1. The mass of an electron in InGAsAs in $0.04m_0$. If a quantum well is formed in this material with a width of 50 Å, calculate the lowest energy of the electron in the quantum well.

$$E = \frac{n^2 \pi^2 \hbar^2}{2m^* L^2} \qquad L = 10\ \text{Å}$$

$$1\ J = 6.24 \times 10^{18}\ eV$$

$$E_1 = \frac{\pi^2 (1.05 \times 10^{-34})^2}{2 * 0.04 \times 9.1 \times 10^{-31} \times 10^{-20} \times 2500}$$

$$= 5.97 \times 10^{-20}\ J = 0.3725\ eV$$

2. Calculate the first four energy levels of the electron in hydrogen atom. If the mass of the electron changes to $0.1\ m_0$ and the relative dielectric constant of a material is 12, calculate the same four energy level. What would be the Bohr radius of the electron in such a material?

$$m \longrightarrow 0.1\ m_0 \qquad \varepsilon = 12$$

$$E = -\frac{m_0 e^4}{2 (4\pi\varepsilon_0)^2 \hbar^2 n^2} \qquad E \propto \frac{m_0}{\varepsilon_0}$$

$$m_0 \longrightarrow \frac{m^*}{m_0}$$

$$\varepsilon \longrightarrow \frac{\varepsilon}{\varepsilon_0}$$

$$E_1 = \frac{-13.6 \left(\frac{Z^2}{n^2}\right) \left(\frac{m^*}{m_0}\right)}{\left(\frac{\varepsilon}{\varepsilon_0}\right)^2}$$

$$= -9.44\ meV$$

$$E_3 = -1.048\ meV$$

$$E_2 = -2.36\ meV$$

3. Calculate the nearest neighbor distance between atoms in Si, GaAs crystals. Take lattice constant of Si as 5.43 Å and that of GaAs is 5.65 Å.

$$N_{Si} = \frac{\sqrt{3}}{4}(5.43) = 2.35\ \text{Å}$$

$$N_{GaAs} = \frac{\sqrt{3}}{4}(5.65) = 2.44\ \text{Å}$$

4. The effective mass of a conduction band electron in a semiconductor is $0.1m_0$. Calculate the energy of this electron if the k vector is 0.3 Å^{-1}.

$$E = \frac{\hbar^2 k^2}{2m^*} = 3.407\ eV$$

5. A conduction band electron in Si is in the (100) valley and has a k-vector of $\frac{2\pi}{a}(1.0, 0.1, 0.1)$. Calculate the energy of electron measured from the conduction bandedge. Here, a is the lattice constant of Si.

Bottom of conducn band = $\frac{2\pi}{a}(0.85, 0, 0)$

$$\Delta k = \frac{2\pi}{a}(0.15, 0.1, 0.1)$$

$$k_l = \frac{2\pi}{a} \times 0.15 = 1.73 \times 10^{9}\ m^{-1}$$

$$k_t = \frac{2\pi}{a} \times 0.1 = 1.157 \times 10^{9}\ m^{-1}$$

$$E = \frac{\hbar^2}{2m_l^*} k_l^2 + \frac{2\hbar^2}{2m_t^*} k_t^2$$

$m_l^* = 0.98\ m_0$

$m_t^* = 0.19\ m_0$

$= 0.65\ eV$

6. Calculate the density of states effective masses of electrons (m_e*) and holes (m_h*) in Si. Take m_l=0.98m_0, m_t=0.19m_0 for electrons and m_{lh}=0.16m_0 and m_{hh}=0.49m_0 for holes.

$$e: m^*_{dos} = (m_1^* \ m_2^* \ m_3^*)^{1/3} \ 6^{2/3} = 1.09\ m_0$$

$$h: m^*_{dos} = (m^{*\,3/2}_{lh} + m^{*\,3/2}_{hh})^{1/3} = 0.55\ m_0$$

7. Calculate the intrinsic carrier density (n_i) for Si (Eg=1.12 eV) at 500K. Take effective masses: m_e^*=1.1m_0 and m_h*=0.56m_0.

$$n_i = p_i = 2\left(\frac{k_B T}{2\pi\hbar^2}\right)^{3/2} (m_e^* \ m_h^*)^{3/4} \exp\left(\frac{-E_g}{2k_B T}\right)$$

$$= 2\left(\frac{0.26 \times \frac{500}{300}}{2\pi \times \hbar^2}\right) (1.1 \times 0.56 \times m_0^2)^{3/4} \exp\left(\frac{-1.1}{2 \times 0.26 \times \frac{500}{300}}\right)$$