

Question 1 a) An isotropic fluid has full (infinite) rotational and translational symmetry in 3 dimensions.

A nematic liquid crystal retains 3D translational symmetry, but full rotational symmetry is reduced to 1 dimension about the \underline{n} director.

The smectic A phase retains 1D rotational symmetry about the \underline{n} director, but the layers mean that there is now only 2D translational symmetry. Translational symmetry along the \underline{n} director is lost.

In the smectic C phase the 2 dimensional translational symmetry is retained, but the 1D rotational symmetry has been reduced to 2-fold due to the molecular tilt in the layers.

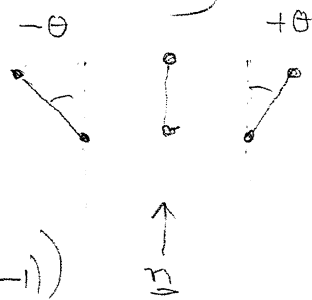
b) The order parameter S of a nematic liquid crystal is given by:

$$S = \left\langle \frac{1}{2} (3 \cos^2 \theta - 1) \right\rangle$$

Show the outer brackets signify an average over the whole sample. θ is the angle between the long molecular axis and the mean direction (\underline{n}).

e.g. Choose a small number of molecules where \underline{n} is clearly defined, e.g. 3 molecules as shown:

where $\theta_1 = -\theta$, $\theta_2 = 0$, $\theta_3 = +\theta$



$$S = \frac{1}{2} (3 \cos^2(0) - 1) + \frac{1}{2} (3 \cos^2(-\theta) - 1) + \frac{1}{2} (3 \cos^2(\theta) - 1)$$

$$= \cos^2 \theta$$

Here $\cos^2 \theta = 0.8 \quad \therefore \theta \approx 27^\circ$

c) α_L and α_T are the lateral and transverse polarisabilities of the molecules.

μ is the molecular dipole moment

β is the angle of the dipole moment to the long molecular axis (the axis of maximum polarisability)

S is the order parameter.

Term 1: The molecular polarisability arises dominantly from delocalised π electrons in the conjugated core of the molecule.

It is relatively independent of frequency and temperature and dominates at high frequencies (i.e. frequencies well above the frequencies associated with molecular motions). This is the induced dipole term that is responsible for the low frequency dielectric properties of non-polar molecules and the high (optical) frequency properties of all molecules.

Term 2: The second contribution comes from charge separation resulting from the effect of an external voltage on the thermally induced motions of polar molecules. It depends on the magnitude and orientation of the permanent dipole of the molecule (μ and β). It is dependent on temperature and frequency. This contribution is "frozen out" at high frequencies i.e. frequencies greater than the spin and tumble frequencies of the molecules. It therefore does not contribute to properties at optical frequencies. This term leads to absorption for polar molecules at low frequencies and is responsible for the high dielectric anisotropy of liquid crystals.

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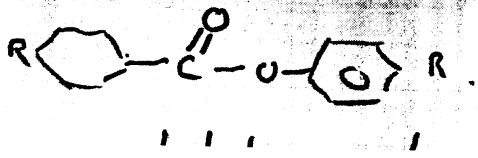
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d) Compound ii) has no conjugated core and the link between the rings is not rigid. Hence the van der Waal forces (dispersion forces) between the molecules are unlikely to be sufficient to give rise to the orientational order characteristic of the nematic phase.

Compound i) Has a conjugated core extending over two aromatic rings and the linking group. It is highly polarisable and will have a relatively high refractive index and birefringence. It also has a strongly polar lateral cyano (CN) group. This results in a strong negative dielectric anisotropy i.e. $\Delta\epsilon = \epsilon_{||} - \epsilon_{\perp}$ is negative.

Compound iii) No side dipoles or lateral polarisability. Strong polarisability along the long molecular axis and a strong axial dipole moment from the cyano (CN) group. This material has a relatively high refractive index, a strong positive birefringence ($\Delta n = n_{||} - n_{\perp}$) and a strong positive dielectric anisotropy ($\Delta\epsilon = \epsilon_{||} - \epsilon_{\perp}$).

