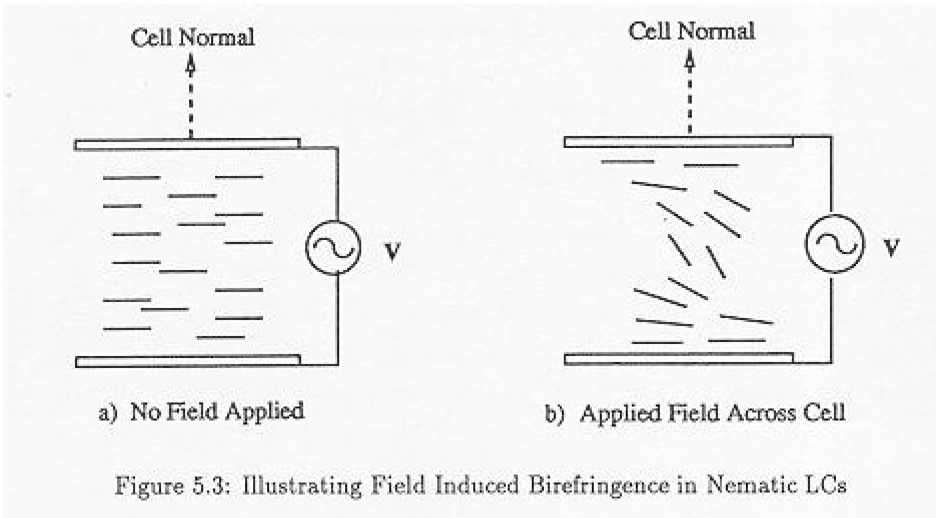

Figure 5.3: Illustrating Field Induced Birefringence in Nematic LCs

As explained earlier, a layer of the LC which everywhere has its director parallel to the polarisation vector of the incident light beam presents a single refractive index, n_e to the beam. Tilting the molecules causes a reduction of this refractive index until the incident polarisation vector and the director are perpendicular, when the refractive index of the material would fall to n_o. As the molecular tilt is non-uniform throughout the thickness of the cell, the extraordinary index of refraction n_e varies accordingly. On the other hand, tilting the molecules towards the cell normal does not alter n_o as an incident light beam polarised perpendicular to the director at the cell surface remains so no matter what the tilt angle may be.

Both phase modulation and amplitude modulation rely on the voltage controllable molecular tilt (and consequent variation of n_e with depth) for their success. Consider a linearly polarised beam of light incident at some angle θ^o to the director at the surface of the cell. The optical path length of the beam component traversing the cell perpendicular to the surface director is given by

$$\delta_o = \frac{2\pi}{\lambda} n_o t \qquad (3)$$

where `z' denotes distance through the cell, `t' is the cell thickness and `V' is the voltage across the cell. The optical path length of the beam component polarised parallel to the surface director is, on the other hand, given by

$$\delta_e = \frac{2\pi}{\lambda} \int_0^t n_e(z,V)\, dz \qquad (4)$$

as n_e is both a function of depth and applied voltage. As such, the parallel, homogeneous cell configuration utilising nematic liquid crystal (of positive dielectric anisotropy) acts as a wave plate of continuously variable retardance. Equation 5.4 is of particular interest for, as shall be shown in the next chapter, the integral is relatively insensitive to variations in the cell thickness. It is more appropriate to discuss this in within the context

of SLM fabrication methods.

Amplitude Modulation

Amplitude modulation is effected by ensuring the incident light field is polarised at 45^o to the surface director. Consequently the components of the beam perpendicular and parallel to the surface director are of equal intensity. Upon emerging from the cell, the relative phase difference between both components, the o- and e- rays, is given by

$$\delta_{e-o} = \frac{2\pi}{\lambda} \left[\int_0^t n_e(z,V)\, dz - n_o\, t \right] \qquad (5)$$

The form of variation [25] of birefringence Δn with voltage is illustrated in figure 5.4 for LC type BDH E7.

