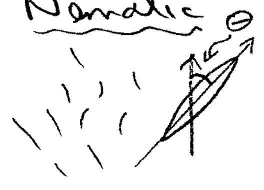
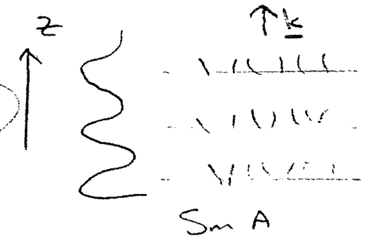
Q1. Nematic: Long range orientational order, no correlations between C of M. (10)



Preferred <average> pointing direction, $\hat{n}$.
$\hat{n} = -\hat{n}$. Molecules geometrically anisotropic but can glide past each other whilst (on average) remaining parallel. Least ordered phase. $S \sim 0.4$–0.6.

(30)

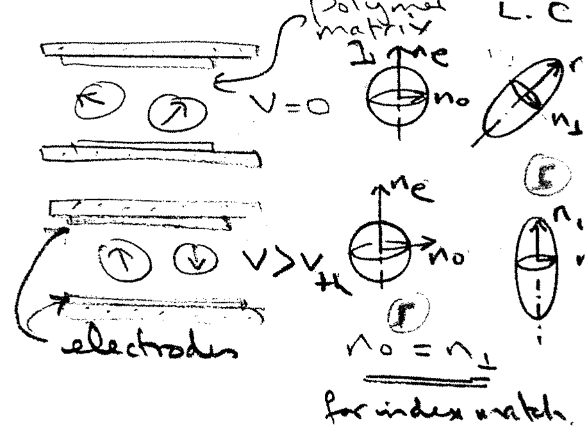


Non tilted. Stratified layer like structure defined by probability density wave.
$\hat{n} \parallel \hat{k}$ (layer normal parallel) (10)
Layer thickness ~ 1 mol. length. Molecules tend to stay in layers but can glide in 2D [illegible]

Experimentally use polarised optical microscope for classical textures, DSC for I→N → ΔH ; N-SmA ΔH=0.
X ray defines layer thickness. (10)

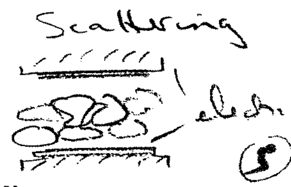
a) Nematic scattering device. Use PDLC to match ref index in 'on' state, scatter light in 'off' state. Droplet size ~ 2–5 μm (5) ∴ strong R.G.Debye scatterer. Ref. indices matched in 'on' state for normal incidence. Optical haze at wider angles (5)

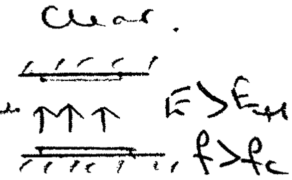
(20)

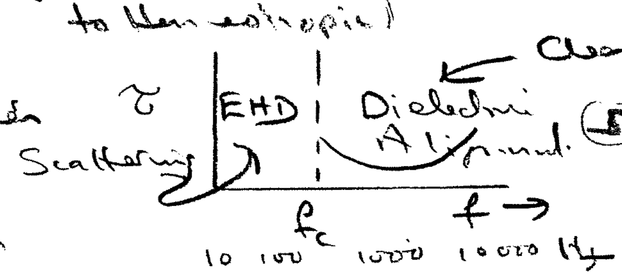


b) Smectic A scattering device
In non field (E) state the focal conic texture gives random scattering domains. Thus the director and layer normal are random. (5) Application of a field at a frequency > f_c (for transition Dynamic Scattering to Homeotropic) (5) gives a clear homeotropic scattering. At low frequencies ionic motion produces layer fluctuations which break up to give a scattering texture. At high frequencies (for Δε>0) dielectric alignment → clear homeotropic texture.

