

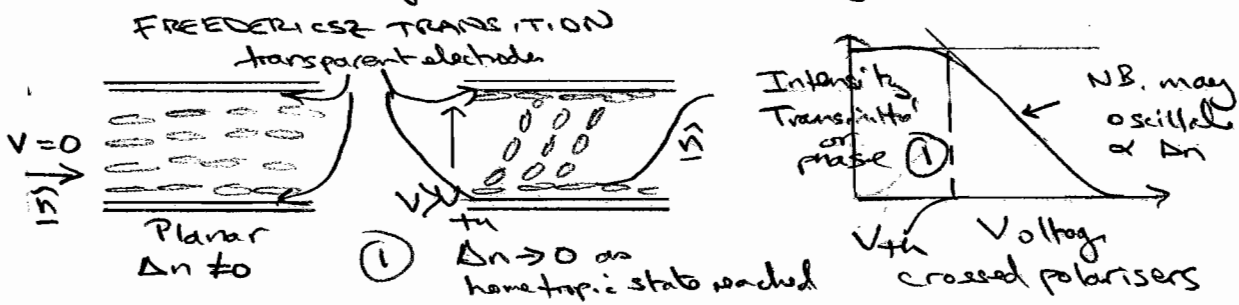
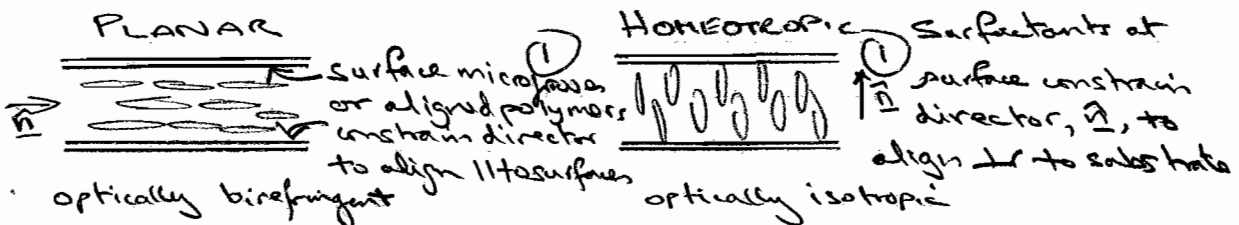
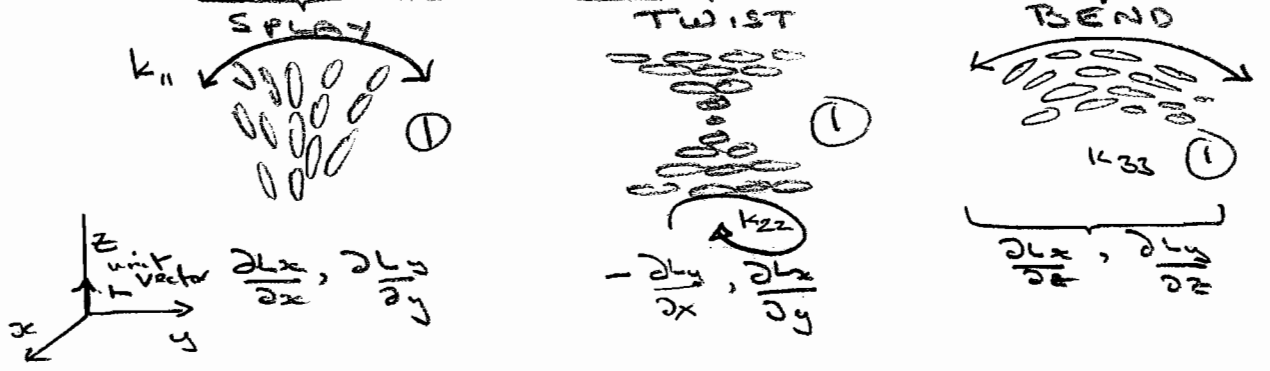
CRIB marks ex 20. 4B17 2008

Q 1(a) Need continuum theory to describe SPLAY, TWIST & BEND, i.e. the director field treated as continuous (not molecular).