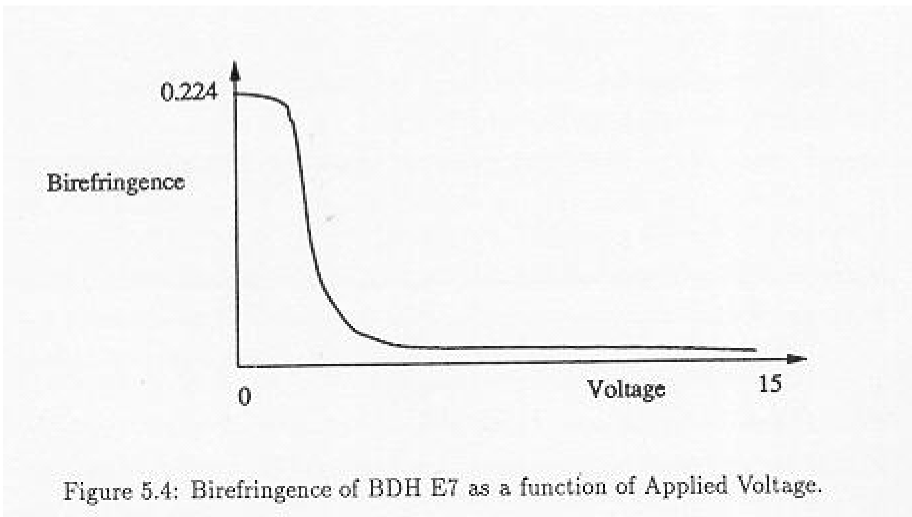

Figure 5.4: Birefringence of BDH E7 as a function of Applied Voltage.

A phase difference of up to 2π is readily obtainable with quite thin cells due to the extremely high birefringence of nematic liquid crystal [57].

It is relatively straightforward to show that the *intensity* of light emerging from an analyser at 90^o to the first polariser in this situation is given by

$$I(V) = I_0 \sin^2\left(\frac{\delta_{e-o}(V)}{2} \right) \qquad (6)$$

where I_0 is the maximum transmitted intensity, so that an optical path difference of $\delta_{e-o}=2m\pi$, m integer, results in a minimum of transmitted light. In practice the voltage is selected to obtain this state, and may also be adjusted to obtain a maximum cell transmittance, as δ_{e-o} is not necessarily $(2m+1)[(\pi)/2]$, m integer, when V is set to zero. A cell which gives maximum transmission is said to be in an `ON' state (applied voltage $V_{ON}$) and one giving minimum transmission as being in an `OFF' state (with applied voltage V_{OFF}).

It should now be apparent how a Spatial Light Modulator can utilise this effect to perform binary amplitude modulation if it is capable of applying two different voltages across any particular pixel. The operation of pixel circuitry in the 16×16 SLM which enables this is described in the next section.

Phase Modulation

Pure phase modulation is effected by ensuring the input light beam is polarised parallel to the surface director. As such only the voltage-dependent extraordinary refractive index of the LC causes the phase delay as the beam passes through the cell. Increasing the voltage across the cell causes molecular tilt towards the cell normal,

reducing n_e on average, and thus decreasing the optical path of the material. By this mechanism a Spatial Light Modulator with variable pixel voltage can advance or retard the phase of the light emerging from a pixel relative to another that from another pixel held at a fixed voltage.

Phase modulation where the difference in phase between light emerging from two pixels is either 0 or π radians is achieved as follows. Consider one pixel of an SLM (or a LC test cell) which has been set up to perform *amplitude* modulation, and the cell is in an `OFF' state. The difference optical path length through the cell for the orthogonal polarisation states of the incident light beam is

$$\delta_e(OFF) - \delta_o = 2\, m\, \pi \tag{7}$$

where m is integer. Now consider a neighbouring pixel (or another test cell) in an `ON' state. The optical path length difference between the orthogonal beam components is now

$$\delta_e(ON) - \delta_o = (2m + 1)\, \pi \tag{8}$$

Note that δ_o is independent of the applied voltage in each case. If the input polariser is now rotated so that the incident polarisation lies completely parallel to the surface director, the difference in optical path for the e- rays in pixels which were `ON' and `OFF' in amplitude mode is

$$\delta_e(ON) - \delta_e(OFF) = \pi \tag{9}$$

so that if the analyser is removed from the system pure binary phase modulation of 0 or π radians between pixels occurs.

This method of phase modulation was chosen by Ranshaw [25] who initiated the study into phase modulation within the Applied Optics Group at Edinburgh University, and indeed is perhaps the only way of achieving pure phase modulation using nematic liquid crystals. The ease with which the relative phase difference is set to π, usually by visual estimation of least and greatest cell transmission with voltage in amplitude mode, is a highly desirable property when working with actual devices.

2 Further LC Light Modulation Mechanisms

Even a partial discussion of the many types of LC effects which have been utilised to effect light modulation is outwith the scope of this thesis. For an introduction to the mechanisms so far exploited within this Group the reader is directed to references [25] (Ranshaw), [56] (Underwood), [58] (MacGregor) and [61] (McKnight).

However, of relevance to the construction techniques used in SLM fabrication, the subject of chapter six, is the light modulation effect which relies upon a thin (1−2μm) layer of ferroelectric liquid crystal. As explained earlier, the chiral smectic LC exhibits a precession of the director throughout the cell, an effect known as chirality. At any given location within the cell, however, all possible director orientations lie on a *cone*. If the cell is made thin enough [58], the director is constrained to lie in one of either two possible orientations, as shown in figure 5.5.