(20)

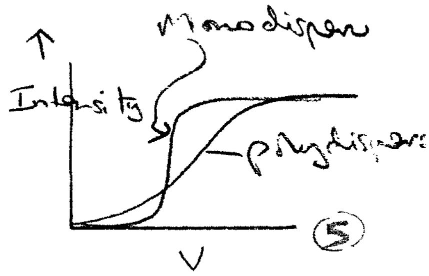






Q1 cont

To optimise electro-optic response,



(5)

For a) **PDLC**. (i) Homogenise droplet size to sharpen threshold and by choosing correct size ~ few microns maximise scattering. To give faster response use lowest limit in size commensurate with max scattering. Increase $\Delta\varepsilon$ to maximise coupling and reduce fields.

(15)

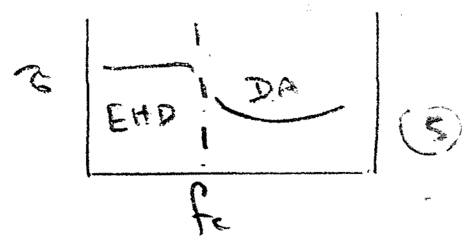
$\tau \propto \frac{\eta d}{V^2 - V_{th}^2}$ (5) $V_{th} \propto \sqrt{\frac{K}{\Delta\varepsilon}}$ (5) Reduce dielectric loss in polymer matrix.

η ~ splay-bend viscosity; d sample thickness.
Use silicone polymers to match dielectric ... ε_{LC}

b) For SmA.

For fast response increase $\Delta\varepsilon$, decrease η.

Difference between τ_{on} scattering to clear V_{th} ∝ $\Delta\varepsilon$ dielectric alignment and clear → scattering



(5)

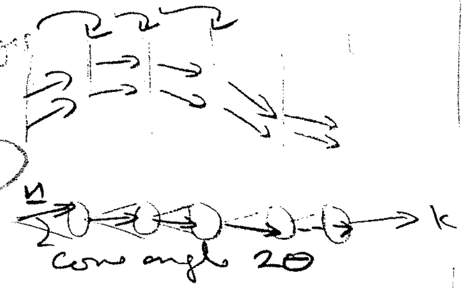
(15)

also electrohydrodynamic instability; $V_{th}^2 \propto (1 - \frac{\sigma_\parallel}{\sigma_\perp})^{-1}$ increase σ. (5)
critical f for Smectics.

However, the induced dynamic size controls scattering ∴ optimum f in EHD regime. (5)

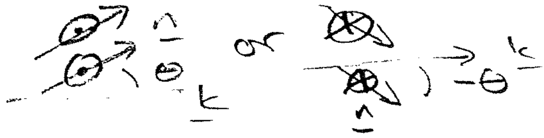
(2) Molecules in chiral smectic C phase (SmC*). $\sum p = 0$

The director is tilted at angle θ to layer normal and director 'spirals' around $\underline{k}$



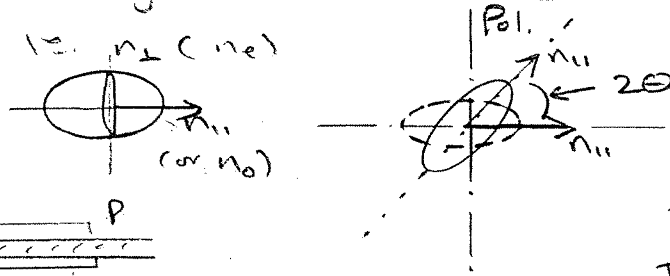
(10)

Surface forces used in 'thin' cell ($d \sim 1$-$2\,\mu m$) to unwind helix. Then the polarisation points 'up' or 'down' & $\underline{n}$ at $+$ or $-\theta$. i.e.



