An Introduction to Semiconductors

Dr. José Ernesto Rayas Sánchez

Some figures of this presentation were taken from the instructional resources of the following textbooks:

A. S. Sedra and K. C. Smith, *Microelectronic Circuits*. New York, NY: Oxford University Press, 2003.

A. R. Hambley, *Electronics: A Top-Down Approach to Computer-Aided Circuit Design*. Englewood Cliffs, NJ: Prentice Hall, 2000.

R. C. Jager, *Microelectronic Circuit Design*. New York, NY: McGraw Hill, 1997.

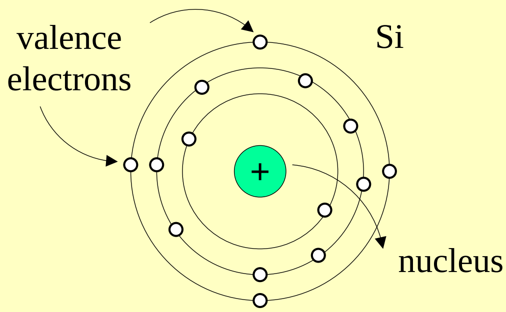
1

Outline

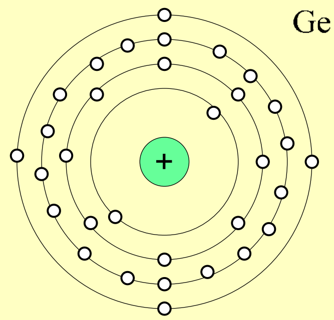
- Atomic structure
- Energy levels and energy bands
- Conductors, semiconductors and insulators
- Drift current in metals
- Drift current in semiconductors
- Doping
- N-type and P-type semiconductors
- Diode physical operation

