Introduction

29 October 2024 14:43

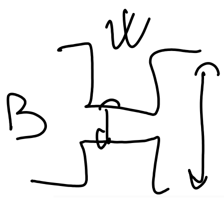
Semiconductor Nanostructures

A.A. 2024/202~~3~~ 5

Course overview and objectives

Lectures overview

1: Bulk semiconductors



2: Semiconductor Nanostructures

Bandstructure

- Overview of bond formation
- Tight-binding
- K-dot-P
- Bandstructure of relevant semiconductors

Semiconductor alloys

- Bulk alloys
- Heterojunction: band alignment at semicondutor interfaces

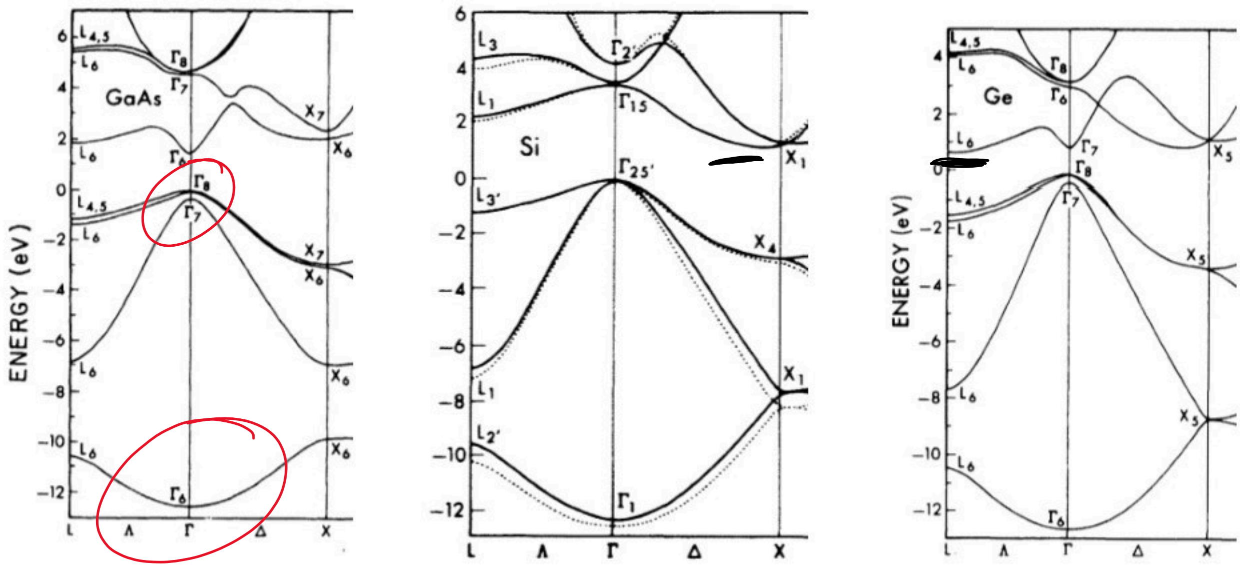
Quantum confinement

- Low dimensional heterostructures
- Effective mass approximation

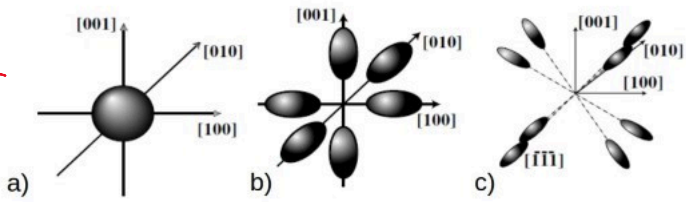
Strain

- Strain effects on the bandstructure
- Degeneracy removal and effective mass modification

