

Lecture 1

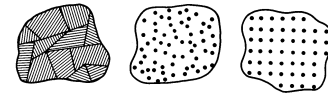
OUTLINE

- Basic Semiconductor Physics
 - Semiconductors
 - Intrinsic (undoped) silicon
 - Doping
 - Carrier concentrations

Reading: Chapter 2.1

What is a Semiconductor?

- Low resistivity => “conductor”
- High resistivity => “insulator”
- Intermediate resistivity => “semiconductor”
 - conductivity lies between that of conductors and insulators
 - generally crystalline in structure for IC devices
 - In recent years, however, non-crystalline semiconductors have become commercially very important



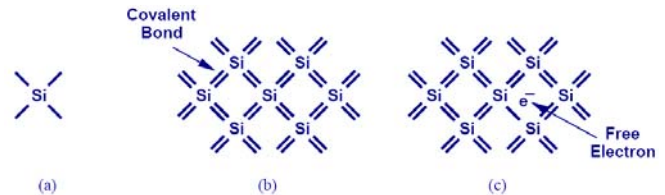
polycrystalline amorphous crystalline

Semiconductor Materials

	III	IV	V	
	Boron (B)	Carbon (C)		
• • •	Aluminum (Al)	Silicon (Si)	Phosphorus (P)	• • •
	Gallium (Ga)	Germanium (Ge)	Arsenic (As)	
		•		
		•		
		•		

Silicon

- Atomic density: 5×10^{22} atoms/cm³
- Si has four valence electrons. Therefore, it can form covalent bonds with four of its nearest neighbors.
- When temperature goes up, electrons can become free to move about the Si lattice.

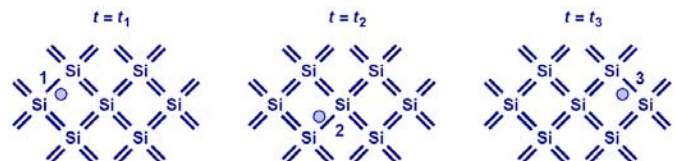


Electronic Properties of Si

- Silicon is a semiconductor material.
 - Pure Si has a relatively high electrical resistivity at room temperature.
- There are 2 types of mobile charge-carriers in Si:
 - Conduction electrons are negatively charged;
 - Holes are positively charged.
- The concentration (#/cm³) of conduction electrons & holes in a semiconductor can be modulated in several ways:
 1. by adding special impurity atoms (dopants)
 2. by applying an electric field
 3. by changing the temperature
 4. by irradiation

Electron-Hole Pair Generation

- When a conduction electron is thermally generated, a “hole” is also generated.
- A hole is associated with a positive charge, and is free to move about the Si lattice as well.



Carrier Concentrations in Intrinsic Si

- The "band-gap energy" E_g is the amount of energy needed to remove an electron from a covalent bond.
- The concentration of conduction electrons in intrinsic silicon, n_i , depends exponentially on E_g and the absolute temperature (T):

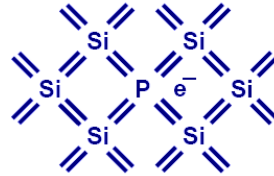
$$n_i = 5.2 \times 10^{15} T^{3/2} \exp \frac{-E_g}{2kT} \text{ electrons / cm}^3$$

$$n_i \cong 1 \times 10^{10} \text{ electrons / cm}^3 \text{ at 300K}$$

$$n_i \cong 1 \times 10^{15} \text{ electrons / cm}^3 \text{ at 600K}$$

Doping (N type)

- Si can be "doped" with other elements to change its electrical properties.
- For example, if Si is doped with phosphorus (P), each P atom can contribute a conduction electron, so that the Si lattice has more electrons than holes, *i.e.* it becomes "N type":



Notation:
 n = conduction electron concentration

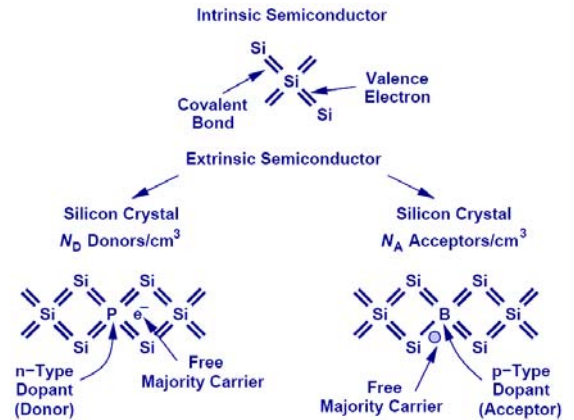
Doping (P type)

- If Si is doped with Boron (B), each B atom can contribute a hole, so that the Si lattice has more holes than electrons, *i.e.* it becomes "P type":



Notation:
 p = hole concentration

Summary of Charge Carriers



Electron and Hole Concentrations

- Under thermal equilibrium conditions, the product of the conduction-electron density and the hole density is ALWAYS equal to the square of n_i :

$$np = n_i^2$$

- This is called mass-action law

N-type material

$$n \approx N_D$$

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

P-type material

$$p \approx N_A$$

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

Terminology

donor: impurity atom that increases n

acceptor: impurity atom that increases p

N-type material: contains more electrons than holes

P-type material: contains more holes than electrons

majority carrier: the most abundant carrier

minority carrier: the least abundant carrier

intrinsic semiconductor: $n = p = n_i$

extrinsic semiconductor: doped semiconductor

Summary

- The band gap energy is the energy required to free an electron from a covalent bond.
 - E_g for Si at 300K = 1.12eV
- In a pure Si crystal, conduction electrons and holes are formed in pairs.
 - Holes can be considered as positively charged mobile particles which exist inside a semiconductor.
 - Both holes and electrons can conduct current.
- Substitutional dopants in Si:
 - Group-V elements (**donors**) contribute conduction electrons
 - Group-III elements (**acceptors**) contribute holes
 - Very low ionization energies (<50 meV)