

# PHYS 3313 SEMICONDUCTOR PHYSICS

Course Website:

<http://physicscourses.okstate.edu/yguo/index.html>

syllabus, lecture notes, homework solutions

## What are semiconductors?

Materials with electrical conductivities between those of insulators and conductors.

Examples: Si, Ge, GaAs

**Energy band pictures of conductors, insulators, and semiconductors:**

**Semiconductor devices:**

Transistors, switches, diodes, detectors, etc

## Overview of the Course:

### Ch.1: The crystal structure of solids

Describing crystal structure of solids

### Ch.2: Introduction to quantum mechanics

- Wave-particle duality
- Discrete energy levels
- Schrodinger's equation

### Ch.3: Introduction to the quantum theory of solids

- Energy bands
- Concept of the hole
- Statistical mechanics

### Ch.4: The semiconductor in equilibrium

- Statistics of p type and n type semiconductors

### Ch.5: Carrier transport phenomena

### Ch.6: Nonequilibrium excess carriers in semiconductors

### Ch.7: The pn junction

### Ch.8: The pn junction diode

# Chapter 1 The Crystal Structure of Solids

## 1.1 Semiconductor Materials

Two classifications:

- Elemental semiconductor materials  
group IV elements
- Compound semiconductor materials  
groups III-V, II-VI elements

Table 1.1

---

III	IV	V
B	C	
Al	Si	P
Ga	Ge	As
In	Sb	

---

Table 1.2

---

elementary semiconductor
Si
Ge
compound semiconductors
AlP, AlAs
GaP, GaAs
InP

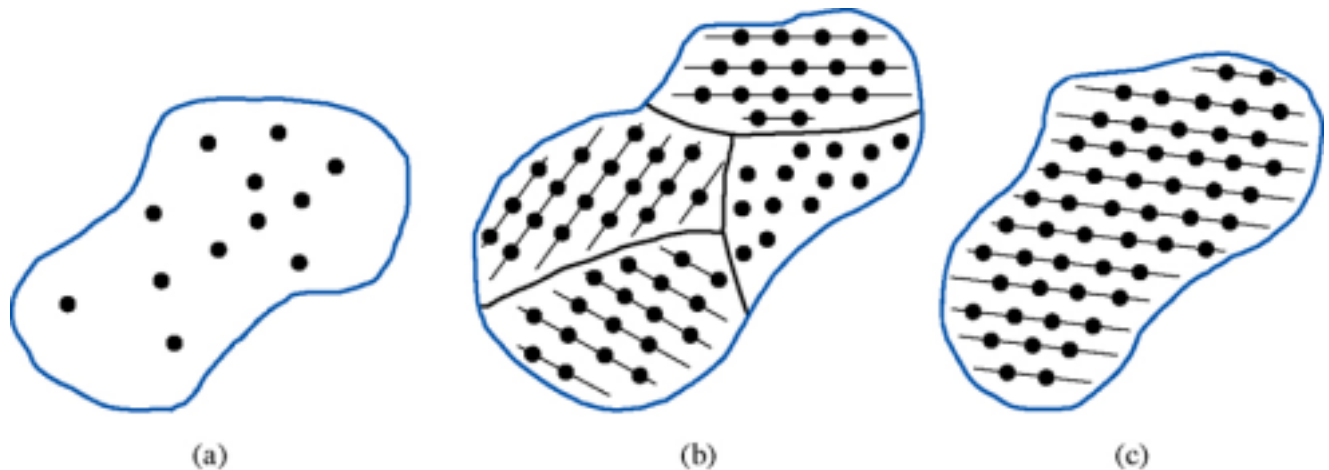
---

## 1.2 Types of Solids

Three general types:

1. **Amorphous**-with order only within a few atomic and molecular dimensions
2. **Single crystal**-with geometric periodicity throughout the entire material
3. **Polycrystalline**-with multiple single-crystal regions (called grains) separated by grain boundary

Fig. 1.1



## 1.3 Space lattices

**Lattice:** a regular periodic array of lattice points in space to represent the structure of a single crystal

**Lattice point:** a structural unit repeated periodically to form the lattice

Example: Fig. 1.2

### 1.3.1 Primitive and unit cell

**Unit cell:** a small volume that can be repeated to fill (form) the entire crystal

**Primitive unit cell:** the smallest unit cell.  
There is one lattice point per cell.

A unit cell is not unique for a given crystal.