Pure shear conserves elastic energy due to molecular slip in nematics

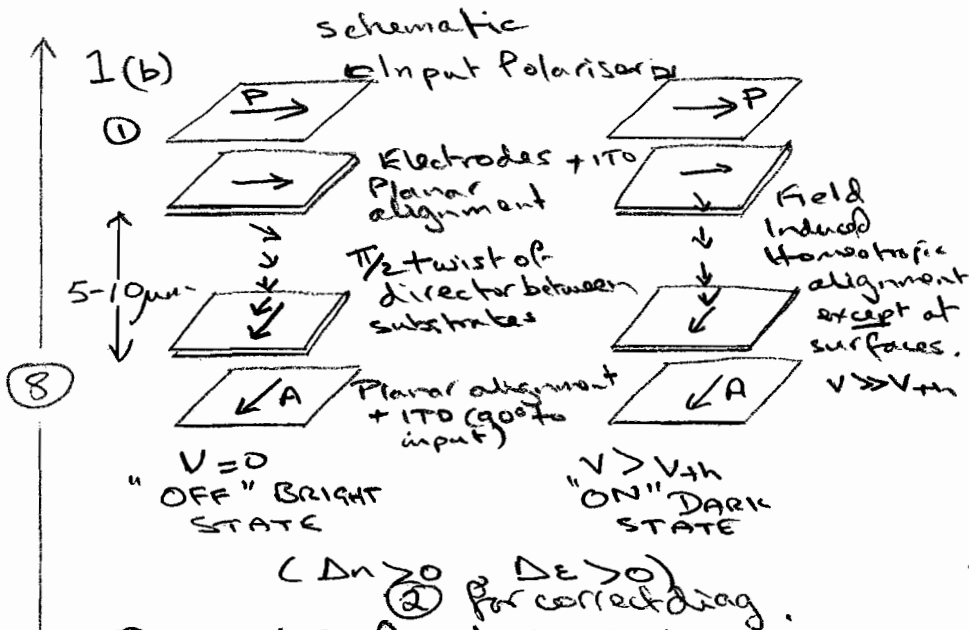
• In Frank continuum theory the FE density, F , / unit vol:-

$$F = \frac{1}{2} k_{11} (\text{div } \underline{n})^2 + \frac{1}{2} k_{22} (\underline{n} \cdot \text{curl } \underline{n})^2 + \frac{1}{2} k_{33} (\underline{n}_\perp \cdot \text{curl } \underline{n})^2$$



SPLAY Fredericke transition for material with $\Delta\epsilon > 0$.
 Apply voltage across planar device \rightarrow homeotropic transition starts at V_{th} . Monitor thro' crossed polarisers with \hat{n} at 45° to Pol. or Analyser. Change in intensity occurs at V_{th} the ENERGY needed to produce Splay.

$$V_{th} = \pi \sqrt{\frac{k_{11}}{\epsilon_0 \Delta\epsilon}} \quad \text{①}$$



① For $V=0$ Polarised light rotated by $\pi/2$ in 'waveguiding mode' via twist provided by orthogonal surfaces. Helix 1/4 turn waveguide the polarisation to twist parallel to output Analyser = Transmission or Bright state.

② Application of $V > V_{th}$ distorts and uncoils helix. This creates homeotropic alignment (except at immediate surface interfaces. Optically isotropic cross waveguiding & Polarisation NOT rotated. Thus crossed P & A \Rightarrow DARK STATE.

③ SURFACE ALIGNMENT necessary to 1, define the OFF state helix and waveguiding of Polarisation. ② Provides threshold (for distortion) necessary for multiplexing. ③ Restores helix twist on field removal (OFF STATE).

1(c) Planar Sample, $\Delta \epsilon = 6$ (> 0); $\therefore \eta_{eff}$, $V_{th} = 2V$, $d = 10\mu m$.
 \therefore Planar \rightarrow Homeotropic for $V \gg V_{th}$

④
$$V_{th} = \pi \left[\frac{k_{11}}{\epsilon_0 \Delta \epsilon} \right]^{1/2} \Rightarrow k_{11} = \frac{V_{th}^2 \cdot \epsilon_0 \cdot \Delta \epsilon}{\pi^2} = \frac{4 \times 8.854 \times 10^{-12} \times 6}{\pi^2}$$

$$= 21.5 \times 10^{-12} \text{ N} \quad \text{①}$$

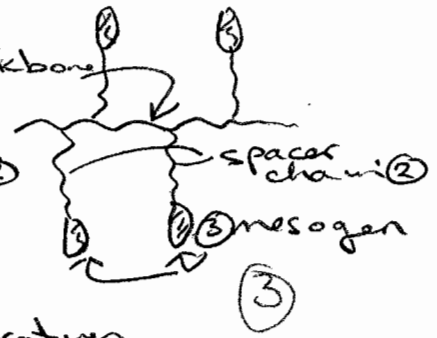
$$\zeta_{off} = \frac{\eta d^2}{k \pi^2} \quad \text{or} \quad \eta = \frac{k \pi^2 \zeta_{off}}{d^2} = \frac{21.5 \times 10^{-12} \times \pi^2 \times 10^{-2}}{100 \times 10^{-12}}$$