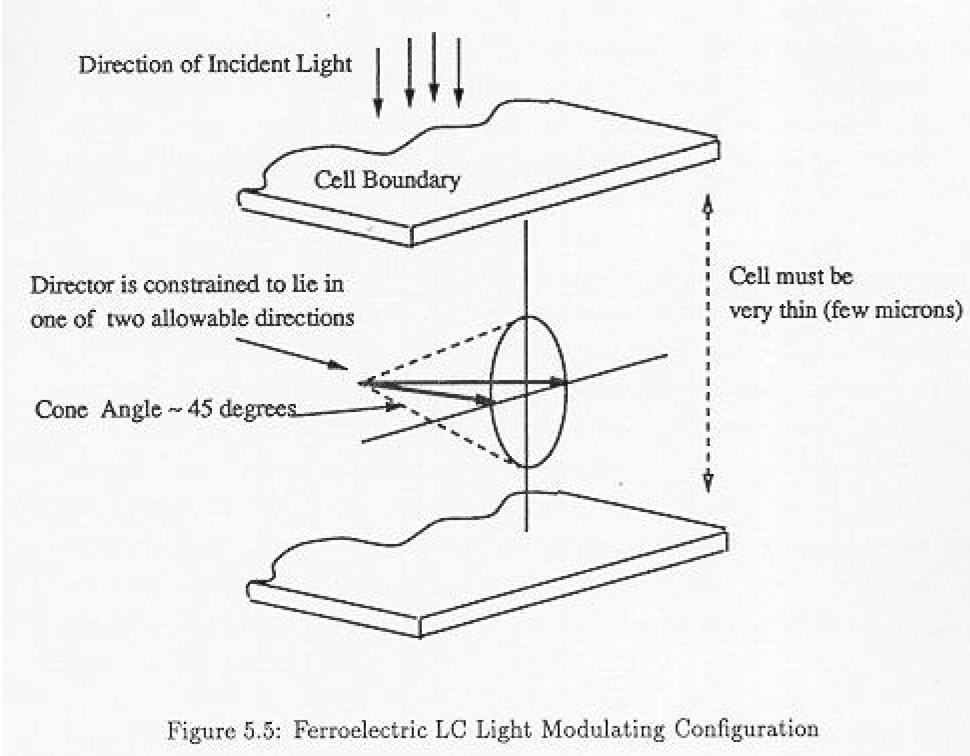

Figure 5.5: Ferroelectric LC Light Modulating Configuration

The LC can be chosen such that the cone angle is very close to 45^{o}, and by a suitable drive scheme the director can be made to lie in either of the two possible orientations. This effect is extremely fast[2] (μsecs) and is also bistable, meaning that once the director orientation has been switched it stays as such without the need for further application of an electric field. A single transistor is therefore all that is required to drive each pixel of a spatial light modulator using this effect, resulting in a high speed, low energy device. One difficulty is however ensuring the LC thickness is uniform throughout the cell. Even small variations in thickness - be they local or due to a minute wedge in the cell - greatly affect the operation of the device and more shall be said of this in the next chapter. The high switching speed of ferroelectric LCs has made them a subject of interest for optical computing, of which an early implementation study has been made by Johnson et al [62].

The Guest Host Effect

The original light modulation mechanism used by the designer of the SLM used in this project[3] led to the type of circuitry on the VLSI backplane being as it is. Therefore, a brief review of the `Guest Host Effect' will assist the reader to form a clearer picture of how the early devices operated. The LC configuration used is of a twisted nematic cell, where the director at the front face of the cell is at 90^{o} to the director at the back of the cell. A more concise account of the effect cannot perhaps be found than that given by Underwood himself, quoted from reference [63].

`The operation of the guest-host LC layer exploits the polarisation guiding properties of the helical structure of the LC inits quiescent state. Plane polarised light entering the cell with its plane of polarisation parallel to the director at the front face of the cell propagates with its polarisation vector always parallel to the director throughout the LC layer. Dye molecules exhibiting a large absorbtion anisotropy preferentially align themselves parallel to the local director. This ensures that the light is strongly absorbed as it travels through the guest-host mixture. Application of an electric field across the cell disrupts the helical structure thereby destroying the close alignment between the axes of the dye molecules and the polarisation vector of the light. The light is only weakly absorbed and there is a strong reflection from the pixel mirror'.

Note that the SLM used operates in reflection mode, so that light passes twice through the cell. This however does not deter from the explanation of the effect. Figure 5.6 illustrates the cell geometry used in this effect.

