1. A single mode fiber: (15 points**)**

A single-mode step-index fiber must has a V number less than 2.405. Assuming a typical single-mode optical fiber has a core of diameter of 8 μm and a refractive index of 1.46. The cladding layer is of diameter of 125 μm and a refractive index of 1.416.

Determine:

(a) the numerical aperture of the fiber (5 points)

(b) the acceptance angle of the fiber (5 points)

(c) What is the single mode cut-off wavelength λ_C of the fiber? (5 points)

2. Reflection of light from a less dense medium: (10 points**)**

A ray of light which is traveling in a glass medium of refractive index n_1=1.460 becomes incident on a less dense glass medium of refractive index n_2=1.440. Suppose that the free space wavelength (λ) of the light ray is 1300 nm.

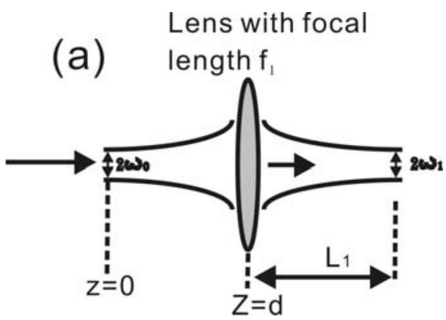
(a) What should be the minimum incident angle for total internal reflection? (4 points)

(b) What is the phase change in the reflected wave when θ_i=87°? (3 points)

(c) What is the penetration depth of the evanescent wave into medium when θ_i=87°? (3 points)

3. The propagation of Rays and Beams: (10 points**)**

Assume a Gaussian beam with a wavelength λ is incident on a lens, with a focus length f_1, placed at z = d as shown in Figure (a). The output beam has a waist ($2\omega_1$) at the distance L_1 after the lens. Use the ABCD law to calculate the beam waist ($2\omega_1$) and the distance L_1. (10 points)



4. Quarter-wave plate (15 points**)**

A quarter-wave plate has a phase retardation of Γ = π/2. Assume that the plate is oriented in a direction with azimuth angle ψ.

(a) Find the polarization state of the transmitted beam, assuming that the incident beam is polarized in the y-direction (5 points)

(b) If the polarization state resulting from (a) is represented by a complex number on the complex plane, show that the locus of these points as ψ varies from 0 to π/2 is a branch of a hyperbola. Obtain the equation of the hyperbola. (5 points)

(c) Quartz is a uniaxial crystal with n_o = 1.54283 and n_e = 1.54152 at λ=1.1592 μm. Find the thickness of an x-cut quartz quarter-wave plate at this wavelength. (5 points)

1. Maximum Resonator Length of Confined Rays.

A resonator is constructed using concave mirror of radii 50 cm and 100 cm. Determine the maximum resonator length for which rays satisfy the confinement condition. (10 points)

2. Attenuation and Gain in a Ruby Laser Amplifier

(a) Consider a ruby crystal with two energy levels separated by an energy difference corresponding to a free-space wavelength $\lambda_0 = 694.3$ nm, with a Lorentzian lineshape width $\Delta\nu = 330$ GHz. The spontaneous lifetine is $t_{sp} = 3$ ms and the refractive index of ruby is $n = 1.76$. The numbers of atoms per unit volume in the lower and upper energy level are denoted N_1 and N_2, respectively. If $N_1+N_2 = 10^{22}$ cm^{-3}, determine the population difference $N=N_1-N_2$ and the attenuation coefficient at the line center $\alpha(\nu_0)$ under conditions of thermal equilibrium at T= 300 K (Hint: you can use Boltzmann distribution) (10 points)

(b) What value should be the population difference N assume to achieve a gain coefficient $\gamma(\nu_0) = 0.5$ cm^{-1} at the central frequency? (5 points)

(c) How long should the crystal be to provide an overall gain of 4 at the central frequency when $\gamma(\nu_0) = 0.5$ cm^{-1}? (5 points)

3. Mechanisms of Spectral line Broadening. Describe at least four mechanisms that cause spectral line broadening of atomic or molecular transition. (10 points)

4. Nonlinear Optics

(a) (5 points) Please explain the phase matching condition.

(b) (5 points) In atomic system, the polarization induced in the medium by the presence of an electric field can be expressed in a Taylor series. Please write down three typical cases for second-order and three-order nonlinear optical phenomena.

1. Consider a InGaAsP-InP laser diode which has an optical cavity of length 250 microns. The peak radiation is at 1550 nm and the refractive index of InGaAsP is 4. The optical gain bandwidth (as measured between half intensity points) will normally depend on the pumping current (diode current) but for this problem assume that it is 2 nm.

(a) What is the mode integer *m* of the peak radiation?(5 points)

(b) What is the separation between the modes of the cavity? (5 points)

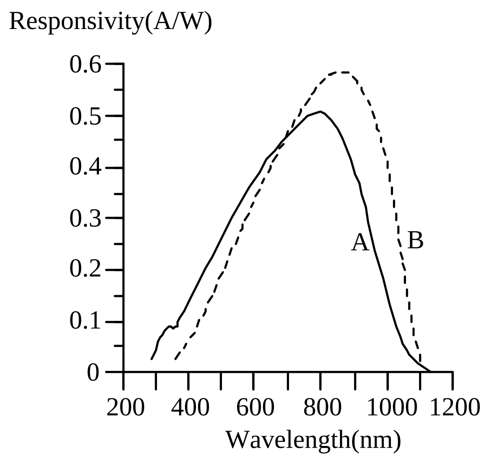
(c) How many modes are there in the cavity? (10 points)

2. Consider two commercial Si *pin* photodiodes, type A and type B, both classified as fast *pin* photodiodes. They have the responsivity shown in following figure. Differences in the responsivity are due to the *pin* device structure. The photosensitive area is 0.125 cm^2 (4 mm in diameter).

(a)Calculate the photocurrent from each when they are illuminated with blue light of wavelength 450nm and light intensity 1 $\mu W\ cm^{-2}$. What is the QE of each device? (10 points)

(b) Will the A or B photodetector be more sensitive to the radiation from a GaAs laser? Why?(5 points)

(c) A photodetector whose area is $5\times10^{-2}\ cm^2$ is irradiated with yellow(λ=600 nm) light whose intensity is 2 mW cm^{-2}. Assuming that each photon generates one electron-hole pair, calculate the number of pairs generated per second. (5 points)



The responsivity of two commercial Si *pin* photodiodes

3. If the width of the relative light intensity vs. photon energy spectrum of an LED is typically around **~3k$_B$T**, what is the linewidth, $\triangle\lambda_{1/2}$, in the output spectrum in terms of wavelength?(a) GaAs LED emits at a peak wavelength of 870 nm(5 points) (b) InGaAsP LED emits at a peak wavelength of 1550 nm. (5 points)

note: $\dfrac{\Delta\lambda}{\Delta E_{ph}} \approx \left|\dfrac{d\lambda}{dE_{ph}}\right|$