VE320 Introduction to Semiconductor Physics and Devices

Recitation Class 1

VE320 Teaching Group SU2022

University of Michigan-Shanghai Jiaotong University
Joint Institute

May 22, 2022

Contents

Course Overview

- Textbook
  - Semiconductor Physics and Devices (4th edition).
  - A translated edition in Chinese also available.
  - If you have time, practice some problems.
- Homework
  - Solutions are mostly available online.
  - Problems requiring drawing a graph does not have an online answer. Ask TAs if finding it difficult.
  - Review homework before exams.
  - We will try to cover some difficult questions in RC.

Course Content

- Semiconductor physics: Ch. 1-6
  - Ch. 1 Crystalline structure of solids
  - Ch. 2 Quantum theory
  - Ch. 3 Quantum theory of solids
  - Ch. 4 Carriers concentration of semiconductors in thermal equilibrium
  - Ch. 5 Carrier flows in thermal equilibrium, and the current
  - Ch. 6 Behaviour of carriers under non-equilibrium
- Semiconductor devices: Ch. 7-12
  - pn junction, Schottky junction, MOSFET, BJT

Semiconductor Definition

- Semiconductors are the materials that have resistivity between $10^{-3} - 10^{9}\Omega{\cdot}$cm.
- Resistivity are influenced heavily by light, temperature, electric field, magnetic field, impurities ...
- Examples include Si, Ge, GaAs, InP ...
- Doping
  - n-type semiconductors: Charge carriers are negative, i.e. electrons doped by donor-type of dopants.
  - p-type semiconductors: Charge carriers are positive, i.e. holes doped by acceptor-type of dopants.

Types of Solids

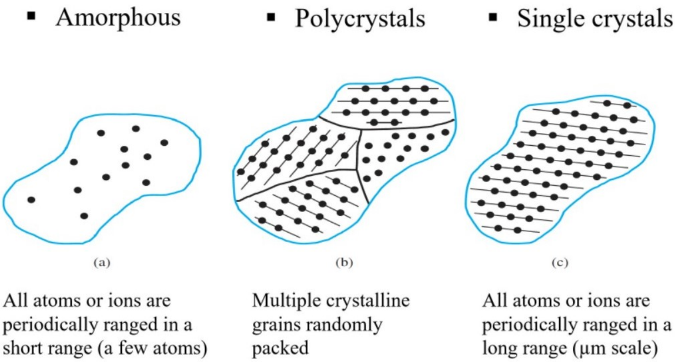


Figure: Types of solids

All semiconductors covered in this course are assumed to be single crystalline.

Cells

- Unit cell
  - Small volume of crystal that can reproduce the entire crystal.
  - Have multiple choices.
- Primitive cell
  - The smallest unit cell.
  - May also have multiple choices.
- volume density $=$ #atom per cell/volume of cell
- surface density $=$ #atom per lattice plane/area of lattice plane

Lattice Types

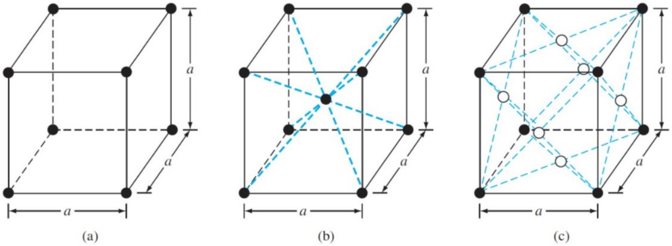


Figure: (a) Simple cubic; (b) Body-centered; (c) Face-centered.

a in the figures is called the lattice constant.

Diamond/Zincblende Structure

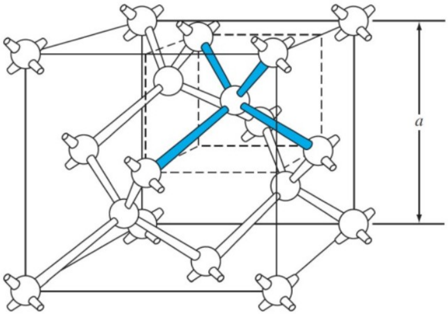
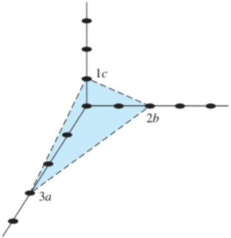


Figure: Diamond structure.