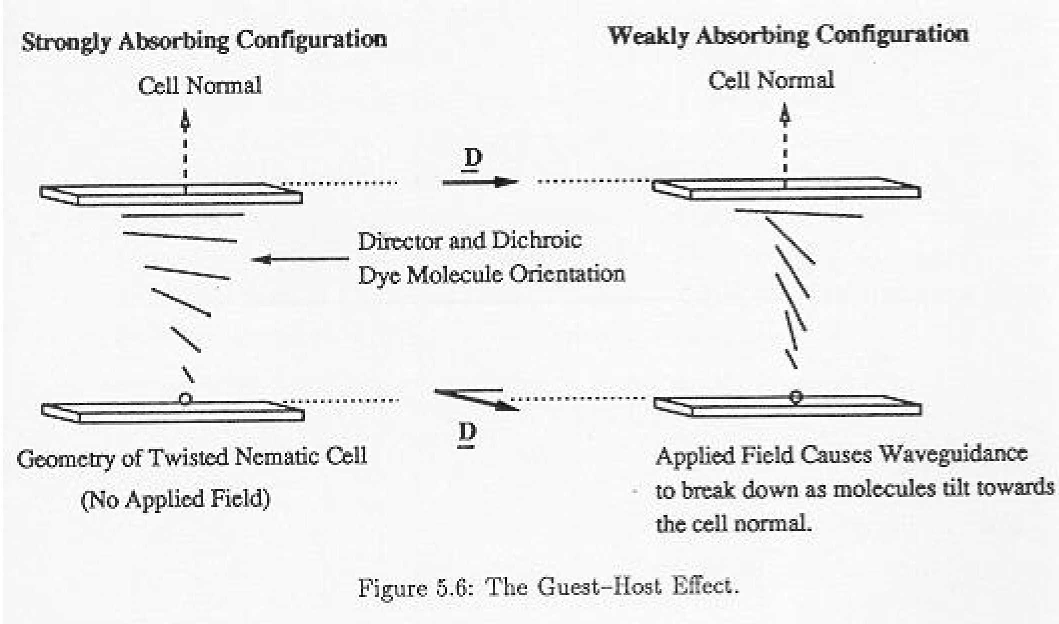

Figure 5.6: The Guest-Host Effect.

In the following section the electronic drive of the SLM is covered, together with a description of modifications which allow the Field Induced Birefringence effect to be used.

3 Operation of the SLM

16×16 SLM Origin and History

The design and manufacture of the 16×16 pixel SLM used in this project was the thesis subject of Ian Underwood [63] who successfully demonstrated amplitude modulation using the guest-host effect in a twisted nematic liquid crystal. Later, Ranshaw [25] investigated the possibility of using the VLSI backplane as the basis for a `Deformable Mirror' spatial light modulator. Ranshaw also instigated the use of the Field Induced Birefringence effect using a parallel aligned homogeneous configuration to effect binary phase modulation. This was secondary to the purpose of his thesis, and only marginally explored. The remaining chapters of this thesis serve to continue this research.

3.1 VLSI Drive Circuitry

Designed as a prototype for testing various liquid crystal effects, the 16×16 SLM comprises of a VLSI backplane which is usually covered by a thin ($\cong$ 12μm) layer of nematic liquid crystal. Each of the 256 pixels incorporates circuitry to apply an AC drive signal to a flat area of aluminium, acting as a mirror, which takes up one quarter of the area of the pixel. A static memory element is incorporated within each pixel, so that once addressed via the data lines the pixel `remembers' the data value assigned. Figure 5.7 shows the circuit diagram for one pixel.

