ECEn 555, Fall 2009
Homework #5
Due November 9, 5:00 pm

5.1 If the irradiance of light doubles after passing once through a laser amplifier 0.5 m long, calculate the small signal gain coefficient k assuming no losses. If the increase in irradiance were only 5%, what would k be?

5.2 Calculate the degree of population inversion required to give a small signal gain coefficient for a CO_2 laser (λ=10.6 μm) of 0.5 m^{-1}. Take the Einstein A coefficient for the upper laser level to be 200 s^{-1}.

5.3 Calculate the mirror reflectances required to sustain laser oscillations in a laser which is 0.1 m long, given that the small signal gain coefficient is 1 m^{-1} (assume the mirrors have the same values of reflectance).

5.4 LED Output Spectrum. Given that the width of the relative light intensity vs. photon energy spectrum of an LED is typically around ~$3k_BT$, what is the linewidth $\Delta\lambda_{1/2}$ in the output spectrum in terms of wavelength?

5.5 LED Output Wavelength Variations. Consider a GaAs LED. The bandgap of GaAs at 300K is 1.42 eV, which changes (decreases) with temperature as $dE_g/dT = -4.5 \times 10^{-4}$ eV K^{-1}. What is the change in the emitted wavelength if the temperature change is 10ºC?

5.6 InGaAsP on InP Substrate. The ternary alloy $In_{1-x}Ga_xAs_yP_{1-y}$ grown on an InP crystal substrate is a suitable commercial semiconductor material for infrared wavelength LED and laser diode applications. The device requires that the InGaAsP layer is lattice matched to the InP crystal substrate to avoid crystal defects in the InGaAsP layer. This in turn requires that $y \approx 2.2x$. The bandgap E_g of the ternary alloy in eV is then given by the empirical relationship,

$$E_g \approx 1.35 - 0.72y + 0.12y^2; \quad 0 \le x \le 0.47$$

Calculate the composition of InGaAsP ternary alloys for peak emission at a wavelength of 1.3 μm.

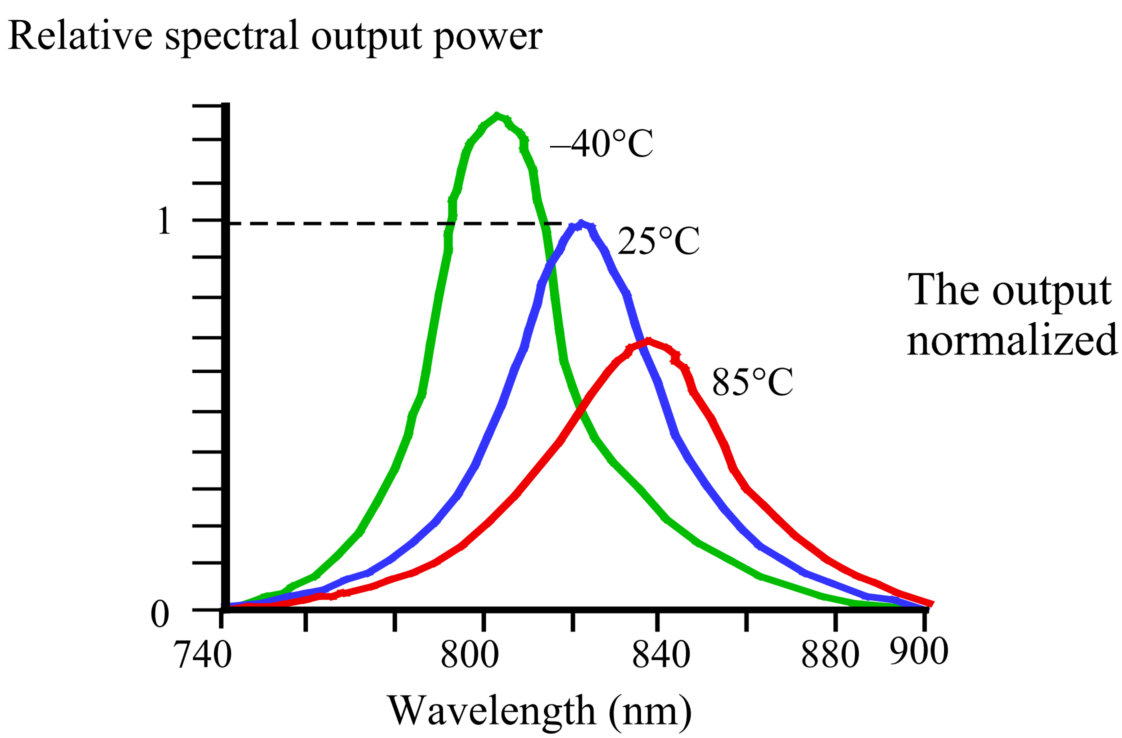
5.7 AlGaAs LED Emitter. An AlGaAs LED emitter for use in a local optical fiber network has the output spectrum shown in the figure below. It is designed for peak emission at 820 nm at 25ºC.

(a) What is the linewidth $\Delta\lambda$ between half power points at temperatures -40ºC, 25ºC, and 85ºC? What is the empirical relationship between $\Delta\lambda$ and T given three temperatures and how does this compare with $\Delta(h\nu) \approx 2.5k_BT$ - $3k_BT$?
(b) Why does the peak emission wavelength increase with temperature?
(c) Why does the peak intensity decrease with temperature?
(d) What is the bandgap of AlGaAs in this LED?
(e) The bandgap, E_g, of the ternary alloys $Al_xGa_{1-x}As$ follows the empirical expression,

$E_g(eV) = 1.424 + 1.266x + 0.266x^2$.

What is the composition of the AlGaAs in this LED?

(f) When the forward current is 40 mA, the voltage across the LED is 1.5V, and the optical power that is coupled into a multimode fiber through a lens is 25μW. What is the overall efficiency?



5.8 External Conversion Efficiency. The *external power or conversion efficiency* η_{ext} is defined as

$$\eta_{ext} = \text{(Optical power output) / (Electrical power output)} = P_o/IV$$

One of the major factors reducing the external power efficiency is the loss of photons in extracting the emitted photons that suffer reabsorption in the pn junction materials, absorption outside the semiconductors, and various reflections at interfaces.

The total light output power from a particular AlGaAs red LED is 2.5 mW when the current is 50 mA and the voltage is 1.6V. Calculate its external conversion efficiency.

5.9 LED-Fiber coupling Efficiency.

(a) It is found that approximately 200 μW is coupled into a multimode step index fiber from a surface emitting LED when the current is 75 mA and the voltage across the LED is about 1.5 V. What is the overall efficiency of operation?

(b) Experiments are carried out on coupling light from a 1310 nm ELED (edge emitting LED) into multimode and single mode fibers.

(i) At room temperature, when the ELED current is 120 mA, the voltage is 1.3V, and light power coupled into a 50 μm multimode fiber with NA (numerical aperture) = 0.2 is 48 μW. What is the overall efficiency?
(ii) At room temperature, when the ELED current is 120mA, the voltage is 1.3V, and light power coupled into a 9 μm single mode fiber is 7 μW. What is the overall efficiency?