EN.520.216 Homework 1

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February 2023

1 Manufacturing Problems

Problem 1 1. 90nm feature size means a size of 24×45nm by 36×45 or 1080 by 1620 $= 1749600\text{nm}^2 \times \left(\frac{1\times10^{-9}\text{nm}}{1\times10^{-3}\text{mm}}\right)^2 = 1.7496e \times 10^{-6}\text{mm}^2$ per transistor. Hence we can have a maximum of $\frac{9}{1.796\times10^{-6}} \approx 5144032$ transistors on the 3mm by 3mm chip.

This makes the assumption that transistors are allowed to be side-to-side with no space between them or that the necessary space is included in the provided area. Also, we assume the chip is single-layer.

2. Same as the previous, 5144032, with the added assumption that both nmos and pmos types are made to be the same size, which would probably not be the case.

3.

2 Device Physics Problems

Problem 2 1. The Fermi function gives the probability that a state *at a given energy* is filled with an electron. Because the total amount of available states at a given energy is large, this is basically equivalent to the fraction of states that are filled by an electron.

2. We use the Fermi function

$$\frac{1}{1 + e^{(E-E_f)/kT}}$$

with $E = E_f + 0.225kT$, giving $\frac{1}{1+e^{0.225}} \approx 0.444$.

3. Here $E >> E_f$ so we consider that most of the states at this level are empty.

Problem 3 We know that $n_i \approx \int_{E_c}^{\infty} g(E)e^{\frac{E-E_{fi}}{kT}}dE$ and $n_d \approx \int_{E_c}^{\infty} g(E)e^{\frac{E-E_{fd}}{kT}}dE$. But now if we just call $E_{fd} = E_{fi} + \Delta E$ where E is just some constant that represents how far the doped fermi level is relative to the intrinsic fermi level, we find that:

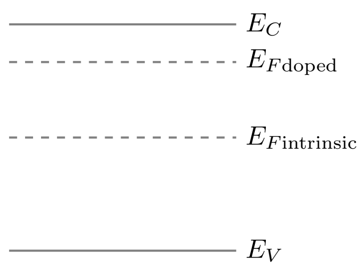
$$\frac{n_i}{n_d} = \frac{\int_{E_c}^{\infty} g(E) e^{\frac{E-E_{fi}}{kT}} dE}{\int_{E_c}^{\infty} g(E) e^{\frac{E-(E_{fi}+\Delta E)}{kT}} dE}$$

$$= \frac{1}{e^{-\Delta E/kT}} \frac{\int_{E_c}^{\infty} g(E) e^{\frac{E-E_{fi}}{kT}} dE}{\int_{E_c}^{\infty} g(E) e^{\frac{E-E_{fi}}{kT}} dE} = \frac{1}{e^{-\Delta E/kT}}$$

$$\ln \frac{10^{10}}{10^{17}} = \frac{-\Delta E}{kt}$$

From this we substitute our known values of k and T, 8.6×10^{-5} and 295, respectively, to find that $\Delta E \approx 0.409$, in other words the Fermi level is 0.409eV above the intrinsic fermi level of 1.1eV, for a total of about 1.5eV.

Problem 4

1. 

2. The acceptor concentration can be calculated from the additional assumption $p = N_A$ and the law of mass action $np = n_i^2$, such that $N_A = p = \frac{(10^{10})^2}{10^{17}} = 10^3$ acceptors/cm3

Problem 5

1. With a similar calculation used in the previous problem, we find

$$E_g = -(2 \times 8.6 \times 10^{-5} \times 300) \ln(\frac{10^{13}}{5.2 \times 10^{15} \times 300^{3/2}})$$

2. Here we need to first find the concentration of electrons as a result of this doping before inserting in the same equation. We find that $n = \frac{n_i^2}{N_A} = \frac{(10^{10})^2}{5 \times 10^{14}} = 0.2 \times 10^6$ hence:

$$E_g = -(2 \times 8.6 \times 10^{-5} \times 300) \ln(\frac{0.2 \times 10^6}{5.2 \times 10^{15} \times 300^{3/2}})$$