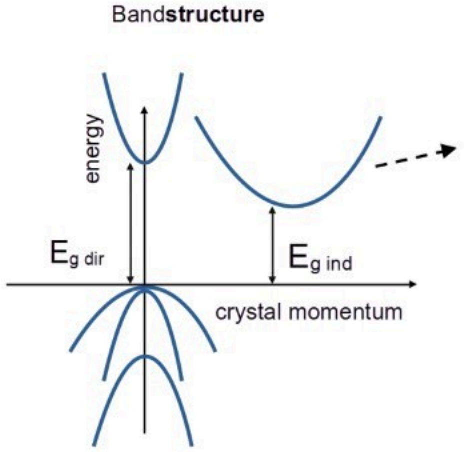
Bulk semiconductors



S-BONDING



Effective mass

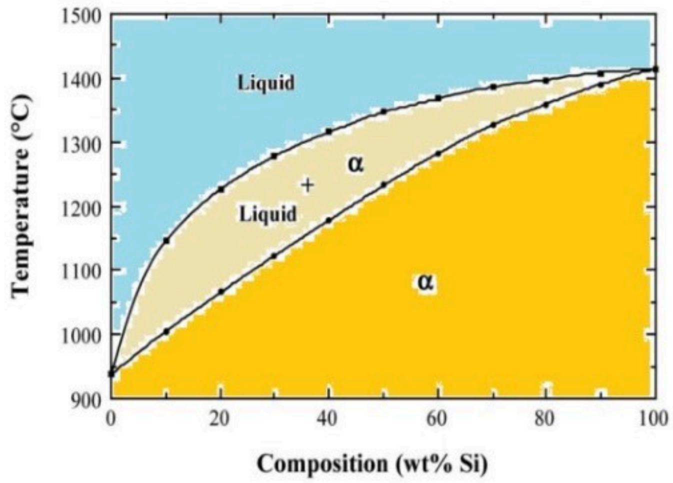


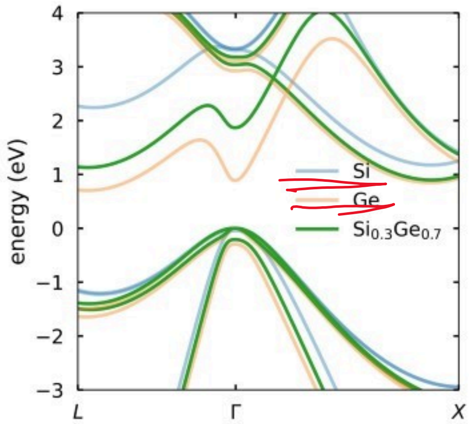
$$\frac{\hbar^2 k^2}{2m^*}$$

- Carrier mobility $v_d = \frac{q\tau_s}{m^*} E_{field}$
- Carrier density $DOS \propto (m^*)^{3/2}$
- Quantum confinement energy

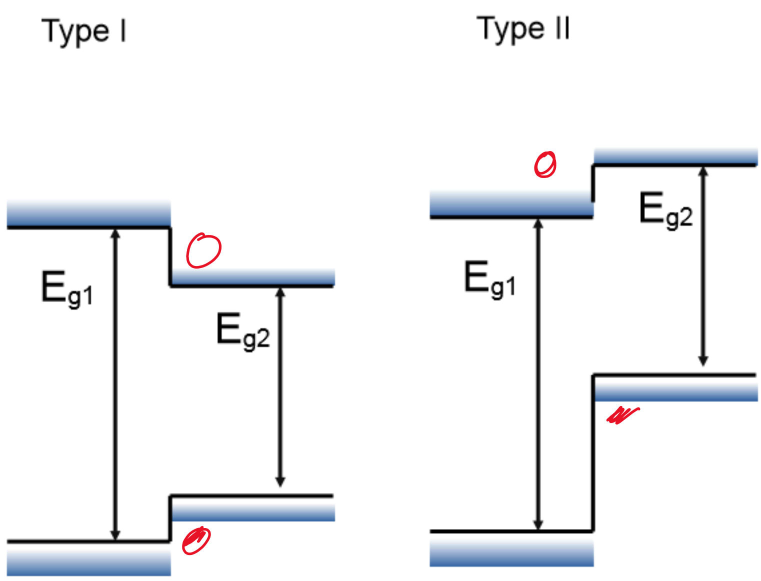
$$E_{QW} = \frac{\hbar^2}{2m^*}\left(\frac{\pi}{a}\right)^2 n^2$$

