Photonics and Integrated Optics (S-104.3410)
Exam, March 8, 2011

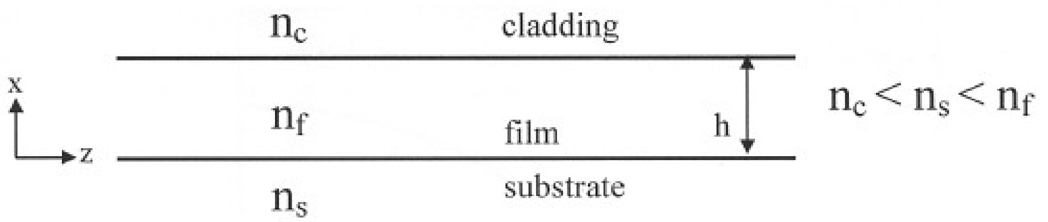
1.

a) Sketch the attenuation (in dB/km) for <u>a typical single-mode silica optical fiber</u> (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 <u>two</u> 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 <u>major</u> 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)**

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

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

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

<u>Hint: For TM modes:</u>

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

3.

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

(3 points)

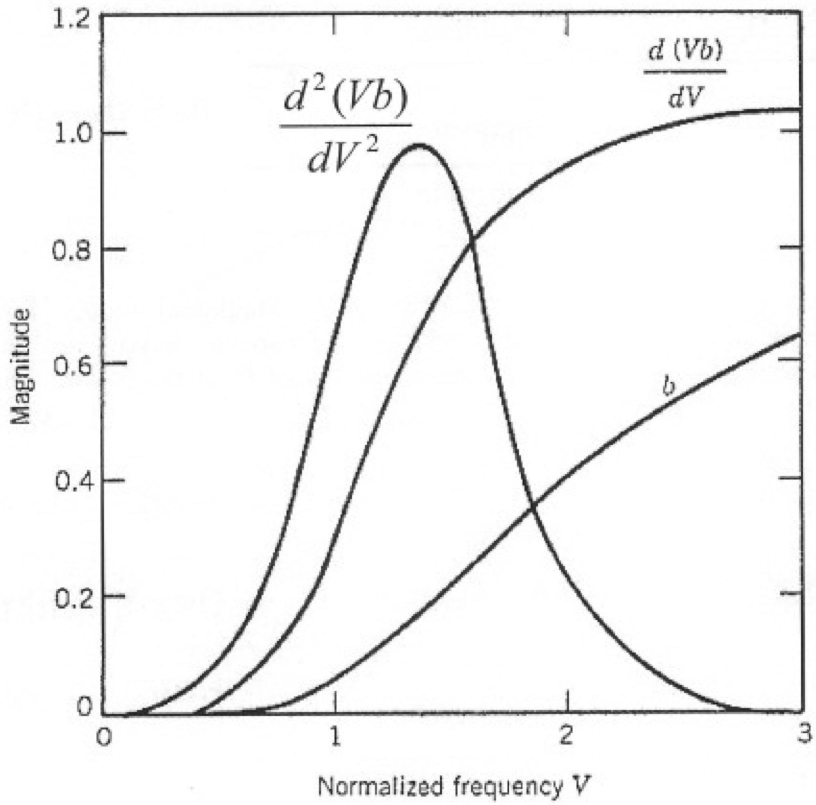
b) Consider a step-index single mode fiber with a core radius a = 2μm, core index of 1.460 and $\Delta = 0.0064$ at 1300 nm wavelength. Knowing that the material dispersion at 1300 nm wavelength is around 3 ps/(nm-km) estimate the dispersion of this fiber at 1300 nm wavelength.

(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.

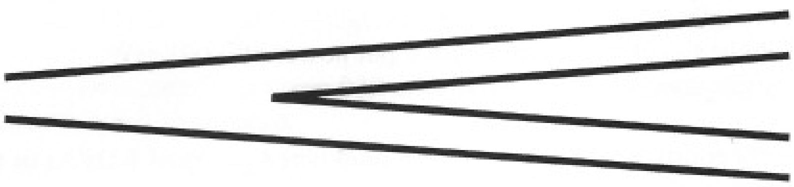


4.

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 schematic and briefly explain the operating principle of

i)	Multimode interferometer (MMI)	**(2 points)**
ii)	Arrayed waveguide grating (AWG)	**(2 points)**

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

(2 points)

6.

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) Figure below shows the calculated population inversion along the Er-doped fiber in a typical EDFA with a single pump laser. The parameters used in modeling were:

- Fiber length: 20 m.
- One input signal at 1550 nm with input power of 0.001 mW.
- Co-propagating pump of 100 mW at 980 nm.

i) Briefly compare the forward and backward pumped EDFAs in terms of noise properties.

ii) Roughly sketch the forward and backward propagating Amplified Spontaneous Emission (ASE) powers (arbitrary values) along the fiber.

iii) Briefly explain the behavior of the population inversion along the fiber.

(3 points)