FREE NOTES · NCERT + JEE/NEET LEVEL

Semiconductor Electronics

Energy bands, intrinsic and extrinsic semiconductors, the p-n junction, forward and reverse bias, diode graphs, rectifiers, special diodes and logic gates.

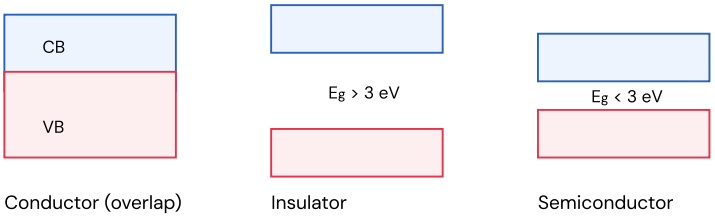
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01 Energy bands

In a solid the atoms are close together, so electron energy levels merge into **bands**.

- **Valence band (VB):** bound (valence) electrons.
- **Conduction band (CB):** free electrons that can carry current.
- **Energy gap (E_g):** the empty region between them (forbidden gap).

02 Conductor, insulator, semiconductor



Identified by the band gap

	E_g	Example
Conductor	0 (overlap)	Copper, aluminium
Semiconductor	Small (Si 1.1 eV, Ge 0.7 eV)	Si, Ge, GaAs
Insulator	Large (> 3 eV, diamond ≈ 5.4)	Diamond, glass

At 0 K a semiconductor behaves like an insulator. Heating moves electrons into the CB ⇒ conductivity rises (resistance falls, unlike metals).

03 Intrinsic semiconductor

Pure Si or Ge. When heat lifts an electron into the CB, it leaves an empty place in the VB: a **hole** (acts like a positive charge).

$$n_e = n_h = n_i$$

Equal numbers of electrons and holes. Current comes from both: $I = I_e + I_h$. Electrons have higher mobility than holes.

04 Extrinsic: n-type & p-type (doping)

Adding a tiny amount of impurity (~1 in 10^6) to a pure semiconductor = **doping**. Conductivity increases greatly.

	n-type	p-type
Dopant	Pentavalent (P, As, Sb)	Trivalent (B, Al, Ga, In)
Name	Donor	Acceptor
Majority carriers	Electrons	Holes
Minority carriers	Holes	Electrons
Extra level	Just below the CB (donor level)	Just above the VB (acceptor level)

$$n_e \times n_h = n_i^2$$

(Mass action law, in thermal equilibrium.)

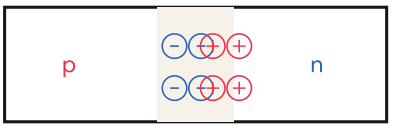
NOTE

Both n-type and p-type are **electrically neutral**. n-type doesn't mean "negatively charged", only "electrons are the majority".

05 p-n junction

Join p and n: electrons **diffuse** from n to p and holes from p to n (concentration difference). Near the junction the mobile charges disappear ⇒ the **depletion layer** (only fixed ions remain).

- + ions on the n side, − ions on the p side ⇒ an internal electric field ⇒ **barrier potential** (Si ≈ 0.7 V, Ge ≈ 0.3 V).
- This field makes minority carriers **drift**. At equilibrium: diffusion current = drift current.



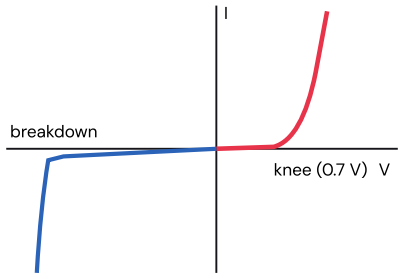
depletion layer

A thin layer of fixed ions at the junction

06 Forward & reverse bias

	Forward bias	Reverse bias
Connection	p → battery +, n → battery −	p → −, n → +
Barrier	Lowered	Raised
Depletion layer	Thinner	Wider
Current	Large (mA), majority carriers	Very small (µA), minority carriers
Resistance	Low	Very high

07 Diode V-I graph



Forward (red) and reverse (blue)

- Forward: beyond the knee/threshold voltage current rises sharply.
- Reverse: very small current until the **breakdown voltage**, then a sudden large current.
- Doesn't obey Ohm's law (non-ohmic).

DYNAMIC RESISTANCE

$$r_d = \Delta V / \Delta I$$

08 Rectifier (AC → DC)

A diode lets current pass in one direction only ⇒ it converts AC to DC.

	Half-wave	Full-wave
Diodes	1	2 (centre-tap) or 4 (bridge)
Output	Only half of each cycle	Both halves (in one direction)
Output frequency	f (50 Hz)	2f (100 Hz)
Efficiency	40.6% (max)	81.2% (max)



Half-wave Full-wave

The output is "pulsating DC". A **filter** smooths it: a capacitor across the load (or an inductor in series).

