8.3.5 An Er:fiber is doped with an Er^{3+} ion concentration of $N_t = 2.2 \times 10^{24}\ m^{-3}$ in its core. This fiber is a cylindrical waveguide that has a core radius of $a = 4.5\ \mu m$. At the $\lambda = 1.53\ \mu m$ wavelength, the Er:fiber has an absorption cross section of $\sigma_a = 5.7 \times 10^{-25}\ m^2$, an emission cross section of $\sigma_e = 7.9 \times 10^{-25}\ m^2$, and an upper laser level lifetime of $\tau_2 = 10$ ms. It can be optically pumped as a three-level system at the pump wavelength of $\lambda_p = 980$ nm, where the absorption cross section is $\sigma_a^p = 2.58 \times 10^{-25}\ m^2$. At the signal wavelength of $\lambda = 1.53\ \mu m$ and the pump wavelength of $\lambda_p = 980$ nm, the guided signal and pump waves respectively have effective mode radii of $\rho = 4.1\ \mu m$ and $\rho_p = 3.3\ \mu m$ for their intensity profiles. The fractions of the signal and pump intensities that overlap with the core doped with active ions are determined by the confinement factors, which are $\Gamma = 0.70$ and $\Gamma_p = 0.72$, respectively. The pump quantum efficiency is $\eta_p = 0.8$.

(a) Find the pumping rates for this Er:fiber to reach transparency and to have an unsaturated gain coefficient of $g_0 = 0.3\ m^{-1}$, respectively, at $\lambda = 1.53\ \mu m$. What are the saturation lifetime and the saturation intensity in each case?

(b) Find the required pump intensities at $\lambda_p = 980$ nm to pump this Er:fiber to transparency and to have an unsaturated gain coefficient of $g_0 = 0.3\ m^{-1}$, respectively.

(c) Find the required pump powers for transparency and for $g_0 = 0.3\ m^{-1}$ by accounting for the overlap between the guided pump beam and the active core.

(d) When this Er:fiber is pumped to have an unsaturated gain coefficient of $g_0 = 0.3\ m^{-1}$ at $\lambda = 1.53\ \mu m$, a guided laser beam at this wavelength that has a power of $P = 1$ mW is sent through this fiber. Find the saturated gain coefficient by accounting for the overlap between the guided signal beam and the active core.

8.4.1 If the spot sizes of both beams in Example 8.7 are increased to $w_0 = 800\ \mu m$, what is the output power from each amplifier?

8.4.2 A Ti:sapphire laser rod of the characteristics described in Problem 8.3.4 has a length of $l = 4$ cm and a cross-sectional diameter of $d = 3$ mm. The refractive index of sapphire is 1.76. The laser rod is uniformly pumped to have an unsaturated gain coefficient of $g_0 = 15\ m^{-1}$ at the wavelength of $\lambda = 800$ nm. The saturation intensity at $g_0 = 15\ m^{-1}$ is $I_{sat} > 2\ GW\ m^{-2}$. A collimated Gaussian signal beam at $\lambda = 800$ nm that has a spot size of $w_0 = 300\ \mu m$ in the rod and a power of $P_s^{in} = 1$ W is sent through the Ti:sapphire amplifier. What is the output signal power from this Ti:sapphire amplifier?

8.4.3 An Er:fiber amplifier of the characteristics described in Problem 8.3.5 has a length of $l = 10$ m. It is uniformly pumped to have an unsaturated gain coefficient of $g_0 = 0.3\ m^{-1}$ at its laser wavelength of $\lambda = 1.53\ \mu m$. After accounting for the overlap between the guided signal beam and the active core, the saturation power at $g_0 = 0.3\ m^{-1}$ is $P_{sat} = 1.49$ mW. If a guided signal beam at $\lambda = 1.53\ \mu m$ that has a power of $P_s^{in} = 10\ \mu W$ is sent through the Er:fiber amplifier, what is the amplified output signal power? What is the output signal power if the input signal power is increased to $P_s^{in} = 1$ mW?

8.5.1 A Nd:YAG crystal is doped with a Nd^{3+} concentration of $N_t = 1.38 \times 10^{26}\ m^{-3}$. For its $\lambda = 1.064\ \mu m$ laser line, the emission cross section is $\sigma_e = 4.5 \times 10^{-23}\ m^2$, the absorption cross section is $\sigma_a = 0$, and the spontaneous lifetime is $\tau_{sp} = 515\ \mu s$. A ruby crystal is doped with a Cr^{3+} concentration of $N_t = 1.58 \times 10^{25}\ m^{-3}$. For its $\lambda = 694.3$ nm laser