6.730 PHYSICS FOR SOLID STATE APPLICATIONS

Department of Electrical Engineering and Computer Science
Massachusetts Institute of Technology

PROBLEM SET 6

Issued: 4-14-99 Due: 4-21-99, at the beginning of class.

Readings:
PSSA Chapter 9 and 10

Problem 6.1 2DEG from a Confining Potential

This problem explores how a two dimensional electron gas (2DEG) in the conduction band can arise from a confining potential.

The conduction band for a three dimensional semiconductor has an energy $E(\mathbf{k})$ for energies greater than the conduction band minimum E_c given by

$$E(\mathbf{k}) = E_c + \frac{\hbar^2}{2}\left(\frac{k_x^2}{m_1} + \frac{k_y^2}{m_2} + \frac{k_z^2}{m_3}\right) .$$

The electrons in the conduction band are now subjected to a confining potential which we model as a particle-in-a-box potential which restricts the electrons to a box in the z-direction of width L,

$$V(\mathbf{r}) = \begin{cases} 0 & \text{if } |z| < L \\ \infty & \text{otherwise} \end{cases}$$

where L is much larger than the lattice constant. Assume the effects of this potential can be treated within the effective mass theorem.

(a) Use the Effective Mass Theorem to find the total energy of the electron wavepacket near the bottom of the conduction band.

(b) Find and sketch the areal density of states $g(E)$ for electrons in the conduction band when their energy is given as in part (a). Note that $g(E)$ has dimensions of number of electrons per unit area per unit energy.

(c)Write down both the total time-dependent envelope function and the total time-dependent wavefunction for the wavepacket for electrons with $k_z = \pi/2L$ but arbitrary k_x and k_y. Such electrons are said to be in the *first subband* and form a two dimensional electron gas.

(d) Assume that $\hbar^2\pi^2/8L^2 \gg k_BT$. How many electrons per unit area can be added to the system before the occupancy of the second sub-band becomes significant.

(e) Discuss how your sketch in part (b) change if the confining potential was

$$V(\mathbf{r}) = \frac{1}{2}m_3\omega_o z^2$$

where ω_o is a positive constant of dimensions of inverse seconds. This parabolic confining potential is usually a better approximation.

In the next problems we will explore the similarities and differences amoung the Drude, Sommerfeld, and Semiclassical Models for conduction. You will need to refer to parts of SSS Sections 6.1—6.3, (`drude`), 7.1—7.3 (`sommer`), and 10.1—10.4 (`peierls`).

Problem 6.2 *Electron Motion in an Electric Field with "no scattering."*
Run and explore the following settings:

`drude`	preset 3 with tau= 10^5ps
`sommer`	preset 2
`peierls`	preset 2 with tau= 10^5ps, and click on "show holes"
`peierls`	preset 3 with tau= 10^5ps, and click on "show holes"

Write a short summary of your findings and use a few pictures to illustrate your points.

Problem 6.3 *Equuilibrium Motion in zero Electric Field with scattering.*
Run and explore the following settings:

`drude`	preset 1
`sommer`	preset 1

Write a short summary of your findings and use a few pictures to illustrate your points. Note be sure to compare the velocity-space and k-space of the two programs. You are not able to do this with `peierls` because it does not have the temperature profile in it.

Problem 6.4 *Equuilibrium Motion in Electric Field with scattering.*
Do Exercises 6.7 for Drude mode, Excercies 7.8 and 7.9 for the Sommerfeld model, and Excercies 10.1 and 10.8 (with "show holes") for the Semiclassical Model. Again, write up a comparision of the results for the three models.