Physics of Semiconductors and Nanostructrures
ECE 4070 / MSE 6050, Spring Semester 2018
Assignment 5

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Policy on assignments: Please turn them in by 5pm of the due date. The due date for this assignment is **Thursday, May 3rd, 2018**.

General notes: Present your solutions *neatly*. Do not turn in rough unreadable worksheets - learn to **take pride in your presentation**. Show the relevant steps, so that partial points can be awarded. BOX your final answers. Draw figures wherever necessary. Please print out this question sheet and staple to the top of your homework. Write your name and email address on the cover.

Problem 1
In class we discussed the carrier density in semiconductor bands and the ballistic current flowing in them for transport in $d = 1, 2, 3$ dimensions. The new posted handout has this written up, and the detailed table.

(a) Consider the 1D case, encountered in semiconductor quantum wires and carbon nanotubes. Use a conduction band effective mass of $m_c^\star = 0.2m_e$, valley degeneracy $g_v = 1$ and spin degeneracy $g_s = 2$. Calculate and plot the source quasi-Fermi level at the source injection point $(E_{Fs} - E_c)$, and the drain quasi Fermi level $(E_{Fs} - qV - E_c)$ as a function of the voltage $0 < V < 2$ Volt for a high electron density $n_{1d} = 5 \times 10^6$/cm at room temperature $T = 300$ K, and explain the plot. Next, plot the ballistic currents vs voltage for electron densities $n_{1d} = 1, 2, 3, 4, 5 \times 10^6$/cm, both at 300 K and at 77K for $0 < V < 2$ Volt. You should observe that in 1D semiconductors the ballistic current does *not* depend on the 1d density at low voltages and low temperatures - why is this so? Why does the current saturate at high voltages?

(b) Now consider the 2D case, which is encountered in Silicon transistors, III-V quantum well high-electron mobility transistors, and 2D crystal semiconductors and metals. For this problem, use a conduction band effective mass of $m_c^\star = 0.2m_e$, valley degeneracy $g_v = 1$ and spin degeneracy $g_s = 2$. Calculate and plot the source quasi-Fermi level at the source injection point $(E_{Fs} - E_c)$, and the drain quasi Fermi level $(E_{Fs} - qV - E_c)$ as a function of the voltage $0 < V < 2$ Volt for a high electron density $n_{2d} = 5 \times 10^{13}$/cm^2 at room temperature $T = 300$ K, and explain the plot. Next, plot the ballistic current per unit width vs voltage for electron densities $n_{1d} = 1, 2, 3, 4, 5 \times 10^{13}$/cm^2, both at 300 K and at 77K for $0 < V < 2$ Volt. You should observe that unlike in 1D semiconductors, the ballistic current per unit width in 2D *does* depend on the 2d density at low voltages and low temperatures - why is this so? Why does the current saturate at high voltages?

In this problem, you have solved the 1d and 2d ballistic transistor problem in disguise. The variation of the carrier density in a transistor is done with a third terminal called the gate. You can use the same method to solve the ballistic FET problem below.

Solve the following exercise problems from the course notes posted on the class website.

Problem 14.1 on Semiconductor Heterostructure Energy Band Diagrams.

Problem 16.1 on Schottky Diode Rectifiers.

Problem 17.1 on Ballistic Field-Effect Transistors that do logic and memory.

Problem 18.1 on Tunneling and Electronic memory.