EECS 170A Section B
Midterm Exam Solution

Fall 2007 – Prof. Burke

Note: No credits will be given to any answers without units.

PROBLEM ONE: (30 points)

A Si semiconductor is doped at $N_A=10^{16}cm^{-3}$.

A) Find the density of holes.

Assume T=300K, $n_i = 10^{10}\ cm^{-3}$
Since $N_D << N_A$ and $n_i << N_A$, the concentration of holes:

$\therefore p \approx N_A = 10^{16}\ cm^{-3}$

(Correct steps, wrong answer: 10 points;
Correct answer: 15 points)

B) Find the density of electrons.

$$n = \frac{n_i^2}{N_A} = \frac{(10^{10})^2}{10^{16}} = 10^4\ cm^{-3}$$

(Only correct equation: 5 points;
Correct steps, wrong answer: 10 points;
Correct answer: 15 points)

PROBLEM TWO: (30 points)

An on-chip resistor is to be made of n-doped silicon, with dimensions 10 μm long, 1 μm wide, and 0.1 μm thick. The desired resistance is 1 MΩ. What doping level should be used?

Assumption: T= 300K

Given: Resistance, $R = 1M\Omega = 10^6\ \Omega$
Length, $L = 10\ \mu m = 10^{-3}\ cm$
Width, $W = 1\ \mu m = 10^{-4}\ cm$
Thickness, $H = 0.1\ \mu m = 10^{-5}\ cm$

$$\therefore \quad Resistivity,\ \rho = \frac{RA}{L} = \frac{10^6 \times 10^{-4} \times 10^{-5}}{10^{-3}} = 1\Omega / cm^{-3}$$

(Only correct equation: 2points;
Correct equation with right value substitution, but wrong answer: 10 points;
Correct answer with wrong unit or wrong unit conversion: 13 points
Correct answer with correct unit and right unit conversion: 15 points)

We want to make the resistor from n-doped silicon, therefore we assume that $N_D >> N_i$ and $N_D >> N_A$:

$$\rho \approx \frac{1}{qn\mu_n} = 1\Omega / cm^{-3} \Rightarrow \mu_n = \frac{1}{qn}(cm^2 / V.s)$$

Use Figure on Page 1 and iteration to find the doping level:

Try $N_D = 10^{16}\ cm^{-3}$:

$$\mu_n = \frac{1}{qn} = \frac{1}{(1.6 \times 10^{-19}) \times 10^{16}} = 0.625 \times 10^3 = 625\, cm^2 / V.s$$

It's smaller than the $\mu_n = 1010\, cm^2/V.s$ *obtained from the graph.*

Try $N_D = 10^{15}\ cm^{-3}$:

$$\mu_n = \frac{1}{qn} = \frac{1}{(1.6 \times 10^{-19}) \times 10^{15}} = 0.625 \times 10^4 = 6250\, cm^2 / V.s$$

It's larger than the $\mu_n = 1020\, cm^2/V.s$ *obtained from the graph.*

Try $N_D = 6x10^{15}\ cm^{-3}$:

$$\mu_n = \frac{1}{qn} = \frac{1}{(1.6 \times 10^{-19}) \times (6 \times 10^{15})} = 0.104 \times 10^4 = 1040\, cm^2 / V.s$$

It's very close to the $\mu_n = 1020\, cm^2/V.s$ *obtained from the graph.*

Since $N_D = 6x10^{15}\ cm^{-3} >> Ni$ *and* $N_D >> N_A$*, so our assumptions are valid.*

$\therefore$ The required doping level, $N_D \approx 6x10^{15}\ cm^{-3}$

(Accepted doping level range: ***$5x10^{15}\ cm^{-3}$*** $\le N_D \le$ ***$7x10^{15}\ cm^{-3}$****)*

(Only correct equation: 2 points;
Correct equation with only one iterative step, but wrong answer: 7.5 points;
Correct equation with iterative steps shown, but wrong answer: 10 points;
Correct equation with iterative steps shown and correct answer: 15 points)

PROBLEM THREE: (40 points)

Concentration questions with a twist.

A) A semiconductor is doped with an impurity concentration of N such that N >> n_i and all the impurities are ionized. Also, n = N and p = n_i^2/N. Is the impurity a donor or an acceptor? Explain.

Since the electron concentration approximately equals to the doping concentration (N), and N>>n_i, the impurity must be a donor in order to increase the electron concentration much higher than the intrinsic carrier concentration.

(Stating "Donor": 5 points
Stating "Electron concentration = doping concentration": 2.5 points
Stating "Electron concentration >> intrinsic carrier concentration" or "Donor donates electrons": 2.5 points)

B) The electron concentration in a piece of Si at 300 K under equilibrium conditions is $10^{15}/cm^3$. What is the hole concentration?

At T=300K, $n_i = 10^{10}\ cm^{-3}$
Givne: $n = 10^{15}\ cm^{-3}$:

$$\therefore p = \frac{n_i^2}{n} = \frac{(10^{10})^2}{10^{15}} = 10^5\,cm^{-3}$$

(Only correct equation: 2 points
Correct steps, wrong answer: 8 points
Correct answer: 10 points)

C) For a silicon sample maintained at T=300 K, the Fermi level is located 0.259 eV above the intrinsic Fermi level. What are the electron and hole concentrations?

$$n = n_i e^{(E_F - E_i)/KT} = 10^{10} e^{(0.259/0.0259)} = 10e^{10}cm^{-3}$$

$$p = n_i e^{(E_i - E_F)/KT} = 10^{10} e^{-(0.259/0.0259)} = 10e^{-10}cm^{-3}$$

Or use *$np = n_i^2$ to find the other carrier concentration when one carrier concentration is already calculated.*

(Only correct equations: 2 points
Correct steps, wrong answer: 4 points for each n and p;
(Correct answer: 5 points for each n and p)

D) In a nondegenerate germanium sample maintained under equilibrium conditions near room temperature, it is known that $n_i=10^{13}/cm^3$, n=10,000p, and $N_A=0$. Determine n and N_D.

$$n = 10000p \text{ ....(Eqn. 1)}$$

$$np = n_i^2 \text{ ....(Eqn. 2)}$$

Substitute Eqn. 1 into Eqn. 2:

$$10000p^2 = n_i^2 = \left(10^{13}\right)^2 \Rightarrow p = 10^{11} cm^{-3}$$

$$\therefore n = 10^{15} cm^{-3}$$

From charge neutrality relationship:

$$p + N_D = n + N_A$$

$$\therefore N_D = 10^{15} + 0 - 10^{11} \approx n = 10^{15} cm^{-3}$$

(Only correct equations: 2 points
Correct steps, wrong answer: 4 points for each n and N_D;
Correct answer: 5 points for each n and N_D)