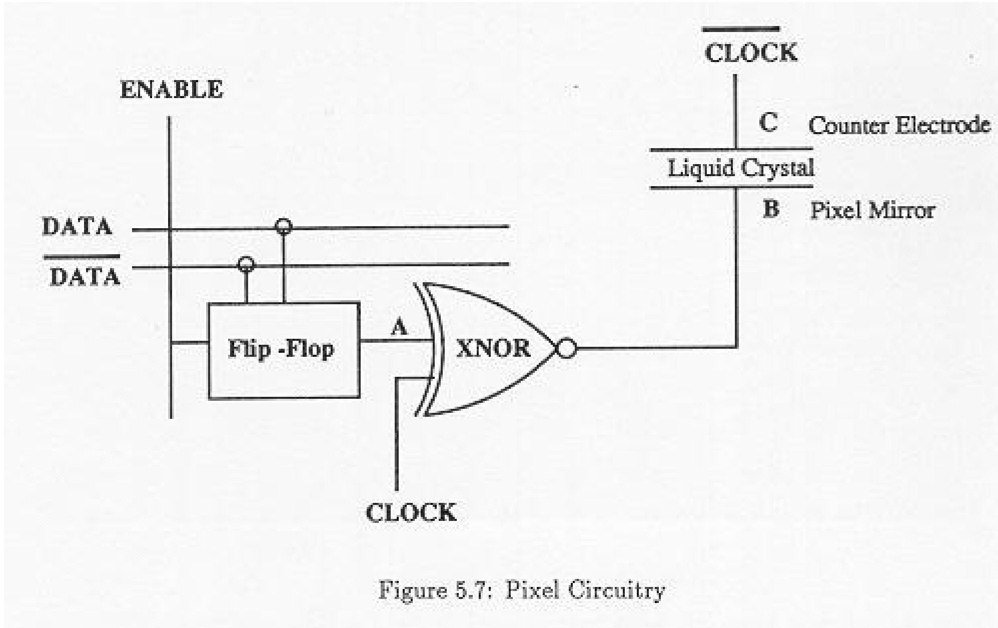

Figure 5.7: Pixel Circuitry

Pulsing the enable line of the pixel causes the flip-flop memory element to load data from the data line, and upon the next enable line pulsing the output state of the flip-flop changes. The output from the flip-flop together with the universal clock signal are used as inputs into an XNOR gate, whose output is applied to the pixel mirror. Now the LC layer is covered by an optically flat glass cube, of which the face in contact with the LC is covered by a thin transparent counter-electrode of indium-tin oxide (ITO). An AC signal which is the logical inverse of the chip clock is applied to the counter-electrode. By studying the truth table for the circuit, table 5.1, it will be observed that the resulting potential difference across the LC layer can be switched from zero to ±5V by the appropriate choice of data signal. [4] (Recall that an AC field is required across the LC layer so as not to cause electrochemical degradation of the material).

A	Clock	B	[$\overline{\text{Clock}}$]	V_{BC}	LC State
0	0	1	1	0	OFF
0	1	0	0	0	OFF
1	0	0	1	–5	ON
1	1	1	0	+5	ON

Table 1: Truth table and state of liquid crystal

By the incorporation of the flip-flop, Underwood allows the data to be loaded *only* when the enable line is pulsed high. The consequences for device addressing are as follows. Imagine the pixel diagram of figure 5.7 is extended vertically to include a column of 16 pixels. The whole column is addressing by setting each of the 16 DATA lines to the required value and pulsing the mutual enable line for that column. The next column is addressed by changing the DATA line values and pulsing the enable line for *that* column and so form until all 16 columns have been addressed. This makes for particularly simple addressing of the device and eliminates the need for constant re-addressing as required by single transistor pixel devices.

In the VLSI fabrication process, the control circuitry is laid down so as to surround the mirror area so that the reflecting aluminium mirror lies atop as flat a surface as possible. To electrically insulate the mirror from the substrate (to which a constant potential is also applied) the mirror is deposited atop a thin layer of silicon oxide. Underwood estimates the mirror to be flat to within ±0.25µm as judged by white light interferograms of the silicon wafer. Mirror flatness is an important requirement for coherent optical processing applications of the device where it is required that the mirror presents a uni-phase reflecting surface to an incident wavefront. Each pixel incorporates a mirror area of 100×100µm within a total pixel area, including circuitry, of 200×200µm. Figure 5.8 shows a highly magnified portion of the device in a white light interference experiment[5] of which the large flat area is the mirror.

