VE311 Homework 2

Liu Yihao 515370910207

Problem 1.

$$\rho = 2.83 \times 10^{-6}\,\Omega\cdot\text{cm} < 10^{-3}\,\Omega\cdot\text{cm}$$

So pure aluminum should be classified as conductor.

Problem 2.

$$j_n^{drift} = Q_n v_n = (-qn)(-v) = 1.6\times10^{-19}\cdot10^{18}\cdot10^{7} = 1.6\times10^{6}\,\text{A/cm}^2$$
$$j_p^{drift} = Q_p v_p = (+qp)(+v) = 1.6\times10^{-19}\cdot10^{2}\cdot10^{7} = 1.6\times10^{-10}\,\text{A/cm}^2$$
$$J = j_n^{drift} + j_p^{drift} \approx 1.6\times10^{6}\,\text{A/cm}^2$$

Problem 3.

$$n_i = \sqrt{BT^3\exp\left(-\frac{E_G}{kT}\right)}$$

(a)

$$Si:\ n_i = \sqrt{1.08\times10^{31}\cdot77^3\cdot\exp\left(-\frac{1.12}{8.62\times10^{-5}\cdot77}\right)} = 5.068\times10^{-19}\,\text{cm}^{-3}$$
$$Ge:\ n_i = \sqrt{2.31\times10^{31}\cdot77^3\cdot\exp\left(-\frac{0.66}{8.62\times10^{-5}\cdot77}\right)} = 2.625\times10^{-4}\,\text{cm}^{-3}$$

(b)

$$Si:\ n_i = \sqrt{1.08\times10^{31}\cdot300^3\cdot\exp\left(-\frac{1.12}{8.62\times10^{-5}\cdot300}\right)} = 6.725\times10^{9}\,\text{cm}^{9}$$
$$Ge:\ n_i = \sqrt{2.31\times10^{31}\cdot300^3\cdot\exp\left(-\frac{0.66}{8.62\times10^{-5}\cdot300}\right)} = 2.267\times10^{13}\,\text{cm}^{-3}$$

(c)

$$Si: \; n_i = \sqrt{1.08 \times 10^{31} \cdot 500^3 \cdot \exp\left(-\frac{1.12}{8.62 \times 10^{-5} \cdot 500}\right)} = 8.363 \times 10^{13}\,\mathrm{cm}^{-3}$$

$$Ge: \; n_i = \sqrt{2.31 \times 10^{31} \cdot 77^3 \cdot \exp\left(-\frac{0.66}{8.62 \times 10^{-5} \cdot 77}\right)} = 8.036 \times 10^{15}\,\mathrm{cm}^{-3}$$

Problem 4.

$$\rho = \frac{1}{\sigma} = \frac{1}{q(n\mu_n + p\mu_p)} = \frac{1}{1.6 \times 10^{-19} \cdot n_i \cdot (2000 + 750)} = 10^5\,\Omega \cdot \mathrm{cm}$$

$$n_i = \sqrt{BT^3 \exp\left(-\frac{E_G}{kT}\right)} = 2.273 \times 10^{10}\,\mathrm{cm}^{-3}$$

$$T = 316.6\,\mathrm{K}$$

Problem 5.

Since $N_A > N_D$, and $N_A - N_D \gg 2n_i$,

$$p \approx N_A - N_D = 4 \times 10^{16}\,\mathrm{cm}^{-3}$$

$$n = \frac{n_i^2}{p} = 2.5 \times 10^5\,\mathrm{cm}^{-3}$$

Problem 6.

(a) Since Ge has one more electron than In, it behaves as a donor impurity.

(b) Since Ge has one less electron than P, it behaves as an acceptor impurity.

Problem 7.

$$N = nV = 10^{16} \cdot 0.5 \times 10^{-4} \cdot 5 \times 10^{-4} \cdot 0.5 \times 10^{-4} = 12500\,\mathrm{atoms}$$

Problem 8.

$$\rho = \frac{1}{\sigma} = \frac{1}{q(n\mu_n + p\mu_p)}$$

Since we want to produce extrinsic silicon with a higher resistivity than that of intrinsic silicon, we should let

$$n\mu_n(N_T) + p\mu_p(N_T) < n_i[\mu_n(0) + \mu_p(0)]$$

Suppose $N_T = N_A$, we can get $n = p = n_i$. So the equation above can be simplified as

$$\mu_n(N_T) + \mu_p(N_T) < \mu_n(0) + \mu_p(0)$$

And we know that the functions $\mu_n(N_T)$ and $\mu_p(N_T)$ are decreasing when N_T is increasing, which means when $N_T > 0$,

$$\mu_n(N_T) < \mu_n(0)$$
$$\mu_p(N_T) < \mu_p(0)$$

So the equation always sets when $N_T > 0$, conceptually. In conclusion, when $N_T = N_A > 0$, it is conceptually to produce extrinsic silicon with a higher resistivity than that of intrinsic silicon.

Problem 9.

$$V_T = \frac{kT}{q} = 8.62 \times 10^{-5} \cdot T\,(\mathrm{V})$$

T (K)	V_T (mV)
50	4.3
75	6.5
100	8.6
150	12.9
200	17.2
250	21.6
300	25.9
350	30.2
400	34.5

Problem 10.

$$j_n^{diff} = qD_n\frac{\partial n}{\partial x} = qV_T\mu_n\frac{\partial n}{\partial x} = 1.6 \times 10^{-19} \cdot 25.9 \times 10^{-3} \cdot 350 \cdot -\frac{10^{18}}{0.5 \times 10^{-4}} = -2.901 \times 10^{-4}\,\mathrm{A/cm^2}$$

Problem 11.

When $x = 0$,

$$j_n^{drift} = q\mu_n nE = 1.6 \times 10^{-19} \cdot 350 \cdot 10^{16} \cdot -20 = -11.2\,\mathrm{A/cm^2}$$
$$j_p^{drift} = q\mu_p pE = 1.6 \times 10^{-19} \cdot 150 \cdot 1.01 \times 10^{18} \cdot -20 = -484.8\,\mathrm{A/cm^2}$$
$$j_n^{diff} = qD_n\frac{\partial n}{\partial x} = 1.6 \times 10^{-19} \cdot 350 \cdot 25.9 \times 10^{-3} \cdot \frac{10^4 - 10^{16}}{2 \times 10^{-4}} = -72.5\,\mathrm{A/cm^2}$$
$$j_p^{diff} = -qD_p\frac{\partial p}{\partial x} = -1.6 \times 10^{-19} \cdot 150 \cdot 25.9 \times 10^{-3} \cdot \frac{10^{18} - 1.01 \times 10^{18}}{2 \times 10^{-4}} = 31.1\,\mathrm{A/cm^2}$$
$$J^T = j_n^{drift} + j_p^{drift} + j_n^{diff} + j_n^{diff} = -537.4\,\mathrm{A/cm^2}$$

When $x = 1.0\,\mu$m,

$$j_n^{drift} = q\mu_n n E = 1.6 \times 10^{-19} \cdot 350 \cdot \frac{10^{16} + 10^4}{2} \cdot -20 = -5.6\,\mathrm{A/cm^2}$$

$$j_n^{diff} = qD_n \frac{\partial n}{\partial x} = 1.6 \times 10^{-19} \cdot 350 \cdot 25.9 \times 10^{-3} \cdot \frac{10^4 - 10^{16}}{2 \times 10^{-4}} = -72.5\,\mathrm{A/cm^2}$$