$$= 2.1 \times 10^{-4} \text{ [kg.m}^{-1}\text{s}^{-1}] \quad \text{①}$$

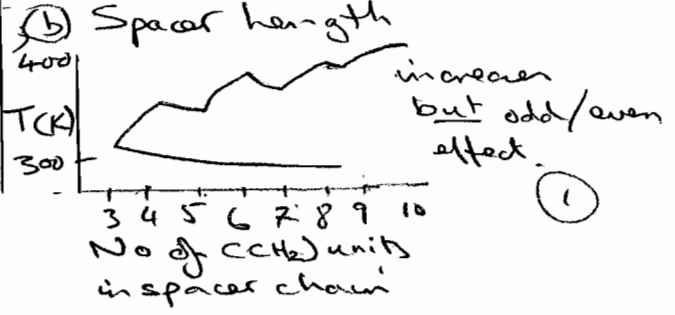
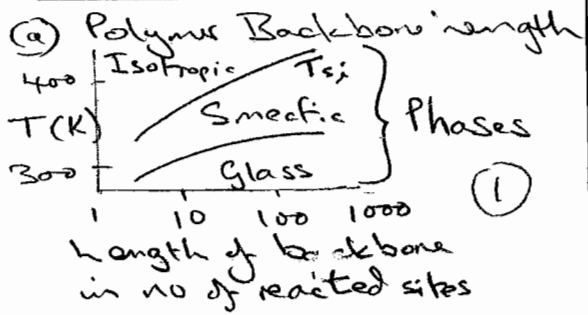
where η = apparent splay viscosity

Q2 (a)

SCLCF composed of semiflexible backbone ① linked via spacer chain ② to liquid crystal (mesogenic) or other functional side groups ③.

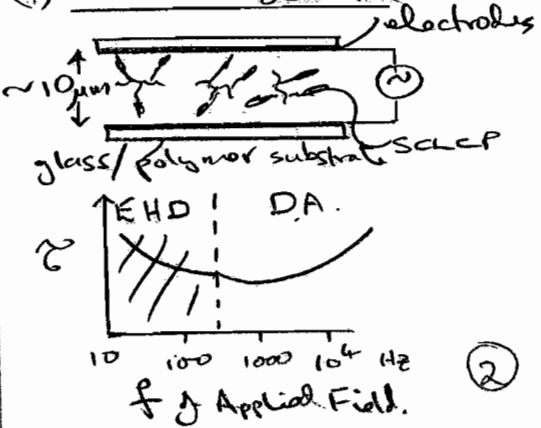


Factors Influencing Transition Temperatures



- (c) Choice of backbone - siloxane more flexible than methacrylate or acrylate. T_g & T_{si} increase with rigidity ①
- (d) Choice of mesogen - High temp/ low temp range materials alter starting point for phase diagrams (cf (a) above) ①
- (e) Dye moieties / dichroic / fluorescent / NLO etc may also be used ①

(b) SCLCF Device

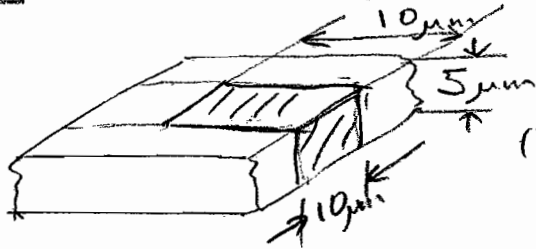


Start with +ve mesogenic material ($\Delta\epsilon > 0$, $\Delta\epsilon = \epsilon_{||} - \epsilon_{\perp}$)

Response time as a function of frequency near to T_{si} . Observe textures using POM. ②

(i) At low frequencies of applied field ($\leq 200-300 \text{ Hz}$) ionic motion (on a.c. field reversal) breaks up the ordered structure so that the local directors become random and domain interfaces give a refractive index mismatch and there is intense scattering of light (opaque). Electro-hydrodynamic instabilities. ②

(ii) At higher frequencies the ions can no longer respond to field reversals and the mesogens align through polar or induced dipolar mechanisms. For a +ve material ($D_E > 0$) this is in the field direction. The directors mutually co-align to give a homeotropic clear texture (Dielectric Alignment) ②



