Problem Set 5   Lasers and LEDs
Due: Weds Nov. 1 2005
Reference: Pierret chaper 9 (LEDs), Solymar and Walsh chap. 12 (lasers). Additional reading from MRS Bulletin

1. Term paper topic
Propose a topic for your term paper - for examples or inspiration see the first handout, or look through copies of MRS Bulletin, Scientific American, Physics Today, etc (available in my office). Write a paragraph mentioning the major materials issues associated with your device. Give the titles of 2 or 3 references (e.g scientific papers) about the topic. (The term paper is 8-10 pages long, due 20 Nov.)

2. Read the articles from MRS Bulletin on organic photovoltaics and on lasers/LEDs for some additional background not covered in Pierret.

3. Consider the photon emission from GaAs in thermal equilibrium. For GaAs at room temperature, $n_i=1.8 \times 10^6/cm^3$ and the radiative electron-hole recombination rate r = $10^{-10} cm^3/s$.
   (a) Compute the electroluminescence rate (# of photons generated per cubic centimeter per second).
   (b) Given the bandgap energy of GaAs as 1.42 eV, compute the optical power density (Watts/cm^3) represented by this emission rate.
   (c) Compute the intensity of light emitted by a 2 μm thick layer of GaAs. Is this intensity significant?
Now consider the photon emission from forward-biased GaAs p-n junction featuring injection electroluminescence emission. Assume a minority carrier lifetime of 50 ns.
   (d) If the injected minority carriers give rise to a steady state increase in minority carrier concentration of $10^{17}/cm^3$, compute the electroluminescence rate.
   (e) Given the bandgap energy of GaAs of 1.42eV, compute the optical power density represented by this emission rate.
   (f) Compute the intensity of light emitted by a 2 μm thick layer of GaAs. Is this intensity significant?
   (g) What is the power emitted from a device of area 200 μm x 10 μm?

4. Consider the design of a "white" LED like that offered in the catalog listing shown below. You will recall that "white" light is actually the combination of all visible colors, and can be effectively modeled by the simultaneous presence of red, green, and blue (RGB). This RGB approach to white light is that used by your color television and color computer monitor. Red light has a wavelength of approximately 650 nm, green light is approximately 530 nm, and blue light is approximately 430 nm.
Two design approaches are available for white light emission. One is to build three small, discrete devices (red, green, and blue), package them within a single LED

package, and operate them simultaneously to yield the white light. The other is to create a single structure that simultaneously generates photons over the visible spectrum (as is the case for the filament of an incandescent light bulb).

Discuss the pros and cons of these two approaches, and comment on the materials you would use in each case. Where possible, explain your selections in terms of output wavelength, efficiency, substrate availability, and reliability, and in the second case, be clear about how a single device can be expected to simultaneously produce a series of different wavelengths throughout the visible region. Be specific in your discussions. You may neglect issues such as how the discrete devices are actually mounted and how they electrically connected. (please be concise, 1 page max.)

5. Based on the following data, design a semiconductor laser to operate at 980 nm. In your answer consider the following:
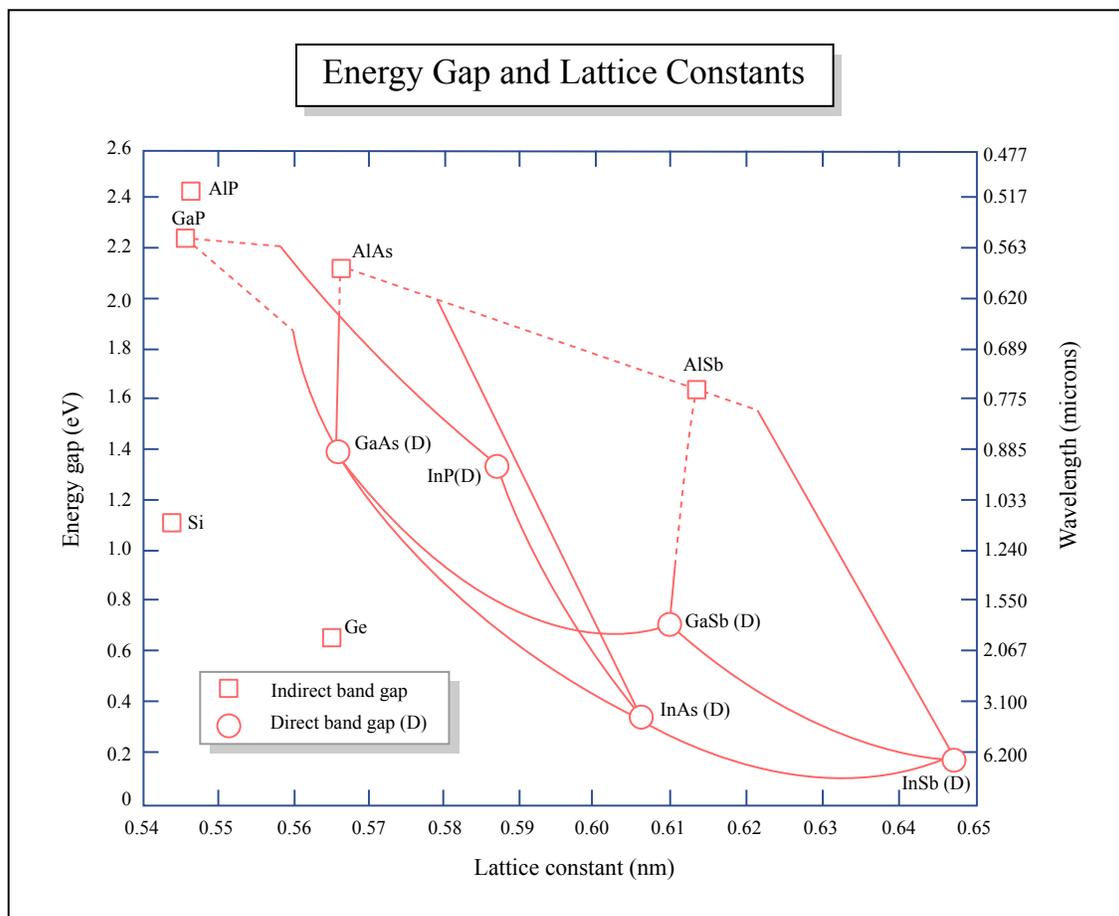
Energy Gap and Lattice Constants (Fig. 14.3, after Cho, 1985).   Figure by MIT OCW.

a) what substrate, core and cladding material to use? If there are several possible combinations, which would you choose?

b) what will the band structure look like? Draw it as accurately as you can, including the effect of doping, for the unbiased case.

c) what factors affect the spectral output of the laser? Illustrate your answer with a sketch of how you expect the intensity of the output light to depend on wavelength (or frequency).

d) What other materials data would you like to have in order to complete your laser design, and why?