Tutorial 9

Electrical Properties

Ohm's law $\boxed{V = IR}$

volts

amperes

ohms

where: ***V*** is the potential or applied electric field (V);
I is the current passing through the conductor (A); and
R is the resistance of the material through which current is flowing (Ω).

Electrical resistivity

$$\rho = R\frac{A}{l}$$

where: ***R*** is the resistance to current flow (Ω)
l is the length of the conductor; and
A is the uniform cross-sectional area of the conductor.

Electrical conductivity

$$\sigma = \frac{1}{\rho}$$

electrical power

$$P = \frac{V^2}{R}$$

- Since $V = IR$, power can also be expressed as:

$$P = I^2 R$$

V is the potential or applied electric field (V);
I is the current passing through the conductor (A); and
R is the resistance of the material through which current is flowing (Ω).

Question 1

(a) Compute the electrical conductivity of a cylindrical silicon specimen 7.0 mm diameter and 57 mm in length in which a current of 0.25 A passes in an axial direction. A voltage of 24 V is measured across two probes that are separated by 45 mm.

(b) Compute the resistance over the entire 57 mm of the specimen.

Question 1 Tut 10

Q4

(a)

$\rho = \frac{1}{\sigma}$

$$\sigma = \frac{1}{\rho} = \frac{I\ell}{VA}$$

$\rho = \frac{RA}{\ell}$

$R = \frac{V}{I}$

ρ = Resistivity →

I = Current → 0.25 A

ℓ = distence between two points → 45mm

V = Voltage → 24V

A = Area

$d = 7 \times 10^{-3}$ m

Solve for σ

$$\sigma = \frac{(0.25)(45\times10^{-3})}{24\left(\frac{\pi}{4}(7\times10^{-3})^2\right)} = 12.2 \text{ S/m}$$

(b) Resistance over entire 57mm length

$\rho = \frac{RA}{\ell}$ $\quad \rho = \frac{1}{\sigma}$

$$\frac{RA}{\ell} = \frac{1}{\sigma} \Rightarrow R = \frac{\ell}{\sigma A}$$

$$\Rightarrow R = \frac{(57\times10^{-3})\text{ m}}{(12.2 \text{ S.m})\left(\frac{\pi}{4}(7\times10^{-3})^2\right)}$$

$$R = 121.4\ \Omega$$

R = Resistence to current flow

ρ = Electrical resistivity

ℓ = length of conductor

A = Uniform C.S.A

Question 2

An aluminium wire 10 m long must experience a voltage drop of less than 1.0 V when a current of 5 A passes through it. Given the electrical conductivity for aluminium at room temperature is 3.8x10^7 S m, Compute the minimum diameter of the wire.

Q5

$\boxed{\text{Question 2}}$ Tut 10

$\sigma = \frac{1}{\rho} \qquad \rho = \frac{RA}{l} \qquad R = \frac{V}{I}$

$\therefore \rho = \frac{VA}{lI}$

$\Rightarrow \sigma = \frac{lI}{VA}$

$\sigma = 3.8 \times 10^7$

$l = 10 m$

$V = 1 V$

$I = 5 A$

$A = \frac{(10 m)(5 A)}{(3.8 \times 10^7 S.m)(1 V)}$

$A = 1.316 \times 10^{-6} m^2$

Calculate the diameter of the wire

$A = \frac{\pi}{4} d^2 \quad \therefore \quad 1.316 \times 10^{-6} = \frac{\pi}{4} d^2$

