ECE 340 Homework X Spring 2003

Due: Friday, March 21, 2003

1. *A n^+-p Si junction with a long p-region has the following properties: N_a =1.5x10^{16}/cm^3; μ_n = 1020 cm^2/V-s; μ_p = 380 cm^2/V-s; t_n =1 μs. If we apply 0.7 V forward bias to the junction at 300 K, what is the electric field in the p-region far from the junction? Draw a band diagram in the p-region far from the junction assuming that the junction is at x=0 and the p-side is in x>0.*

Solutions:

$$n_p = \frac{n_i^2}{p_p} = 1.5\times10^4 cm^{-3},$$

$$D_n = m_n kT/q = 0.0259\times1020 = 26.42cm^2/s$$

$$L_n = \sqrt{26.42\times10^{-6}} = 0.00514cm$$

since it's an n$^+$-p Si junction,

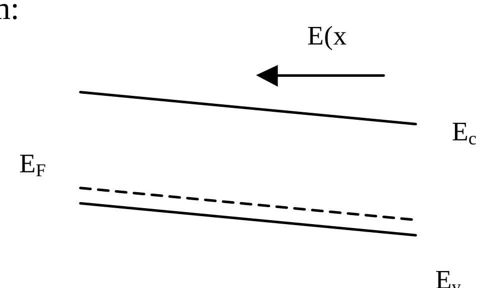
$$J = q\frac{D_n}{L_n} n_p (e^{qV/kT} - 1) = 1.6\times10^{-19}\times\frac{26.42}{0.00514}15000\times(e^{0.7/0.0259} - 1) = 6.74A/cm^2$$

Far away from junction, the diffusion current goes to zero, the current composed of drift current:

$$J(x=\infty) = J_p^{drift} = J(x=0) = qm_p N_a \mathrm{E}$$

$$\mathrm{E} = \frac{6.74}{1.6\times10^{-19}\times380\times1.5\times10^{16}} = 7.39V/cm$$, E is toward –x direction since p is on x>0

Band diagram:



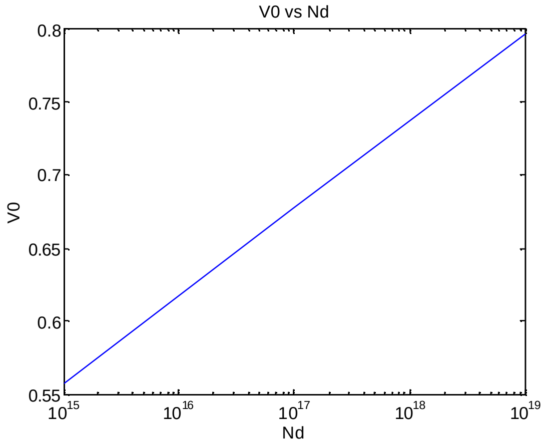
2. *Consider the following Si p-n junctions operating at 300 K.*
   (a) Using Eq. (5-8), calculate the contact potential V_o for N_a = 5x10^{14} and 5x10^{18}/cm^3, with N_d = 10^{15}, 10^{17}, 10^{19}/cm^3 in each case and plot V_o vs. N_d.
   *(b) Plot the maximum electric field **E_o** vs. N_d for the junctions described in (a).*
   (c) Plot the width of the depletion region W vs. N_d for the junctions described in (a).
   *(d) Given that N_a = 10^{14} (and repeat for 10^{19}/cm^3) and N_d = 10^{19}/cm^3, determine the reverse bias needed to yield a maximum electric field **E_o** in the junction which exceeds 5x10^5 V/cm. and what is the depletion width under the reverse biasing?*