All energy absorbed

(i)
$$\text{Time at track} = \frac{\text{track length}}{\text{writing speed}}$$

$$= \frac{10 \times 10^{-6}}{2} \text{ [m]} \text{ [m.s}^{-1}\text{]}$$

$$= \underline{\underline{5 \mu\text{s}}} \text{ ②}$$

(ii) Temperature Increase. Assume uniform nignore ρ profile, Energy Absorbed = Power \times time

$$= 500 \times 10^{-3} \times 5 \times 10^{-6} \text{ [J]}$$

$$= 2.5 \times 10^{-6} \text{ J.}$$

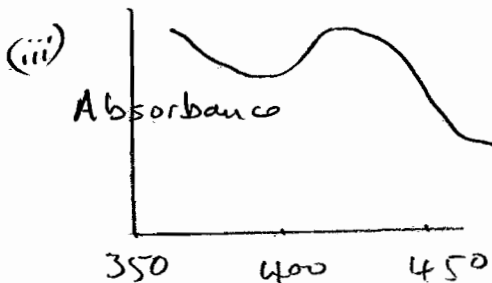
Heat energy absorbed
 density \downarrow
 volume \swarrow
 $m = \rho v$

Heat energy $\Delta H = m \cdot c_p \cdot \Delta T$
 or $\Delta T = \frac{\Delta H}{m c_p}$

$$= \frac{2.5 \times 10^{-6}}{10^2 \times 10 \times 10^{-6} \times 5 \times 10^4 \times 10 \times 10^{-6} \times 50 \times 10^3} \text{ [J]}$$

$$\frac{\text{[kg.m}^{-3}\text{]} \cdot \text{[m}^3\text{=v]}}{\rho} \quad \text{J.kg}^{-1}\text{K}^{-1} = c_p$$

$\Delta T = 1000 \text{ K}$ ③

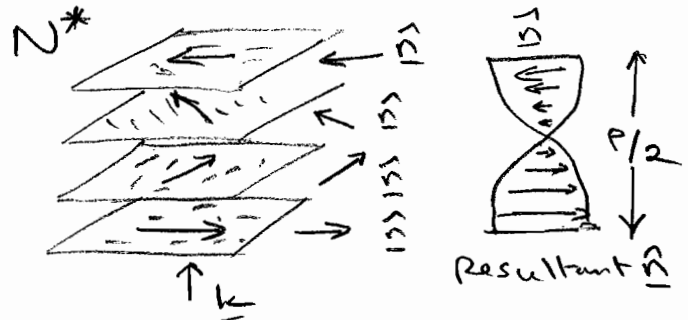


Designed for dye absorbance to peak at 400nm
 U.V absorption of LC.

①

Q.3. (a)

Molecules aligned in nematic like layers ($\sim 0.1 - 0.2 \mu\text{m}$) apart which rotate w.r.t each other so



that the director traces out a helix, where P is the pitch for 360° rotation. (nematic disorder within the pseudo layers). (3)

Planar means planes parallel to substrates and layers of equal \hat{n} rotate but \perp to layer normal k
REFLECTIVE PROPERTIES.

(i) Constructive Interference + director fluctuations ($\sim \hat{n}$) give a narrow band of 'Bragg' reflected colours.

(ii) Reflected wavelength follows Bragg conditions for the λ peak ($\lambda_p = \bar{n} p$) for normal incidence

(iii) Band width of reflected light $\Delta\lambda$ depends on the material birefringence Δn .

(iv) Reflected light is circularly polarised with same handedness as helix.

(v) Opposite handedness transmitted.

(vi) For non-normal incidence reflected light is elliptically polarised and $\lambda_p = \bar{n} p \cos \theta$ where $\theta =$ angle of incidence. \bar{n} is mean refractive index. (3)

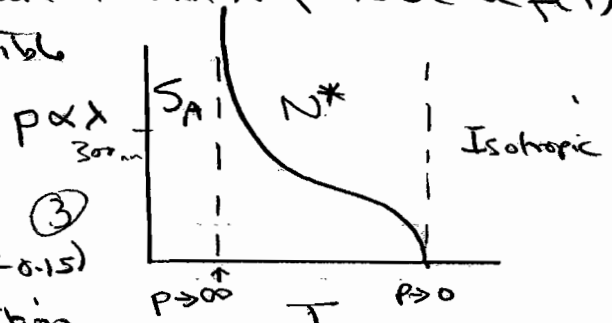
(b) For THERMOMETRY we require λ and $\therefore p$ to be a f(T)

(i) p uncontrolled to give visible reflections

(ii) p is a f(T)