$d = \sqrt{\frac{4 \times (1.316 \times 10^{-6})}{\pi}}$

$d = 0.0013 m$

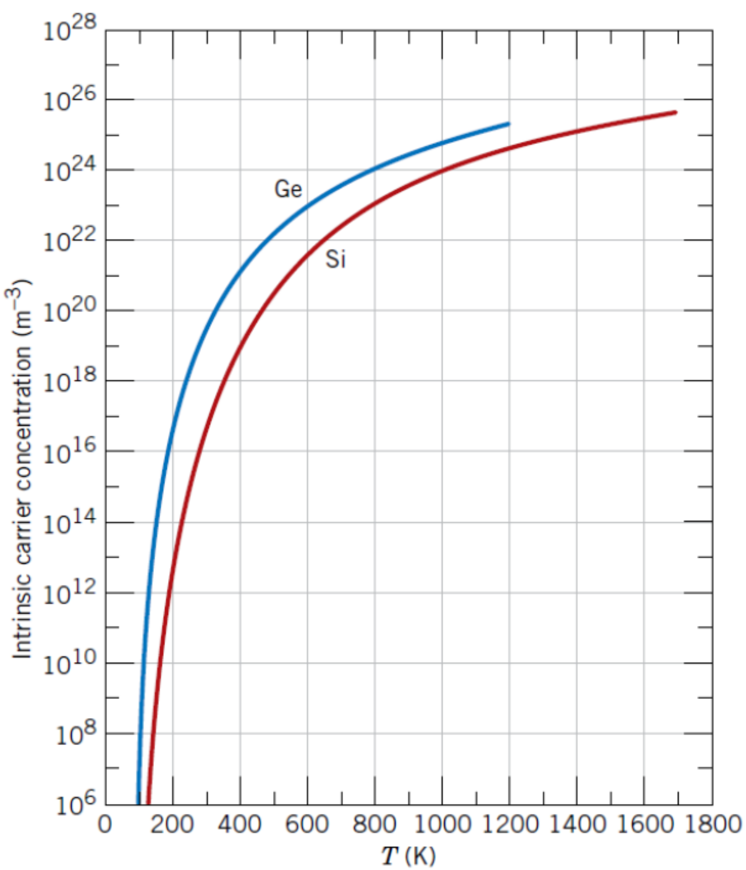
or ~~0.~~ 1.3 mm

Question 3

For intrinsic germanium, the electrical conductivity at room temperature is 2.20 S/m. If the charge of an electron is -1.602×10^{-19} C, and the electron and hole mobilities are 0.38 m^2/V.s and 0.18 m^2/V.s respectively:

a) Calculate the intrinsic carrier concentration n_i of the germanium at room temperature (25°C)

b) Compare your answer from part (a) to the information provided in Figure 1



Q4

Tutorial Sheet 10

$\sigma = 2.20$ Siemens/meter
$q = -1.602 \times 10^{-19}$ C
$\mu_n = 0.38\ m^2/V \cdot s$
$\mu_p = 0.18\ m^2/V \cdot s$

Intrinsic semiconductor

$$\sigma = n_i |q| (\mu_n + \mu_p)$$

Solve for n_i - intrinsic carrier concentration

$$n_i = \frac{2.20\ S/m}{(1.602 \times 10^{-19} C)(0.38 + 0.18)\ m^2/V.s}$$

$$\boxed{n_i = 2.45 \times 10^{19}\ m^{-3}}$$

From graph @ T = 25°C = 298K
T = 298 K

$n_i \approx 10^{19.4}\ m^{-3}$

$$\boxed{n_i \approx 2.51 \times 10^{19}\ m^{-3}}$$

Question 4

Using the information provided in Figure2, a and b:

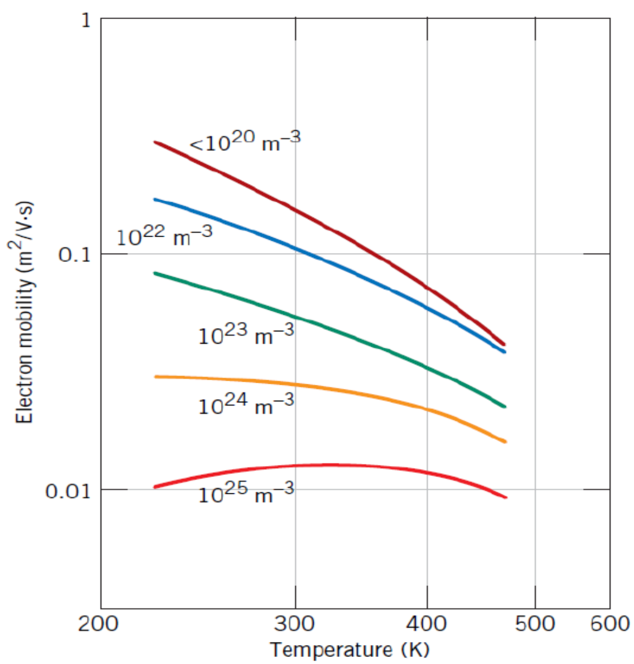
a) Calculate the electrical conductivity of intrinsic silicon at 150 °C –

- use <10^{20} m^{-3} graphs below to find electron and hole mobilities.

