6.012 Microelectronic Devices and Circuits Fall 2007

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Problem Set #2

Assigned: September 12, 2007
Due: September 19, 2007 at recitation

PLEASE WRITE YOUR RECITATION SESSION TIME ON YOUR PROBLEM SET SOLUTION

Problem 1. [15 points] *Adapted from Problem 3.3 of Fonstad*

(a) Calculate the thermal velocity, v_θ (cm/s), of an electron in silicon at room temperature, assuming it has a thermal kinetic energy of $\frac{1}{2}\mathbf{m}^*\mathbf{v}^2 = \frac{3}{2}\mathbf{kT}$ where kT is 0.025 eV. The effective mass m* of an electron in silicon is about 26 percent of the mass of an electron in free space (9.1×10^{-31} kg). Be careful about your units.

(b) Calculate the electric field necessary to produce drift velocity of electrons in silicon, v_d, equal to v_θ, assuming that electron mobility, μ_n=1000 cm^2/V.s

(c) Calculate the flux of electrons from (b) assuming that the silicon sample is n-type doped to10^{15} cm^{-3}.

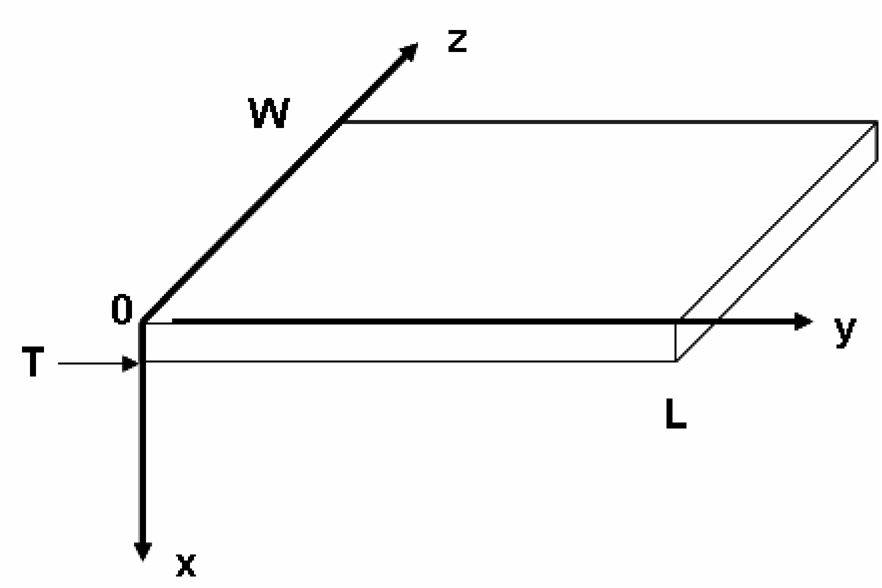
(d) Assuming that the electron drift velocity cannot exceed the thermal velocity, i.e. $v_d \le v_\theta$ calculate the current density in the sample in (c) when the electric field is 100 kV/cm.

Problem 2. [25 points] *Adapted from Problem 3.4 of Fonstad*

(a) Consider a sample (slab) of n-type silicon L long, W wide, and T thick (see Figure below) that is nonuniformly doped in such a manner that the equilibrium majority carrier population varies throughout its thickness as $n_o(x)$ (electrons/cm^3) ; i.e. there is no dependence of n_o on y or z. Assuming a constant electric field in the y-direction, E_y, and that the mobility μ_n is constant, independent of the doping level, show that the electron drift current is given by: $I_{drift} = W\mu_n(-Q_N)E_y$ where $Q_N = -q\int n_o dx$ is the areal density of the electron charge. (Hints: Assume that current conduction is lateral, i.e. parallel to the surface. Mentally divide the sample into thin slabs of material dx wide, and add the conductances of these slabs connected in parallel.)

(b) Now assume that while there still is no dependence of $Q_N(y)$ on z, a gradient of $Q_N(y)$ is maintained over the sample in the y-direction. Assuming that μ_n is constant, show that the diffusion current is given by: $I_{diff} = -WD_n(dQ_N/dy)$.

