Photonics and Integrated Optics (S-104.3410)
Exam, October 25, 2011

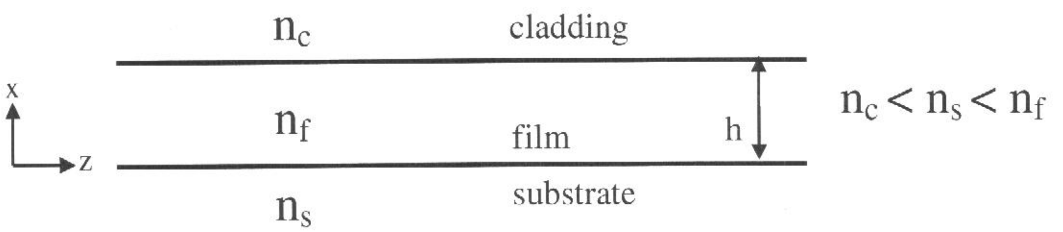
1.

a) Sketch the attenuation (in dB/km) for a typical single-mode silica optical fiber (used in modern Telecommunications) as a function of wavelength within the wavelength range of 800 nm - 1800 nm. The sketch should show the distinct features of the attenuation spectrum and give an approximate value for the minimum attenuation. **(3 points)**

b) Briefly discuss the two main intrinsic attenuation mechanisms fundamentally limiting the minimum attenuation in a typical single-mode silica optical fiber. **(2 points)**

c) Briefly discuss and identify in your graph the major extrinsic cause for attenuation and how it has recently been eliminated. **(1 points)**

2.



Derive the *characteristic equation* for TM (Transverse Magnetic) modes for an asymmetric 3-layer slab waveguide with the geometry shown above. In your derivation, start from the field solutions below (i.e. after the continuity of H_y at the boundaries has already been applied): **(6 points)**

$$H_y = Ae^{\gamma_s x}, \qquad x<0 \quad \text{substrate}$$

$$H_y = A\cos\kappa_f x + B\sin\kappa_f x, \qquad 0<x<h \quad \text{film}$$

$$H_y = (A\cos\kappa_f h + B\sin\kappa_f h)e^{-\gamma_c (x-h)}, \qquad h<x \quad \text{cover}$$

Hint: For TM modes:

$$\frac{\partial H_y}{\partial x} = i\omega\varepsilon E_z, \quad i\beta H_y = i\omega\varepsilon E_x, \quad \frac{\partial E_z}{\partial x} + i\beta E_x = i\omega\mu_0 H_y$$

3.

a) Briefly discuss the <u>three</u> different types of dispersion mechanisms in a <u>single mode fiber</u>.

(3 points)

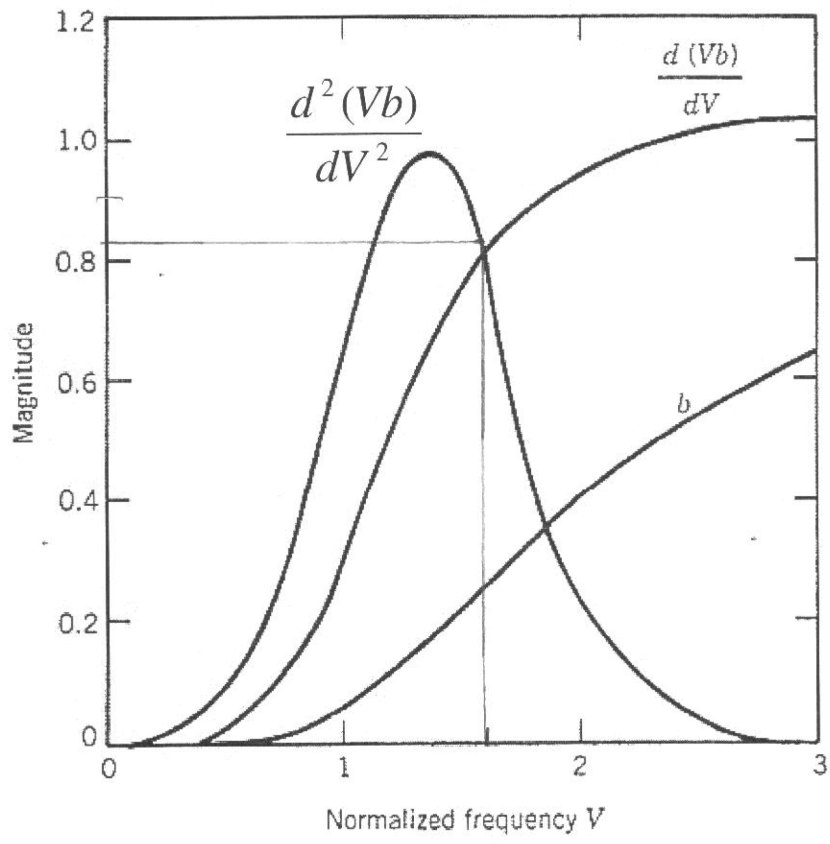
b) Consider a step-index single mode fiber with a core radius a = $2\mu m$, core index of 1.460 and $\Delta = 0.0064$ at 1300 nm wavelength. Knowing that the material dispersion at 1300 nm wavelength is around 3 ps/(nm-km) estimate the dispersion of this fiber at 1300 nm wavelength.