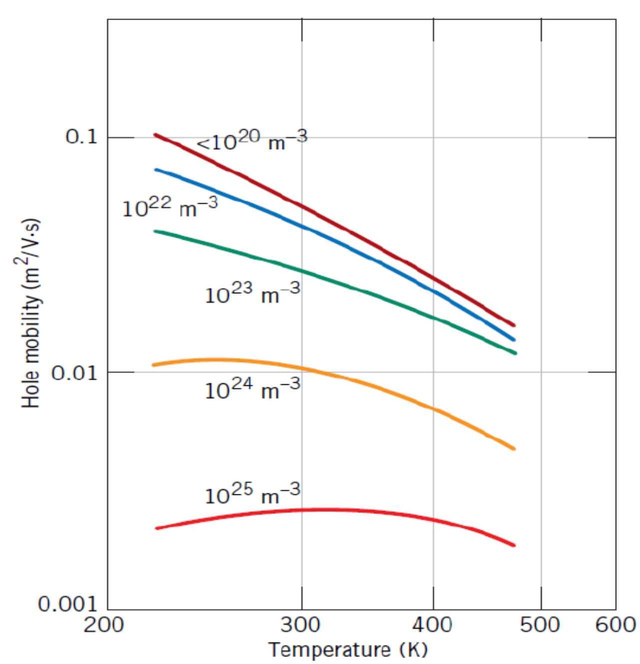
b) Calculate the room temperature electrical conductivity of a high-purity silicon which has been doped with 10^{23} m^{-3} arsenic atoms

- use 10^{23} m^{-3} graph below to find hole mobility

c) Calculate the electrical conductivity of this same doped silicon at 100 °C



(a)



(b)

25

$q = -1.602 \times 10^{-19}\,C$

Dopant level $= 10^{23}\,m^{-3}$

Electricconductivity

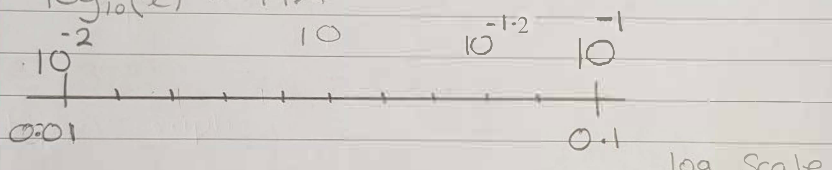
① Intrinsic Silicon $\sigma = n_i|q|(\mu_n + \mu_p)$

② Doped Silicon n-type $\sigma \cong n|q|\mu_n$

p-type $\sigma \cong p|q|\mu_p$

Logarithmic scale

$\log_{10}(x) = 19.4$



From graph @ 423K $n_i = 10^{19.6}$

$= 4 \times 10^{19}\,m^{-3}$

From graphs @ 423K and $< 10^{20}\,m^{-3}$

$\mu_n = 10^{-1.2}$

$= 0.06\,m^2/V.s$

$\mu_p = 10^{-1.65}$

$= 0.022\,m^2/V.S$

$\sigma = n_i|q|(\mu_n + \mu_p)$

$\sigma = (4 \times 10^{19}\,m^{-3})|1.602 \times 10^{-19}\,C| \times (0.06 + 0.022)\,m^2/V.s$

$\boxed{\sigma = 0.52\,S/m}$

Arsenic act as a donor -> n-type

(b) @ Room temp Silicon doped with $10^{23}\,m^{-3}$ arsenic atoms

Extrinsic Region ⇒ arsenic donated e^- ~~atoms~~

$\sigma \cong n|q|\mu_n$ electron mobility

From graph μ_n @ 298K $\approx 10^{-1.2}$

$\approx 0.063\,m^2/V.s$

Hence

$\sigma_{298K} \cong (10^{23}\,m^{-3})(1.602 \times 10^{-19}\,C)(0.063\,m^2/V.s)$