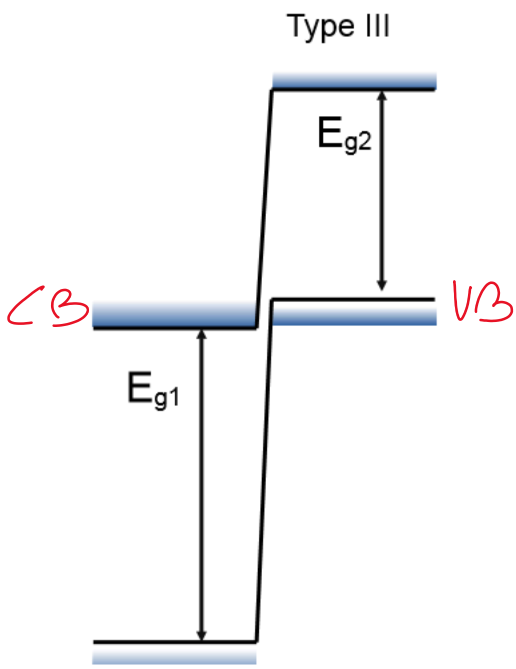
Semiconductor alloys





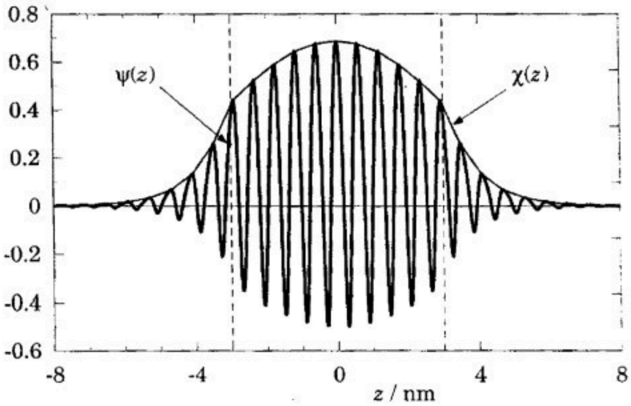
Band alignment





Quantum Confinement

Envelope function approximation



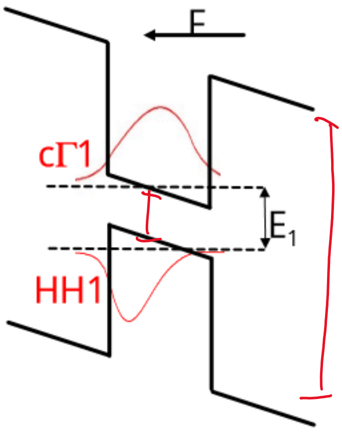
$$-\frac{\hbar^2}{2}\nabla\cdot\left[\frac{1}{m_{eff}}\nabla\Psi_{env}(\mathbf{r},t)\right]+V(\mathbf{r})\Psi_{env}(\mathbf{r},t)=i\hbar\frac{\partial}{\partial t}\Psi_{env}(\mathbf{r},t)$$

Ψ_{env} continuous

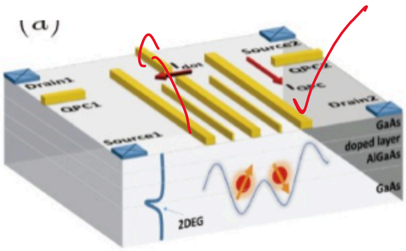
$\frac{1}{m_{eff}}\nabla\Psi_{env}$ continuous