Example: Fig. 1.3

A primitive unit cell in a 2D structure is defined by two vectors  $\bar{a}, \bar{b}$  (axis). Every equivalent lattice point in the 2D crystal can be found by

$$\bar{r} = p\bar{a} + q\bar{b} \quad p, \text{ and } q \text{ are integers}$$

Example: Fig. 1.3

A primitive unit cell in a 3D structure is defined by three vectors  $\bar{a}, \bar{b}, \bar{c}$  (axis). Every equivalent lattice point in the 3D crystal can be found by

$$\bar{r} = p\bar{a} + q\bar{b} + s\bar{c} \quad p, q, s \text{ are integers}$$

Example: Fig. 1.4

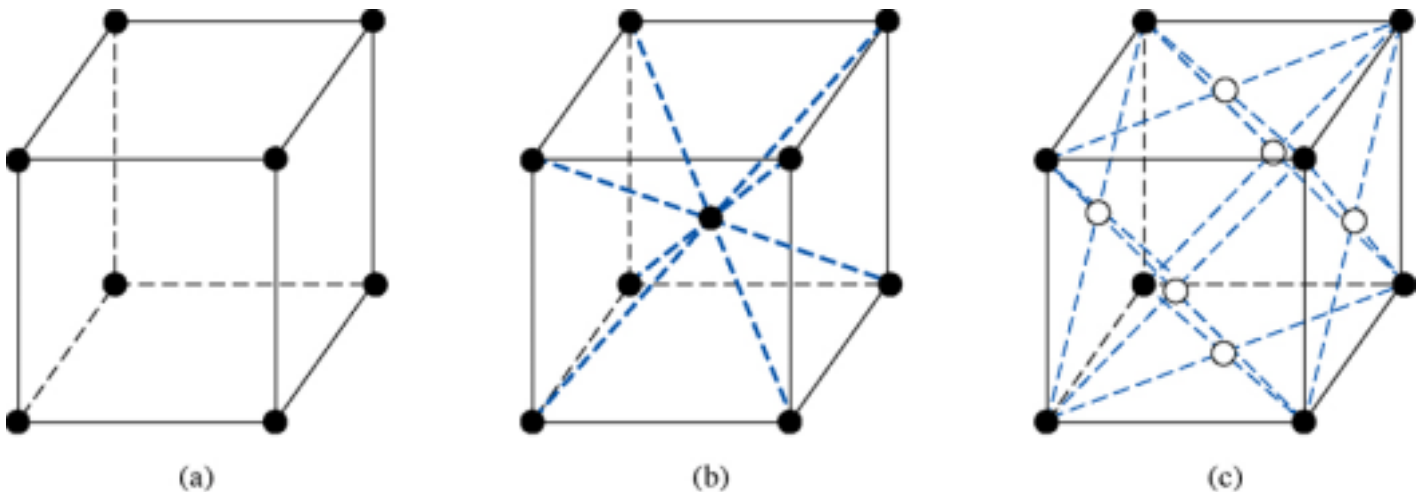
## 1.3.2 Basic crystal structures

Three common types:

- Simple cubic
- Body-centered cubic (bcc)
- Face-centered cubic (fcc)

**Fig. 1.5:** structure and conventional unit cells of simple cubic, bcc, and fcc lattice.

Volume of the unit cell =  $a^3$ ,  $a$  = lattice constant (edge of the cell)



Question: What are the number of atoms per unit cell in a simple cubic, bcc, and fcc lattice?

E1.1 The lattice constant of a fcc structure is  $a=4.75\text{\AA}$ . What is the volume density of atoms?