$\cong 1009\,S/m$ or $(\Omega \cdot m)^{-1}$

(c) @ 373K $\mu_n = 0.04\,m^2/V.s$

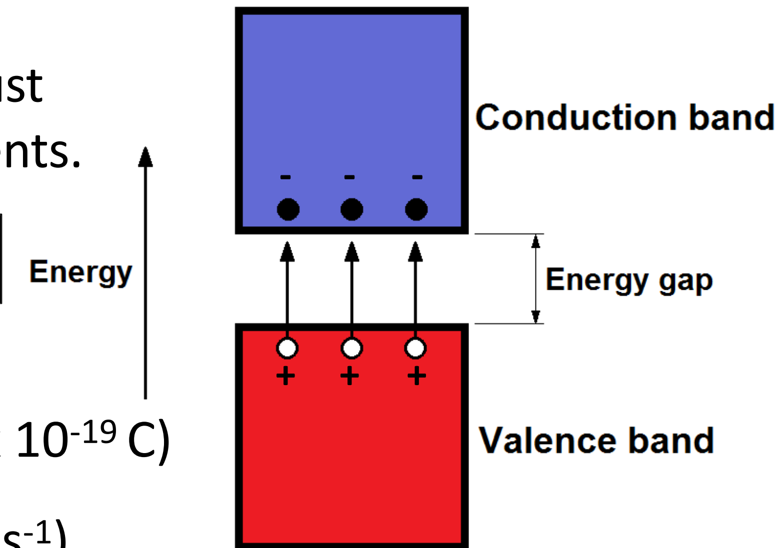
$\sigma_{373K} \cong (10^{23}\,m^{-3})(1.602 \times 10^{-19})C\,(0.04)\,m^2/V.s$

$\cong 640\,(\Omega \cdot m)^{-1}$ or S/m

Intrinsic semiconductors

Because there are two types of charge carriers (free electrons and holes), the expression for electrical conduction must account for the electron and hole currents.

$$= |q|\mu_p p + |q|\mu_n n = |q|(\mu_p p + \mu_n n)$$



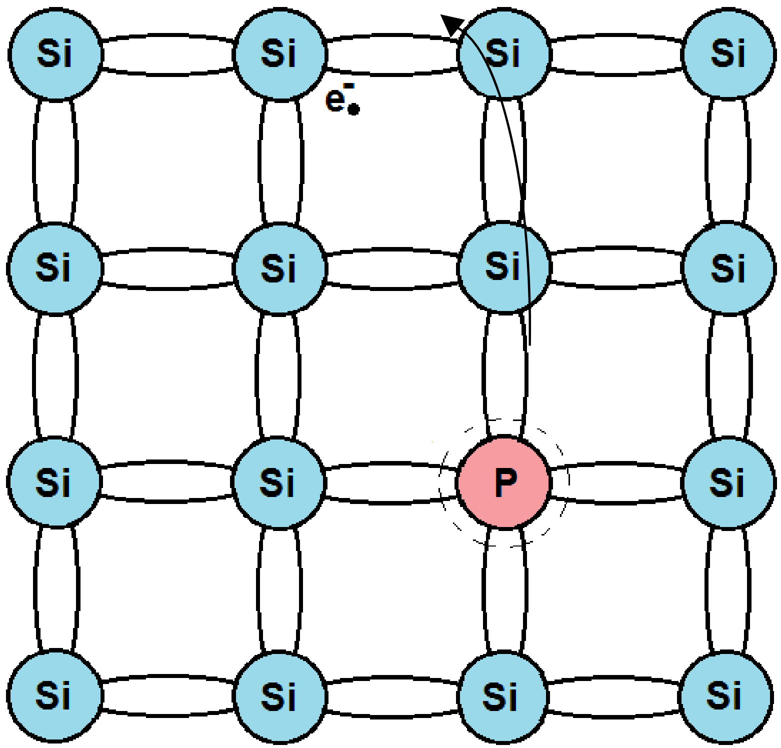
where: q = charge of an electron (-1.6×10^{-19} C)
μ_p = mobility of holes ($m^2V^{-1}s^{-1}$)
μ_n = mobility of electrons ($m^2V^{-1}s^{-1}$)
p = number of holes per m^3
n = number of electrons per m^3