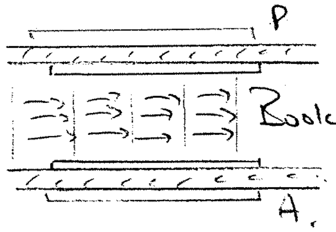
Molecule have $\Delta\varepsilon < 0$

i.e. dipole across molecule. This is the SSFLC. Application of an external field into or out of plane gives $+\theta$ or $-\theta$ and hence the refractive index indicatrix (of Δn) is reorientated to give an optical switch between crossed polarisers. i.e. $n_\perp$ (n_e) (10)



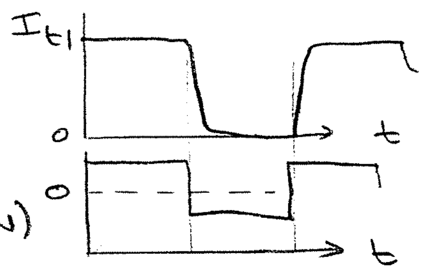
$\Delta\varepsilon = \varepsilon_\parallel - \varepsilon_\perp$

An. $\Delta n = n_\parallel - n_\perp$ (15)



P and A crossed

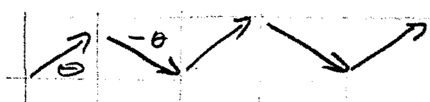
Two stable states $\pm\theta$



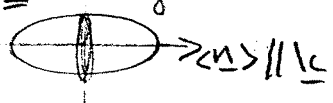
Two state switching.

For Antiferroelectric switching.

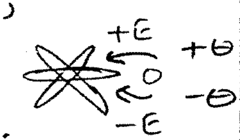
Alternate layers have alternate tilt without field applied



SmC$^*_{\underline{A}}$ layer

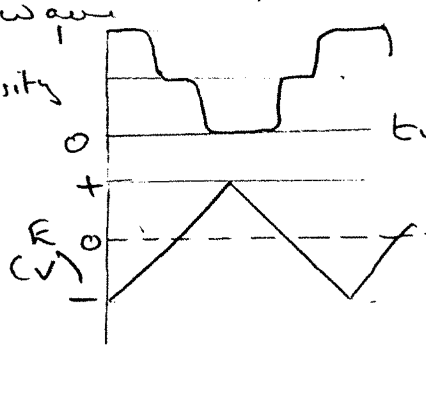


∴ Indicatrix in direction of layer normal. This gives 3 states $+E, 0, -E$ for the indicatrix. i.e. $+\theta, 0, -\theta$.



(15)

switching, illustrated by Δ wave is then 3 state



(15)

(2) Continued

$$I_t = I_0 \sin^2(4\theta)\sin^2\left(\pi \frac{\delta n . d}{\lambda}\right).$$

Optimum value of $4\theta = 90°$ for max switch $\theta = 22.5$ (10)

and align one state ‖ to Pol. or An.

(30) a) $\lambda/4$ plate : Phase $= \pi/2$ (linear pol ⇒ circ. pol)

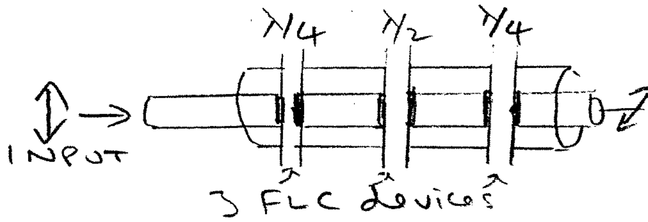
$$\therefore \frac{\delta n \pi d}{\lambda} = \frac{\pi}{2} \Rightarrow \delta n = \frac{500 \times 10^{-9}}{2 \times 2 \times 10^{-6}} \Rightarrow 0.125$$ (10)

b) $\lambda/2$ plate ∴ phase retardation π ⇒ $\Delta n = 0.25$. (10)

Telecomms device. $\lambda/4$ or $\lambda/2$.

eg Fibre Optic Polarisation Control.

