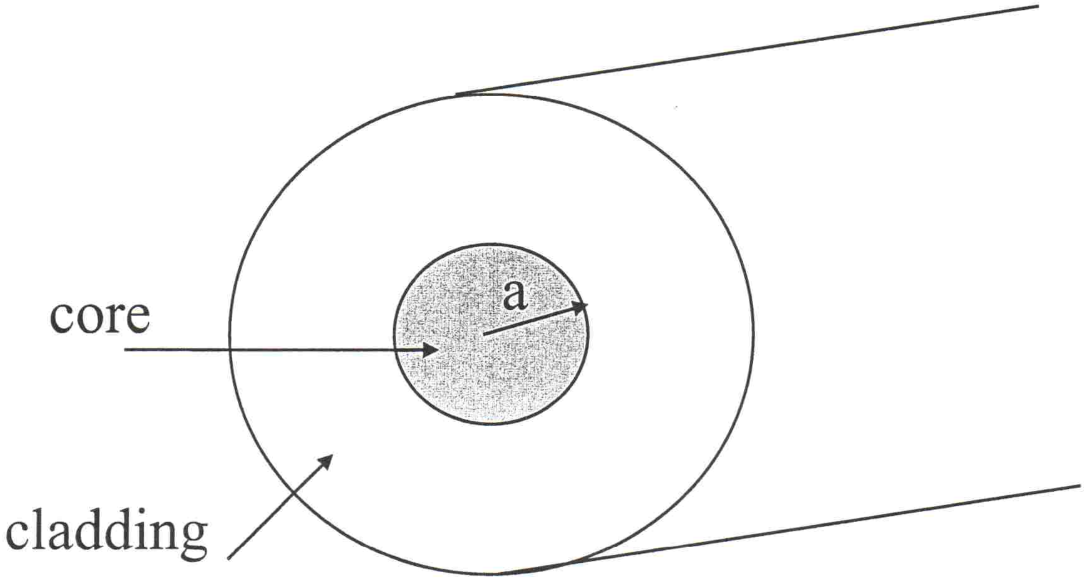
Photonics and Integrated Optics (S-104.3410)
Exam, May 7, 2008

1.



Consider light propagation in a step-index optical fiber (pictured above) 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:

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

a) 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 use Bessel function relations). **(3 points)**

b) Explain the meaning of transverse modes in a step index fiber and show how the "characteristic equation" simplifies (no need to use Bessel function relations). **(2 points)**

c) With *weakly guiding* approximation, sketch the electric and magnetic field lines for the LP_{01} -mode in a cross section of a <u>single mode fiber</u> (indicate also the radial dependence of the fields). **(1 points)**

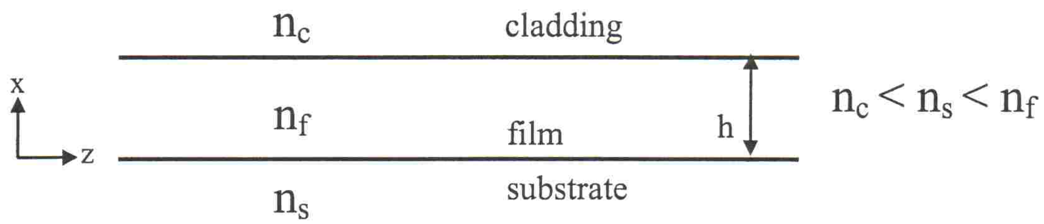
2.

a) Draw a graph illustrating the total dispersion of a typical single mode optical fiber within the wavelength range of 1200 – 1700 nm. Your graph should show approximate values of the dispersion. Draw also lines that indicate how the total dispersion is composed of two separate dispersion mechanisms. **(3 points)**

b) Explain the basic principle of using a dual-mode fiber for the compensation of chromatic dispersion of a single-mode fiber. **(1 point)**

c) Consider a dispersion compensating fiber (length=L/5) that is used to compensate for the chromatic dispersion of a standard single-mode fiber (length=L) within a broad wavelength region (e.g. the full C-band; ~ 1530 – 1565 nm). Describe how the dispersion of the dispersion compensating fiber should be chosen (No need to go into quantitative details). **(2 points)**

3.