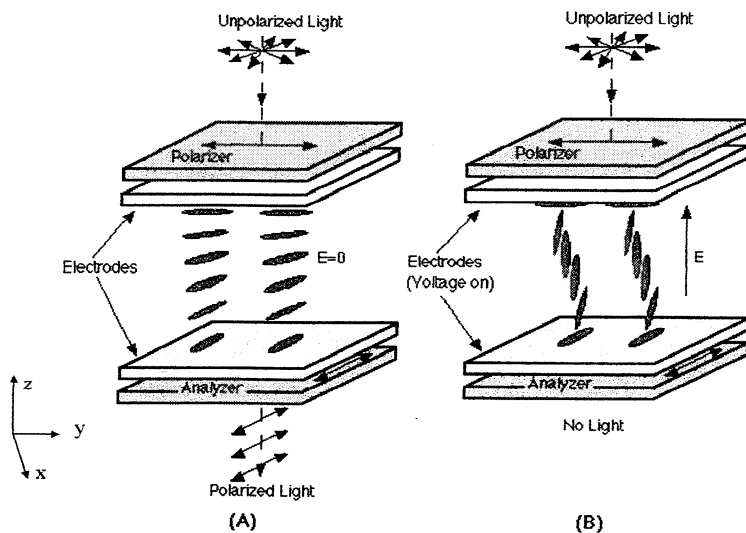
Compound iv) The conjugation in the molecular core has been limited by making one of the ring structures non-aromatic (it is a cyclohexane, PCH ring). This lowers the refractive index and the positive birefringence. Since this material has an ester linkage between the two rings it has a modest side dipole due to lateral bond to oxygen :-



The material has a weak negative

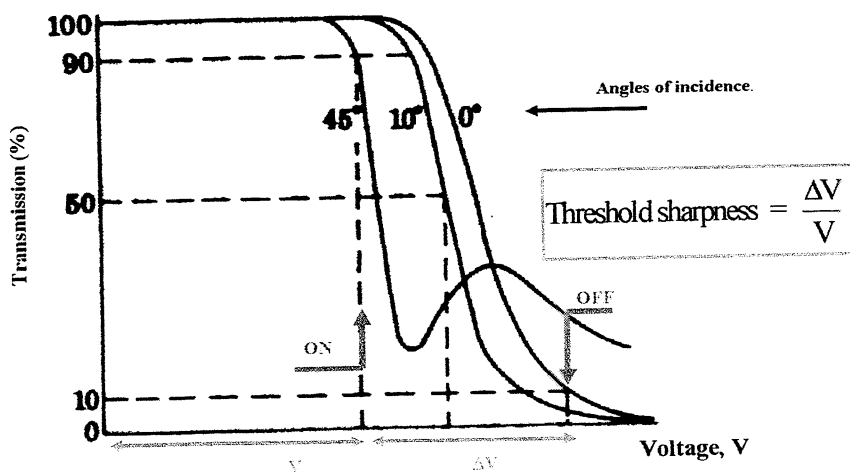
Question 2

a)



The twisted nematic electro-optic effect.

Optical Transfer Characteristic of a normally white (NW) Twisted Nematic Display ---



Measured in transmission at angles of incidence in the low threshold voltage quadrant.

b) The number of pixel rows that can be addressed depends on the threshold sharpness $\Delta V/V$ above. Since the optical transfer characteristic is dependent on the angle of incidence of the light, the threshold sharpness must be defined (as above) over the expected viewing angle.

The multiplexability is dependant on the threshold sharpness because nematic liquid crystals respond to the mean RMS voltage over one or more frames. The voltage selection ratio $(\frac{V_{on}}{V_{off}})$

approaches unity as the number of rows addressed increases, so that a very sharp threshold is required.

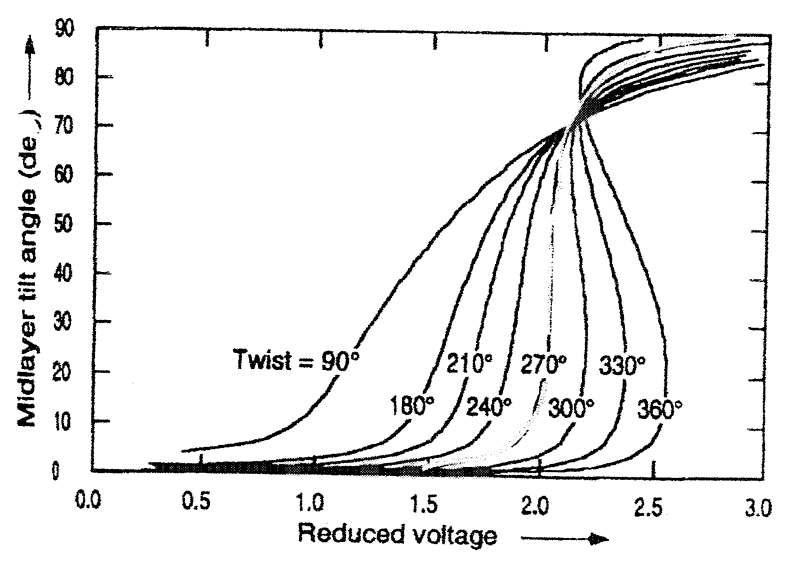
$$c) \frac{V_{on}}{V_{off}} = \sqrt{\frac{\sqrt{N} + 1}{\sqrt{N} - 1}}$$

