Cole Shanks
54950860

ECE 413 Semiconductor Lasers

L. Chrostowski

Homework – Semiconductors, Optical Gain

Semiconductors

1. Derive the expression between the photon energy (in eV) and the wavelength (in μm).

h (Planck's Constant) = 6.626×10^{-34} J·s

c (Speed of light) = 2.998×10^{8} m/s

$\therefore hc = 1.99 \times 10^{-25}$ J·m

Converting to eV (electron volts):

$1 eV = 1.602 \times 10^{-19}$ J

$$1.99 \times 10^{-25} \text{ J} \cdot \text{m} \cdot \frac{1 eV}{1.602 \times 10^{-19} \text{ J}} = 1.24 \times 10^{-6} \text{ eV} \cdot \text{m}$$

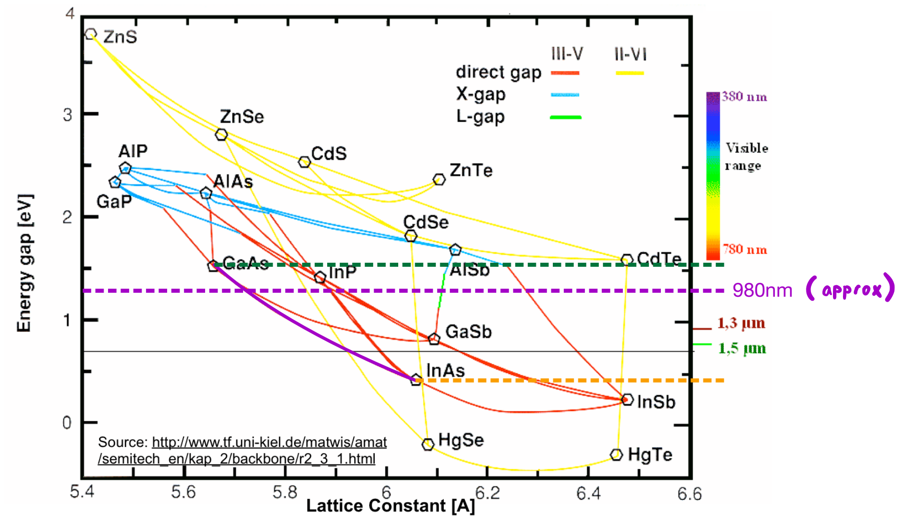
Wavelength is given by

$$\lambda = \frac{hc}{E}$$

$\therefore$ Therefore, photon energy as a function of wavelength is given by the expression

$$\boxed{E[\text{in eV}] = \frac{1.24 \times 10^{-6}}{\lambda}}$$

2. What semiconductor (estimate the compositions) would be used for the gain material in a 980 nm laser, if it is grown on a GaAs substrate? (980 nm lasers are used as pump lasers for making optical fiber amplifiers).



- GaAsInAs Semiconductor
- 80% GaAs
- 20% InAs

3. We are constructing a buried-heterostructure laser using a bulk active region of $GaAs$. The following are the parameters for the laser:

- E_g = bandgap energy = 1.43 eV, T = room temperature = 300 K, n_i = intrinsic carrier concentration in the active layer = $2.1 \times 10^6 cm^{-3}$, τ = electron-hole recombination lifetime = 3 ns, assume equal effective masses for conduction and valence bands ($= m_e$).
- L = cavity length = 250 μm, w=width of active area = 2 μm, d = thickness of active area = 0.2 μm, α_{int} = internal losses = 10 cm^{-1}, Γ = active area confinement factor = 0.5, μ_g = index of refraction of the active area semiconductor = 3.65

In this problem, we are dealing with an *intrinsic* bulk material as the gain medium.

We can approximate the carrier density using the Boltzmann exponential statistics. The quasi-Fermi levels are approximated as:

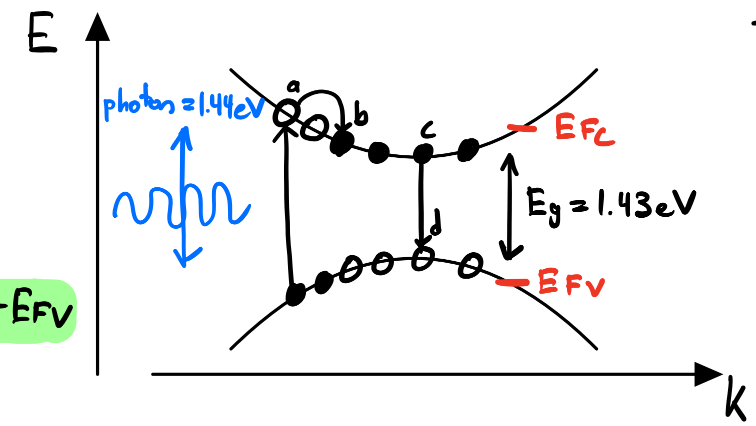
$$E_{FC} = E_i + KT \ ln\left(\frac{n}{n_i}\right), \quad E_{FV} = E_i - KT \ ln\left(\frac{p}{n_i}\right)$$

where E_i is the midband energy level (located at the center of the bandgap), E_{FC} (E_{FV}) is the conduction (valence) band quasi-Fermi level, and n and p are the concentration densities of injected electrons and holes.