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)**

$H_y = Ae^{\gamma_s x}$,	x<0	substrate
$H_y = A\cos\kappa_f x + B\sin\kappa_f x$,	0<x<h	film
$H_y = (A\cos\kappa_f h + B\sin\kappa_f h)e^{-\gamma_c(x-h)}$,	h<x	cover

4.

a) Draw a diagram of a simple forward pumped 1-stage Er-Doped Fiber Amplifier (EDFA). In your diagram, use <u>only three components</u> in addition two the Er-doped fiber, and name all the components. Also briefly explain the function of each component.

(3 points)

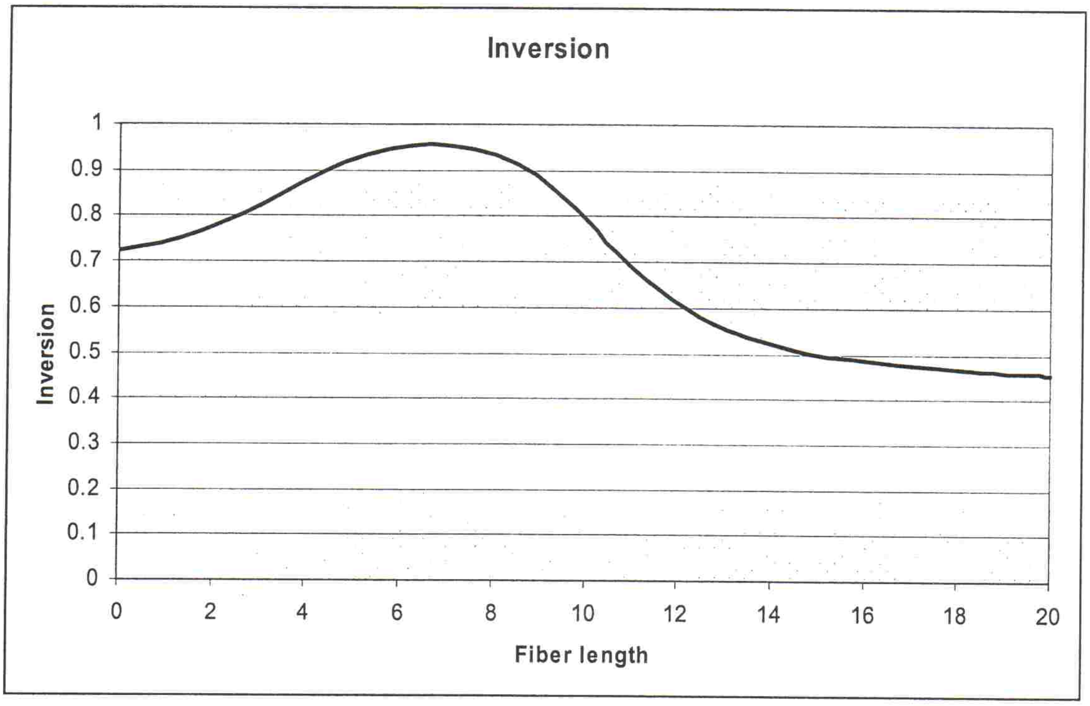
b) Figure below shows the calculated population inversion along the Er-doped fiber in a typical EDFA with a single pump laser. The parameters used in modeling were:

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

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

(3 points)



5.

b) Explain the principle of the effective index method in calculation of the propagation constants (effective indices) of channel waveguides.

(3 points)

c) Briefly describe the principle of a planar waveguide electrooptic intensity modulator using a Mach-Zehnder interferometer structure in a "push-pull" configuration. Mention also two advantageous features of the "push-pull" configuration. **(3 points)**

6.

a) Briefly explain the principle of using fiber Bragg gratings for chromatic dispersion compensation. **(2 points)**

b) Briefly explain what is an eye diagram and the eye opening penalty (EOP).

(2 points

c) Briefly explain what happens to a transform limited Gaussian pulse when it is launched to a standard single-mode fibe (non-linearities are not involved here) **(1 points)**

d) Assume that you want to build a Raman amplifier for 1550 nm wavelength using only one pump laser. What pump wavelength would you choose?

(1 points)