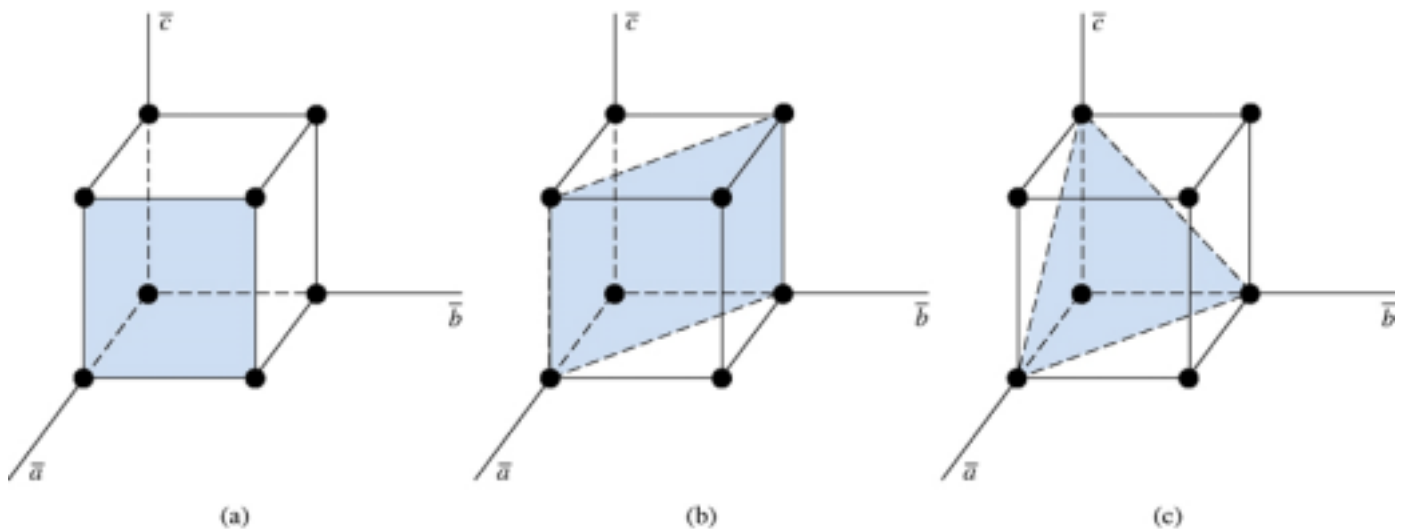
Prob. 1.3(a) Assume that each atom is a hard sphere with the surface of each atom in contact with the surface of its nearest neighbor. Determine the percentage of total unit cell volume that is occupied in a simple cubic lattice.

### 1.3.3 Crystal planes and Miller indices

To describe the orientation of a crystal surface (planes), we use Miller indices:

- Find the intercepts of the plane on the axes (the values of  $p, q, s$ )
- Take the reciprocals of these numbers. Multiply them by the lowest common denominator to obtain smallest three integers ( $hkl$ ) (Miller indices). The plane is referred as ( $hkl$ ) plane.

**Example:** Fig. 1.7



Knowing the indices (hkl), one can determine:

