
EE566 Solid State Devices

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Dept of Electrical Engineering

University of Notre Dame

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Assignment 2

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Reading

Chapters 3 & 4 of textbook.

Problem 1¹

We learnt that the electron density in a bulk (3D) semiconductor in the most general case is given by $n_{3d} = N_C^{3d} F_{1/2}(\eta)$, where N_C^{3d} is the conduction band effective density of states, $F_{1/2}(\dots)$ is the Fermi-Dirac integral of order 1/2, and $\eta = (E_F - E_C)/kT$. Similar results exist for electrons free to move in 2D and 1D.

a) Show that if electrons are confined to move in *two dimensions*, the sheet density (in $/\text{cm}^2$) is given by

$$n_{2d} = N_C^{2d} F_0(\eta) = N_C^{2d} \ln(1 + e^\eta),$$

where $N_C^{2d} = m^* kT / \pi \hbar^2$. Use the 2D DOS $g_{2d}(E) = m^* / \pi \hbar^2 \cdot \theta(E - E_c)$, where $\theta(E - E_c)$ is the unit-step function. Plot $E_F - E_C$ as a function of the 2DEG density (typical values are $10^{11} / \text{cm}^2 < n_{2d} < 10^{12} / \text{cm}^2$) for $T = 0, 77, \& 300 \text{ K}$ for a 2DEG located in a GaAs quantum well. Show that at low temperatures, n_{2d} becomes *independent* of temperature. Give examples of devices where electron motion is 2-dimensional.

b) Show that if electrons are confined to move in one dimension, linear density (in $/\text{cm}$) is given by

$$n_{1d} = N_C^{1d} F_{-1/2}(\eta),$$

Where $N_C^{1d} = \sqrt{2m^* kT / \pi \hbar^2}$. Use the 1D DOS $g_{1d}(E) = \sqrt{2m^* / \pi^2 \hbar^2 (E - E_c)}$. Show that under non-degenerate conditions, the Boltzmann approximation $n_{1d} \approx N_C^{1d} e^{(E_F - E_c)/kT}$ still holds. Give examples of 1D devices.

Problem 2

Concentration gradients in a semiconductor lead to diffusion currents. However, the flow of charges causes electric fields, which limit the flow of a net current through equal and opposite flow of drift current. To show this, you are given a piece of semiconductor that has an *arbitrary* doping profile $N_D(x)$ along the x -axis.

a) Find the *internal* electric field profile $E(x)$ that develops inside the semiconductor at a temperature T . Explain all your steps at arriving at this result.

b) What happens to the electric field as the temperature changes?

c) Verify from your result that $E(x) = 0$ for a constant doping profile.

d) Plot the field for a silicon sample at room temperature and mobility $\mu = 400 \text{ cm}^2 / \text{V.s}$ where the doping profile from the surface ($x = 0$) is given by $N_D(x) = N_0 e^{-x/\lambda}$ ($N_0 = 10^{18} / \text{cm}^3$, $\lambda = 100 \text{ nm}$).

Problem 3

(On drift and diffusion currents) -

Solve problem 3.17 from the textbook.

¹ Remember to use proper units and label every figure/plot. Turn in your answers worked out neatly. Please attach this question sheet to your solution when you turn it in.