Massachusetts Institute of Technology
Department of Electrical Engineering and Computer Science
6.012
Microelectronic Devices and Circuits
Spring 2007
February 14, 2007 - Homework #1
Due - February 21, 2007

Problem 1

A piece of silicon is doped with $N_a = 2\text{x}10^{15}$ cm^{-3} and $N_d = 1\text{x}10^{15}$ cm^{-3}

a) What is the majority carrier? Is the silicon type n or type p?
b) Find the electron and hole concentration and mobility at room temperature.
c) We want increase the electron concentration to $1\text{x}10^{17}$ cm^{-3}. What is the additional dopant type and concentration? What is the new electron mobility?

a) $N_a > N_d$. **Holes. P-type**.
b) Total impurities = $N_a + N_d = 3\text{x}10^{15}$ cm^{-3}.
According to figure 2.8.
μ_p = **475 cm^2 (Vs)$^{-1}$**
μ_n = **1300 cm^2 (Vs)$^{-1}$**
$N_a - N_d >> n_i$
$p_0 = N_a - N_d =$ **10^{15} cm^{-3}**
$n_0 = n_i^2/p_0 =$ **10^5 cm^{-3}**
c) $N_d' - N_a = 10^{17}$
$N_d' = N_d$(current) + N_d(additional)
Need **$1.01\text{x}10^{17}$** additional donors per cm3.
μ_n = **775 cm^2 (Vs)-1**

Problem 2

A piece of silicon is doped with $N_d = 1\text{x}10^{15}$ cm^{-3}. Below is a table for the intrinsic electron concentration for three different temperatures.

n_i	Temperature
$1\text{x}10^{10}$ cm^{-3}	300 K (room temp.)
$1\text{x}10^{15}$ cm^{-3}	600 K
$1\text{x}10^{17}$ cm^{-3}	1150 K

a) Calculate the total hole and electron concentration for all three different temperatures.

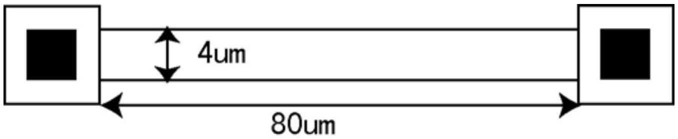
a)
T = 300, $N_d >> n_i$
$n = N_d = 1\text{x}10^{15}$ cm^{-3} $p = n_i^2/n = 1\text{x}10^5$ cm^{-3}

T = 600, $N_d \sim n_i$
$n = N_d /2 + N_d /2(1 + 4\, n_i^2/ N_d^2)^{1/2} = 1.62\text{x}10^{15}$ cm^{-3} $p = n_i^2/n = 6.18\text{x}10^{14}$ cm^{-3}
T = 1150, $N_d << n_i$
$n = n_i = 1\text{x}10^{17}$ cm^{-3} $p = n_i^2/n = 1\text{x}10^{17}$ cm^{-3}

Problem 3

Given a uniformly n-type ion-implanted layer with thickness t = 1 um and doping concentration $N_d = 10^{17}$ cm^{-3}.

a) What is the sheet resistance?
b) What is the resistance of the layout shown below? Assume that the contacts each contribute .65 squares.

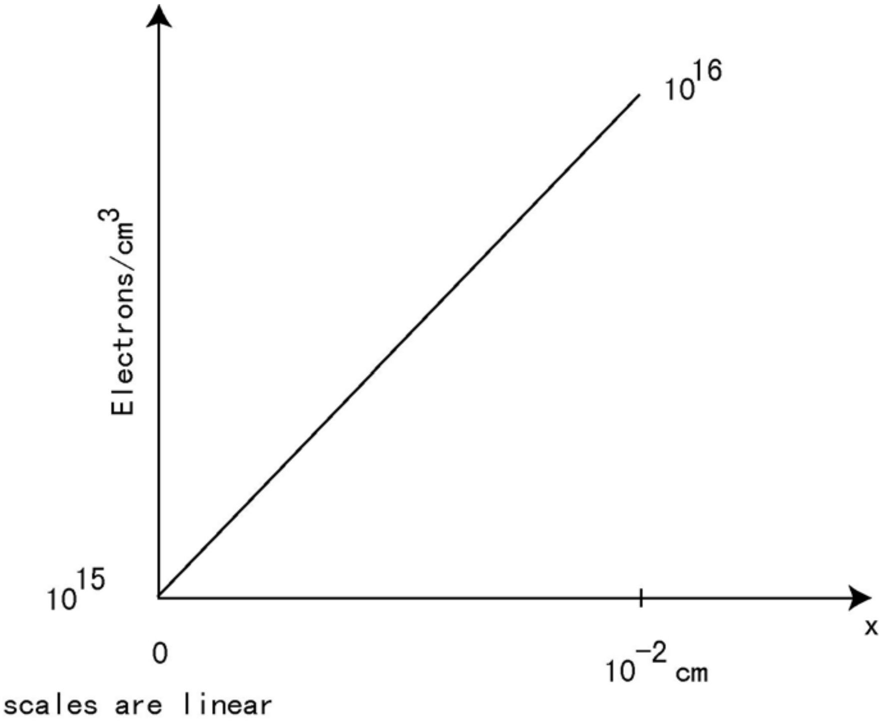


c) By adding additional dopants, we make a new n-type ion-implanted resistor with an average doping concentration $N_{d1} = 2\text{x}10^{17}$ cm^{-3} over the depth 0 < d < 0.5 µm and $N_{d2} = 10^{17}$ cm^{-3} over the depth 0.5 µm < d < 1 µm. Find the new sheet resistance.