(a) Sketch the E vs. k band diagram for the semiconductor, when the semiconductor is transparent to light at an energy of $E_\nu = 1.44eV$. Label the quasi-Fermi levels. Label the possible optical transitions for this light energy, and identify the possible momentum values.

possible transitions:
a-b
b-c
c-d

Transparency is achieved when the photon coming in (1.44eV) is equal to the quasi-fermi gap ie: 1.44eV = EFC − EFV



(b) What is the relationship between n and p, for this case?

In this case, n = p

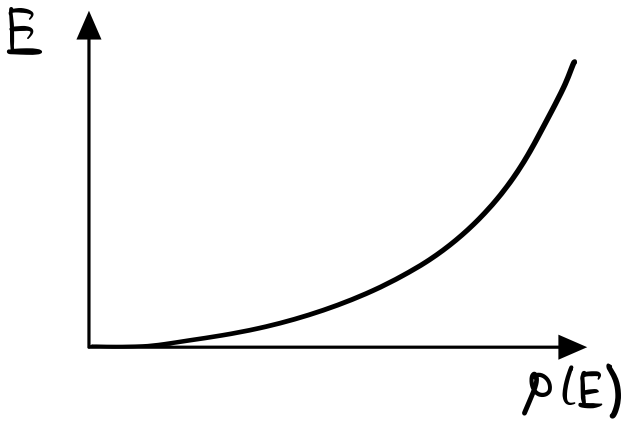
(c) Find an expression for the (electron) carrier density, N_{tr}, required to achieve transparency (which corresponds to the onset of population inversion in a semiconductor) at a light energy of $E_\nu = 1.44eV$.

Onset of inversion occurs at $h\nu = F_c - F_v$

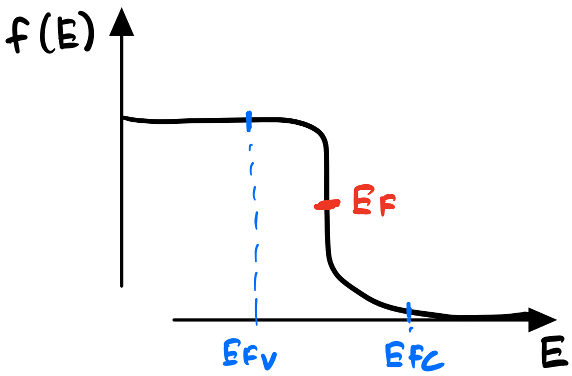
So 1.44eV =

(d) What is the value of N_{tr} at room temperature?

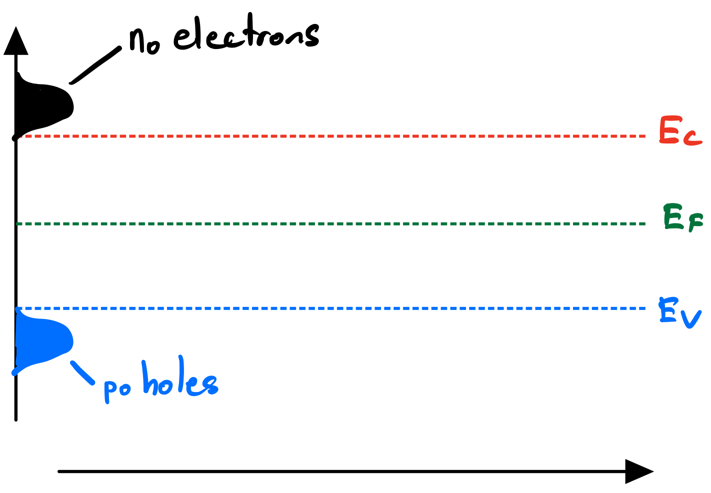
(e) Sketch the density of states of this semiconductor, versus energy.



(f) Sketch the Fermi function, versus energy.



(g) Sketch the concentration of electrons and holes, versus energy.



(h) Calculate a more accurate value of N_{tr} by considering the Fermi-Dirac carrier distribution and the density of states.

(i) Assuming that the electron-hole recombination lifetime (τ) is independent of pumping, find an expression for the required bias current, I_o, to achieve transparency. You can neglect the presence of possible leakage currents.

Find the value of I_o for the given laser structure.

(j) If this semiconductor has the current I_o applied (i.e. an LED), sketch the spontaneous emission spectrum, versus wavelength (label relevant wavelengths). At approximately what wavelength is the spontaneous emission the highest? At what wavelength(s) is the semiconductor transparent? At what wavelengths is the semiconductor amplifying? At what wavelengths is the semiconductor absorbing?

Semiconductor Optical Gain

4. Find the expression for the optical gain $\gamma(\omega)$ for GaAs, at $T = 0K$. Describe the procedure to find this parameter for a given carrier density.

   Evaluate and plot the gain $\gamma(\omega)$ of a GaAs semiconductor under the following conditions, with a population inversion:

$$
\begin{aligned}
&N_{elec} = N_{hole} = 3 \times 10^{18} cm^{-3} \\
&m_c = 0.07 \cdot m_{electron} \\
&m_h = 0.4 \cdot m_{electron} \\
&T = 0K \\
&T_2 \rightarrow \infty \\
&\tau = 1ns
\end{aligned}
$$

   How would the gain profile change if the temperature is raised? (estimate and sketch)