Dr. J. E. Rayas Sánchez 2

Examples of Atomic Structures

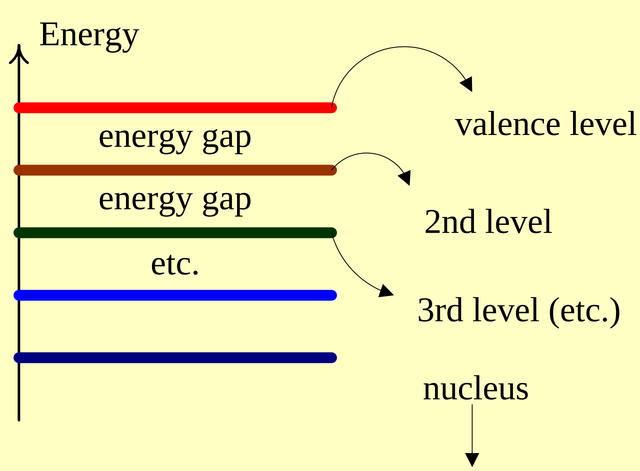


Si : 14 electrons



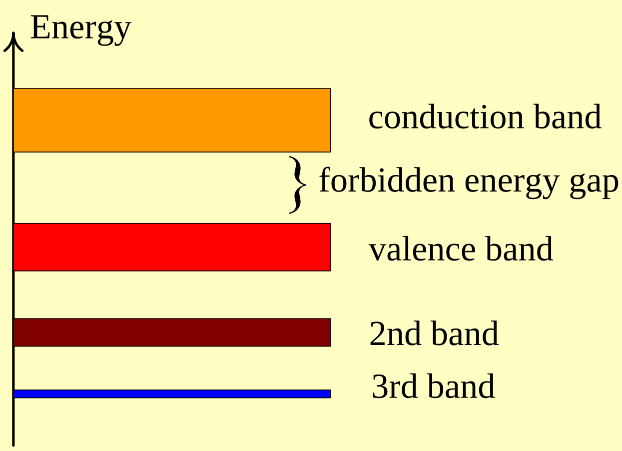
Ge = 32 electrons

Energy Levels in an Isolated Atom

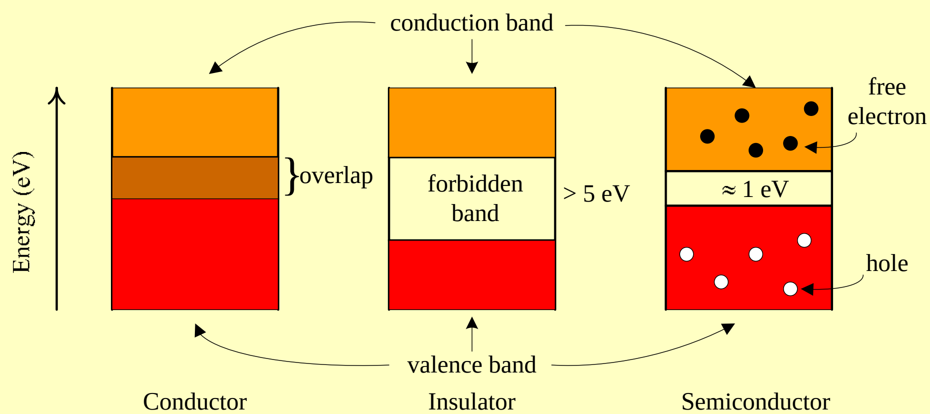


Electrons can only exist at some discrete permissible energy levels

Energy Bands in a Solid Material



Conductors, Insulators and Semiconductors



Forbidden band for Si = 0.785eV at 0 Kelvins

Forbidden band for Ge = 1.21eV at 0 Kelvins

Current Flow in Metals: Drift Current

$\boldsymbol{E}$ Electric field intensity (V/m)

$\boldsymbol{J}$ Electric current density (A/m^2)

σ Conductivity (Ω^{-1}/m)

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

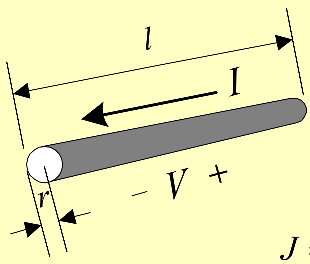
$$\sigma = nq\mu$$

n Concentration of free-electrons (m^{-3})

μ Electron mobility (m^2/Vs)

q Electron charge (1.6×10^{-19} C)

Current Flow in Metals – Example



r = 300 μm, l = 5 mm, I = 10 μA

If the wire is made of aluminum, calculate the voltage drop V

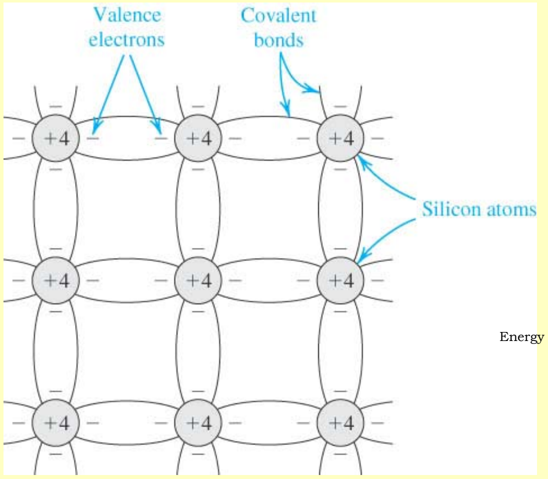
$$J = \frac{I}{A} = \frac{10\mu\text{A}}{\pi(300\mu\text{m})^2} = 3.54\text{mA}/\text{cm}^2$$

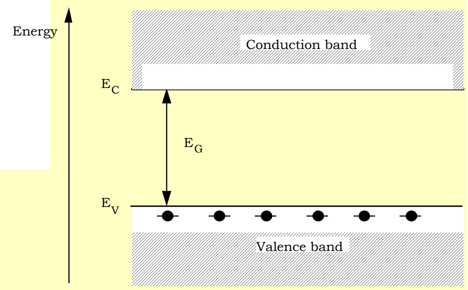
$\sigma_{\text{Al}} = 3.816\times10^7\ \Omega^{-1}$/m at 20 °C