Quantum Confinement

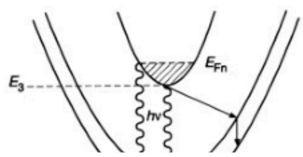
Quantum confined Stark effect

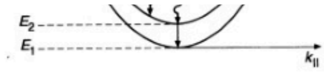


Split-gate quantum dots

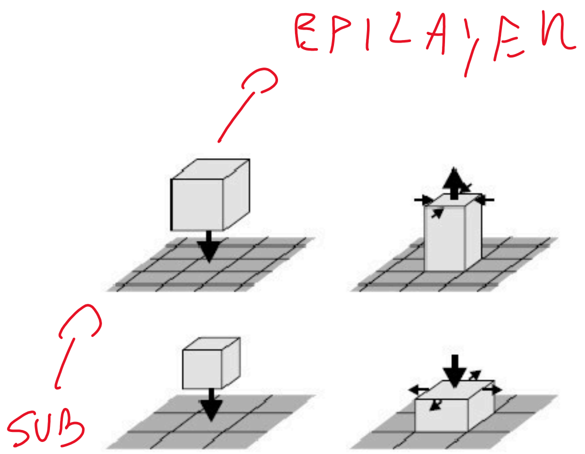


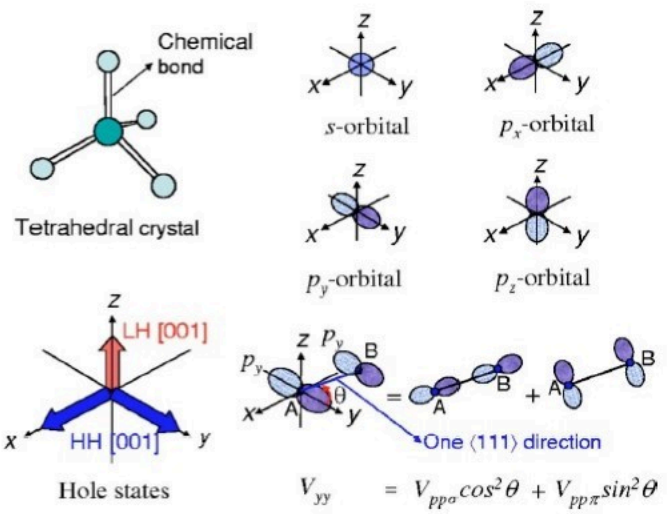
Quantum cascade laser



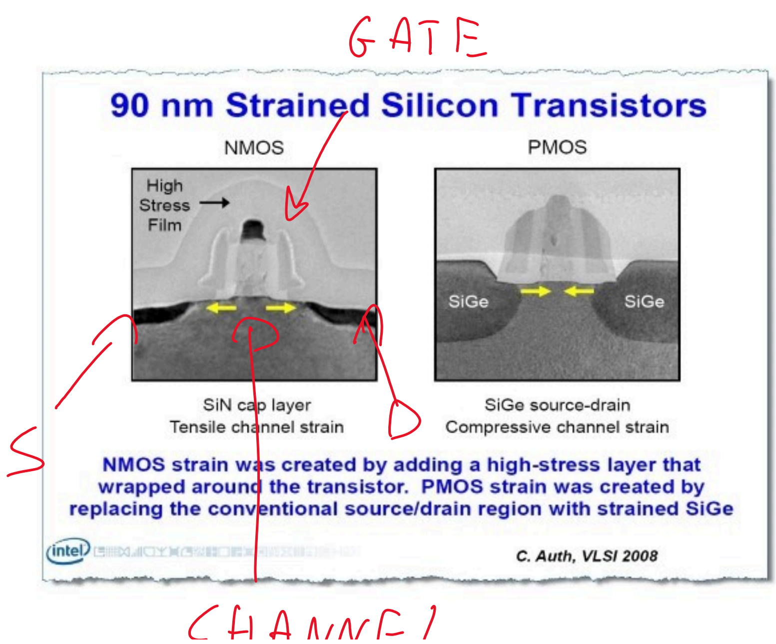


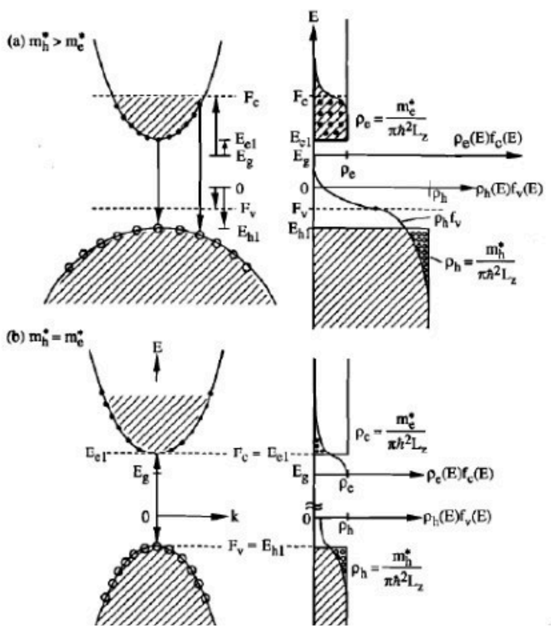
Epitaxial strain





Strain engineering





Contact information and teaching material

<u>Contact information:</u>

Giovanni Isella

Tel: 031 332 7303/7612

e-mail: giovanni.isella@polimi.it

http://lness.como.polimi.it

Question time: Thursday morning
https://politecnicomilano.webex.com/meet/giovanni.isella

<u>Recommended (but not mandatory) bibliography</u>:

"Electronic and optoelectronic properties of semiconductors structures" Jasprit Singh Ed. Cambridge University Press

"The physics of low-dimensional semiconductors-an introduction" John H. Davies Ed. Cambridge University Press

<u>Exam:</u> written + oral

Contact information and teaching material

<u>WeBeep</u>

For each lecture there will be an associated folder with the related teaching material that will be updated lecture-by-lecture

097511 - SEMICONDUCTOR NANOSTRUCTURES (ISELLA GIOVANNI) (097512 - PHYSICS OF SEMICONDUCTOR NANOSTRUCTURES [I.C.] [sezione A])

Introduction

The course provides a conceptual framework for understanding the essential Physics of low-dimensional semiconductors where quantum confinement and strain effects are exploited for tailoring electronic and optical properties.

The physical properties of a variety of semiconducting materials, including compound semiconductors and heterostructures, will be analysed on the base of their electronic bandstructure outlining their potentiality in opto-electronics, photovoltaics and spintronics applications.