(iii) Narrow band colours (3)

$\Delta\lambda = \Delta n p$ ($\Delta n \sim 0.05 - 0.15$)



For 2nd order phase transition

the pitch diverges approaching the S_{m1} transition \rightarrow temp sensitive colour reflection. The pitch may vary

⑥

from 300nm \rightarrow 1 μ m over a 1-2°C temperature range at this transition. Could be made broader by composition. Thus reflected colour easily seen from blue to red with decreasing temperature and narrow band reflections (\approx 2-5 nm)

✓ 1st Order transition - pitch is constant ③

(c) Problem $\lambda_p = \bar{n} \cdot p$ — mean ref. index p ← pitch } ①

$$\frac{\Delta \lambda}{\lambda_p} = \frac{\Delta n}{\bar{n}}$$

$$\therefore \lambda_p = 1.5 \times 433 \text{ (nm)} = \underline{\underline{650 \text{ nm}}} \quad ①$$

$$\Delta \lambda = \lambda_p \frac{\Delta n}{\bar{n}} = \frac{650 \times 0.15}{1.5}$$

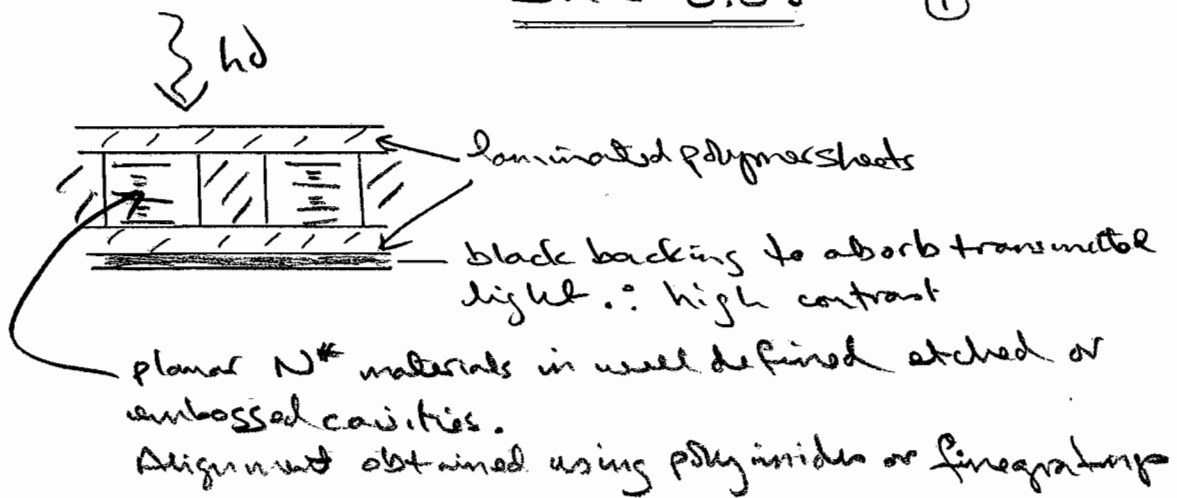
$$\Delta \lambda = \underline{\underline{65 \text{ nm}}} \quad ①$$

For $\Delta \lambda = 13 \text{ nm}$ $\Delta n = \bar{n} \cdot \frac{\Delta \lambda_p}{\lambda_p}$

$$= \frac{1.5 \times 13 \text{ nm}}{650 \text{ nm}}$$

$$\underline{\underline{\Delta n = 0.03}} \quad ①$$

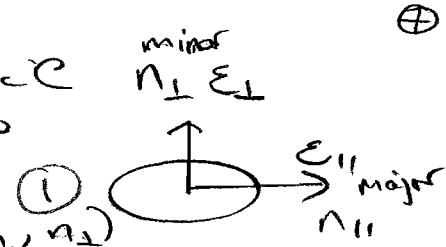
⑥



②

④ (a) Molecules in a chiral smectic C phase (SmC*) normally have $\Delta E < 0$

to give a net dipole moment (at $f < 10^{14}$ Hz) across the major axis (E_{\perp}, n_{\perp})

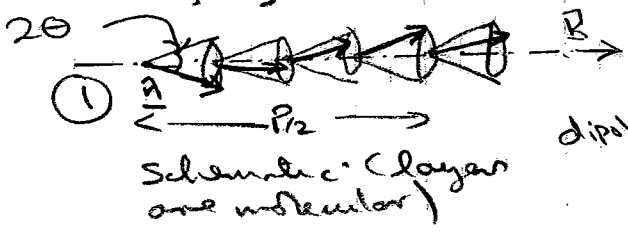


In an SmC phase the layered molecular arrangement is tilted, at some angle θ , to the layer normal \hat{k} .