$$E = J/\sigma = 0.93\mu\text{V/m},$$

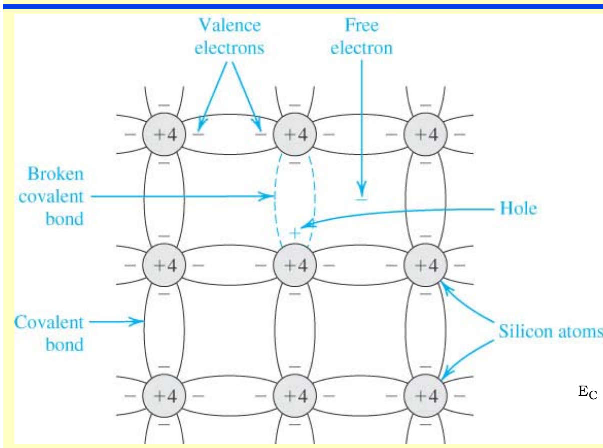
$$V = El = (0.93\mu\text{V/m})(5\times10^{-3}\text{m}) = 4.63\text{nV}$$

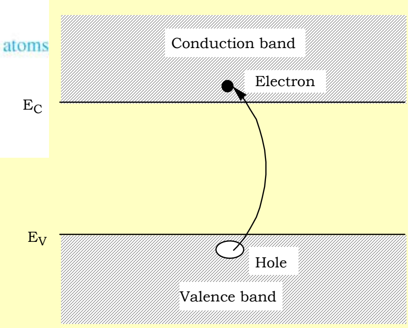
Intrinsic Silicon Crystal at 0 Kelvins



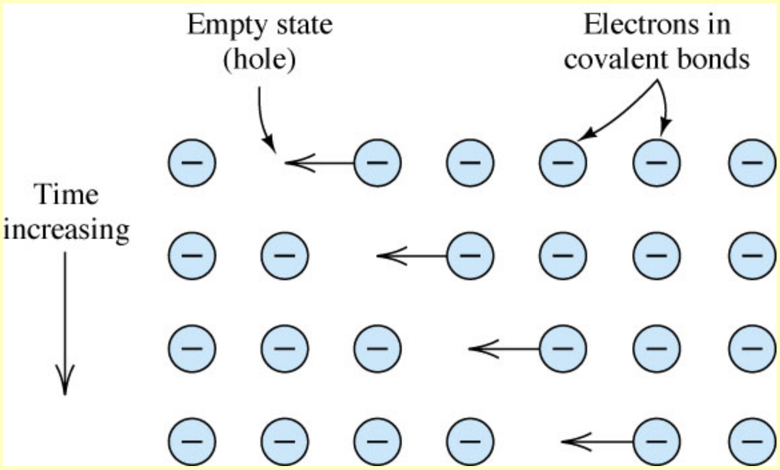


Intrinsic Silicon Crystal at *T* > 0 Kelvins





Holes Displacement



Dr. J. E. Rayas Sánchez 11

Drift Current in Semiconductors

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

$$\boldsymbol{J} = (\sigma_n + \sigma_p)\boldsymbol{E}$$

$$\boldsymbol{J} = q(n\mu_n + p\mu_p)\boldsymbol{E}$$

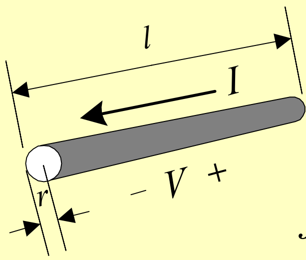
- n Concentration of free-electrons (m^{-3})
- p Concentration of holes (m^{-3})
- μ_n Mobility of free-electrons (m^2/Vs)
- μ_p Mobility of holes (m^2/Vs)

For an intrinsic semiconductor, $n = p = n_i$ (intrinsic concentration of carriers)

$$\boldsymbol{J} = qn_i(\mu_n + \mu_p)\boldsymbol{E}$$

Dr. J. E. Rayas Sánchez 12

Drift Current in Semiconductors – Example



r = 300 μm, l = 5 mm, I = 10 μA

If the wire is made of intrinsic silicon, calculate the voltage drop V

$$J = \frac{I}{A} = \frac{10\mu\text{A}}{\pi(300\mu\text{m})^2} = 3.54\text{mA}/\text{cm}^2$$

