EE170A: Principles of Photonics

Midterm Fall 2015; November 5th 2015, 10 to 11:50 am, 2100A Broad Hall

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Closed book, but with 1-sheet (2-sides of 8.5” × 11” paper) of notes. Please use calculator.

Question 1. (20 points) Lossy optical medium

Consider a thick piece of GaAs material, ignoring the reflection or refraction at interfaces.

1.a. (7 points) The complex susceptibility of GaAs at an optical wavelength of $\lambda = 850$nm is $\chi = 12.17 + i0.49$. What is the complex refractive index at $\lambda = 850$nm?

1.b. (7 points) What is the absorption coefficient at $\lambda = 850$nm? For a beam at 850nm wavelength, how long can it travel before losing 99% of its energy to absorption in the medium?

1.c. (6 points) GaAs has an energy bandgap of 1.424 eV at room temperature and absorbs any photon that has an energy higher than this value. For what optical wavelengths is GaAs transparent?

Question 2. (20 points) Crystals and wave plates

A crystal has the following permittivity tensor at $\lambda = 1$ μm,

$$\epsilon = \epsilon_0 \begin{bmatrix} 2.28 & 0 & 0 \\ 0 & 2.25 & -0.05196 \\ 0 & -0.05196 & 2.19 \end{bmatrix}$$

2.a. (7 points) Find the principal axes and the corresponding principal indices for this crystal.

2.b. (7 points) Is the crystal birefringent or nonbirefringent? If it is birefringent, is it uniaxial or biaxial? If it is used to make a quarter-wave plate for $\lambda = 1$ μm, what is the *minimum* plate thickness?

2.c. (6 points) At what wavelength does a quarter-wave plate in (b) function as a half-wave plate if the dispersion in the refractive indices of the plate is neglected? At what wavelength does light traveling through the plate always return to its input polarization state?

Question 3. (30 points) Wavelength demultiplexing by directional couplers

Wavelength demultiplexing can be achieved by directional couplers. A directional coupler can be made from two slab waveguides. Consider a symmetric slab waveguide with a core thickness of 2 μm. Ignoring the waveguide material dispersion, we find the indices to be $n_1 = 1.50$ and $n_2 = 1.46$.

3.a. (8 points) Is this waveguide single moded or multimoded at $\lambda = 1.5$ and 1.3 μm?

3.b. (7 points) What is the range of wavelength in which this waveguide is single moded?

3.c. (7 points) Consider a symmetric directional coupler using two identical single moded waveguides for both $\lambda = 1.5$ and 1.3 μm. Given the coupling coefficients at $\lambda = 1.5$ and 1.3 μm as $\kappa_{1.5}$ and $\kappa_{1.3}$ respectively, what are the coupling efficiencies η as a function of coupling length l for each wavelength respectively?

3.d. (8 points) Both the two wavelengths enter the device from port 1. If the device is to direct all of the optical power at 1.5 μm to port 4 and keep all of the optical power at 1.3 μm to port 3, what condition should be satisfied for the coupling length l ?

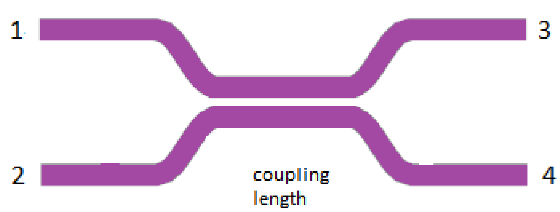

Figure 1 Directional coupler.

Question 4. (30 points) Grating waveguide couplers

In this problem we design an InGaAsP/InP DFB laser for 1.55 μm. The laser waveguide is a symmetric slab waveguide with $n_1 = 3.54$ in the waveguide core and $n_2 = 3.4$ in the cladding regions. The thickness d of the waveguide core is to be chosen so that the structure is single moded with a confinement factor of $\Gamma = 0.67$ for the TE_0 mode. A sinusoidal grating of period Λ, depth d_g, and duty factor $\xi = 1/2$, as shown in the below Figure 2, is to be fabricated at the lower core-cladding boundary. For simplicity, we consider only the operation of the TE mode, and the below graph might be helpful.

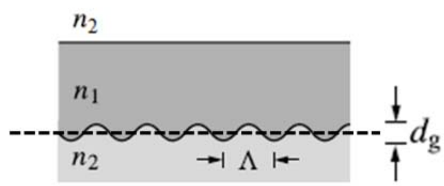

Figure 2 InGaAsP/InP DFB waveguide.

4.a. (7 points) Find the thickness, d, of the waveguide core.
4.b. (7 points) What is the propagating constant β of the TE_0 mode?
4.c. (7 points) What is the grating period Λ?
4.d. (9 points) If the depth of the grating is d_g = 127 nm, find the length of the grating required for a reflectivity of 50%.

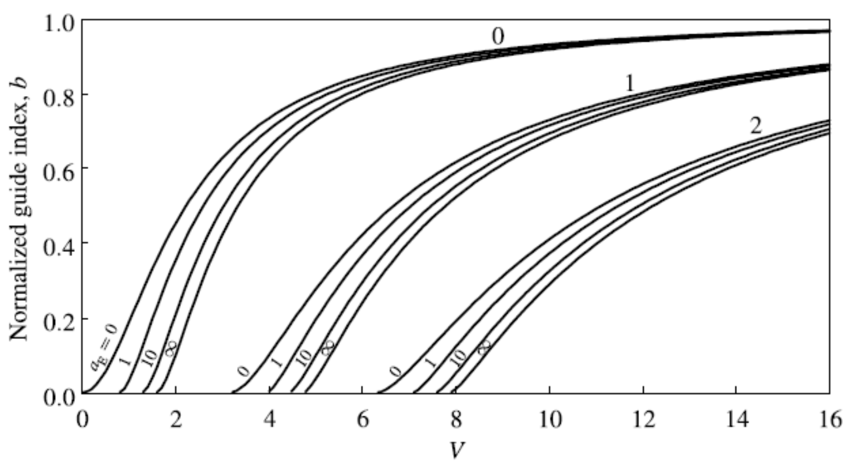

Figure 3 Allowed values of normalized guide index b as a function of the V number and the asymmetry factor a_E for the first three guided TE modes. The cutoff value V_c for a mode is the value of V at the intersection of its dispersion curve with the horizontal axis.