Solutions

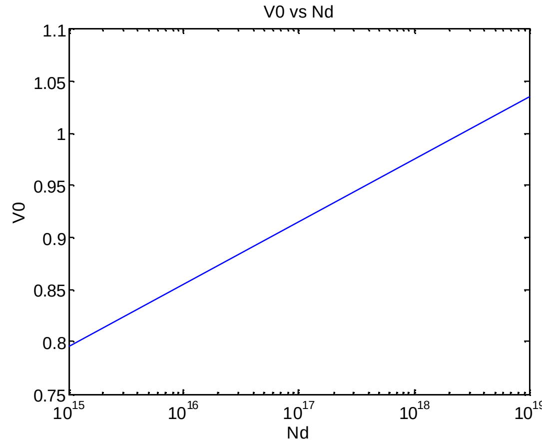
The relevant equations used in part (a), (b), (c) are:

$$V_0 = \frac{kT}{q}\ln\frac{N_a N_d}{n_i^2},\quad \mathrm{E}_0 = -\frac{qN_d x_{n0}}{e} = -\sqrt{\frac{2qV_0}{e}\left(\frac{N_a N_d}{N_a + N_d}\right)},\quad W = \sqrt{\frac{2eV_0}{q}\left(\frac{1}{N_a} + \frac{1}{N_d}\right)},$$

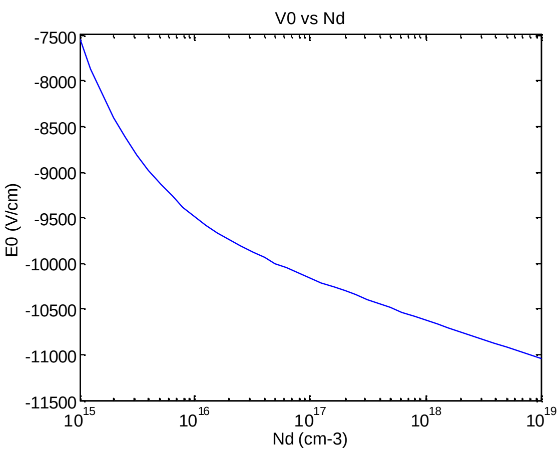
N_a (cm^{-3})	5×10^{14}	5×10^{14}	5×10^{14}	5×10^{18}	5×10^{18}	5×10^{18}
N_d(cm^{-3})	1×10^{15}	1×10^{17}	1×10^{19}	1×10^{15}	1×10^{17}	1×10^{19}
V_0 (volts)	0.5574	0.6767	0.7960	0.7960	0.9152	1.0345