For Si at 300 Kelvins:

n_i = 1.5 ×10^{10} /cm^3, μ_n = 1,300 cm^2/Vs, μ_p = 500 cm^2/Vs

$$E = \frac{J}{qn_i(\mu_n + \mu_p)} = \frac{3.54\text{mA/cm}^2}{(1.6\times10^{-19}\text{C})(1.5\times10^{10}/\text{cm}^3)(1800\text{cm}^2/\text{Vs})}$$

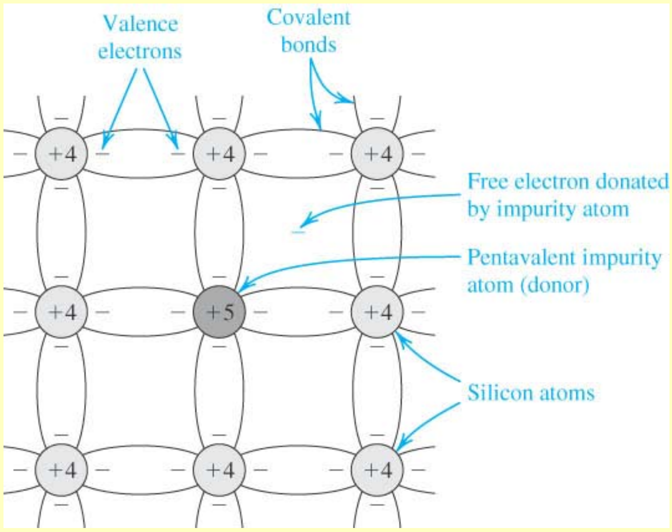
$$E = 819.4\text{V}/\text{cm}$$

$$V = El = (819.4\text{V/cm})(5\text{mm}) = 409.7\text{V}$$

Doping Semiconductors

- A pure semiconductor = intrinsic semiconductor
- A doped semiconductor = extrinsic semiconductor
- Doping is made to
  - Increase semiconductor's conductivity
  - Decrease sensitivity to temperature of semiconductor's conductivity
- Doping = process of adding impurities
- Two kinds of impurities:
  - Donor impurities → n-type semiconductor
  - Acceptor impurities → p-type semiconductor

