Device Physics 3129: Optical Device Problems

1. (a) Suppose you were asked to develop a flat screen television display. Describe the properties you would consider in choosing a display device technology for this application.

   (b) A thin film electroluminescent display device is to operate at 550 nm. The emission spectrum of the luminescent material spans 400 - 650 nm. To obtain emission in the normal direction (perpendicular to the plane of the device) at 550 nm the material is placed in a microcavity. What thickness should the microcavity have if only this wavelength is to be emitted in the normal direction?

   (b) Will the device emit a longer or shorter wavelength when viewed off axis? Explain your answer.

2. The energy associated with the elastic deformation of a nematic liquid crystal may be written in the form

$$F_{elastic} = \frac{1}{2}\left[K_1(\nabla.\mathbf{n})^2 + K_2(\mathbf{n}\cdot\nabla\times\mathbf{n})^2 + K_3(\mathbf{n}\times\nabla\times\mathbf{n})^2\right].$$

   The following forms for the spatial variation of the director may be used to represent splay, twist and bend respectively

$$\mathbf{n} = \hat{\boldsymbol{\rho}}, \quad \mathbf{n} = \cos\alpha z\,\mathbf{i} + \sin\alpha z\,\mathbf{j}, \quad \mathbf{n} = \sin\phi\,\mathbf{i} - \cos\phi\,\mathbf{j}.$$

   Sketch the form of the director in each case and verify that only one of the elastic energy terms is non-vanishing for each case.

3. A homogeneously aligned nematic liquid crystal cell bounded by the planes $z = 0$ and d has a director profile given by

$$\phi = a\sin\left(\frac{\pi z}{d}\right)$$

   where ϕ is the angle between the director and the y axis (the director lies in the yz plane).

   Write down the form of the director and show that the elastic free energy may be written in the form

$$F = \frac{K}{2}\left(\frac{a\pi}{d}\right)^2\left(1 - \frac{\phi^2}{a^2}\right)$$

when the elastic constants $K_1 = K_3 = K$. Hence show that the effective electric field ($-\nabla_{\mathbf{n}} F$) due to the elastic interaction has the form

$$\frac{K\phi}{a^2}\left(\frac{a\pi}{d}\right)^2\left(\frac{-\mathbf{j}}{\sin\phi}+\frac{\mathbf{k}}{\cos\phi}\right)$$

and that the torque due to the elastic interaction has the form

$$2K\frac{\partial^2\phi}{\partial z^2}\mathbf{i}.$$

4. A homogeneously aligned nematic liquid crystal cell is addressed using a voltage across the plates that make up the cell. If initially a voltage is applied and then removed, the decay time of the orientation of the liquid crystal is given by

$$\tau_{decay} = \frac{\gamma d^2}{k\pi^2}$$

while the rise time following the application of a voltage is given by,

$$\tau_{rise} = \frac{\gamma d^2}{k\pi^2}\left(\left(\frac{V}{V_c}\right)^2 - 1\right)^{-1}$$

where d is the cell thickness, and, γ and k are the viscosity and elastic constant of the liquid crystal and have values of 0.01 Nsm^{-1} and 10^{-12} N respectively. The cell is constructed so that the rise and fall times are the same.

(a) If a repetition rate of 30Hz (i.e. a cycling time of 1/30 s in activating the LC cell) is required, what thickness should the cell be?
(b) What value of the drive voltage (in terms of the critical voltage) will be required to match the rise and fall times?
(c) Explain the physical origin of the critical voltage.
(d) With the aid of diagrams explain the principle of operation of the liquid crystal phase modulator and the twisted nematic cell.

5. A planar waveguide has a refractive index of 1.5, a thickness of 5 microns and is bounded by air. Using a ray model, and assuming that there is no phase change on reflection from the guide boundary,

estimate the number of modes the guide may support when the guided light has a frequency of 5×10^{14} Hz.

6. A step index fibre has a numerical aperture of 0.16, a core refractive index of 1.47 and a core diameter of 200 μm.
(a) calculate the acceptance angle of the fibre
(b) calculate the refractive index of the cladding
(c) calculate the maximum number of modes that can be carried for a wavelength of 0.85 μm.
(d) estimate the intermodal dispersion for the fibre

7. Sketch the attenuation spectrum of a typical single-mode fibre used for long distance telecommunications. Identify and explain all the main features that contribute to the attenuation.

What is the limiting factor in the attenuation and how could the attenuation be improved?

The following data were obtained in a fixed-wavelength cutback measurement to determine the attenuation of a fibre at 823 nm. Use the data to calculate the fibre attenuation in dB m^{-1} at this wavelength, and estimate the error in the measurement.

Length (m)	0.3	0.6	1.1	1.7	2.3	2.9	3.5	4.1
Power out (mW)	153	127	97	70	50	34	25	15