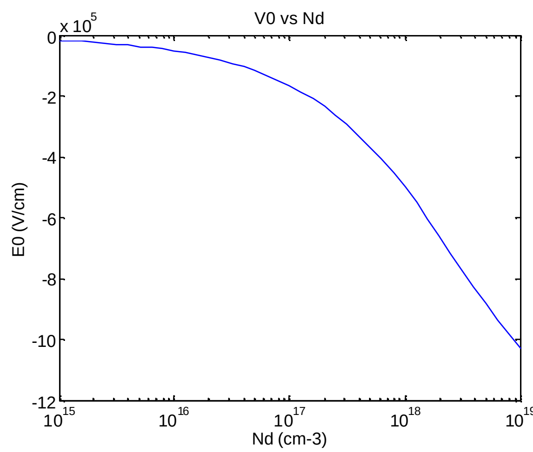
$N_a = 5x10^{14}$ /cm^3



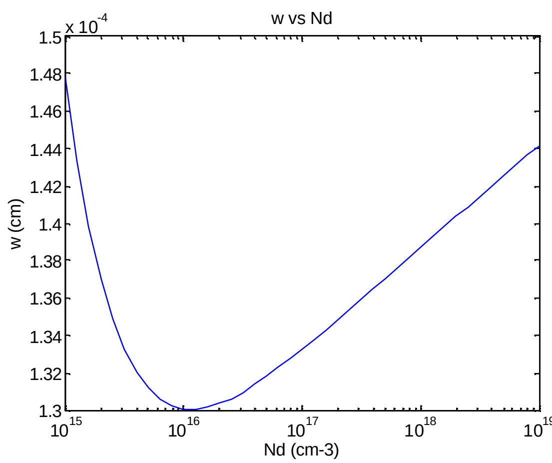
$N_a = 5x10^{18}$/cm^3

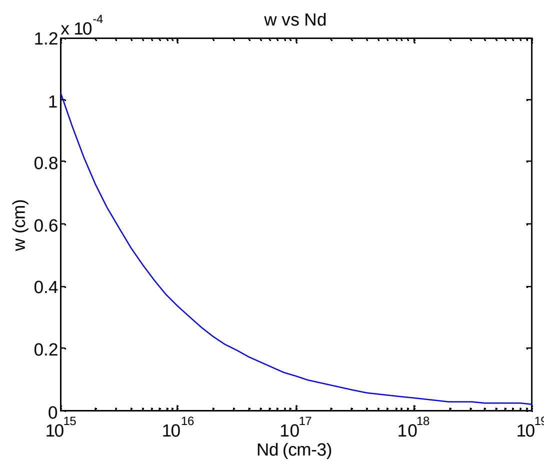


$N_a = 5x10^{14}$ /cm^3



$N_a = 5x10^{18}$/cm^3





(d), For $N_a = 5x10^{14}$ /cm^3, $V_0 = \frac{kT}{q}\ln\frac{N_a N_d}{n_i^2} = 0.754V$

$$\left|E_0\right| = \frac{qN_d x_{n0}}{e} = \sqrt{\frac{2q\left(V_0 + V_r\right)}{e}\left(\frac{N_a N_d}{N_a + N_d}\right)} > 5\times10^5 V/cm$$

$$V_r > \left(5\times10^5\right)^2 \frac{e}{2q}\left(\frac{1}{N_a}+\frac{1}{N_d}\right) - V_0 = 8158V$$

This is an extremely high voltage. According to Fig. 5-22, the avalanche is going to happen at this voltage (even though the electrical field is not very high).

If assuming avalanche breakdown doesn't happen:

$$W = \sqrt{\frac{2eV}{q}\left(\frac{1}{N_a}+\frac{1}{N_d}\right)} = 326mm$$

(This is also a very large W, even though the electrical field is not very high, the electron/hole accelerated over such long distance can reach a large enough kinetic energy to cause "impact ionization", and therefore avalanche breakdown as shown in Fig 5-21).

For $N_a = 10^{19}$ /cm^3, $V_0 = \frac{kT}{q}\ln\frac{N_a N_d}{n_i^2} = 1.05V$

$$V_r > \left(5\times10^5\right)^2 \frac{e}{2q}\left(\frac{1}{N_a}+\frac{1}{N_d}\right) - V_0 = -0.887V$$

Therefore, we don't need any reverse bias.

If using $V_r = 0V$, $\quad W = \sqrt{\frac{2e(V_0+V_r)}{q}\left(\frac{1}{N_a}+\frac{1}{N_d}\right)} = 1.66\times10^{-6}cm$

If using $V_r = -0.887V$,$W = \sqrt{\frac{2e(V_0+V_r)}{q}\left(\frac{1}{N_a}+\frac{1}{N_d}\right)} = 6.5\times10^{-7}cm$

3. *A p^+-n silicon diode (V_O = 0.926 volts) has a donor doping of 10^{17}/cm^3 and an n-region width = 1 μm. Assume that the diode has a uniform cross sectional area of 0.001 cm^2. Refer to Fig. 5-22 for the following questions.*
(a) Does it break down by avalanche or punchthrough? Determine the depletion capacitance when the breakdown happens.
(b) If the doping is only $1\text{x}10^{16}$/cm^3, what is the minimum n-region width for punchthrough not to take place?

(a), From Fig 5-22, $V_{br} = 11Volts$.

$$W_{br} = \sqrt{\frac{2e(V_0+V_{br})}{qN_d}} = 0.395mm < 1mm$$

Avalanche breakdown will happen before punch-through.

$$C = \frac{eA}{W_{br}} = \frac{11.8\times8.85\times10^{-14}\times0.001F}{3.95\times10^{-5}} = 2.65\times10^{-11}F$$

(b), $V_{br} = 60Volts$.

$$W_{br} \approx x_n \ge \sqrt{\frac{2e(V_0+V_{br})}{qN_d}} = 2.82mm$$