(3 points)

Recall:

$$D = -\frac{\lambda}{c}\frac{\partial^2 n_{core}}{\partial \lambda^2} - \frac{n_{core}\Delta}{c\lambda} V \frac{d^2(Vb)}{dV^2} \quad \text{and} \quad \Delta = \frac{n_{core} - n_{clad}}{n_{core}}$$

Hint: The graph below may help.

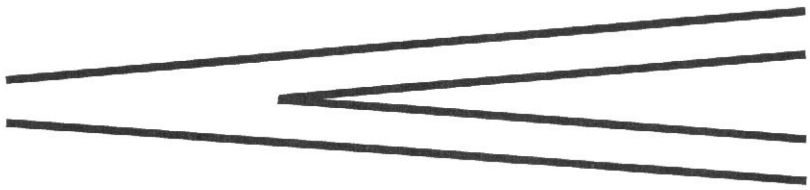


4.

a) Consider a planar **symmetric single-mode** waveguide Y-branch (or Y-junction) sketched below. Explain what happens at the junction when you couple light:

i) from the common port at left
ii) from **only one** of the ports (e.g. upper port) at right

(3 points)



b) Briefly describe the principle of a planar waveguide electro-optic intensity modulator using a Mach-Zehnder interferometer structure in a "push-pull" configuration. Mention also <u>two</u> advantageous features of the "push-pull" configuration.

(3 points)

5.

a) Draw a sketch of a simple **backward** pumped 1-stage Er-Doped Fiber Amplifier (EDFA). In your diagram, use only three components in addition to the Er-doped fiber, and name all the components. Also briefly explain the function of each component.

(3 points)

b) Consider light propagation in a step-index optical fiber with a core radius a, core refractive index n_{core} and cladding refractive index n_{clad}. The "characteristic equation" for a step index fiber can be written as:

$$\frac{\beta^2 \nu^2}{a^2}\left[\frac{1}{\gamma^2}+\frac{1}{\kappa^2}\right]^2 = \left[\frac{J_\nu'(\kappa a)}{\kappa J_\nu(\kappa a)}+\frac{K_\nu'(\gamma a)}{\gamma K_\nu(\gamma a)}\right]\left[\frac{k_0^2 n_{core}^2 J_\nu'(\kappa a)}{\kappa J_\nu(\kappa a)}+\frac{k_0^2 n_{clad}^2 K_\nu'(\gamma a)}{\gamma K_\nu(\gamma a)}\right]$$

In analyzing step index optical fibers a *weakly guiding* approximation is often justified. Explain what it means and show how the "characteristic equation" simplifies to a form that does not explicitly contain β (no need to explicitly show how Bessel function relations are used).

(3 points)

6.

a) Draw a schematic and briefly explain the operating principle of a multimode interferometer (MMI).

(2 points)

b) Explain an efficient way to electrically modulate refractive index of silicon in order to realize e.g. a modulator.

(2 points)

c)

i) Give at least two advantages for *high index contrast* over *low index contrast* in waveguides in integrated optic devices.

ii) What is the main advantage for *low index contrast* over *high index contrast* in an integrated optic device when used as a part of a telecommunication system?

(2 points)