3.1 Show that the external quantum efficiency of a planar LED is given approximately by $\eta_{ext} = n^{-1}(n+1)^{-2}$, where n is the refractive index of the semiconductor–air interface. Consider Fresnel reflection and total internal reflection at the output facet. Assume that the internal radiation is uniform in all directions.

3.4 The active region of a 1.3-μm InGaAsP laser is 250 μm long. Find the active-region gain required for the laser to reach threshold. Assume that the internal loss is 30 cm^{-1}, the mode index is 3.3, and the confinement factor is 0.4.

3.9 A 250-μm-long InGaAsP laser has an internal loss of 40 cm^{-1}. It operates in a single mode with the modal index 3.3 and the group index 3.4. Calculate the

photon lifetime. What is the threshold value of the electron population? Assume that the gain varies as $G = G_N(N - N_0)$ with $G_N = 6 \times 10^3\ s^{-1}$ and $N_0 = 1 \times 10^8$.

4.1 Calculate the responsivity of a *p–i–n* photodiode at 1.3 and 1.55 μm if the quantum efficiency is 80%. Why is the photodiode more responsive at 1.55 μm?

4.2 Photons at a rate of 10^{10}/s are incident on an APD with responsivity of 6 A/W. Calculate the quantum efficiency and the photocurrent at the operating wavelength of 1.5 μm for an APD gain of 10.

4.6 Consider a 0.8-μm receiver with a silicon *p–i–n* photodiode. Assume 20 MHz bandwidth, 65% quantum efficiency, 1 nA dark current, 8 pF junction capacitance, and 3 dB amplifier noise figure. The receiver is illuminated with 5 μW of optical power. Determine the RMS noise currents due to shot noise, thermal noise, and amplifier noise. Also calculate the SNR.

4.7 The receiver of Problem 4.6 is used in a digital communication system that requires a SNR of at least 20 dB for satisfactory performance. What is the minimum received power when the detection is limited by (a) shot noise and (b) thermal noise? Also calculate the noise-equivalent power in the two cases.