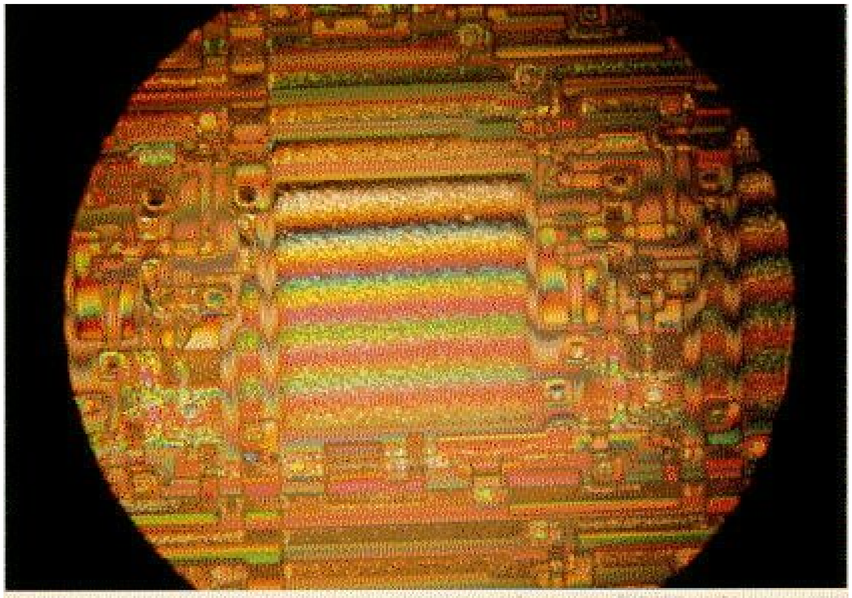

Figure 5.8: Magnified portion of the 16 × 16 SLM

Figure 5.8: Magnified portion of the 16×16 SLM

3.2 Two Mode Drive Scheme

For his original light modulation mechanism, the Guest-Host effect, Underwood required only that the voltage across the liquid crystal be either zero volts (an OFF state) or some higher value corresponding to an ON state, typically 5V. Although sufficient for the guest-host effect within a twisted nematic cell, the reader may recall that the FIB effect requires two non-zero voltages across the LC layer to define the ON and OFF states. The modification involved is slight and again is due to Ranshaw. The reader is referred to the logic circuitry of figure 5.9 which is essentially identical with figure 5.7 but for the additional DC bias signal applied to the counter-electrode.

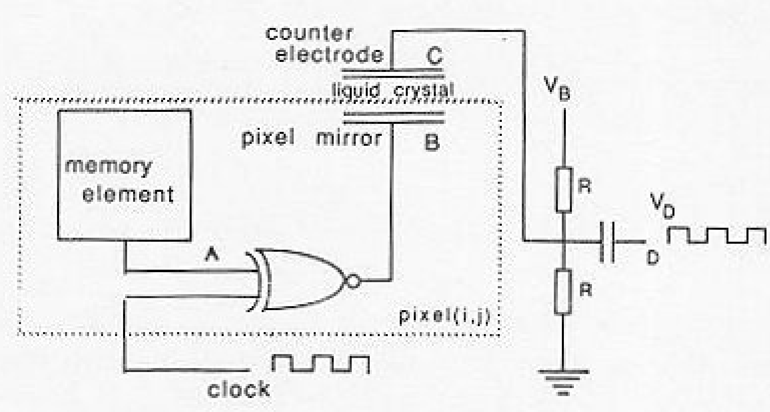

Figure 5.9: Dual Voltage Drive Scheme for FIB Effect.

Figure 5.9: Dual Voltage Drive Scheme for FIB Effect.

The clock signal is an AC square wave alternating between zero and V_B volts and is applied as before to the pixel mirror. The voltage signals applied to the counter electrode are however modified in this drive scheme. An AC signal centered about zero volts and with peak to peak value V_D is applied to the counter electrode, together with a DC bias voltage of amplitude [(V_B)/2]. Examination of table 5.2 shows that the resulting potential difference across the LC layer is an AC voltage signal with different amplitudes for both the ON and OFF states.

	Truth table			node voltages			L.C. voltages
	A	ck	B	B	D	C	
"OFF"	0	0	1	V_B	0	$(V_B-V_D)/2$	+/-$(V_B+V_D)/2$
	0	1	0	0	V_D	$(V_B+V_D)/2$	
"ON"	1	0	0	0	0	$(V_B-V_D)/2$	+/-$(V_B-V_D)/2$
	1	1	1	V_B	V_D	$(V_B+V_D)/2$	

Table 5.2: Truth Table for Dual Mode Drive Scheme Copy table 2 my paper

Table 2: Truth Table for Dual Mode Drive Scheme

It is easier to see how the results come about, however, by studying figure 5.10 which illustrates the waveforms involved.

High Speed Switching in FIB Mode

Although the VLSI backplane can switch a pixel between states in a a few tenths of a microsecond, the liquid crystal response is very much slower. Recalling the explanation of the FIB effect, two distinct voltages V_{ON} and V_{OFF} are required to produce the required optical path differences between the extraordinary rays through the liquid crystal. The selection of these voltages has been shown to be relatively straightforward, resulting in the binary phase difference between ON and OFF pixels of

$$\delta_e(ON) - \delta_e(OFF) = m\,\pi \qquad (10)$$

where m is an integer and is not equal to zero. The value of m is significant in that it shows the choice of voltages is not unique. Let two sets of voltages be considered here. If V_{OFF} is chosen to be relatively small, yet V_{ON} is much larger then the situation corresponds to that of figure 5.11.