The effect of quantum confinement in 2-dimensional (quantum wells), 1-dimensional (quantum wires) 0-dimensional (quantum dots) heterostructures will be analyzed also in view of their application in intersubband photodetectors and optical modulators.

Strain effects on the bandstructure will be addressed with a focus on strained-Si technology and strain effects on lasing both in III-V and group IV semiconductors.

Materials

Check the materials provided by the professor.

Notice board

Check course announcements. Interact with the professor, tutors and your fellow students via the forum.

Recordings

Rewatch the recorded course lectures.

Lectures Booklet

A booklet with the lecture's notes is being prepared: it's a work-in-progress far from being complete!

Contents

1 Semiconductor systematics **3**
- 1.1 The arithmetic of semiconducting materials . . . 3
- 1.2 Lattice parameters and bandgaps . . . 5
- 1.3 III-V and II-VI semiconductors . . . 6
- 1.4 Substrates and epilayers . . . 8

2 Tight-binding calculation of semiconductors bandstructure **10**
- 2.1 Linear combination of atomic orbitals . . . 10
- 2.2 The tight-binding approximation for a 1D atomic chain . . . 16
- 2.3 Tight-binding approximation for a diamond lattice and sp^3 orbitals . . . 23
- 2.4 Spin-orbit interaction and valence band structure . . . 31

3 The k·p method and the effective mass approximation **35**
- 3.1 The $\mathbf{k} \cdot \mathbf{p}$ method . . . 35
- 3.2 Effective Mass . . . 38
  - 3.2.1 Electron effective mass in single and multi-valley semiconductors . . . 38
  - 3.2.2 Hole effective mass . . . 43