3C43 LASERS & MODERN OPTICS

Problem sheet 4 – Electro-optics and non-linear optics

Question 1.

a) Draw a labelled diagram of the structure of an acousto-optic modulator and explain how the device can be used to shift the frequency of an optical beam. [3]

a) Find expressions in terms of the wavelength in vacuo of the incident light, λ_0, the refractive index, *n*, and the speed of sound, *v*, in the modulator crystal and the frequency of the r.f. drive, *f*.

i) for the angular deflection and [2]

ii) for the frequency-shift induced by the modulator [2]

b) Describe how an acousto-optic modulator can be employed to mode-lock a laser. For such an application, show that the cavity round-trip time, τ, and the modulator drive-frequency, *f*, must satisfy $f\tau = 1$. [3]

c) An imperfectly collimated laser-beam of wavelength 852nm is incident on a TeO_2 acousto-optic modulator, which is oriented to maximize the intensity of the first-order diffracted beam with a modulator driving frequency of 132MHz. Without changing the alignment, the r.f. frequency is gradually increased, until at 145MHz the diffracted beam disappears. The refractive-index and the speed of sound in TeO_2 are 1.5 and 4.3 km/s respectively.

i) Draw a sketch diagram to show the direction in which the diffracted beam is deflected as the r.f. frequency is increased. [2]

ii) What is the angular divergence of the incident laser-beam? [3]

Question 2.

a) Write down the equation defining the *linear electro-optic coefficient , r*. [1]

b) Show how the equation for the index ellipsoid is altered in the presence of a static electric field in the z-direction, $\mathcal{E}_z$, for an electro-optic material with a single non-zero component of the electro-optic tensor r_{63}. [2]

c) Hence show that the half-wave voltage of a longitudinal electro-optic modulator is

$$V_\pi = \frac{\lambda_0}{2r\,n_0^3}$$

where n_0 is the refractive index at wavelength λ_0. [2]

d) Describe, with reference to a suitable diagram, how such a modulator can be used to control the intensity of a beam of light. [3]

e) An electro-optic modulator as in e) using a crystal of refractive index $n_0 = 1.5$ and $r = 9.73 \times 10^{-11} m/V$ is used to impose a sinusoidal intensity modulation on a beam of light of wavelength 1032 nm. If the intensity modulation has an r.m.s. deviation of 1%, what is the r.m.s. control voltage required? [4]

Question 3.

a) Explain what is meant by *phase-matching* in second-harmonic generation and show that the condition for it to be achieved is that $n_\omega = n_{2\omega}$, where n_ω and $n_{2\omega}$ are the refractive indices at the fundamental and second-harmonic frequencies respectively. [3]

b) Explain the quantum model of second-harmonic generation, and show, using suitable equations, which quantities are conserved in the interaction. [3]

c) Show how the results of b) are consistent with the phase-matching condition, $n_\omega = n_{2\omega}$. [1]

d) A second-harmonic crystal, designed for use with a Nd:YAG laser and for type-I phase-matching, has its entrance and exit faces cut at an angle of θ_m to the optic axis. Find the value of θ_m given the following data: [4]

	1064 nm	532 nm
n_o	1.4852	1.4985
n_e	1.4356	1.4462

e) Explain why second-harmonic generation is usually carried out in crystalline solids whereas for third-harmonic generation gaseous media are usually employed. [2]