09 Special diodes (JEE)

Diode	Bias	Use
Zener diode	Reverse (at breakdown)	Voltage regulator: keeps output voltage constant
LED	Forward	Light from electron-hole recombination; $E_g \geq 1.8$ eV (visible). Low power, long life
Photodiode	Reverse	Detects light; current rises with light
Solar cell	No bias	EMF from light; Si, GaAs ($E_g \approx 1$–1.8 eV ideal)

10 Logic gates (JEE)

Gate	Boolean	Output is 1 when
OR	$Y = A + B$	Any input is 1
AND	$Y = A \cdot B$	Both inputs are 1
NOT	$Y = \bar{A}$	Input is 0
NAND	$Y = \overline{(A \cdot B)}$	Not both 1
NOR	$Y = \overline{(A + B)}$	Both 0
XOR	$Y = A \oplus B$	Inputs differ

UNIVERSAL GATES

Any gate can be built from NAND or NOR alone. Join both NAND inputs ⇒ NOT. De Morgan: $\overline{(A \cdot B)} = \bar{A} + \bar{B}$, $\overline{(A + B)} = \bar{A} \cdot \bar{B}$.

11 JEE Extra + Tricks

JEE LEVEL

- NAND and NOR are **universal gates** (any gate can be built from them). NAND = NOT of AND; NOR = NOT of OR.
- De Morgan: $(A + B)' = A' \cdot B'$; $(A \cdot B)' = A' + B'$.
- Full-wave rectifier output frequency = 2f (100 Hz for 50 Hz mains); half-wave = f.
- Zener diode used as voltage regulator in reverse breakdown; series resistor drops extra voltage.
- Diode in circuit: forward biased ⇒ treat as short (ideal) or 0.7 V (Si); reverse ⇒ open.
- Doping: pentavalent (P, As) ⇒ n-type; trivalent (B, Al, In) ⇒ p-type. $n_e n_h = n_i^2$.

12 Solved numericals

Q1. Si has $n_i = 1.5 \times 10^{16}$ m^{-3}. Doping gives $n_e = 4.5 \times 10^{22}$ m^{-3}. n_h? Which type?
$n_h = n_i^2/n_e = 2.25 \times 10^{32}/4.5 \times 10^{22} = 5 \times 10^9$ m^{-3}. Electrons are the majority ⇒ n-type. **Ans: 5×10^9 m^{-3}, n-type**

Q2. 50 Hz AC through a full-wave rectifier. Output ripple frequency?
2f = 100 Hz. **Ans: 100 Hz**

Q3. A diode's V rises from 0.7 to 0.8 V and I from 10 to 30 mA. Dynamic resistance?
$r_d = 0.1/0.02 = 5\ \Omega$. **Ans: 5 Ω**

Q4. An LED emits 620 nm light. Band gap?
E = 1240/620 = 2 eV. **Ans: 2 eV**

Q5. A = 1, B = 0. Outputs of NAND and NOR?
AND = 0 ⇒ NAND = 1. OR = 1 ⇒ NOR = 0. **Ans: 1, 0**

13 Common mistakes

- Thinking n-type is negatively charged (it's neutral).
- Thinking a semiconductor's resistance rises on heating (it falls).
- Connecting p to - in forward bias (p → +).
- Using a Zener as a regulator in forward bias (it works at reverse breakdown).
- Writing f for a full-wave output frequency (it's 2f).

14 Formula sheet

Intrinsic	$n_e = n_h = n_i$
Mass action	$n_e n_h = n_i^2$
Conductivity	$\sigma = e(n_e\mu_e + n_h\mu_h)$
Dynamic resistance	$r_d = \Delta V/\Delta I$
Rectifier frequency	half f, full 2f
Photon / band gap	$E_g = 1240/\lambda(\text{nm})$ eV
Gates	$A + B$, $A \cdot B$, $\bar{A}$, De Morgan

15 Practice questions

1. Boron is added to Si. Which type, and majority carrier?
2. Depletion layer in reverse bias?
3. Which bias does a photodiode use?
4. Both inputs of a NOR gate are 0. Output?

ANSWERS

1) p-type, holes · 2) Becomes wider · 3) Reverse · 4) 1

16 Quick revision: 5 minutes before the exam

BANDS

- Si 1.1 eV, Ge 0.7 eV; insulator > 3 eV.
- Heating ⇒ semiconductor R falls.
- $n_e n_h = n_i^2$.

DOPING

- n: P, As (donor), electrons majority.
- p: B, Al (acceptor), holes majority.
- Both neutral.

JUNCTION

- Forward: p → +, barrier lowered.
- Reverse: barrier raised, μA current.
- Full-wave 2f, half-wave f.

SPECIAL

- Zener: reverse, regulator.
- LED forward; photodiode reverse.
- NAND, NOR universal.

Have a doubt? Ask the AI Doubt Solver at padhaiadda.netlify.app, or take the mock test on this chapter.