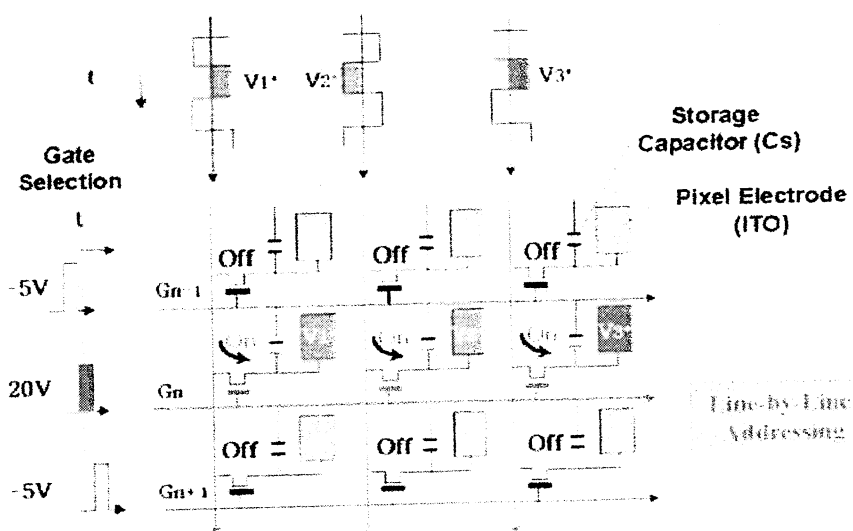
In this case } $N=20$

$$\frac{V_{on}}{V_{off}} = \sqrt{\frac{\sqrt{20} + 1}{\sqrt{20} - 1}} = \sqrt{\frac{4.47 + 1}{4.47 - 1}} = \sqrt{1.576} = 1.25$$

d) The threshold sharpness can be increased by increasing the twist imposed on the nematic liquid crystal from 90° to (usually) 240° or 270° . Such devices are called super twisted nematic (STN) displays and allow more rows to be passively multiplexed (up to a maximum of around 200). Because the voltage selection is now much smaller and also because the higher twist degrades the optical properties, the appearance of such falls significantly below that of a directly switched nematic display. Carefully designed optical compensation foils are used to improve the appearance.

Increasing the twist angle: The Supertwist Display.





The disadvantages of passive multiplexing can be avoided by placing switching transistors at every pixel so that no error voltages appear on unselected pixel rows and unselected pixels. Also (because the electrooptic effect is a field effect, and the resistivity of the liquid crystal is high) the voltage applied to the pixel whilst its row is being addressed charges up the pixel capacitance and is retained for the full frame. Addressing is still line-at-a-time, with the pixel voltages applied to the columns and the rows enabled sequentially.

- e) Pixels comprising light emitting diodes differ from liquid ^{crystal} pixels in two important respects :-
- i) LEDs respond to the transient voltage applied and do not give an integrated response to the RMS voltage.
 - ii) The pixel is a forward biased diode during light emission and therefore has a relatively low resistance. In active matrix addressing the pixel capacitance cannot store charge to maintain light emission over an addressed frame in the same way that liquid

- crystal pixel in a TFT display can.

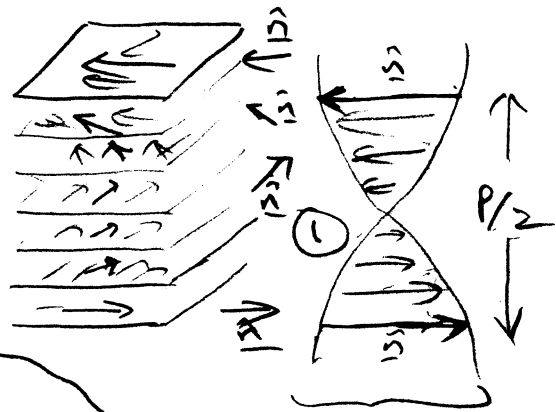
The "low low" of passive multiplexing does not apply because of i). The optimum choice of row and column waveforms is different because the pixels are not RMS responding (in fact so-called $\frac{1}{3}$ select voltages are used to simply maximise the voltage ratio whilst each row is being addressed (not averaging over a complete frame).

