Chapter 14 — Semiconductor and Electronics Devices

1.1 Semiconductor Fundamentals

1. Conductivity

$$\sigma = e(n\mu_e + p\mu_h)$$

Where:

- σ = electrical conductivity
- n = electron concentration
- p = hole concentration
- μ_e = electron mobility
- μ_h = hole mobility
- e = electronic charge

For an intrinsic semiconductor:

$$\sigma_i = en_i(\mu_e + \mu_h)$$

2. Resistivity

$$\rho = 1/\sigma$$

Therefore,

$$\rho = \frac{1}{e(n\mu_e + p\mu_h)}$$

3. Current density

$$J = \sigma E$$

Therefore,

$$J = e(n\mu_e + p\mu_h)E$$

4. Mobility

$$\mu = \frac{v_d}{E}$$

Where:

- v_d = drift velocity
- E = electric field

1.2 Intrinsic Semiconductor

For an intrinsic semiconductor:

$$n = p = n_i$$

Where: n_i is intrinsic carrier concentration.

The mass-action relation is:

$$np = {n_i}^2$$

For intrinsic semiconductor:

$${n_i}^2 = n_i \times n_i$$

1.3 Extrinsic Semiconductor

n-type semiconductor

Donor impurity → pentavalent impurity
Examples:
P, As, Sb, Bi
Majority carriers:
Electrons
Minority carriers:
Holes
For strongly doped n-type semiconductor:

$$n \approx N_D$$

And

$$p = \frac{{n_i}^2}{N_D}$$

Where: N_D = donor concentration

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p-type semiconductor

Acceptor impurity → trivalent impurity
Examples:
B, Al, Ga, In
Majority carriers: Holes
Minority carriers: Electrons
For strongly doped p-type semiconductor:

$$p \approx N_A$$

And

$$n \approx \frac{{n_i}^2}{N_A}$$

Where N_A = acceptor concentration.

Charge neutrality condition

$$n + N_A = p + N_D$$

This is an important numerical relation.

1.4 Energy Band Gap

For a semiconductor:

$$E_g = E_C - E_V$$

Where:

- E_C = conduction-band energy
- E_V = valence-band energy
- E_g = forbidden energy gap

Typical values:

Si: $E_g \approx 1.1eV$
Ge: $E_g \approx 0.7eV$

1.5 p–n Junction

When p-type and n-type semiconductors are joined:

- electrons diffuse from n → p
- holes diffuse from p → n
- recombination occurs near junction
- immobile ions remain
- depletion region develops
- electric field is established
- potential barrier is formed

Approximate barrier potential at room temperature:

For Si: $V_B \approx 0.7\ V$
For Ge: $V_B \approx 0.3\ V$

Important concept

At equilibrium:

Diffusion current = Drift current

Therefore,

Net current = 0

1.6 p–n Junction Biasing

Forward bias

p-side → positive terminal
n-side → negative terminal

Effects:

- depletion width decreases
- barrier potential decreases
- current increases significantly

Reverse bias

p-side → negative terminal
n-side → positive terminal

Effects:

- depletion width increases
- barrier potential increases
- only a small reverse saturation current flows before breakdown

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1.7 Diode V–I Characteristics

For a diode:

I = f(V)

Static resistance

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

Dynamic resistance

$$r_d = \frac{\Delta V}{\Delta I}$$

The dynamic resistance is the slope-related small-signal resistance around an operating point.

Cut-in/Knee voltage

For silicon:

$$V_\gamma \approx 0.7\ V$$

For germanium:

$$V_\gamma \approx 0.3\ V$$

Diode equation — JEE extension

$$I = I_0\left[e^{\left(\frac{V}{\eta V_T}\right)} - 1\right]$$

Where:

- I_0 = reverse saturation current
- η = ideality factor
- V_T = thermal voltage

At room temperature:

$$V_T \approx 26\ \text{mV}$$

1.8 Rectification

Rectification means conversion of:

AC → pulsating DC

Two important types:

1. Half-wave rectifier
2. Full-wave rectifier

1.9 Half-Wave Rectifier

For ideal half-wave rectifier:

Average/DC current

$$I_{dc} = \frac{I_m}{\pi}$$

RMS current

$$I_{rms} = \frac{I_m}{2}$$

Average/DC voltage

$$V_{dc} = \frac{V_m}{\pi}$$

RMS voltage

$$V_{rms} = \frac{V_m}{2}$$

Rectification efficiency

$$\eta_{max} \approx 40.6\%$$

Ripple factor

$$r \approx 1.21$$

Output frequency

$$f_{out} = f$$

Where, f is input AC frequency.

1.10 Full-Wave Rectifier

For an ideal full-wave rectifier:

Average/DC current

$$I_{dc} = \frac{2I_m}{\pi}$$

RMS current

$$I_{rms} = \frac{I_m}{\sqrt{2}}$$

Average/DC voltage

$$V_{dc} = \frac{2V_m}{\pi}$$

RMS voltage

$$V_{rms} = \frac{V_m}{\sqrt{2}}$$

Maximum rectification efficiency

$$\eta_{max} \approx 81.2\%$$

Ripple factor

$$r \approx 0.482$$

Output frequency

$$f_{out} = 2f$$

This is an important difference from a half-wave rectifier.

1.11 Peak Inverse Voltage (PIV)

Centre-tapped full-wave rectifier

PIV per diode:

$$PIV = 2V_m$$

Bridge rectifier

PIV per diode:

$$PIV = V_m$$

Note: The exact symbol V_m must be interpreted according to the transformer/circuit definition being used.

1.12 Capacitor Filter

A capacitor connected across the load reduces the ripple in rectified output.
Basic idea:

Large capacitance → better smoothing

For a simple capacitor filter, approximately:

$$V_{ripple} \propto \frac{1}{fC}$$

Thus:

- larger C → smaller ripple
- larger f → smaller ripple

For the same load conditions, a full-wave rectifier gives a higher ripple frequency than a half-wave rectifier.