- The distance between parallel planes
- Surface concentration of atoms

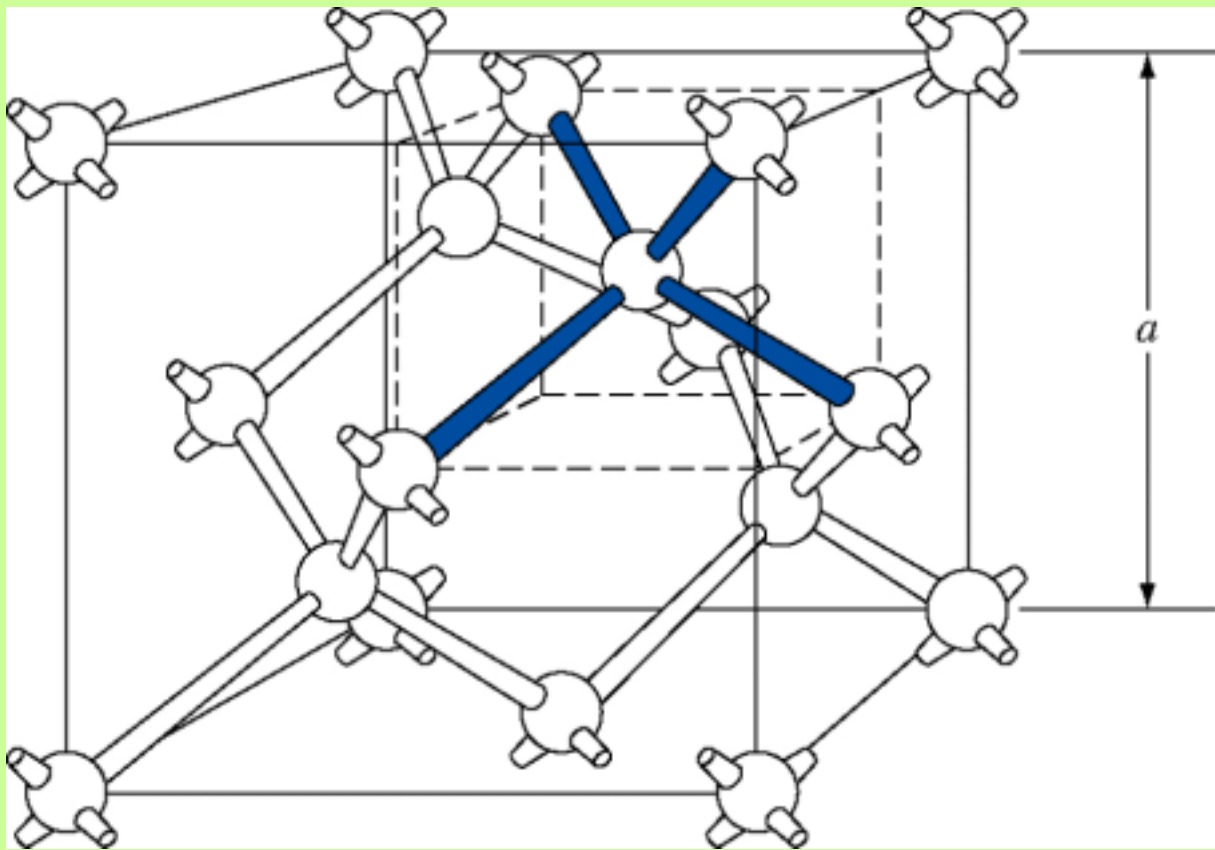
**E1.3** Determine the distance between nearest (110) planes in a simple cubic lattice with a lattice constant of  $a_0=4.83 \text{ \AA}$  (Ans:  $3.42 \text{ \AA}$ )

**E1.4** The lattice constant of a fcc structure is  $4.75 \text{ \AA}$ . Calculate the surface density of atoms for (a) a (100) plane and (b) a (110) plane

### 1.3.4 The diamond structure

- Two fcc structures displaced from each other along the body diagonal by one-fourth of its length (Fig. 1.10)

Figure 1.10



- Each atom has four nearest-neighbor atoms in a tetrahedral structure (Fig. 1.11)