Each pixel row activates only whilst it is being addressed and fades whilst the rest of the frame is addressed. Hence each row must be illuminated approximately N times brighter than the full screen brightness, (where N = the number of pixel rows), since it is only illuminated for $\frac{1}{N}$ th of the time.

In active matrix addressing of LED structures circuitry has to be provided to latch and maintain the power at ~~each~~ each pixel. Hence the liquid crystal pixel resembles a simple one transistor dynamic RAM cell, whilst that for an active matrix LED display resembles a static RAM cell.

Chiral ex 20

Q3(a) Molecules arranged in
nematic like layers. The
director \vec{n} of which
is tilted w.r.t each
adjacent layer. The director
traces out a helix of
pitch p . Pseudo layers on
the molecular width scale.



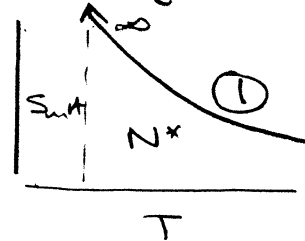
If $p \sim \lambda$ then layers selectively
reflect light thru 'Bragg' like
interference. i.e. constructive interference
from layers of like \vec{n} directors. $\lambda = \bar{n} \cdot p$
where \bar{n} is mean refractive index.

2D Projection of \vec{n}

[4] (3)

For such materials, as an $N^* \rightarrow SmA^*$ transition
is approached, the pitch diverges to infinity due to
the 2nd Order phase transition.
 $p = \infty$ in SmA^* phase.

\therefore Reflected color = f(T). $\lambda \propto p$



Controlling the strength of
this transition - the λ vs T

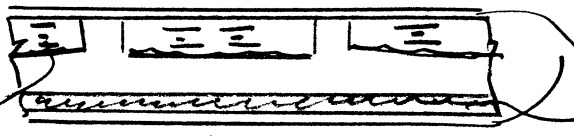
colour play range may be controlled. between $\sim 0.1^\circ$ & 10°
wide range for the visible spectrum.

Reflection colour goes from blue \rightarrow red as T decreases.
Spectrum may be resolved to nm. \therefore very sensitive to ΔT .
i.e. calibrate λ as f(T).

(Reflection circles by polarised at \perp incidence)
with some handedness or helix of \vec{n}

[4] (3)
[4]

(b)



embossed or photolithi
voids filled with

N^* material in planes texture to ensure
maximum reflection at normal incidence
& \therefore 'pure' spectral line ($\lambda = \bar{n} p$ as θ)

laminated polymer sheets
black backing to absorb
non reflected light and to
give optical contrast.

[4]

Q13
Problem

$$\lambda_{\text{peak}} = \bar{n} \cdot p \quad \text{mean ref index} \quad \text{pitch} \quad \text{@ normal incidence} \quad \text{--- (1)}$$

$$\bar{n} = \frac{1}{2} (n_{||} + n_{\perp}), \quad \Delta n = n_{||} - n_{\perp} = 0.04$$

differentiate (1) $\Delta \lambda_{\text{peak}} = \Delta n \cdot p$

$$\text{or } \frac{\Delta \lambda_{\text{peak}}}{\lambda_{\text{peak}}} = \frac{\Delta n}{\bar{n}} \quad \text{(1)}$$

$$n = 1.6 \Rightarrow \lambda_p = 1.6 \times 300 = \underline{\underline{480 \text{ nm}}} \quad \text{(2)}$$

$$\Delta \lambda = \frac{\lambda_{\text{peak}} \cdot \Delta n}{\bar{n}} = \frac{480 \times 0.04}{1.6} \text{ nm} = \underline{\underline{12 \text{ nm}}} \quad \text{(2)}$$

Polarization state is circular. (2)

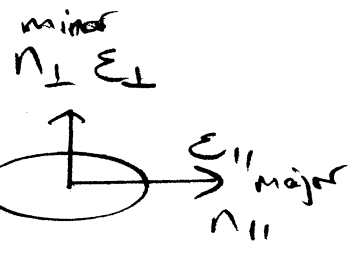
[8]

(NB)

In CR-BS marks given ex 20.
Hhhl.