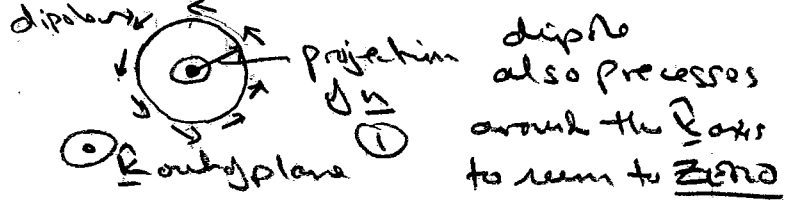
$\Delta n = n_{\parallel} - n_{\perp}$
 $\Delta E = E_{\parallel} - E_{\perp}$

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 . (1)



Helix pitch $\sim \mu\text{m}$ thus in a typical sample of mm length the director turns (~ 1000 's) around the cone. Thus the transverse dipole also precesses around the P_2 axis to sum to zero



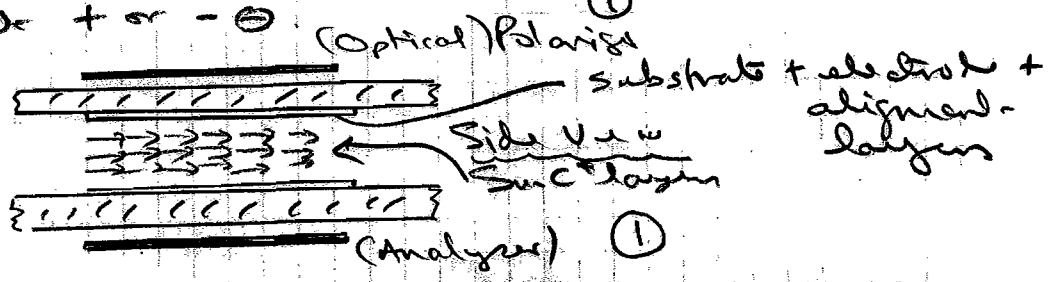
Thus the bulk phase is not Ferroelectric. $\sum P = 0$

[4]

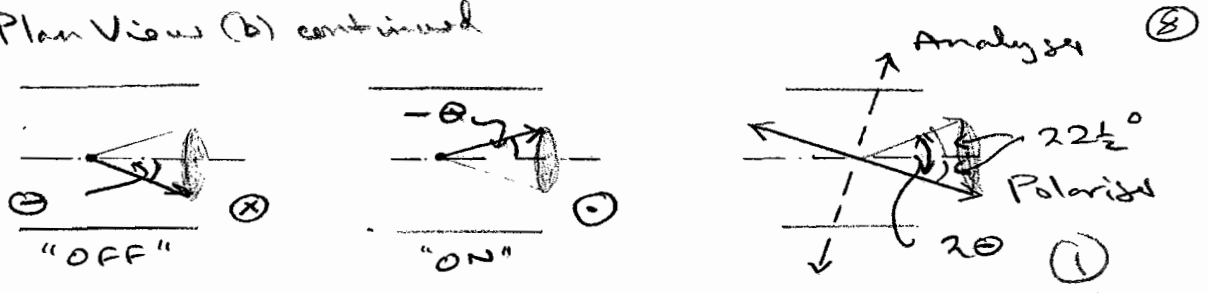
(b) To produce a device surface alignment forces are used to align \hat{n} in the horizontal (say) plane in very thin devices ($d \sim 1-2 \mu\text{m}$). (1) In plan \hat{n} is then constrained by the layer thickness to $\pm \theta$.

The dipoles will then sum to give a Polarisation up or down ($\pm \theta$ positions). (1) 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 $+$ or $- \theta$. (1)

[5]