(20)

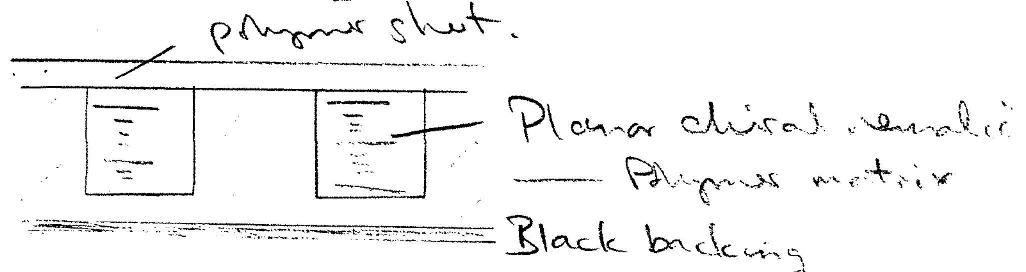


Each element switches
a) linear → circular
b) circ → opposite circ
c) circ → linear crossed with opposite input direction

20

Other FLC devices might be as phase modulators, index rotators etc.

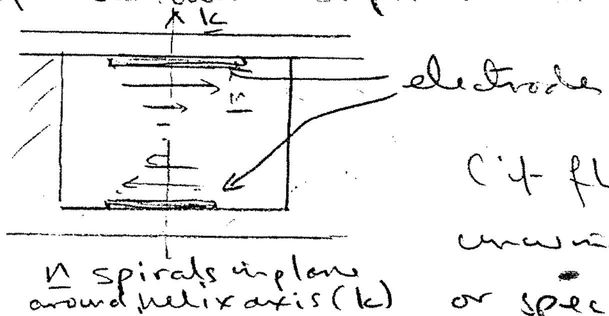
(B) continued.



(20)

N^* in planar texture ⇒ "Bragg" reflections of circularly polarised light. Black backing absorbs transmitted light. (10)
∴ Colour contrast against black backing. As helix unwinds the reflected colour changes.

The above N^* device is a molecular mirror! or Fabry Perot device due to the effective large plane separation $\sim \lambda/2$.
If electrodes incorporated into the device and the liquid crystal has $\Delta\varepsilon > 0$ the director will either tilt (if flexoelectric) or the helix will unwind. Either way the "metallic like" (10) or specular reflection will be switch off or deflected.



For N^* phase $\lambda_r = p\bar{n}\cos\Theta$ —① where Θ = angle of incidence. (5)

(40)

For helix $\bar{n} = \frac{1}{2}(n_{\parallel} + n_{\perp})$ (mean on rotation) —②

Δn = Birefringence $= n_{\parallel} - n_{\perp}$ —③ } (5)

a) Normal incidence $\lambda_{peak} = \bar{n}p = \left\{\frac{1.3 + 1.5}{2}\right\} \cdot 500$

$\Rightarrow \underline{700 nm}$ (5)

b) Bandwidth $\Delta\lambda$, From ① differentiate $= \Delta\lambda = p\,\Delta n$

$\Delta n = 1.5 - 1.3 = 0.2$, $p = 500$ ∴ $\underline{\underline{\Delta\lambda = 100 nm}}$

(5)