Q4

Molecules in a chiral smectic C



phase (SmC*) normally have $\Delta \epsilon < 0$

to give a net dipole moment (at $f < 10^6$ Hz) across the major axis (E_1, n_{\parallel})

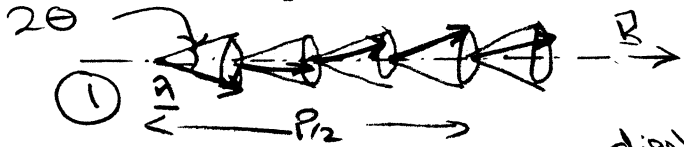
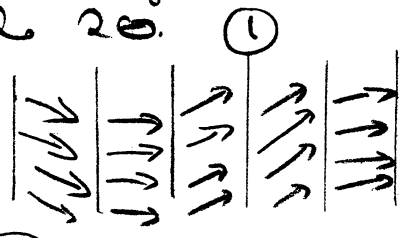
In an SmC phase the layered molecular arrangement is tilted, at some angle θ , to the layer normal \hat{k} .

$$\Delta n = n_{\parallel} - n_{\perp}$$

$$\Delta \epsilon = \epsilon_{\parallel} - \epsilon_{\perp}$$

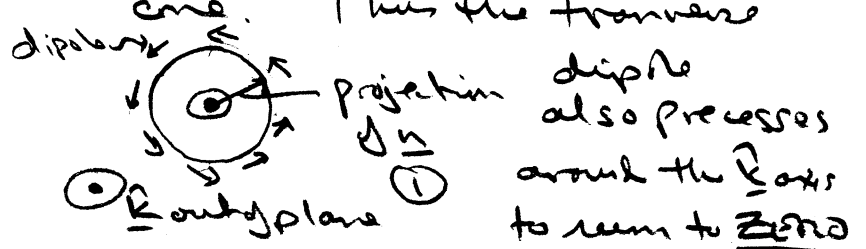
and in the SmC* phase the chirality twists the director in a helix so that \hat{n} precesses around \hat{k} .

ie through one pitch \hat{n} moves around a cone of angle 2θ .



Schematic (layer one molecular)

Helix pitch $\sim \mu\text{m}$ thus in a typical sample of mm length the director turns (~ 1000 's) around the cone.



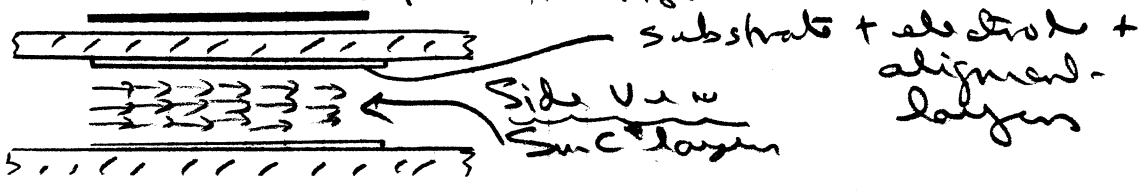
Thus the bulk phase is not Ferroelectric. $\sum P = 0$

[4]

To produce a device surface alignment forces are used to align \hat{n} in the horizontal (say) plane in very thin devices ($d \sim 1-2 \mu\text{m}$). In plan \hat{n} is then constrained by the layer thickness to $\pm \theta$.

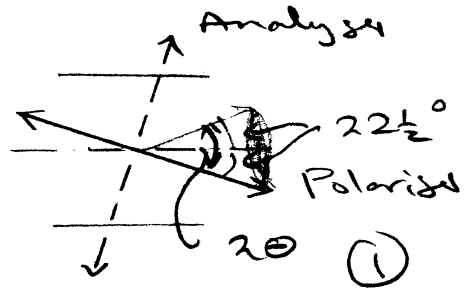
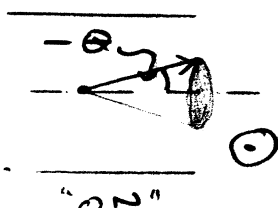
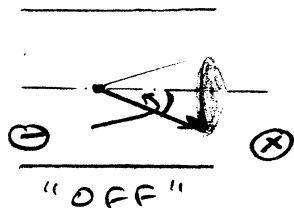
The dipoles will then sum to give a Polarisation up or down ($\pm \theta$ position). The device then becomes ferroelectric on application of a field E to give P_{up} or P_{down} depending on polarity. On field removal there are 2 stable states at $\pm \theta$.

