1. A semiconductor optical amplifier has a gain of Go=30dB and the gain variation due to finite facet reflectivity must be limited to 3dB.
    a. Find the require reflectivity.
    b. If N such amplifiers are used in series, what is the required reflectivity.

For problems 2-9 assume N_t=8E18 cm^{-3}, A=50μm^2, and use the parameters in Table 1 and following figures

Table 1: EDFA parameters

Material	τ_{sp} **(λ<1400nm)**	τ_{sp} **(λ>1400nm)**
Silicate L22	0.001ms	14.5ms
Fluorozirconate F88	0.001ms	9.4ms

2. Why is it impractical to create an EDFA using the doping denoted as Silicate L22 to amplify an optical signal at 980nm? Be sure to use an equation to prove your answer. (It has nothing to do with the emission or absorption cross-sections.)

3. What is the minimum pump power required for gain for the following EDFAs?
    a. Silicate L22 pumped at a wavelength of 980nm.
    b. Fluorozirconate F88 pumped at a wavelength 1480nm.

4. A Fluorozironcate F88 EDFA is pumped at a wavelength of □p=1480nm, with a pump power equal to 5 times the minimum pump power required for gain. If the amplifier has a length of L=5m, what is the total gain? Assume the signal wavelength is □s=1554nm.

5. An amplifier is constructed a peak gain of G=30dB. Let's define the amplifier wavelength range as the wavelength range over which the normalized gain variation is less than 10dB.
    a. Which of the amplifier materials (Silicate L22 or Fluorozirconate F88) has the largest wavelength range?
    b. What is the wavelength range for the best material?

6. The pumping efficiency is defined as the gain divided by the pumping power in units of dB/mw.
    a. What is the EDFA material, pump wavelength, and amplified wavelength that produce the highest pumping efficiency?
    b. What is the pumping efficiency for (a) if the pump power is 5 times the minimum pump power for gain and the amplifier length is L=5m.

7. What is the gain of a Silicate L22 amplifier if □p=980nm, □s=1550nm, Pp=10mw, L=5m, Ps=100μW?

8. If the signal rate is much larger than the pumping rate (Ws >> Wp), what is optimum length?

9. An optical receiver has the following specifications: R=0.9 A/W, Pmin=-20dBm with B=10Gbps and BER=10^{-12}. The optical fiber has an attenuation of □=0.2 dB/km (this attenuation includes any splice losses), the transmitted optical power minus all other losses (coupling, loss margin, etc.) is 2mW, and the wavelength is □=1550nm. Ignore any dispersion limits in this problem.
    a. What is the maximum link length?
    b. What is the maximum link length if an EDFA is used as a pre-amplifier (right before the receiver)? The EDFA has the following specifications G=30dB, n_{sp}=2.0, and □=5.0.
    c. What is the maximum link length if an EDFA is used near the middle of the optical communications link? The EDFA has the following specifications G=30dB, n_{sp}=2.0, and □=5.0.
    d. What is the maximum link length if 4 EDFAs are used? The EDFA has the following specifications G=30dB, n_{sp}=2.0, and □=5.0.

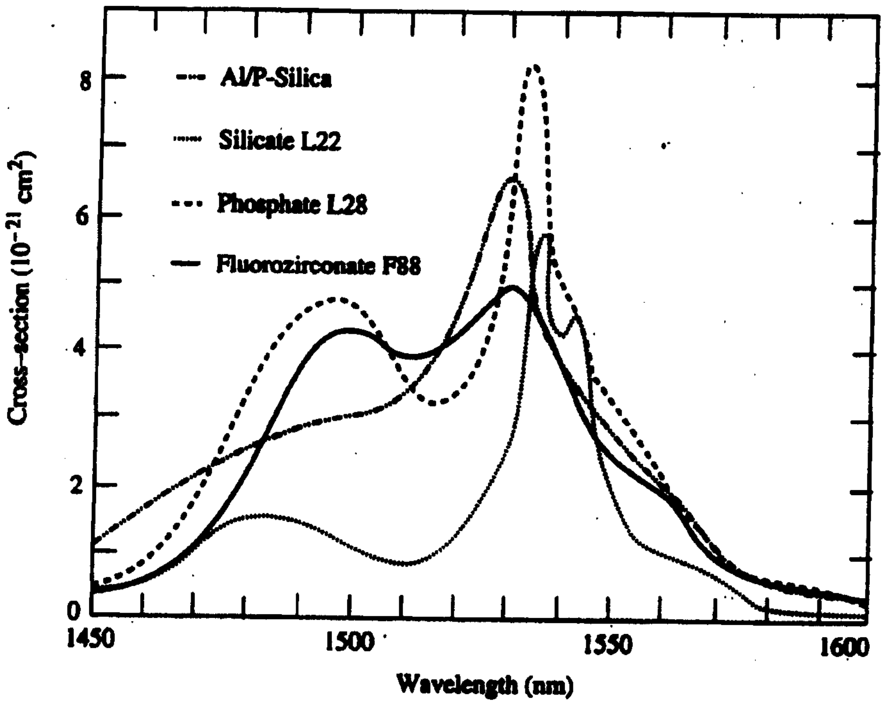

Figure 17.15 Absorption cross section of Er^{3+} at 1450 nm.