Q4 Plan Views (b) continued



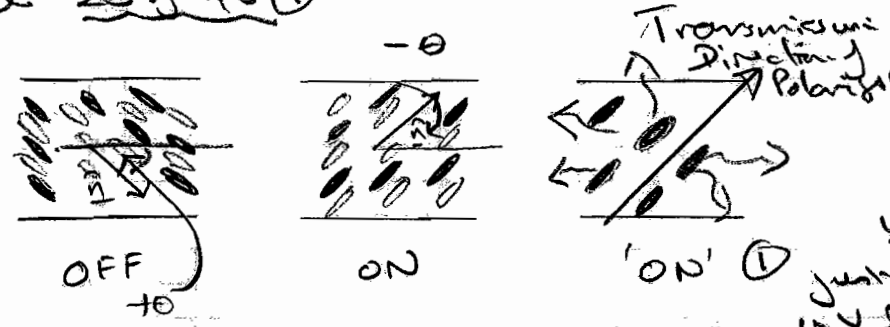
For birefringent device the alignment direction is chosen such that \hat{n} is parallel to the input optical polarisation. Thus light in the device experiences only one refractive index ($n_{||}$). This direction is crossed with the Analyser to give a DARK OFF ~~was~~ transmission state. If the Polarisation (Electrical) was down the application of a field in the opposite (or UP) direction reverses the Polarisation. \hat{n} then precesses from $+\theta$ to $-\theta$ (i.e. a 2θ switch). Thus \hat{n} is now @ 2θ to the input polariser 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 filter maybe effect material Δn

[8]

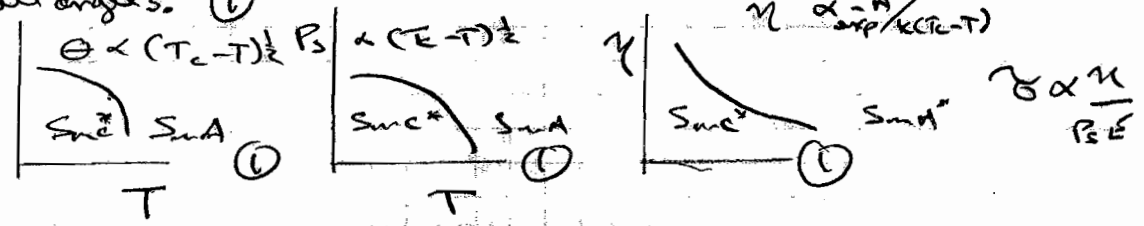
(c) In DPH device Absorbing and Fluorescent dyes included that coalign with \hat{n} . The device acts initially as a switchable polariser itself that permits/absorbs. This requires only one polariser or a switch angle $2\theta \neq 90^\circ$.

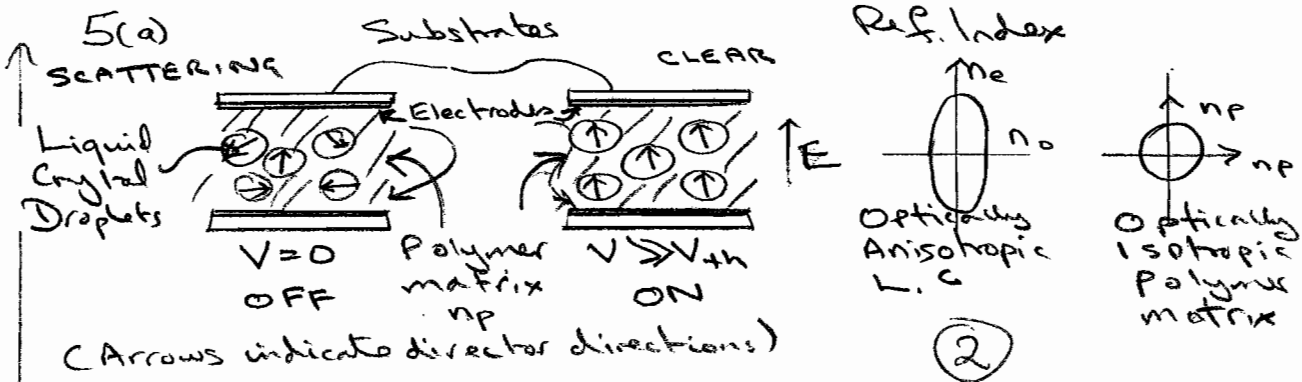


The dye absorption axis same as \hat{n} . So with \perp LP no absorption just non visible UV light (OFF)

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

[8]