Q5



↑
d
+

Q4 Plan Views



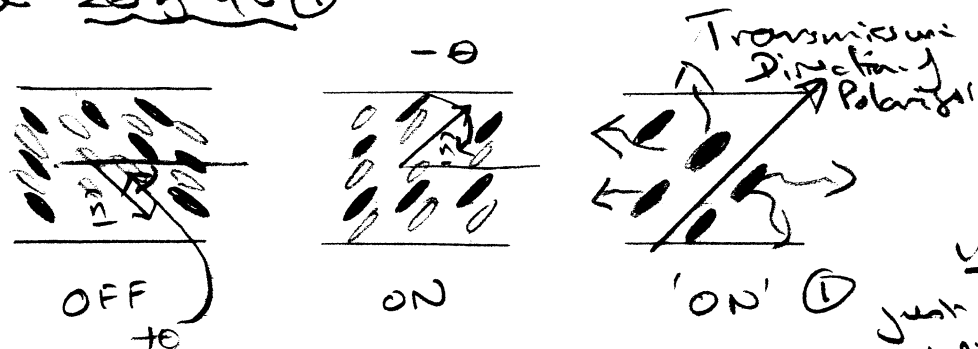
For birefringent device the alignment direction is chosen such that \hat{n} is parallel to the input optical Polarizer. Thus light in the device experiences only one refractive index ($n_{||}$). This direction is crossed with the Analyzer to give a DAEK OFF non transmission state. If the Polarization (Electrical) was down the application of a field in the opposite (or UP) direction reverses the Polarization. \hat{n} then precesses from $+\theta$ to $-\theta$ (i.e. a 2θ switch). Thus \hat{n} is now @ 2θ to the input polarizer and provided that $2\theta \neq 90^\circ$ there will be light transmission since the light passes through a birefringent material ($n_{||} \neq n_{\perp}$)

$I_t = I_0 \sin^2 4\theta \sin^2 \frac{\Delta n d}{\lambda}$

I_t = transmitted light optimum $2\theta = 45^\circ$ incident tilt or conical effect material Δn

[8]

In DGH device Absorbing and Fluorescent dyes included that coalign with \hat{n} . Thus the device acts initially as a switchable polarizer itself that permits ^{at larger} \hat{n} which it absorbs. This requires only one polarizer or a switch angle $2\theta \neq 90^\circ$.



The dye absorption axis same as \hat{n} . So with $\perp P$ no absorption just non visible UV light (OFF)

with absorption axis \parallel to P just light \rightarrow absorption of UV \rightarrow visible fluorescence over all angles.

$\theta \propto (T_c - T)^{1/2} P_3 \propto (E - T)^{1/2}$

$\eta \propto \frac{A}{\lambda^2 P (E - T)}$

$\gamma \propto \frac{\eta}{P E}$

[8]

Q5a)