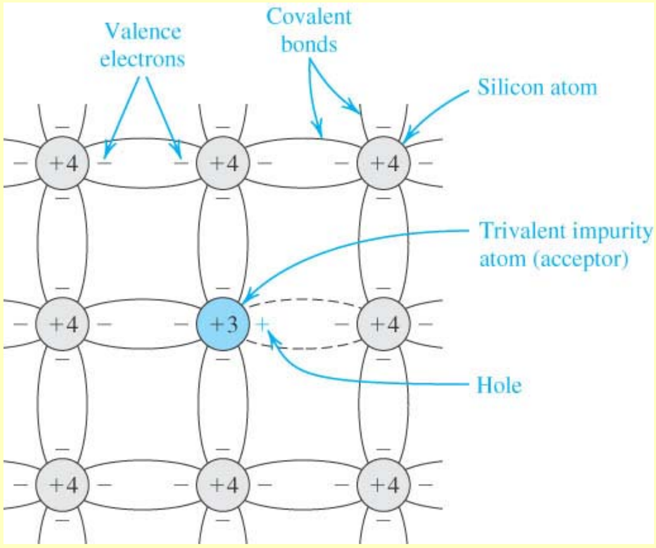
Doping with Donor Impurities: n-type



Typical pentavalent elements: Sb, P, As

Dr. J. E. Rayas Sánchez 15

Doping with Acceptor Impurities: p-type



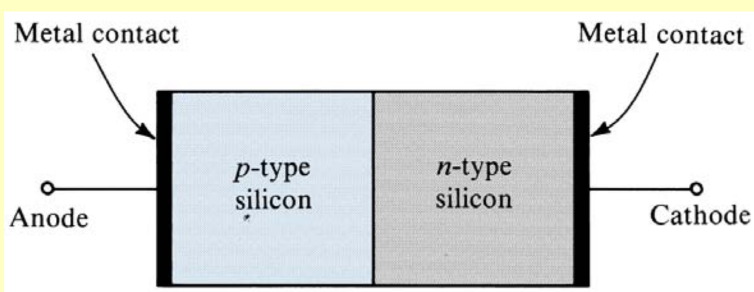
Typical trivalent elements: B, Ga, In

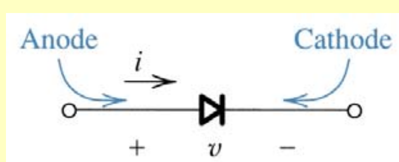
Dr. J. E. Rayas Sánchez 16

Most Used Elements in Semiconductor Industry

IIB	IIIA	IVA	VA	VIA
	5 B Boron 10.811	6 C Carbon 12.01115	7 N Nitrogen 14.0067	8 O Oxygen 15.9994
	13 Al Aluminum 26.9815	14 Si Silicon 28.086	15 P Phosphorus 30.9738	16 S Sulfur 32.064
30 Zn Zinc 65.37	31 Ga Gallium 69.72	32 Ge Germanium 72.59	33 As Arsenic 74.922	34 Se Selenium 78.96
48 Cd Cadmium 112.40	49 In Indium 114.82	50 Sn Tin 118.69	51 Sb Antimony 121.75	52 Te Tellurium 127.60
80 Hg Mercury 200.59	81 Ti Thallium 204.37	82 Pb Lead 207.19	83 Bi Bismuth 208.980	84 Po Polonium (210)

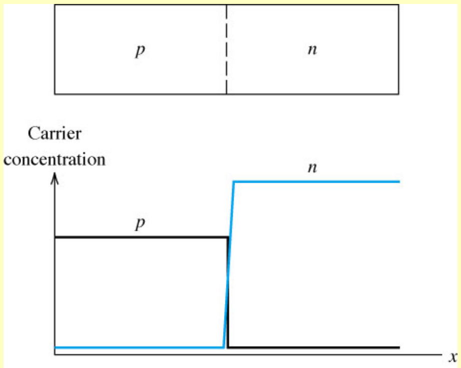
Junction Diode



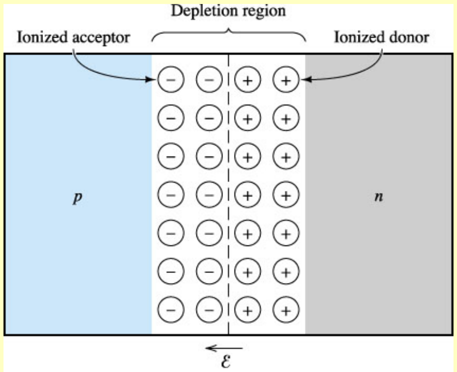


Junction Diode Operation

Initial carrier concentration:

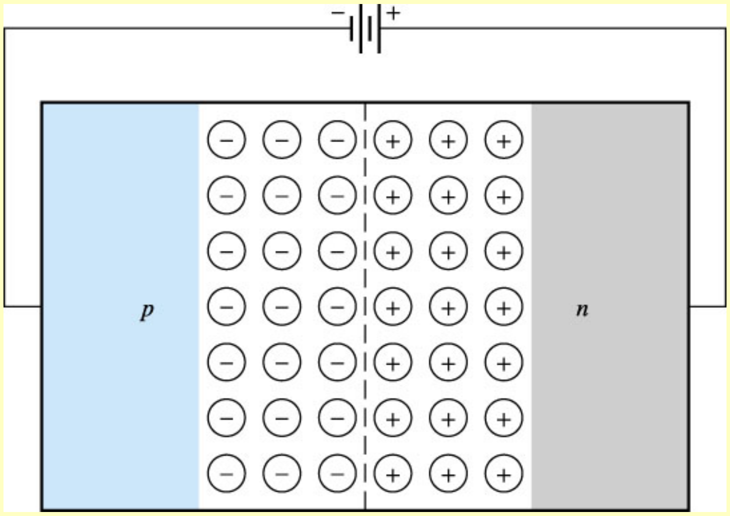


Formation of depletion region:



Junction Diode Operation (cont)

Depletion region increases with reverse voltage:



Diode Operation – Summary

- If forward biased
  - Current is due to majority carriers
- If reverse biased
  - Current is due to minority carriers