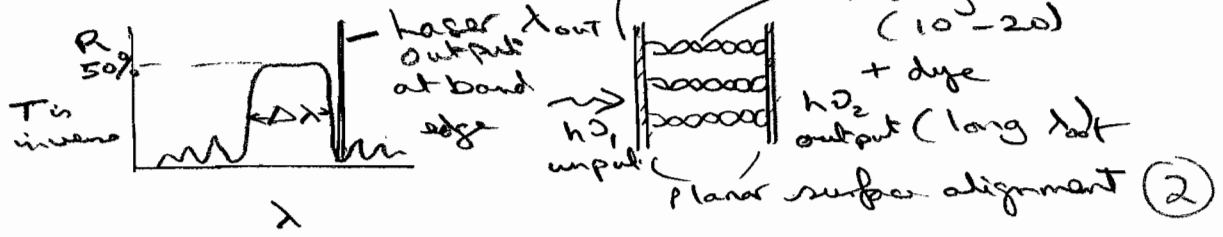




(4) Droplets of L.C. suspended in an ISOTROPIC (n_p) polymer matrix so that the polymer ref. index is equal in all directions. The LC is birefringent (i.e. $n_e > n_o$ BUT $n_o = n_p$). In OFF state LC director in droplets is random. \therefore Ref index mismatch at LC/polymer interface + Snell's law reflection & refraction = SCATTERING. In ON state $V \gg V_{th}$ the LC director aligns along the field (E) direction. Since $n_o = n_p$ in this state for normally incident light (as in a projector) the Refractive Indices match & NO SCATTERING occurs. \Rightarrow CLEAR STATE). There are no polarisers, optical absorption or loss thus ideal for projection. (2)

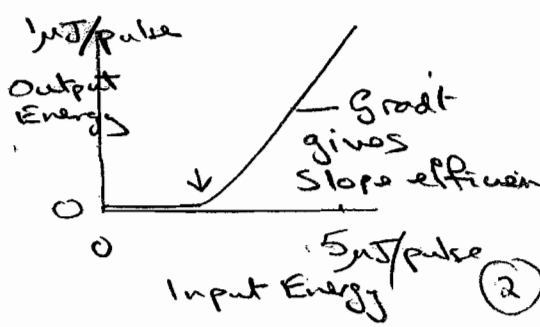
OPTIMISATION - Droplet size chosen to maximise scattering i.e. droplet size $\sim \lambda$ incident. However, small droplets give faster switching off times (due to surface interactions) whilst larger droplets give more scattering but slower responses. V_{th} depends on droplet size, lower for larger droplets, higher for small droplets \Rightarrow broad threshold curve. Therefore make monodisperse suspensions. Large n_e w.r.t n_o gives a better scattering (high Δn). Can include 'black' or coloured dyes to optimise contrast (i.e. Scattering + Absorption in OFF state. Neither in ON state. Increase ΔE of LC & minimise E losses by adjusting ρ & E of polymer matrix. (2)

5⑤ Resonator $\Delta\lambda = \Delta n p$



The N^* phase sets up the Photonic Band Gap for circularly polarized light with planar alignment. Add Fluorescent dye (DCM) to N^* phase to act as gain medium. Pump with frequency doubled YAG laser ($\lambda = 530\text{nm}$). Choose dye that absorbs near 530 \rightarrow up conversion leads to longer λ for the fluorescence. Light internally reflected in PBR until DOS $\rightarrow \infty$ at band edge ($\nu_p \rightarrow 0$) and lasing emission occurs typically $\lambda_{out} \sim 600\text{nm}$ plus.

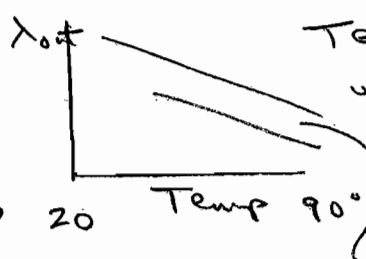
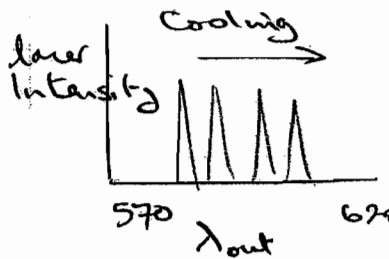
High $\Delta n \rightarrow$ higher efficiency & lower threshold
 \bar{n} defines λ_{out} . [Could include dye energy diagram here]



- Efficiency $\propto \langle S \rangle$ the order parameter
- Observation of clear lasing threshold & gain via slope efficiency ($\sim 30\%$)
- Narrow pulse width
- Beam Profile \sim Gaussian ($\sim T_{ens}$)
- Directional, Coherence length

For well aligned films $\Delta\lambda \sim 0.01\text{nm}$

Differentiates from other emission which is broad band & multidirectional. Scatter phenomenon



Temp tuning in N^* material where p is $f(T)$. Helix distorts ($\lambda = \bar{n} p$) and unwinds \rightarrow longer λ_{out} . Pitch jump give modes.

[Could also describe E field tuning of helix or electrooptic N^*]