

Introduction to Semiconductor Materials

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Key concepts, classifications, properties, and applications

1. What Is a Semiconductor?

Aspect	Description
Definition	A material whose electrical conductivity lies between that of a conductor (e.g., copper) and an insulator (e.g., glass).
Band Theory	At absolute zero the valence band is full and the conduction band is empty. A modest energy gap (0.1–3 eV) separates them, allowing electrons to be thermally or optically excited into the conduction band.
Intrinsic vs. Extrinsic	<i>Intrinsic</i> – pure crystal, conductivity determined solely by temperature. <i>Extrinsic</i> – doped with impurity atoms, conductivity controlled by carrier concentration.

2. Crystal Structure & Common Materials

Material	Crystal Structure	Bandgap (eV)	Typical Use
Silicon (Si)	Diamond cubic	1.12 (indirect)	Microelectronics, solar cells
Germanium (Ge)	Diamond cubic	0.66 (indirect)	High-speed transistors, infrared detectors
Gallium Arsenide (GaAs)	Zincblende	1.42 (direct)	RF/microwave, optoelectronics (LED, laser)
Silicon Carbide (SiC)	Hexagonal (4H, 6H)	3.2 (indirect)	Power devices, high-temperature sensors
Gallium Nitride (GaN)	Wurtzite	3.4 (direct)	LEDs, high-electron-mobility transistors (HEMT)
Indium Phosphide (InP)	Zincblende	1.34 (direct)	Photonic integrated circuits

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CdTe, CIGS, Perovskites	Various	1.0–1.6 (direct)	Thin-film photovoltaics

3. Electrical Properties

Property	Symbol	Typical Value (Si, 300 K)	Influence
Carrier concentration (intrinsic)	(n_i)	$(1.5 \times 10^{10}, \text{cm}^{-3})$	Increases exponentially with temperature
Electron mobility	(μ_n)	$\sim 1400 \text{ cm}^2/\text{V}\cdot\text{s}$	Higher mobility → faster device operation
Hole mobility	(μ_p)	$\sim 450 \text{ cm}^2/\text{V}\cdot\text{s}$	Lower than electrons in Si
Resistivity	(ρ)	$10^3 \text{ }\Omega\cdot\text{cm}$ (intrinsic)	Reduced by doping (down to $\text{m}\Omega\cdot\text{cm}$)
Conductivity	$(\sigma = q(n\mu_n + p\mu_p))$	—	Directly proportional to carrier density and mobility

Key equations

- **Intrinsic carrier concentration:**

$$[n_i = \sqrt{N_C N_V}; \exp\left(-\frac{E_g}{2kT}\right)]$$

where (N_C, N_V) are effective density of states, (E_g) the bandgap.

- **Drude conductivity:** $(\sigma = q n \mu)$.

4. Doping – Creating Extrinsic Semiconductors

| Dopant Type | Added Element (Si example) | Created Carrier | Energy Level (relative to