Quantum and Solid State Physics

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Contents

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Part I

Quantum Physics

Part II
Solid State Physics

1 Lecturer Information

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2 Required Reading

1. Griffiths, D. Introduction to quantum mechanics
2. Streetman, B. Solid State Electronic Devices

3 Additional Reading

1. Kittel, Introduction to solid state physics, John Wiley & Sons.
2. Tang: Fundamentals of quantum mechanics, Cambridge press.
3. Miller, Quantum mechanics for scientists and engineers.
4. Pierret. Advanced semiconductor Fundamentals, Prentice Hall.
5. Ashcroft, Solid State Physics, Harcourt college publishers.

4 Electrons

Definition 1 (Particle nature of electrons)**.** An electron behaves as a negatively charged charge carrying particle.
The magnitude of the charge on it is

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

Its mass is

$$m_0 = 9.11 \times 10^{-31}\mathrm{kg}$$

Definition 2 (Wave nature of electrons)**.** Electrons exhibit wave-like properties, in addition to particle-like properties.
The energy transmitted by a wave is

$$\begin{aligned} E &= h\nu \\ &= \frac{hc}{\lambda} \end{aligned}$$

where

$$\begin{aligned} h &= \text{Planck's constant } \left(6.626 \times 10^{-34}\right) \\ \nu &= \text{frequency} \\ c &= \text{speed of light} \\ \lambda &= \text{wavelength} \end{aligned}$$

5 Semiconductors

Law 1 (Ohm's Law)**.** *The voltage across two points on a conductor is directly proportional to the current through the conductor. The constant of proportionality is called the resistance of the conductor.*

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

Law 2 (Microscopic Ohm's Law)**.**

$$\overrightarrow{J} = \sigma \overrightarrow{E}$$

where $\overrightarrow{J}$ *is the current density,* σ *is the conductivity,* $\overrightarrow{E}$ *is the electric field in the resistor.*

Definition 3 (Resistivity)**.** If

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

where R is the resistance of the resistor, L is the length of the resistor, and A is the cross-sectional area of the resistor, then ρ is called the resistivity of the resistor.
$\sigma = \frac{1}{\rho}$ is called the conductivity of the resistor.
They are constant for a particular material.

5.1 Control Factors

The major factors which affect the conductivity of a material are

1. Temperature
2. Chemical composition
    (a) Atomic bonding
    (b) Crystal structure
    (c) Charge carriers in the crystal
3. Optical effects
4. Doping

5.2 Chemical Makeup

II	III	IV	V	VI
	B	C	N	O
	Al	Si	P	S
Zn	Ga	Ge	As	
Cd	In			

1. Easily available, hence economical
2. Performs better at higher temperatures
3. Can be converted to silica on heating

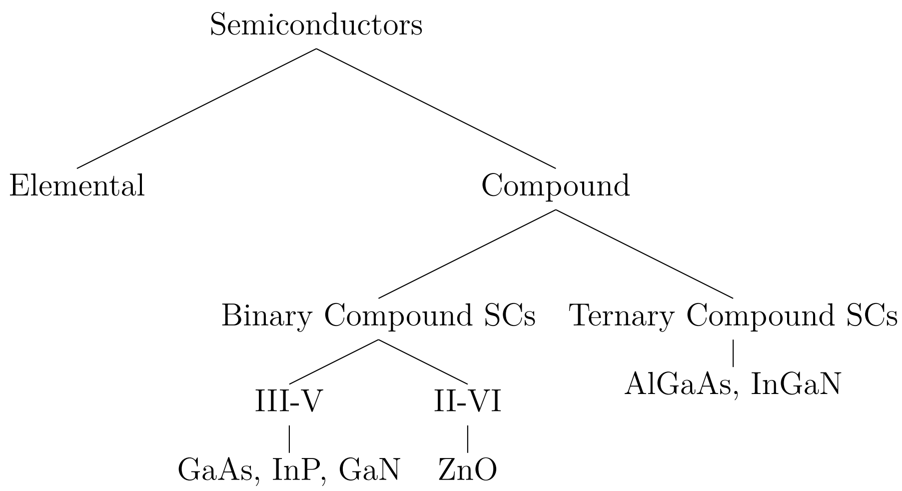


Figure 1: Classification of Semiconductors

Exercise 1.
A sample of Germanium has resistivity $\rho = 0.46\Omega\text{m}$. The dimensions of the sample are

$$\begin{aligned} l &= 50\mu\text{m} \\ h &= 0.2\mu\text{m} \\ w &= 1\mu\text{m} \end{aligned}$$

Find the resistance of the sample and the conductivity of the material.

