

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.

$$j_n^{drift} = Q_n v_n = (-qn)(-v) = 1.60 \times 10^{-19} \text{ C} \cdot 10^{18} \text{ cm}^{-3} \cdot 10^7 \text{ cm/s} = 1.60 \times 10^6 \text{ A/cm}^2$$

$$j_p^{drift} = Q_p v_p = (+qp)(+v) = 1.60 \times 10^{-19} \text{ C} \cdot 10^2 \text{ cm}^{-3} \cdot 10^7 \text{ cm/s} = 1.60 \times 10^{-10} \text{ A/cm}^2$$

$$J = j_n^{drift} + j_p^{drift} \approx 1.60d \times 10^6 \text{ A/cm}^2$$

Problem 3.

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

(a)

$$Si : n_i = \sqrt{1.08 \times 10^{31} \text{ K}^{-3} \cdot \text{cm}^{-6} \cdot (77 \text{ K})^3 \cdot \exp\left(-\frac{1.12 \text{ eV}}{8.62 \times 10^{-5} \text{ eV/K} \cdot 77 \text{ K}}\right)} \approx 5.068 \times 10^{-19} \text{ cm}^{-3}$$

$$Ge : n_i = \sqrt{2.31 \times 10^{31} \text{ K}^{-3} \cdot \text{cm}^{-6} \cdot (77 \text{ K})^3 \cdot \exp\left(-\frac{0.66 \text{ eV}}{8.62 \times 10^{-5} \text{ eV/K} \cdot 77 \text{ K}}\right)} \approx 2.625 \times 10^{-4} \text{ cm}^{-3}$$

(b)

$$Si : n_i = \sqrt{1.08 \times 10^{31} \text{ K}^{-3} \cdot \text{cm}^{-6} \cdot (300 \text{ K})^3 \cdot \exp\left(-\frac{1.12 \text{ eV}}{8.62 \times 10^{-5} \text{ eV/K} \cdot 300 \text{ K}}\right)} \approx 6.725 \times 10^9 \text{ cm}^{-3}$$

$$Ge : n_i = \sqrt{2.31 \times 10^{31} \text{ K}^{-3} \cdot \text{cm}^{-6} \cdot (300 \text{ K})^3 \cdot \exp\left(-\frac{0.66 \text{ eV}}{8.62 \times 10^{-5} \text{ eV/K} \cdot 300 \text{ K}}\right)} \approx 2.267 \times 10^{13} \text{ cm}^{-3}$$

(c)

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

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

Problem 4.

$$\rho = \frac{1}{\sigma} = \frac{1}{q(n\mu_n + p\mu_p)} = \frac{1}{1.60 \times 10^{-19} \text{ C} \cdot n_i \cdot (2000 + 750) \text{ cm}^2/\text{V} \cdot \text{s}} = 10^5 \Omega \cdot \text{cm}$$
$$n_i = \sqrt{BT^3 \exp\left(-\frac{E_G}{kT}\right)} = 2.273 \times 10^{10} \text{ cm}^{-3}$$
$$T = 316.6 \text{ K}$$

Problem 5.

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

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

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

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.

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

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

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

where

$$N_T = N_D + N_A$$

Suppose $N_D = N_A$, 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 $N_D = N_A > 0$, it is conceptually to produce extrinsic silicon with a higher resistivity than that of intrinsic silicon.

Problem 9.

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

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.

$$\begin{aligned}
 j_n^{diff} &= qD_n \frac{\partial n}{\partial x} = qV_T \mu_n \frac{\partial n}{\partial x} \\
 &= 1.60 \times 10^{-19} \text{ C} \cdot 0.025 \text{ V} \cdot 350 \text{ cm}^2/\text{V} \cdot \text{s} \cdot -\frac{10^{18} \text{ cm}^{-3}}{0.5 \times 10^{-4} \text{ cm}} \\
 &= -2.80 \times 10^4 \text{ A/cm}^2
 \end{aligned}$$

Problem 11.

When $x = 0$,

$$\begin{aligned}
 j_n^{drift} &= q\mu_n n E = 1.60 \times 10^{-19} \text{ C} \cdot 350 \text{ cm}^2/\text{V} \cdot \text{s} \cdot 10^{16} \text{ cm}^{-3} \cdot -20 \text{ V/cm} = -11.2 \text{ A/cm}^2 \\
 j_p^{drift} &= q\mu_p p E = 1.60 \times 10^{-19} \text{ C} \cdot 150 \text{ cm}^2/\text{V} \cdot \text{s} \cdot 1.01 \times 10^{18} \text{ cm}^{-3} \cdot -20 \text{ V/cm} = -484.8 \text{ A/cm}^2
 \end{aligned}$$

$$j_n^{diff} = qD_n \frac{\partial n}{\partial x} = 1.60 \times 10^{-19} \text{ C} \cdot 350 \text{ cm}^2/\text{V} \cdot \text{s} \cdot 0.025 \text{ V} \cdot \frac{(10^4 - 10^{16}) \text{ cm}^{-3}}{2 \times 10^{-4} \text{ cm}} = -70 \text{ A/cm}^2$$

$$j_p^{diff} = -qD_p \frac{\partial p}{\partial x} = -1.60 \times 10^{-19} \text{ C} \cdot 150 \text{ cm}^2/\text{V} \cdot \text{s} \cdot 0.025 \text{ V} \cdot \frac{(10^{18} - 1.01 \times 10^{18}) \text{ cm}^{-3}}{2 \times 10^{-4} \text{ cm}} = 30 \text{ A/cm}^2$$

$$J^T = j_n^{drift} + j_p^{drift} + j_n^{diff} + j_p^{diff} = -536 \text{ A/cm}^2$$

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

$$j_n^{drift} = q\mu_n n E = 1.60 \times 10^{-19} \text{ C} \cdot 350 \text{ cm}^2/\text{V} \cdot \text{s} \cdot \frac{10^{16} + 10^4}{2} \text{ cm}^{-3} \cdot -20 \text{ V/cm} = -5.6 \text{ A/cm}^2$$

$$j_p^{drift} = q\mu_p p E = 1.60 \times 10^{-19} \text{ C} \cdot 150 \text{ cm}^2/\text{V} \cdot \text{s} \cdot \frac{(1 \times 10^{18} + 1.01 \times 10^{18}) \text{ cm}^{-3}}{2} \cdot -20 \text{ V/cm} = -482.4 \text{ A/cm}^2$$

$$j_n^{diff} = qD_n \frac{\partial n}{\partial x} = 1.60 \times 10^{-19} \text{ C} \cdot 350 \text{ cm}^2/\text{V} \cdot \text{s} \cdot 0.025 \text{ V} \cdot \frac{(10^4 - 10^{16}) \text{ cm}^{-3}}{2 \times 10^{-4} \text{ cm}} = -70 \text{ A/cm}^2$$

$$j_p^{diff} = -qD_p \frac{\partial p}{\partial x} = -1.60 \times 10^{-19} \text{ C} \cdot 150 \text{ cm}^2/\text{V} \cdot \text{s} \cdot 0.025 \text{ V} \cdot \frac{(10^{18} - 1.01 \times 10^{18}) \text{ cm}^{-3}}{2 \times 10^{-4} \text{ cm}} = 30 \text{ A/cm}^2$$