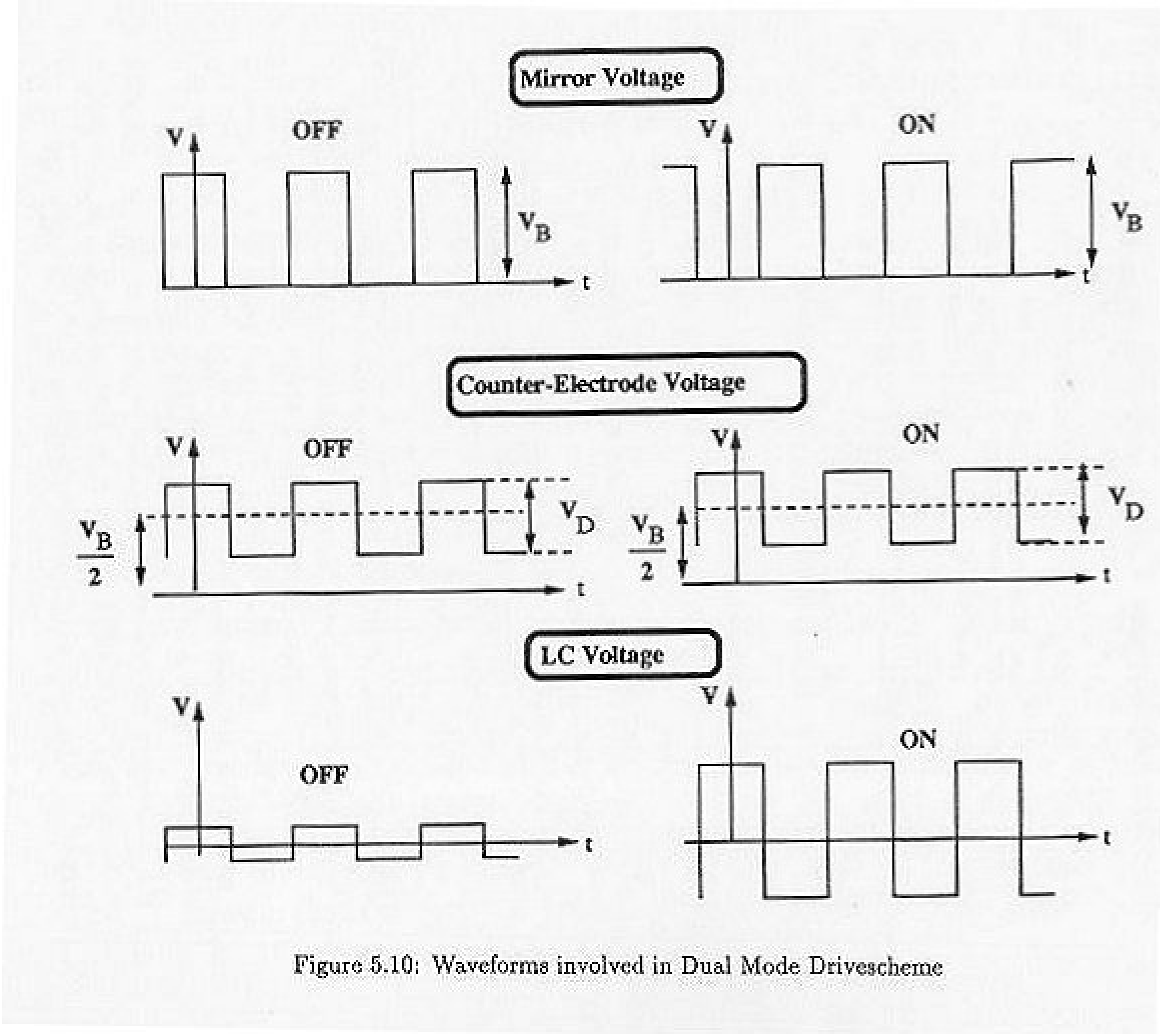

Figure 5.10: Waveforms involved in Dual Mode Drivescheme

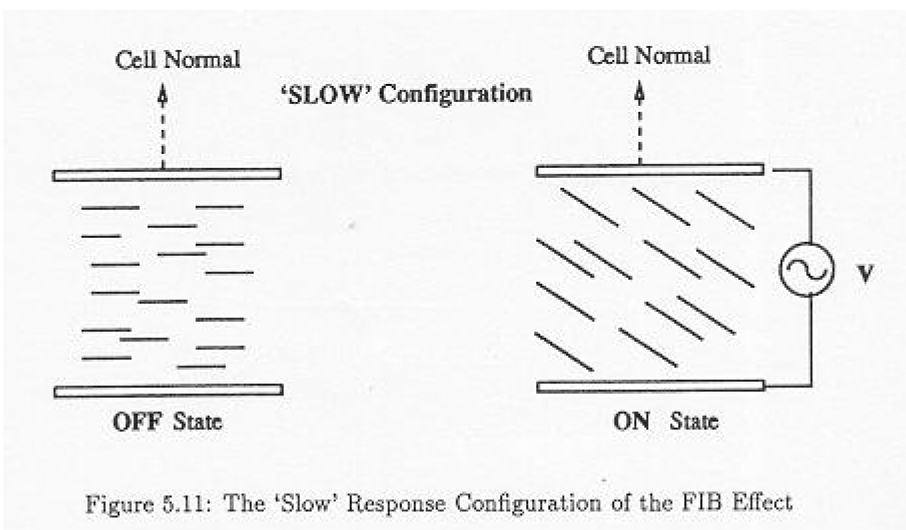

Figure 5.11: The `Slow' Response Configuration of the FIB Effect

The phase difference between ON and OFF states obeys equation 5.10 but in switching an ON state to an OFF state a large molecular reorientation is required. The OFF state voltage, being small, means that the LC effectively relaxes to the OFF state of its own accord with little help from the applied field. It is well known that molecular orientations are, on an electronic timescale, extremely slow due to the viscosity of the liquid crystal. In fact, the free relaxation time τ of such a configuration can be shown to of form [57]

$$\gamma_1 d^2$$

$$\tau = \frac{\quad}{K\pi^2} \qquad (11)$$

where `$\gamma_1$' is the rotational viscosity of the LC, `d' is the cell thickness and `K' is an elastic constant for the particular molecular reorientation. Generally, τ lies in the tenths of seconds [57], [25] range for a 12μm nematic LC cell.

Now consider the effect of raising V_{OFF} to a much higher value but still such that equation 5.10 is obeyed. This state corresponds to one where the LC molecules are already considerably tilted from their quiescent configuration, but do not have that much further to go to reach the configuration belonging to the V_{ON} state. This is shown in figure 5.15.

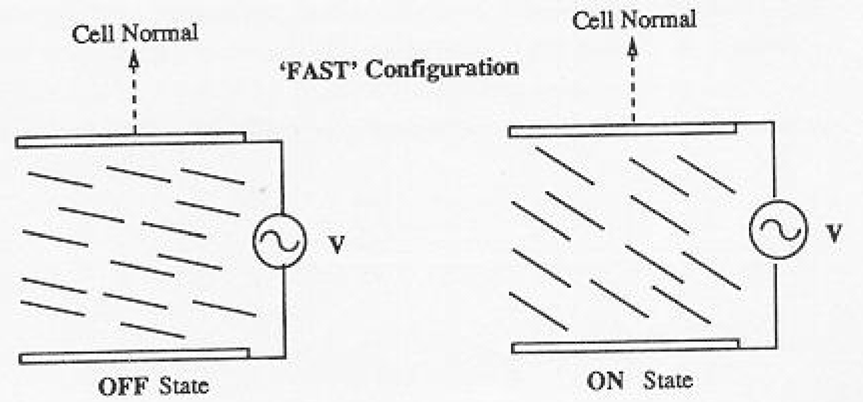

Figure 5.12: The 'Fast' Response Configuration of the FIB Effect.

Figure 5.12: The `Fast' Response Configuration of the FIB Effect.

The intuitive expectation is of a much faster response to a change between OFF and ON states of the liquid crystal due to the much smaller reorientation angle of the molecules in these states. This has been demonstrated experimentally, and for a 12μm thick test cell has shown an improved response time of the order of 10 milliseconds. In the actual