Solution 1.

$$\begin{aligned} \rho &= 0.46\Omega\,\text{m} \\ &= 46\Omega\,\text{cm} \end{aligned}$$

Therefore,

$$\begin{aligned} \sigma &= \frac{1}{\rho} \\ &= \frac{1}{46\Omega\,\text{cm}} \\ &= 0.022\Omega^{-1}\,\text{cm}^{-1} \end{aligned}$$

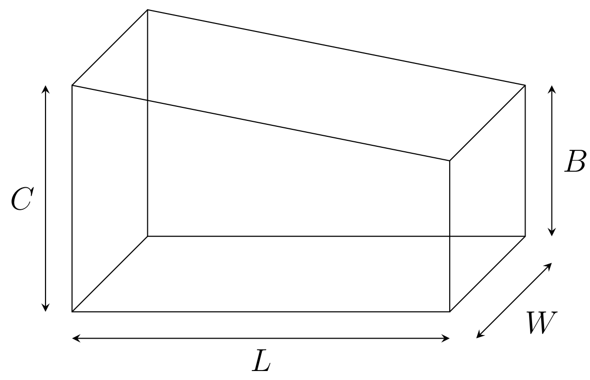
Therefore,

$$\begin{aligned} l &= 50\mu\text{m} \\ &= 50 \times 10^{-4}\text{cm} \end{aligned}$$

Therefore,

$$\begin{aligned} R &= \rho \frac{l}{A} \\ &= 11500 \times 10^{-4} \Omega \end{aligned}$$

Exercise 2.
A sample of Germanium has resistivity σ. The dimensions of the sample are as shown.



Find the relationship between R and σ.

Solution 2.
Consider a slice with height h, width w, and thickness $\mathrm{d}x$. Therefore, the cross-sectional area of the elemental slice is

$$\begin{aligned} \mathrm{d}A &= wh \\ &= w\left(\frac{B-C}{L}x + C\right) \\ &= w\left(\frac{Bx - C(L-x)}{L}\right) \end{aligned}$$

Therefore,

$$\begin{aligned} \mathrm{d}R &= \frac{\mathrm{d}x}{\sigma w h} \\ &= \frac{L\,\mathrm{d}x}{\sigma w\left(Bx - C(L-x)\right)} \end{aligned}$$

6 Types of Materials

Atoms tend to arrange themselves in such a way that the resultant energy is minimized.

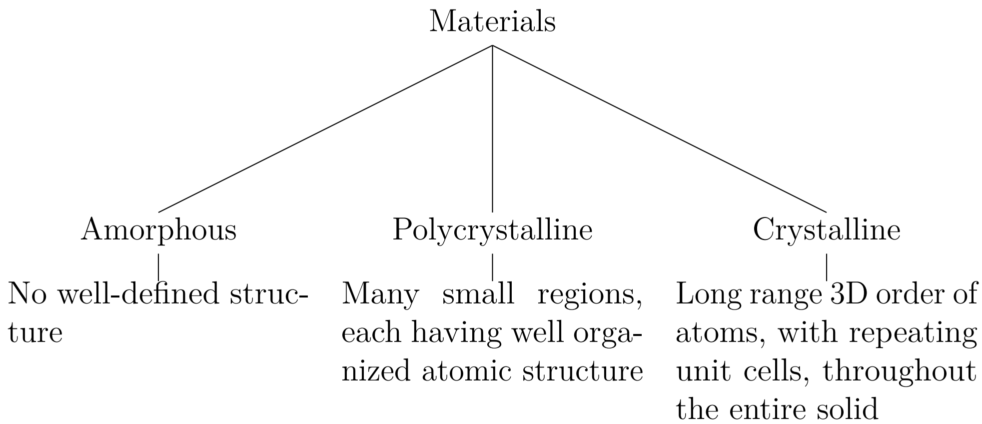


Figure 2: Classification of Materials

Semiconductor devices can use all of these types of materials.

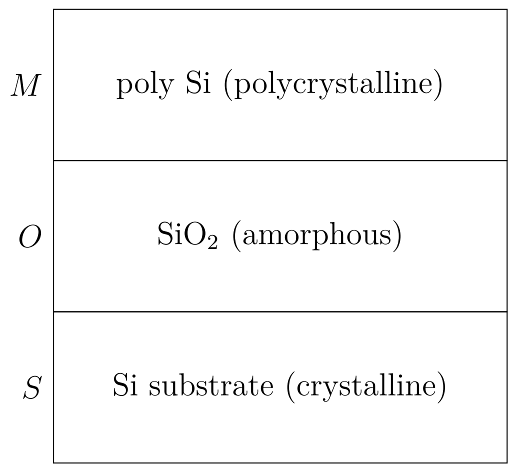


Figure 3: MOS which uses all three types of materials

7 Bohr's Model

According to Bohr's model of the atom, electrons can have discrete energy levels only. The electrons in an atom are arranged in the order of filling

electronic shells, given by the Aufbau Principle.
The energy of a free electron is called E_{vac}. This is used as a reference energy.