- In a diamond structure, all atoms are of the same type.
- In a zincblende structure, two different types of atoms are present, e.g., GaAs.

Miller Index



$$(3, 2, 1) \xrightarrow{\text{Reciprocal}} \left(\frac{1}{3}, \frac{1}{2}, 1\right) \xrightarrow{\text{multiply lcd}} (2, 3, 6)$$

Figure: Miller index.

- All parallel planes are entirely equivalent.
- In a cubic, [hkl] directions are perpendicular to (hkl) planes.

Preliminaries

- For matters
    - $p = mv$, $E = \frac{1}{2}mv^2$, $p = \frac{h}{\lambda}$
- For photons
    - $p = mv$, $E = h\nu$, $\nu = \frac{c}{\lambda}$
- Wave number $k = \frac{2\pi}{\lambda}$
- Uncertainty principle $\Delta p \Delta x \geq \hbar$ and $\Delta E \Delta t \geq \hbar$ where $\hbar = \frac{h}{2\pi}$

Solutions of Differential Equations

- $\frac{\partial^2 y}{\partial x^2} = k^2 y \rightarrow y = Ae^{kx} + Be^{-kx}$
- $\frac{\partial^2 y}{\partial x^2} = -k^2 y \rightarrow y = Ae^{jkx} + Be^{-jkx} = C\sin(kx) + Dcos(kx)$

Time-Independent Schrodinger Equation

- $-\frac{\hbar^2}{2m}\frac{\partial^2\Psi}{\partial x^2} + V(x)\Psi = E\Psi$
- Physical meaning: $|\Psi(x)|^2 = \Psi(x) \cdot \Psi^*(x)$ is the probability density function.
- Solution when $V(x) = V_0$
    - If $E > V_0$, $\Psi(x) = Ae^{-jkx} + Be^{jkx}$ where $k = \sqrt{\frac{2m(E-V_0)}{\hbar^2}}$.
    - If $E < V_0$, $\Psi(x) = Ae^{-kx} + Be^{kx}$ where $k = \sqrt{\frac{2m(V_0-E)}{\hbar^2}}$.
    - The first term towards $-x$, the second term towards $+x$.
- Boundary condition
    - $\Psi(x)$ is continuous.
    - $\frac{d\Psi(x)}{dx}$ is continuous when $V < \infty$.
    - $\int_{-\infty}^{\infty} \Psi(x)\Psi^*(x)dx = 1$
    - $|\Psi(x)| < \infty$

Infinite Quantum Well

- Formulation $-\frac{\hbar^2}{2m}\frac{\partial^2\Psi}{\partial x^2} + V(x)\Psi = E\Psi,\quad \begin{cases} V(x) = +\infty, & x \le 0 \text{ or } x \ge a \\ V(x) = 0, & 0 < x < a \end{cases}$
- General solution $\Psi(x) = A\mathrm{e}^{-ikx} + B\mathrm{e}^{ikx}$
- Boundary condition
  - $\Psi(x)|_{x=a,0} = 0$
  - $\int_0^a \Psi(x)\Psi^*(x)dx = 1$
- Results
  - $k = \frac{n\pi}{a}, n = 1, 2, \ldots$ ($\pm n$ have the same physical meaning; a particle must have non-zero energy)
  - $E = \frac{k^2\hbar^2}{2m} = \frac{n^2\pi^2\hbar^2}{2ma^2}$
  - $\Psi(x) = \sqrt{\frac{2}{a}}\sin(kx)$

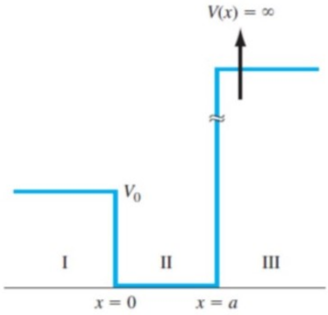
Example

Consider the one-dimensional potential function shown in the figure below. Assume the total energy of an electron is $E < V_0$.

a) Write the wave solutions that apply in each region.

b) Write the set of equations that result from applying the boundary conditions.

c) Show explicitly why, or why not, the energy levels of the electron are quantized.



Questions?