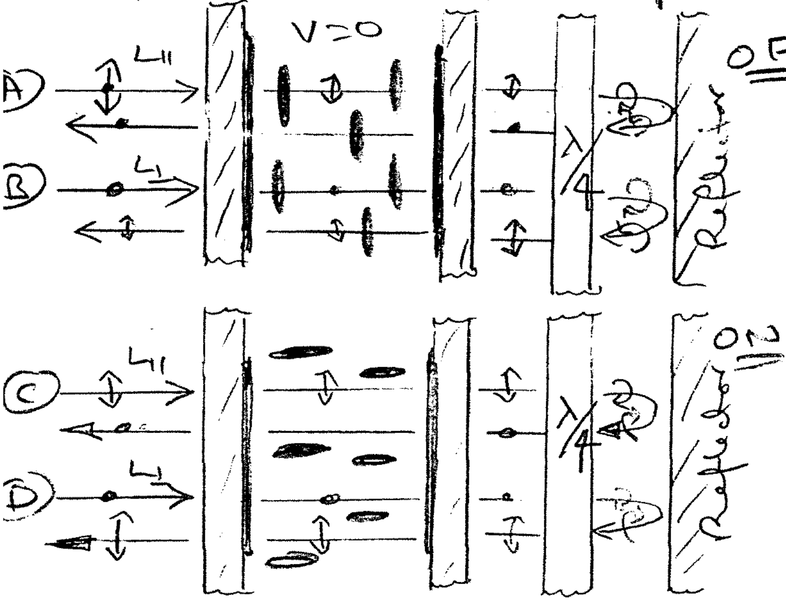
For non normal incidence the $\cos\Theta$ term means that the wavelength decreases i.e. "blue shift"

Polarisation. Normal Incidence → RH helix ⇒ RH Reflection Circular Pol. (5)
Non Normal → Elliptically polarised light

(4) Dye Guest-Host Nematic

[NB The candidates could describe a DGH incorporating a λ/4 plate or a White Taylor Display. Either is acceptable]

Polariser Free i.e. Unpolarised light



OFF In Dye Guest Host absorbing dye with a +ve absorption anisotropy i.e. uniaxial (6)

$\varepsilon_{\parallel} - \varepsilon_{\perp} = \Delta\varepsilon > 0$ $\varepsilon_{\perp}$ $\varepsilon_{\parallel}$ $\varepsilon_{\perp}$ (5)

$\varepsilon_{\perp} \approx 0$

is incorporated in a nematic matrix. Thus the major absorption axis follows the director n.

(10)   V > V_{th}.   Quarter wave O.A. at 45° to axis

Therefore in OFF state use planar alignment. (5)

Construction incorporates λ/4 plate matched to peak absorption λ.

OFF State

For unpolarised light consider two components ∥ and ⊥r to director

$L_{\parallel}$ to n Route (A) $L_{\parallel}$ absorbed partially traversing device to λ/4 plate. $L_{\parallel}$ changed to circular polarisation of one handedness which is reversed on reflection (π phase change). After reflection + passage thro' λ/4 plate component left is rotated into $L_{\perp}$ direction which then passes back out. (10)

$L_{\perp}$ to n Route (B). $L_{\perp}$ not absorbed on initial pass — follows same process as (A) but re-enters nematic layer with polarisation rotated by 90° (i.e. in $L_{\parallel}$ direction) after reflection + passing via λ/4 plate. This component is then absorbed by planar dye. Thus in 'OFF' state all polarisation being absorbed. (10)

In ON case $L_{\parallel}$ and $L_{\perp}$ is always in direction of $\varepsilon_{\perp}$ due to uniaxial symmetry ∴ NO absorption. So for white incident light the "OFF" state is Coloured (by subtraction) & ON state is white. ∴ Use either Red, Green, or Blue transmitting dyes. Wavelength specific because of λ/4 plate

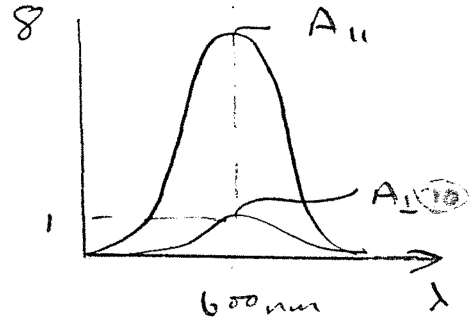
4 cont....

$\lambda_{peak} = 600nm$, Dichroic Ratio (Definition) $= \frac{Abs_{\parallel}}{Abs_{\perp}} = \frac{1+2S}{1-S} = DR$ (10)

where S = Order Parameter. (5)

$A_{\parallel}$ for planar 'off' alignment

$A_{\perp}$ for perpendicular 'on' alignment in electric field.