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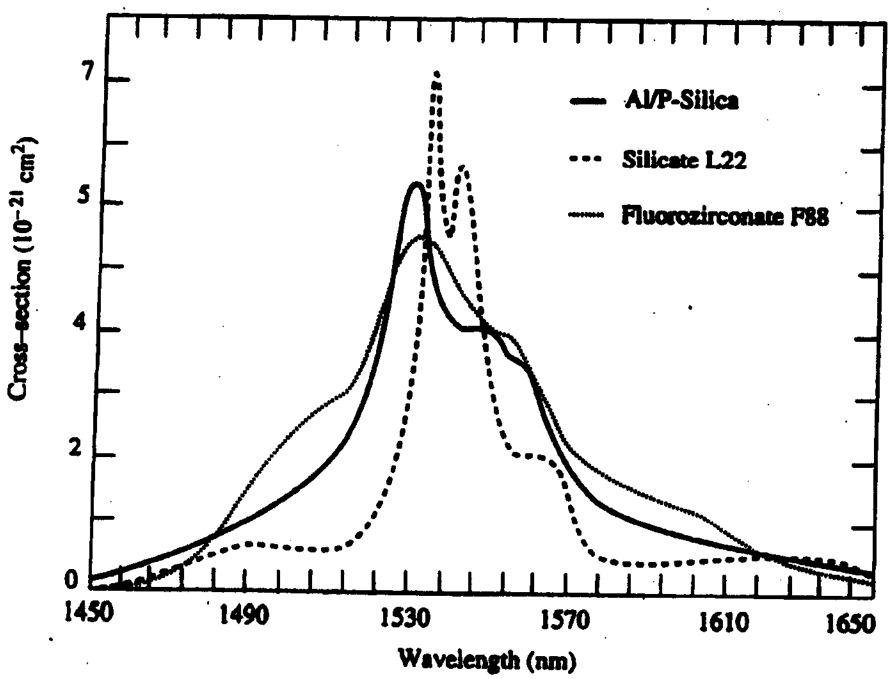

Figure 17.16 Emission cross section of Er^{3+} at 1540 nm.

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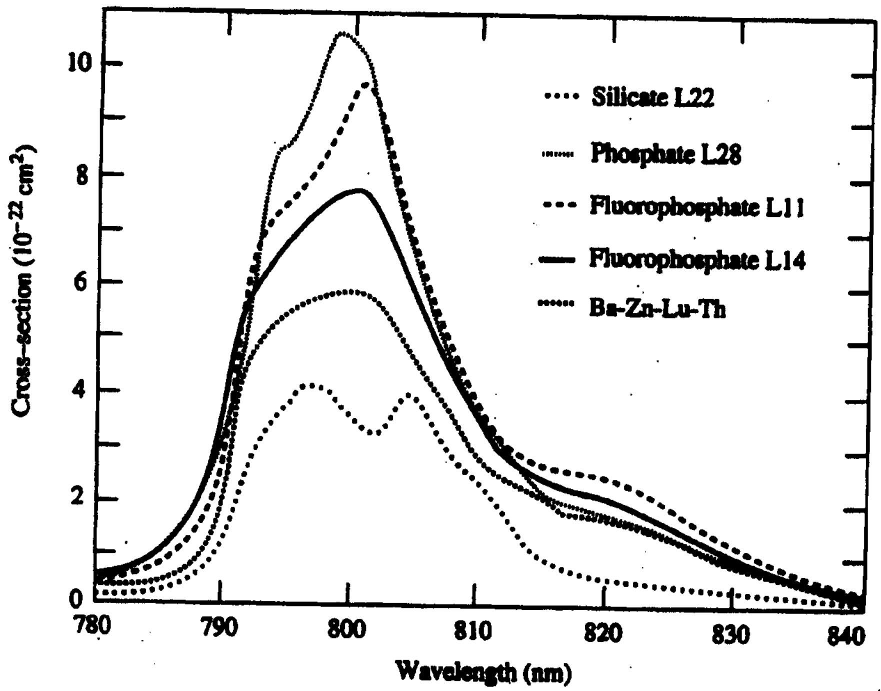

Figure 17.13 Absorption cross section of Er^{3+} at 800 nm.

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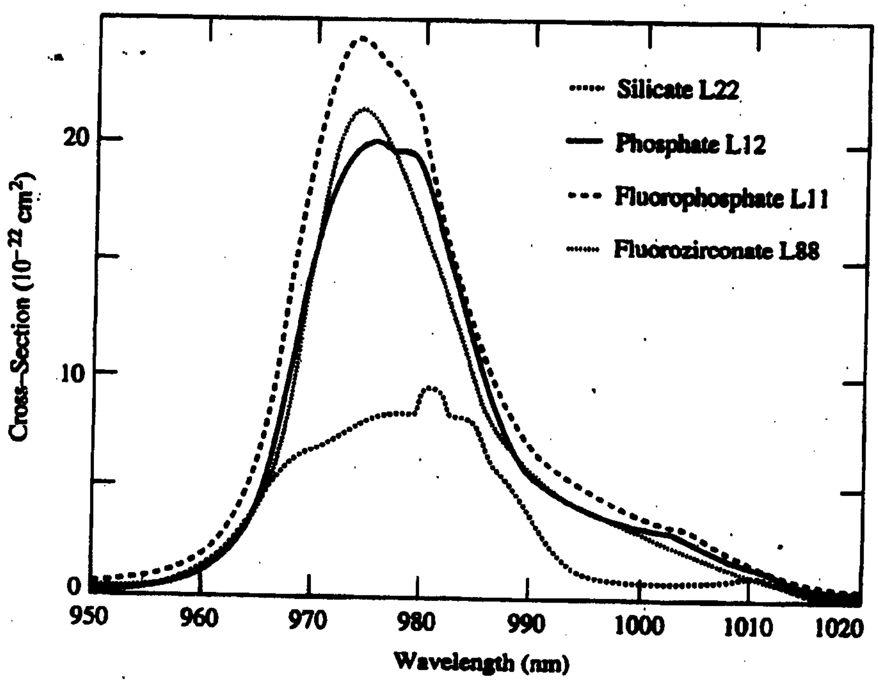

Figure 17.14 Absorption cross section of Er^{3+} at 980 nm.

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