HeNe/Solid State Laser

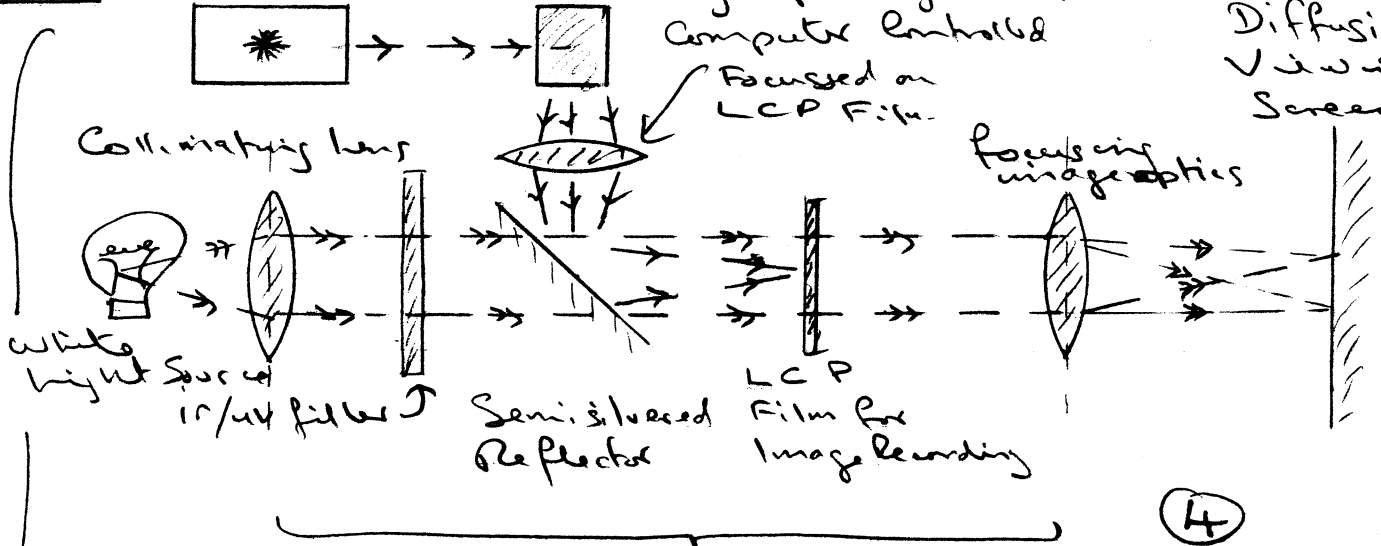
x 20

High Speed Galv. deflector

Computer Controlled

Focused on LCP Film

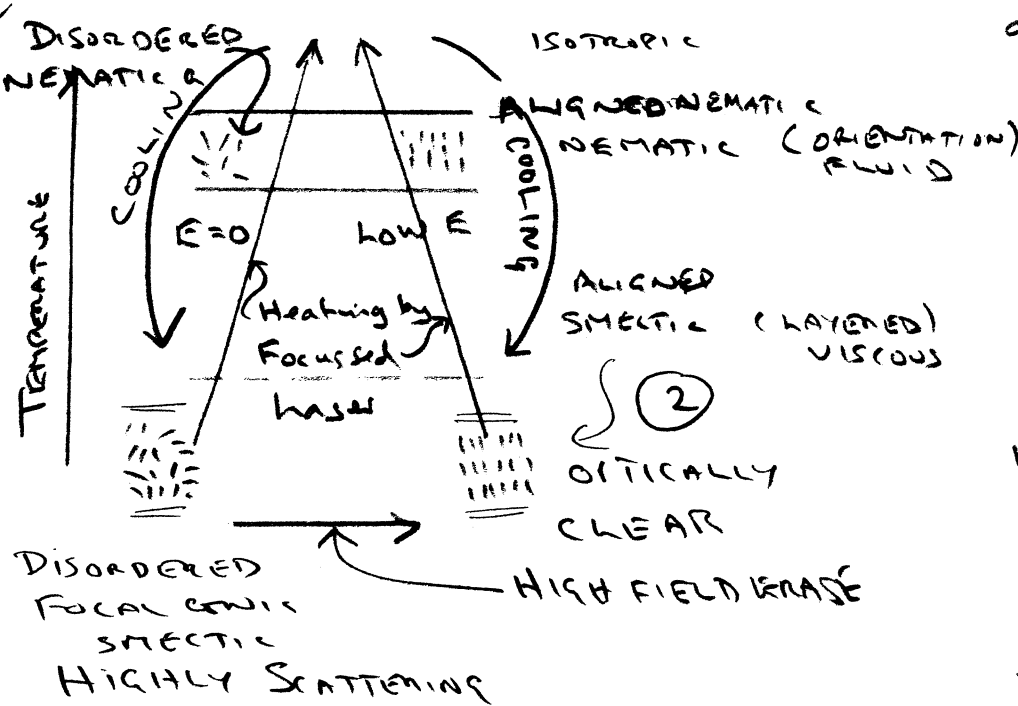
Diffusive Viewing Screen



Projection Optics

Description around each component / dimensions / performance
 white light source (450-700nm), uv filter to reduce degradation
 Projection Optics to image LCP film on screen - Resolution near diffraction limit $\lambda/2$; LCP film $\sim 10\mu m$ thick
 HeNe / Solid state (red) source include Blue dye to improve sensitivity; Galv. deflector + Focusing onto LCP to scan line by line & create image $\sim 2048 \times 1024$
 white time $\sim 1-2s$ for whole screen. (2)

Selective Write & Erase.

