Lecture 1

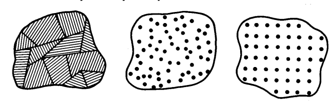
OUTLINE

- 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



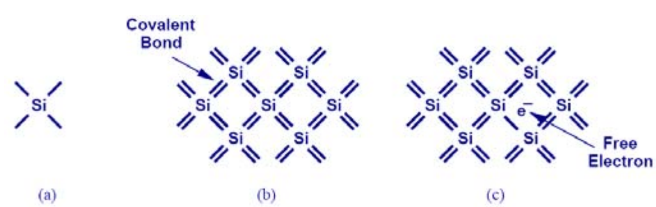
polycrystalline amorphous crystalline

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 x 10^{22} atoms/cm^3
- 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.

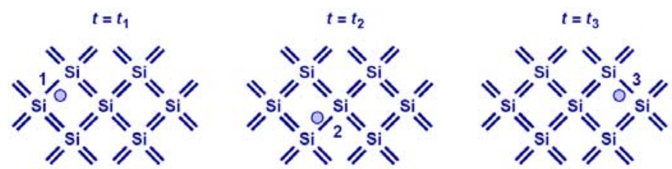


Electronic Properties of Si

- **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 (#/cm^3) 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):

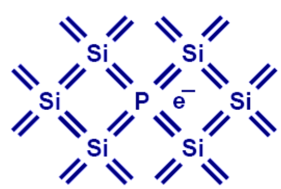
$$n_i = 5.2 \times 10^{15} T^{3/2} \exp \frac{-E_g}{2kT} \; electrons / cm^3$$

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

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

Doping (N type)

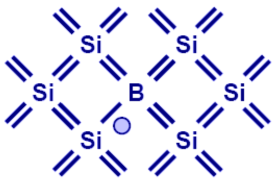
- Si can be "doped" with other elements to change its electrical properties.
- For example, if Si is doped with phosphorus (P), each P atom can contribute a conduction electron, so that the Si lattice has more electrons than holes, *i.e.* it becomes "N type":



Notation:
n = conduction electron concentration

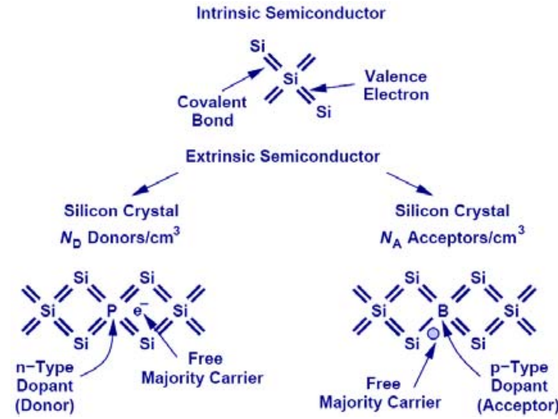
Doping (P type)

- 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	P-type material
$n \approx N_D$	$p \approx N_A$
$p \approx \frac{n_i^2}{N_D}$	$n \approx \frac{n_i^2}{N_A}$

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)