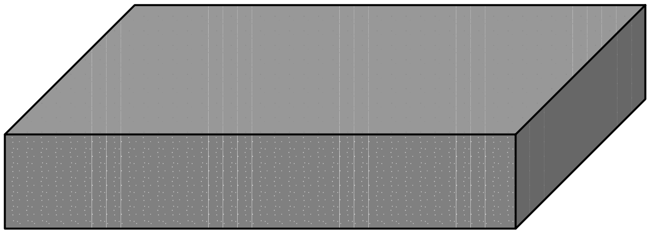
a)$(qN_d\mu_n t)^{-1} = (1.6\text{x}10^{-19}$ x 10^{17} x 775 x $10^{-4})$ = **806 Ω/ϕ**
Note t = 10^{-4} cm.
b) Total number of squares = .65x2 + 80/4 = 21.3
Resistance = Ω_ϕ x number of squares = 806 x 21.3 =**17.2 k Ω**
c) Think of this as two resistors in parallel; one on top and one on bottom.
$\Omega_{top/\phi} = (1.6\text{x}10^{-19}$ x $2\text{x}10^{17}$ x 600 x $5\text{x}10^{-5})^{-1}$ = 1041 Ω/ϕ
$\Omega_{bot/\phi} = (1.6\text{x}10^{-19}$ x 10^{17} x 775 x $5\text{x}10^{-5})^{-1}$ = 1613 Ω/ϕ
Total sheet resistance = $(\Omega_{top/\phi})//(\Omega_{bot/\phi})$ = 1041 x 1613 / (1041 + 1613)= **633 Ω/ϕ**

Problem 4

A slab of silicon has the following electron distribution.

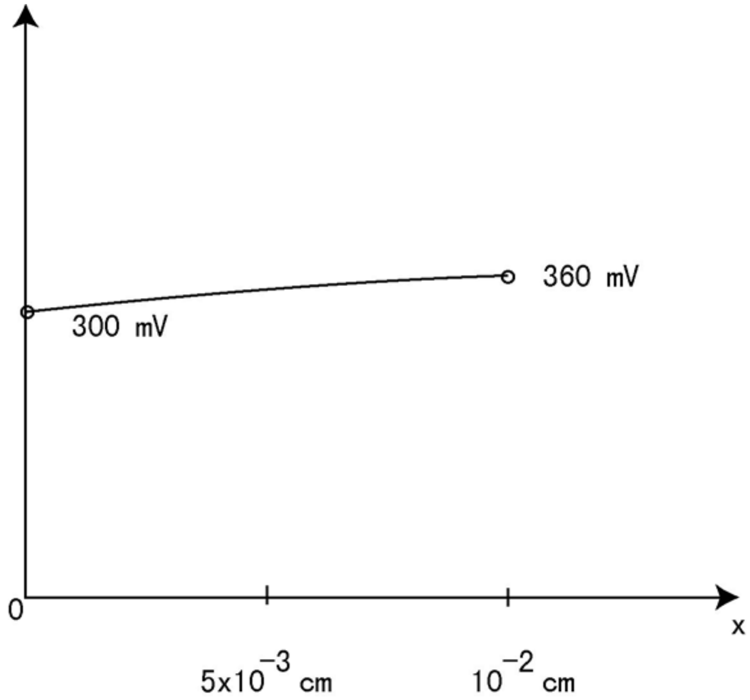


a) Assume thermal equilibrium. Plot the potential ϕ.
b) What is the electron diffusion current density? Hole diffusion current density? Assume $D_n = 2 \times D_p = 26$ cm^2/s
c) The hole and electron diffusion current densities do not sum to zero; however, the silicon cannot have a net current since it is an open circuit. Explain what is happening.



Silicon Slab

a) Using $\phi(x) = 60 \text{ mV} * \log(n(x)/10^{10})$



b) The slope of the line is $10^{16} – 10^{15} / 10^{-2} = 9\times10^{17}$.
$J_{diff,n} = qD_n(dn/dx) = 26 \times 9\times10^{17} \times 1.6\times10^{-19} = 3.744$ A cm^{-2}

Assume room temperature, so $p = n_i^2/n$. To simplify the problem, assume that the hole concentration is also in a straight line. Using the endpoints, $p(x=0) = 10^5$ and $p(x=10^{-12}) = 10^4$. Slope is -9×10^6.

$J_{diff,p} = -qD_p(dp/dx) = 0.5 \times 26 \times 9\times10^6 \times 1.6\times10^{-19} = 1.872\times10^{-11}$ A cm^{-2}

Notice $J_{diff,n} >> J_{diff,p}$

c) The voltage difference across the silicon produces a drift current that cancels out the diffusion current. Again, the electron drift current is much larger than the hole drift current because the electron concentration is much greater.