(30)

Calc ⇒ $8 = \frac{1+2S}{1-S}$

∴ $S = 0.7$ (5)

DGH versus TN Cell.

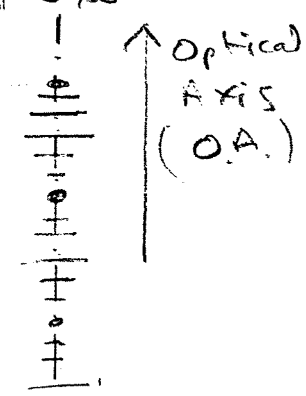
	GH	TN
Brightness	V. good	< good
Contrast	Medium	Good
View Angle	V. Good	Restricted
Construction → Complexibility	1 or 0 Polarisers	2 Polarisers
Multiplexing	poor	good.

(15)

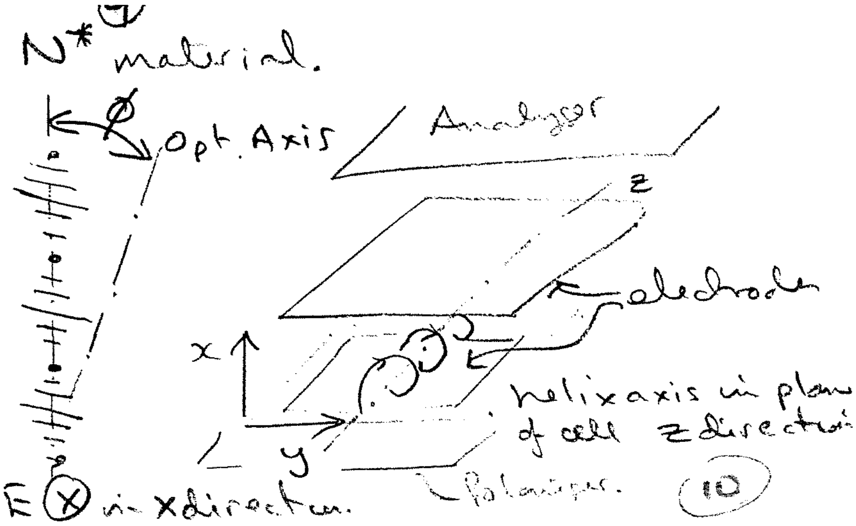
(20)

Make device emissive by using a fluorescent dye i.e. absorbed energy re-emitted at lower or higher λ. (5)

(5) Flexoelectric using N^* material.



E = 0
"OFF"



"ON" (10)

Flexoelectricity is the L.C analogue of piezoelectricity in crystals due to curvature strain of the director under an external field. In an N^* material (of short pitch to avoid diffraction effects) the helix is constrained by surface forces to lie in the plane of the device. Thus the helix appears as a uniaxial phase plate, with its optic (ne) axis along the helix axis. Application of E(x) couples with the flexoelectric dipoles to produce an "in plane" rotation φ of the optic axis.

$\tan\phi = \frac{\bar{e}}{K.k} E$ (accept $\tan\phi \propto E$) ⇒ linear rotation of the OA (20) with magnitude of E and dependent on direction of E i.e. field reversal ⇒ switch φ → −φ. ∴ Bipolar E ⇒ 2φ switch.

Thus the refractive index indicatrix rotates with magnitude and sign of applied field. [K ⇒ mean elastic constant

$k = 2\pi/p$ the helix wavevector.

$\bar{e}$ = flexoelectric coefficient

For Phase Modulation $\phi \propto E$ (10)

∴ A triangular input field produces a triangular output for φ reasonably small (i.e. in linear region of $\sin^2$ transmission function. Other important features φ is independent of T. Response time τ independent of E $\left[\tau = \frac{\gamma_1}{k^2 K}\right]$.

