ECE 5205 Homework assignment 5 (turn in 3-20-2014) Total points: 20

1. Consider acceleration of a "cold" and a "warm" electron between two membrane electrodes made of n+ silicon. The distance between the membrane electrode is 50 nm. The potential difference between the two electrodes is 1V. The "cold" electron starts at the negative electrode with zero kinetic (initial) energy and is accelerated across the gap of 50 nm. The "warm" electron of 0.6 eV kinetic (initial) energy enters the high field region through a hole in the positive electrode.

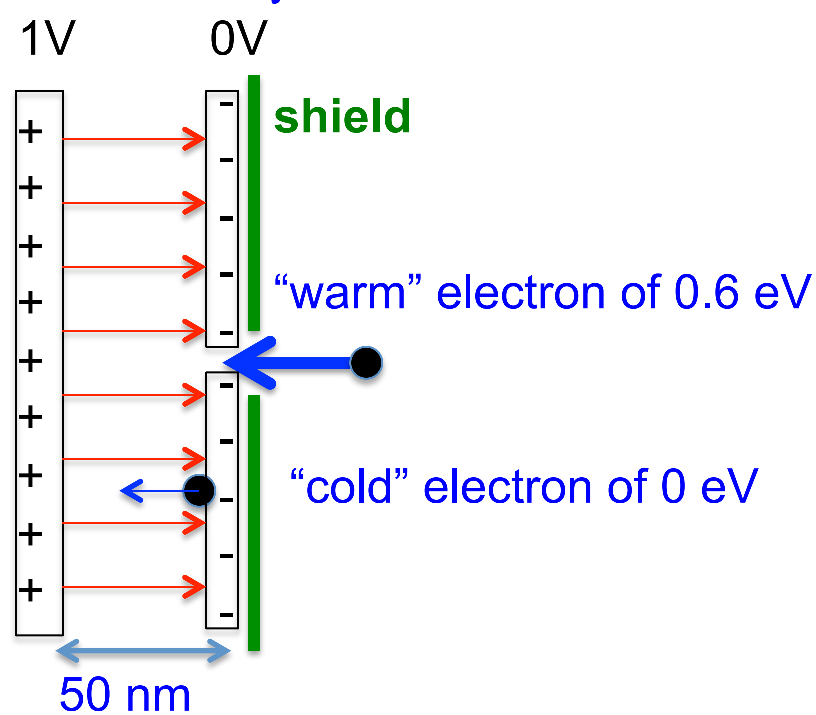
a) What is the electric field between the electrodes in V/cm?

b) What is the energy of the cold and warm electron when they hit the left electrode?

c) What are the corresponding velocities of the cold and warm electron? (Hint: use the trick $m \rightarrow mc^2$ for easy calculation)

d) Which electron will be able to create electron-hole pair when it smashes into the positive electrode? Justify your answer.

(4 points)



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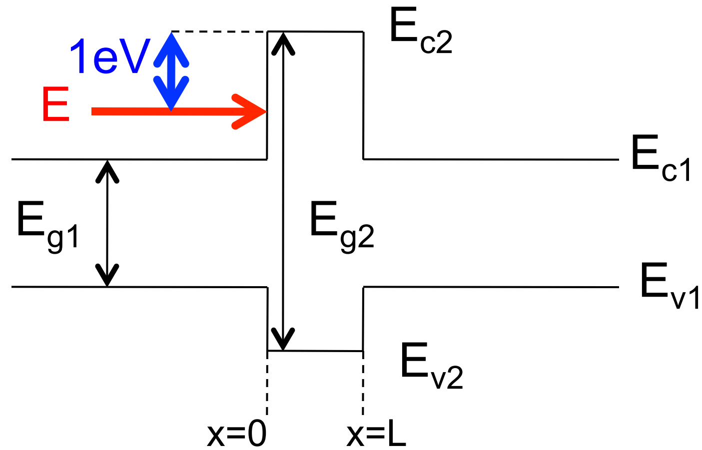
2. Coexistence of avalanche and band-to-band tunneling: In Si p^+n junctions avalanche and BTBT occur in about similar conditions. Consider a p^+n Si junction with $N_D=8\times10^{17}$ cm^{-3} (assume that $N_A=1.5\times10^{20}$ cm^{-3}). Look-up the breakdown voltage of such a junction from the curves provided in the lecture notes. We suspect that at this voltage an appreciable tunnel current begins to flow. Estimate the tunneling distance for BTBT. (4 points)

3. Let us consider a **tunneling structure** as shown below. This structure consists of semiconductor material of band gap E_{g1}. We grow a thin (2nm) layer of another semiconductor material with larger band gap of E_{g2}. Then we add a thick material of the first material.



Now suppose an electron in the conduction band approaches the thin layer at energy 1 eV below the top of the barrier. What is the probability that the electron will penetrate the barrier?

For rectangular barrier the relation between the q.m. wavefunction before the barrier (x=0) and behind the barrier is:

$$\psi(x=L) = \psi(x=0)\times\exp\left[-\sqrt{(2m^* 4\pi^2/h^2)(E_{g2}-E)}\times L\right]$$

Assume $m^*=m_o$ for an electron effective mass.

Tunneling probability Θ is given by:

$$\Theta = \left|\frac{\psi(x=L)}{\psi(x=0)}\right|^2$$

$$T = \frac{\psi^*(L)\psi(L)}{\psi^*(0)\psi(0)} = \exp\left[-2L\sqrt{\frac{2m(U-E)}{\hbar^2}}\right]$$

(3 points)

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4. **Zener Tunneling** in GaAs and in In As at an applied field of $2x10^5$ V/cm with following parameters:

$$m^*(GaAs) = 0.065m_o \qquad m^*(InAs) = 0.02m_o$$

$$E_g(GaAs) = 1.5eV \qquad E_g(InAs) = 0.4eV$$

Use the tunneling formula for triangular barrier in semiconductors:

$$\Theta = \exp\left(-\frac{4\sqrt{2m^*}E_g^{3/2}}{3e(h/2\pi)E_{el}} \right)$$

Comment on you results. (3 points)

5. **An abrupt silicon p⁺n** junction has N_D=$4x10^{15}$cm^{-3}. What must be the minimum n-region length such that avalanche breakdown occurs before the depletion reaches the ohmic contact of the n-side of the pn junction? (Hint: look up what is the voltage breakdown for such a junction.) (3 points)

6. **Space charge width:** Consider a pn junction at T=300K with symmetric doping concentration of N_D=N_A=$5x10^{19}$cm^{-3}. Assuming the abrupt junction approximation is valid, determine the space charge width at a forward-bias voltage of V_a=0.40V. (3 points)