experimental use of devices constructed for this project high speed was not a crucial factor, rather the optical quality of the device. The effects of voltage on switching speed were observed to be in accordance with the ideas presented in this section and generally the voltages adjusted to obtain a `reasonably' fast change of state.

3.3 Summary

The Spatial Light Modulator used in this project utilises liquid crystal technology. In order that the main experimental results of this thesis be fully appreciated, (chapters six, seven and eight), this chapter provides a concise introduction to the nature and physics of liquid crystals. It has been shown how nematic liquid crystals may be used to perform both binary amplitude or binary phase modulation if suitable control voltages are provided. Modifications to the basic drive scheme of Underwood used in his 16×16 SLM which allow this device to perform phase modulation have been shown, and an interface[6] between the SLM and a BBC Master series computer is depicted in appendix G. A common light modulation mechanism of ferroelectric liquid crystals was briefly described, which shall be of interest once more in the following chapter which describes the fabrication of an actual SLM in detail.

Footnotes:

[1]The effects of molecular oscillations on the director have been theoretically analysed by MacGregor, PhD thesis, University of Edinburgh 1989, with regards to light transmission through a LC test cell [58].

[2]It can be shown that switching speed is proportional to the square of the cell thickness [57].

[3]Ian Underwood, PhD Thesis 1987, University of Edinburgh

[4]Circuit diagram 5.7 and truth table 5.1 courtesy of Underwood.

[5]Courtesy Dr. Ian Underwood

[6]Designed and constructed by A. Chalabi and G. Bradford, modifications due to A. Garrie, Applied Optics Group, University of Edinburgh.

File translated from T_EX by T_TH, version 3.05.
On 27 Oct 2001, 23:41.