Device not too sensitive to angle of incidence [Properties of Ref. index ellipsoid]

For φ = 22.5 (Switching thru' 45° in bipolar pulse) E ~ 5V/μ and τ ~ 100μs. (10)

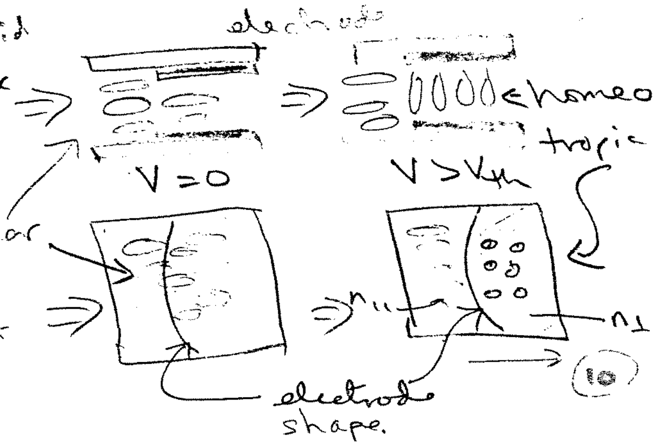
50

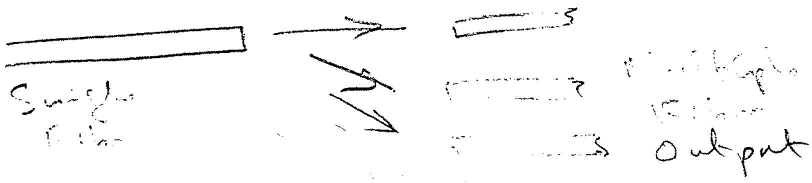
(5) Continued....

Quasi-optics, in telecomms (Creation of optical interface)

The idea here is to align a liquid crystal film to give a bulk uniform refractive index and then use electrodes and an applied field to reorient the director & hence refractive index ellipsoid thus generating a refractive index change at the edge of the field pattern. (10)

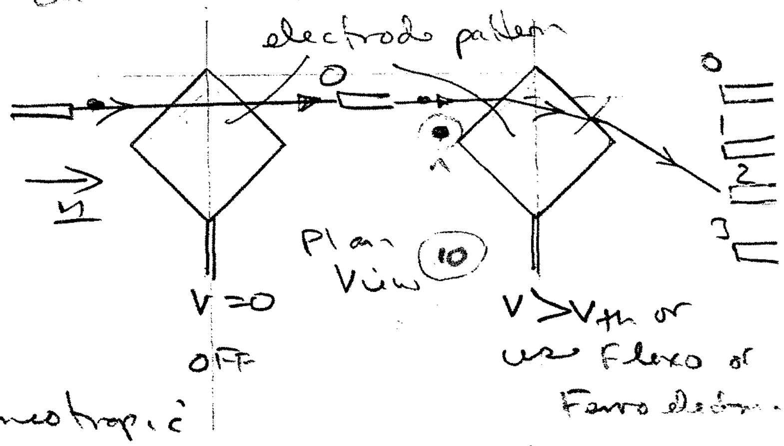
In example shown ref index change





∴ Use shaped electrode — triangular (prism) or circular (lens)

to produce deflection ie.



Use planar alignment in propagation direction for off state. Couple to fibre 0.

To switch apply field ⇒ homeotropic alignment & refractive index "experienced" switches from $n_o \Rightarrow n_e$

This creates a prism of ref. index in cell and deflects beam to 1, 2, 3 etc. Use broad threshold material to give defined bulk gradual change in ref. index. Could use Antiferroelectric or Flexoelectric (10) to give linear change [illegible] gradual deflection [illegible].

The devices as described are polarisation dependent (which is a disadvantage). However switching times are ~10-100μs which is 3 orders of magnitude faster than [illegible]