HW #1

Due **Feb. 26** (Thu) in class

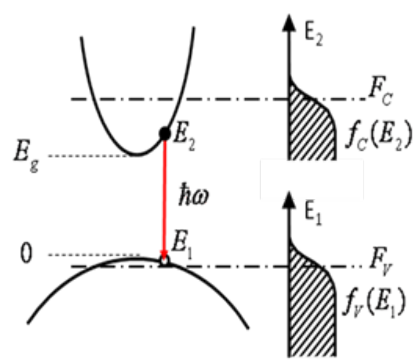
Please submit **Hard Copy**. Please remember to put down **your name** and **SID**.

1. We have derived the expressions for the 3-d (bulk) and 2-d (quantum well) electron density of states in class. Follow the same procedure, derive the 1-d electron density of state function for a "quantum wire" with dimension of L_x and L_y in the x and y direction, and unconfined in the z direction.
   a. Derive the 1-D electron density of state function, $\rho_{1D}(E)$.
   b. Find the first three energy levels for $L_x = L_y = 5$ nm, assume the electron effective mass $m_e^* = 0.1 \cdot m_0$, where m_0 is the free electron mass.
   c. Find the electron concentration if the Fermi level is located just below the second energy level (as you find in Part b.). For simplicity, assume T = 0 Kevin.

2. Consider a "quantum box" (also called quantum dot or QD) with dimensions of $L_x \times L_y \times L_z$.
   a. Derive the 0-D electron density of state function, $\rho_{0D}(E)$.
   b. Find the first three energy levels for $L_x = L_y = L_z = 5$ nm, assume the electron effective mass $m_e^* = 0.1 \cdot m_0$, where m_0 is the free electron mass.
   c. Find the electron concentration if the Fermi level is located just below the second energy level (as you find in Part b.). For simplicity, assume T = 0 Kevin.

3. Refer to the diagram on the right. Under biased condition, both conduction and valence bands are populated. The electron distribution in conduction band is described by Fermi-Dirac distribution, $f_C(E_2)$, with quasi-Fermi energy F_C. The electron distribution in valence band is described by Fermi-Dirac distribution, $f_V(E_1)$, with quasi-Fermi energy F_V. Here, E_1 and E_2 are related by an optical transition (i.e., they have the same k). For optical matrix element, use

$$\left|\hat{e} \cdot \vec{P}_{cv}\right|^2 = \frac{m_0}{6} E_p \quad \text{with} \quad E_p = 25.7 \text{ eV}$$



   a. Use the energy reference below (i.e, $E_V = 0$ and $E_C = E_g$, the bandgap energy), find E_1 and E_2 as functions of the photon energy, $h\omega$.
   b. Derive $f_C(E_2(\hbar\omega))$ as a function of $h\omega$.
   c. Derive $f_V(E_1(\hbar\omega))$ as a function of $h\omega$.
   d. Assuming $E_g = 1$ eV, $F_C - F_V = 1.2$ eV, $m_e^* = 0.1 m_0$, $m_h^* = 0.4 m_0$. Calculate and plot the emission probability $f_e(\hbar\omega) = f_C(E_2(\hbar\omega)) \cdot \left[1 - f_V(E_1(\hbar\omega))\right]$ for photon energies from 0.8 to 1.5 eV. Plot for two temperatures: T = 0 and T = 300 K.
   e. Repeat part d) for the Fermi inversion factor: $f_g(\hbar\omega) = f_C(E_2(\hbar\omega)) - f_V(E_1(\hbar\omega))$
   f. Plot the gain spectra for T = 0 and T = 300 K for the condition given in d).
   g. Plot the spontaneous emission spectra for T = 0 and T = 300 K for the condition given in d).