For intrinsic semiconductors:

$$n = p = n_i \longrightarrow = |q|n_i(\mu_p + \mu_n)$$

where: n_i = intrinsic charge carrier concentration

n-type extrinsic semiconductors

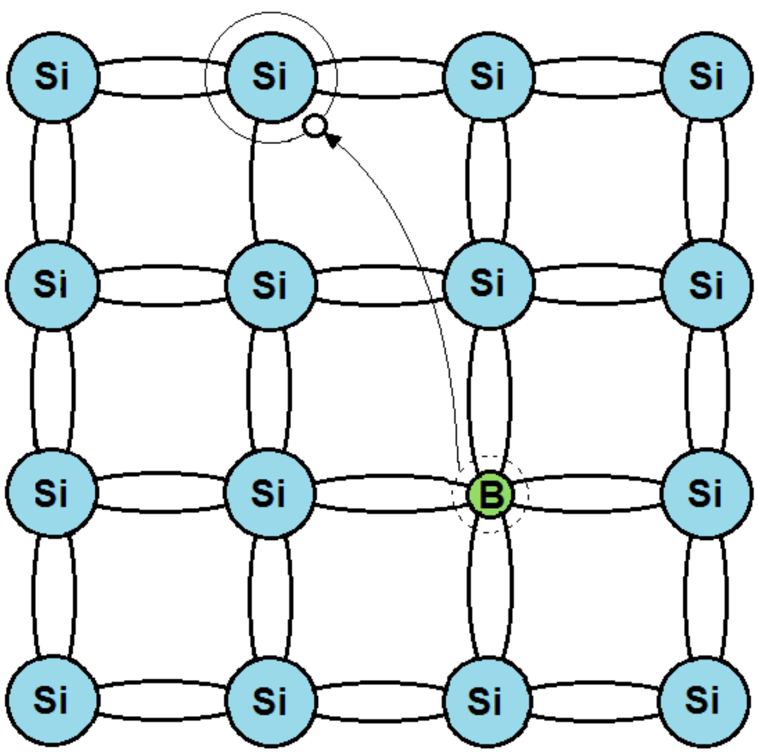


- The impurity is known as a ***donor***, because it produces conduction electrons without leaving holes in the valence band.
- Electrons are the majority charge carriers, while holes are minority carriers.

→ *n*-type extrinsic semi-conductor

$$\boxed{\;=\ |q|n\mu_n}$$

p-type extrinsic semiconductors



- A hole exists in the valence state of the impurity atom. If the hole moves away from the impurity, the bonding state is filled by accepting a valence electron from a tetravalent atom.
- The impurity is termed an **acceptor**.
- The majority charge carriers are holes.

→ *p*-type extrinsic semi-conductor

$$\boxed{= |q| p \mu_p}$$

Units

$\sigma = (\Omega . m)^{-1}$

$n_i = m^{-3}$

$e = C$

$\mu = m^2 / V.s$

$\Omega = \frac{V}{A}$

$\Omega^{-1} = \frac{A}{V}$

$A = \frac{C}{sec}$

$$n_i (m^{-3}) = \frac{\sigma (\Omega^{-1} . m^{-1})}{e (C) . \mu \left(\frac{m^2}{V.s}\right)}$$

units only

$$= \frac{\Omega^{-1} . m^{-1}}{C . m^2} . V. s$$

$$= \frac{A}{V} . \frac{s}{C} . m^{-3} . V$$

$$= \frac{A}{\cancel{V}} . \frac{1}{\cancel{A}} . V . m^{-3}$$

$$= m^{-3}$$

$\boxed{\text{Note}}$ $\mu = m^2 / V.s$ (m^2/Volt. sec) [Mobility]

n_i (m^{-3}) : Number of conduction electrons per unit volume
or Intrinsic carrier concentration

σ ($\Omega^{-1} . m^{-1}$) or Siemens/m or S/m
Electrical Conductivity