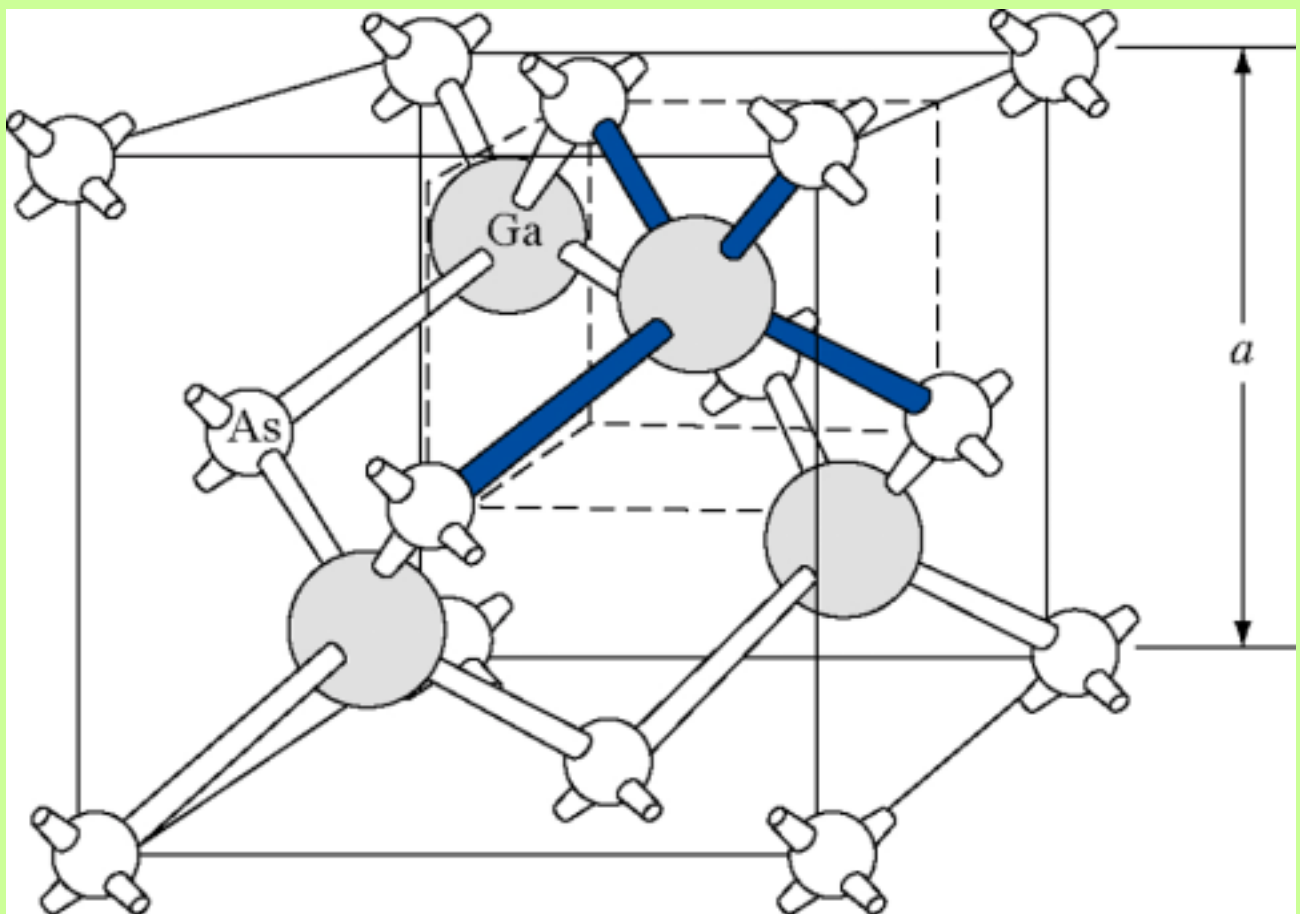
Examples: C, Si, Ge

- The conventional unit cell contains 8 atoms

**The zincblende structure:** two different types of atoms in the lattice.

Example: compound semiconductors such as GaAs  
Fig. 1.13

**Figure 1.13**



## 1.4 Atomic bonding

What holds a crystal together?

The attractive electrostatic interaction between electrons and nuclei.

Why one particular crystal structure is favored over another for a given type of atoms?

Total energy of the system tends to reach a minimum value.

Thus, the crystal structure is closely related to atomic interactions/bonding.

## Four types of bonds:

- **Ionic bond**

Element in group I + element in group VI I

Example: NaCl

- **Covalent bond**

Example: diamond structure (C,Si,Ge).

Fig. 1.16

- **Metallic bond**

Example: metal atoms

- **Van der Waals bond (weakest bond)**

Example: inert gas atoms

## 1.5 Imperfections and impurities in solids

### 1.5.1 Imperfections in solids

#### Point defects:

- Vacancy - a missing atom (Fig. 1.17(a))
- Interstitial - an extra atom (Fig. 1.17(b))

**Line dislocation**-a row of atoms missing (Fig. 1.18)

### 1.5.2 Impurities in solids

- Substitutional impurities - located at normal lattice sites (Fig. 1.19(a))
- Interstitial impurities - located between normal sites (Fig. 1.19(b))

Doping: adding impurities to change conductivity of the semiconductor material.