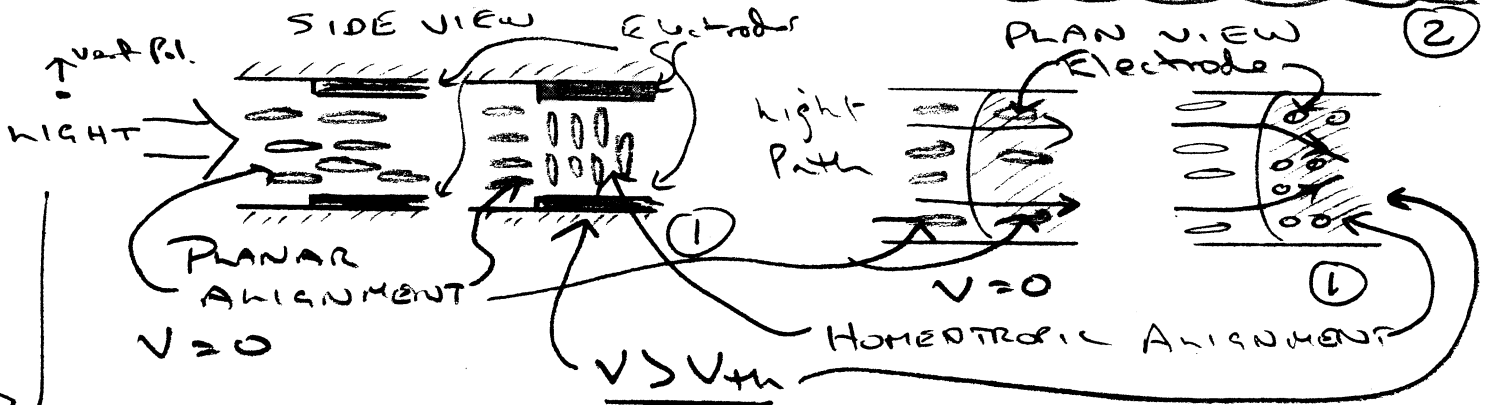


WRITE

- a) NO FIELD ($E=0$)
 Focussed laser local temp. jump ($1-2\mu m$ spot/pixel) into isotropic. Cools rapidly to give scattering texture (opaque) ($\sim 1ms$) (1)
- b) ERASE
 LOW FIELD. Same process as a) except on cooling through the material the low field ($1-10V$) aligns the material to the clear homeotropic state [Too low to align nematic] (2)

REFRESH TOTAL ERASE in high field ($\sim 100V / 10\mu m$ or more)

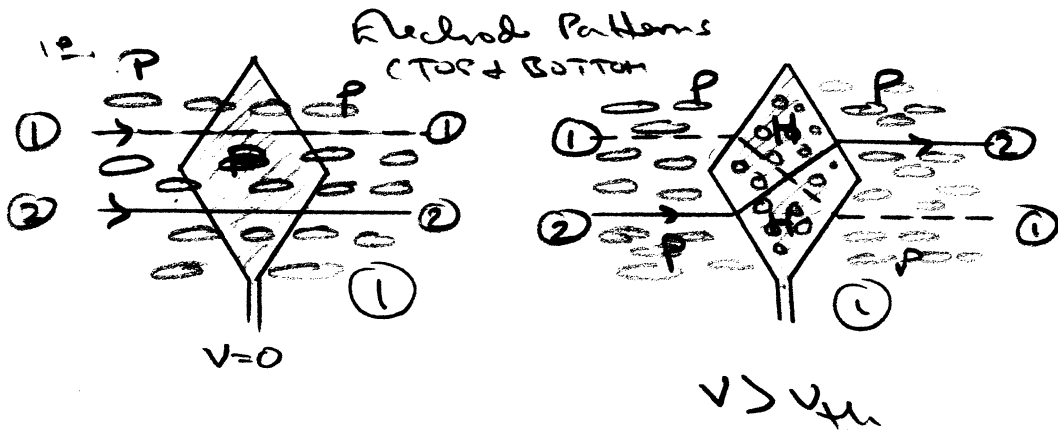
Q5b) Quasi Optics - The creation of Optical Interfaces and Component by aligning birefringent liquid crystals (materials) at an electrode boundary



Thus incoming light from LHS (between electrodes) for $V=0$ experiences only the ordinary ref. index.

For $V > V_{th}$ Fredericksz transition in electrode region to homeotropic. Thus at the electrode boundary vertically polarised light experiences the extra ordinary ref index (ne) on the LHS [6] gives a lens effect or draw [device $\sim 5\mu\text{m thick}$]

Optical Switch could be Mach Zehnder or 2×2 Cross bar etc



Planar Surface Alignment, Nematic material on $V = V_{th}$ for Fredericksz Transition. LHS reverse field & system goes back to initial state.

[4]