VE311 Homework 2

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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.

$$j_n^{drift} = Q_n v_n = (-qn)(-v) = 1.60\times10^{-19}\,\text{C}\cdot10^{18}\,\text{cm}^{-3}\cdot10^{7}\,\text{cm/s} = 1.60\times10^{6}\,\text{A/cm}^2$$
$$j_p^{drift} = Q_p v_p = (+qp)(+v) = 1.60\times10^{-19}\,\text{C}\cdot10^{2}\,\text{cm}^{-3}\cdot10^{7}\,\text{cm/s} = 1.60\times10^{-10}\,\text{A/cm}^2$$
$$J = j_n^{drift} + j_p^{drift} \approx 1.60d\times10^{6}\,\text{A/cm}^2$$

Problem 3.

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

(a)

$$Si:\; n_i = \sqrt{1.08\times10^{31}\,\text{K}^{-3}\cdot\text{cm}^{-6}\cdot(77\,\text{K})^3\cdot\exp\left(-\frac{1.12\,\text{eV}}{8.62\times10^{-5}\,\text{eV/K}\cdot77\,\text{K}}\right)} \approx 5.068\times10^{-19}\,\text{cm}^{-3}$$

$$Ge:\; n_i = \sqrt{2.31\times10^{31}\,\text{K}^{-3}\cdot\text{cm}^{-6}\cdot(77\,\text{K})^3\cdot\exp\left(-\frac{0.66\,\text{eV}}{8.62\times10^{-5}\,\text{eV/K}\cdot77\,\text{K}}\right)} \approx 2.625\times10^{-4}\,\text{cm}^{-3}$$

(b)

$$Si:\; n_i = \sqrt{1.08\times10^{31}\,\text{K}^{-3}\cdot\text{cm}^{-6}\cdot(300\,\text{K})^3\cdot\exp\left(-\frac{1.12\,\text{eV}}{8.62\times10^{-5}\,\text{eV/K}\cdot300\,\text{K}}\right)} \approx 6.725\times10^{9}\,\text{cm}^{9}$$

$$Ge:\; n_i = \sqrt{2.31\times10^{31}\,\text{K}^{-3}\cdot\text{cm}^{-6}\cdot(300\,\text{K})^3\cdot\exp\left(-\frac{0.66\,\text{eV}}{8.62\times10^{-5}\,\text{eV/K}\cdot300\,\text{K}}\right)} \approx 2.267\times10^{13}\,\text{cm}^{-3}$$

(c)

$$Si:\ n_i = \sqrt{1.08 \times 10^{31}\,\mathrm{K}^{-3} \cdot \mathrm{cm}^{-6} \cdot (500\,\mathrm{K})^3 \cdot \exp\left(-\frac{1.12\,\mathrm{eV}}{8.62 \times 10^{-5}\,\mathrm{eV/K} \cdot 500\,\mathrm{K}}\right)} \approx 8.363{\times}10^{13}\,\mathrm{cm}^{-3}$$

$$Ge:\ n_i = \sqrt{2.31 \times 10^{31}\,\mathrm{K}^{-3} \cdot \mathrm{cm}^{-6} \cdot (500\,\mathrm{K})^3 \cdot \exp\left(-\frac{0.66\,\mathrm{eV}}{8.62 \times 10^{-5}\,\mathrm{eV/K} \cdot 500\,\mathrm{K}}\right)} \approx 8.036{\times}10^{15}\,\mathrm{cm}^{-3}$$

Problem 4.

$$\rho = \frac{1}{\sigma} = \frac{1}{q(n\mu_n + p\mu_p)} = \frac{1}{1.60 \times 10^{-19}\,\mathrm{C} \cdot n_i \cdot (2000 + 750)\,\mathrm{cm}^2/\mathrm{V} \cdot \mathrm{s}} = 10^5\,\Omega \cdot \mathrm{cm}$$

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

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

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.

$$N = nV = 10^{16}\,\mathrm{atoms/cm}^3 \cdot 0.5 \times 10^{-4}\,\mathrm{cm} \cdot 5 \times 10^{-4}\,\mathrm{cm} \cdot 0.5 \times 10^{-4}\,\mathrm{cm} = 12500\,\mathrm{atoms}$$

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.

$$\begin{aligned} j_n^{diff} &= qD_n \frac{\partial n}{\partial x} = qV_T\mu_n \frac{\partial n}{\partial x} \\ &= 1.60 \times 10^{-19}\,\mathrm{C} \cdot 25.9 \times 10^{-3}\,\mathrm{V} \cdot 350\,\mathrm{cm^2/V \cdot s} \cdot -\frac{10^{18}\,\mathrm{cm^{-3}}}{0.5 \times 10^{-4}\,\mathrm{cm}} \\ &= -2.901 \times 10^{-4}\,\mathrm{A/cm^2} \end{aligned}$$

Problem 11.

When $x = 0$,

$$j_n^{drift} = q\mu_n nE = 1.60 \times 10^{-19}\,\mathrm{C} \cdot 350\,\mathrm{cm^2/V \cdot s} \cdot 10^{16}\,\mathrm{cm^{-3}} \cdot -20\,\mathrm{V/cm} = -11.2\,\mathrm{A/cm^2}$$

$$j_p^{drift} = q\mu_p pE = 1.60 \times 10^{-19}\,\mathrm{C} \cdot 150\,\mathrm{cm^2/V \cdot s} \cdot 1.01 \times 10^{18}\,\mathrm{cm^{-3}} \cdot -20\,\mathrm{V/cm} = -484.8\,\mathrm{A/cm^2}$$

$$j_n^{diff} = qD_n \frac{\partial n}{\partial x} = 1.60 \times 10^{-19}\,\mathrm{C} \cdot 350\,\mathrm{cm^2/V \cdot s} \cdot 25.9 \times 10^{-3}\,\mathrm{V} \cdot \frac{(10^4 - 10^{16})\,\mathrm{cm^{-3}}}{2 \times 10^{-4}\,\mathrm{cm}} = -72.5\,\mathrm{A/cm^2}$$

$$j_p^{diff} = -qD_p\frac{\partial p}{\partial x} = -1.60\times10^{-19}\,\mathrm{C}\cdot150\,\mathrm{cm^2/V\cdot s}\cdot25.9\times10^{-3}\,\mathrm{V}\cdot\frac{(10^{18}-1.01\times10^{18})\,\mathrm{cm^{-3}}}{2\times10^{-4}\,\mathrm{cm}} = 31.1\,\mathrm{A/cm^2}$$

$$J^T = j_n^{drift} + j_p^{drift} + j_n^{diff} + j_n^{diff} = -537.4\,\mathrm{A/cm^2}$$

When $x = 1.0\,\mu\mathrm{m}$,

$$j_n^{drift} = q\mu_n nE = 1.60\times10^{-19}\,\mathrm{C}\cdot350\,\mathrm{cm^2/V\cdot s}\cdot\frac{10^{16}+10^4}{2}\,\mathrm{cm^{-3}}\cdot -20\,\mathrm{V/cm} = -5.6\,\mathrm{A/cm^2}$$

$$j_n^{diff} = qD_n\frac{\partial n}{\partial x} = 1.60\times10^{-19}\,\mathrm{C}\cdot350\,\mathrm{cm^2/V\cdot s}\cdot25.9\times10^{-3}\,\mathrm{V}\cdot\frac{(10^4-10^{16})\,\mathrm{cm^{-3}}}{2\times10^{-4}\,\mathrm{cm}} = -72.5\,\mathrm{A/cm^2}$$