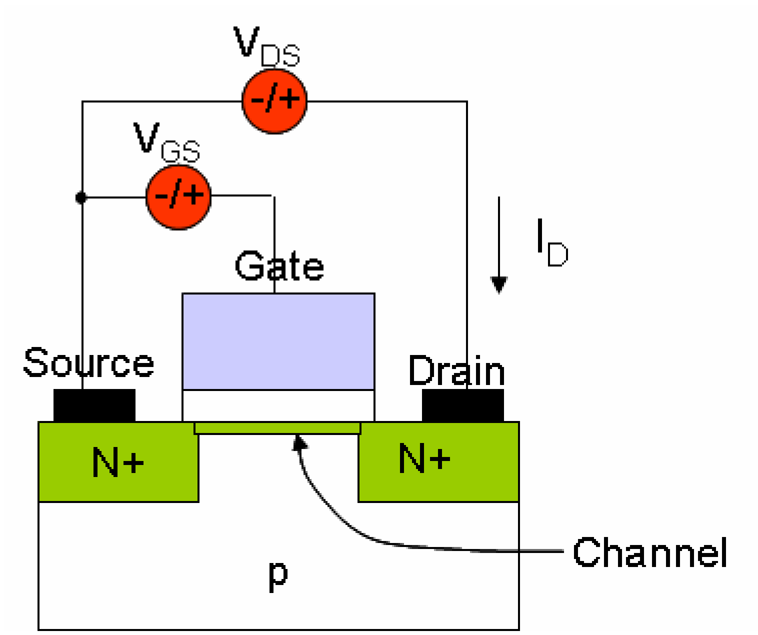
(c) Assume that what maintains the gradient in $Q_N(y)$ in (b) are the boundary values, $Q_N(0)$ and $Q_N(L)$. Provided that only diffusion current flows through the sample, show that the current is given by: $I_{diff} = (W/L)D_n\,[Q_N(0) - Q_N(L)]$.


z
W
0
y
T
L
x

Problem 3. [60 points] In this problem you will characterize with WebLab a metal-oxide-semiconductor field effect transistor (MOSFET) device operating as a voltage controlled variable resistance, as was described in 6.002. Soon, in 6.012, you will learn the detailed physics of operation of the MOSFET, but for purposes of this problem you do not need them.

A n-type MOSFET connected as shown below and operated within the indicated voltage limits can be considered as a voltage controlled conductor with conductance given by:

$$G_D = I_D/V_{DS} = B(V_{GS} - V_T)$$



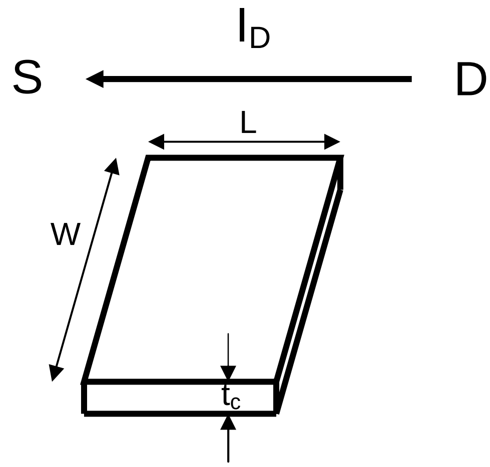
$3\ V < V_{GS} < 6\ V$ and $|V_{DS}| < 0.1\ V$

a) *(10 points)* Plot the drain current vs. the drain-to-source voltage [I_D(A) vs. V_{DS}(V)] for different values of V_{GS}(V) in the above range for each of the biases. Comment on the linearity of the I_D vs. V_{DS} characteristics.

b) *(10 points)* Calculate the value of G_D at V_{GS}=5 V, V_{DS}=0.1 V.

c) *(10 points)* You are told that the way this device works is via control of the sheet resistance of an electron layer of thickness, t_c=1 nm (1 nm = 10^{-7} cm) in the channel. The channel is rectangular between source and drain which constitute the ohmic contact to the conductive layer.

The length of the channel is L=5 μm (1 μm = 10^{-4} cm) and the width is W=37500 μm. Calculate the sheet resistance R_S at V_{GS}=3 V in units of ohms per square.



d) *(10 points)* You are also told that the mobility of electrons in this conductive layer is μ=500 cm^2/V.s. Assuming uniform electron concentration, n_c, throughout the channel layer, i.e. in x, y, and z directions, calculate the concentration, n_c (cm^{-3}) at V_{GS}=3V.

e) *(10 points)* In devices where the thickness of conductive layers is much smaller than the other two dimensions it is more convenient to talk about areal densities instead of volume densities. Calculate the areal density of electrons, N_N (electrons/cm^2), and the areal charge density, $Q_N=-qN_N$, (C/cm^2) in the channel for case (d).

f) *(10 points)* Download your data from part (a) and plot G_D vs. V_{GS}, and Q_N vs. V_{GS} at V_{ds}=0.05 V.