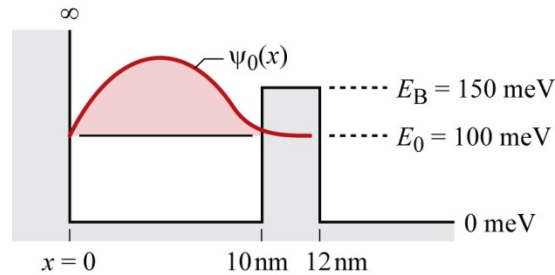


Final Exam, Fall 2008

ECSE-6920 – Physical Foundations of Solid-State Devices, Prof. Schubert

Note: (i) Put your name on paper, show your work, underline results, and always show units.
(ii) Textbook, manuscript, excerpts, and calculators are allowed.

1. Consider the diagram shown below and assume that $\psi_0(x)$ is the wave function of an electron and that $\psi_0(x)$ is essentially confined to the well region, that is, $\int_0^{L_{QW}} \psi_0^*(x) \psi_0(x) \approx 1$.



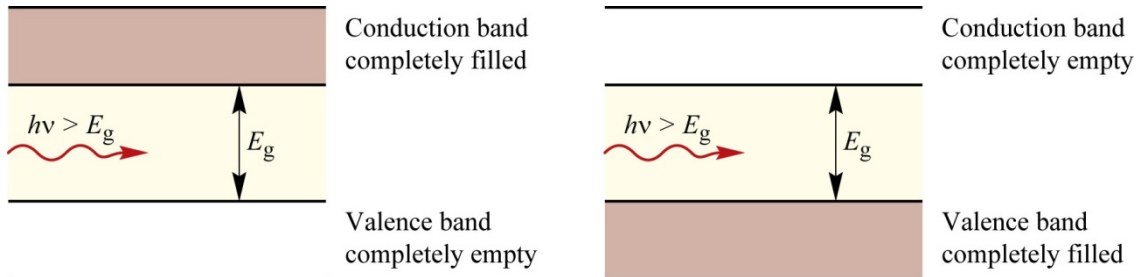
- (a) Calculate the approximate value of the expectation value of the potential energy.
 - (b) Give the approximate numerical value of the electron's kinetic energy.
 - (c) Assuming that the effective electron mass is $m_e^* = 0.1 \times m_e$, calculate the velocity of the electron.
 - (d) The electron oscillates between the two walls. Calculate the mean time that elapses between two collisions of the electron with the right-hand side wall.
 - (e) Calculate the attempt rate, that is, the electron's number of attempts to escape per second.
 - (f) Calculate the electron's tunneling probability through the quantum barrier ($L_{QB} = 20 \text{ \AA} = 2 \text{ nm}$).
 - (g) Whenever the electron collides with the right-hand side wall, it attempts to escape. Calculate the average time the electron is located inside the well before successfully escaping from the well.
 - (h) What is the energy uncertainty ΔE of the state?
 - (i) Does ΔE increase as the "transparency" of the barrier increases?
 - (j) Make the analogy to an optical Fabry-Perot resonator. Does the line width $\Delta\lambda$ increase as the transparency of the two reflectors increase? Explain.
2. (a) Write down the Einstein relation.
- (b) In a semiconductor at $T = 0 \text{ K}$, can the carrier mobility be $\mu \neq 0$?
 - (c) In a semiconductor at $T = 0 \text{ K}$ can $D \neq 0$?
 - (d) Assume an electric field \mathcal{E} is applied to semiconductor. Give the distance x a carrier with mobility μ drifts as function of time as a general function (no numeric values).
 - (e) Assume a diffusing carrier with diffusion constant D . Give diffusion distance x as a function of time as a general function (no numeric values).
 - (f) Explain in words the physical origin of the different time dependency functions, diffusion $x_{\text{diffusion}}(t)$ and drift $x_{\text{drift}}(t)$.

3. Consider the left-hand-side part of the figure below which shows a band occupation in a semiconductor.

- What process will occur when the photon is incident on the semiconductor?
- Write the formula for the quantum mechanical probability per unit time for this process.

Next, consider the right-hand-side part of the figure below.

- What process will occur when the photon is incident on the semiconductor?
- Write the formula for the quantum mechanical probability per unit time for this process.
- Are probabilities calculated under (b) and (d) the same or are they different? Explain.



4. Let us assume that GaAs and Si both would have a lattice-atom concentration of about 5×10^{22} atoms per cm^3 . For some applications, it is desirable that the electrically active doping concentration be as high as possible. Assume that GaAs is doped with Si occupying exclusively the Ga site. Assume further that Si is doped with P.

- What conductivity type will result when doping the semiconductors?
- What is the concentration of potentially available donor sites in GaAs?
- What is the concentration of potentially available donor sites in Si?
- Based on the above two values of the potentially available sites, which of the two semiconductors would you expect to allow for a higher doping concentration?
- Do you happen to know which of the two semiconductors, GaAs or Si, allows for higher electrically active dopant concentrations and thus higher carrier concentrations?