EEE 6212
Semiconductor Materials

Dr Thomas Walther (1st part) and Dr Ian Farrer (2nd part)

offices: Mappin Building, 1st floor, E150d and E153a
emails: t.walther@sheffield.ac.uk and i.farrer@sheffield.ac.uk
tel. 25891 (TW) or 25860 (IF)

Lecture 1: Introduction

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- description and aim of this module
- objectives
- syllabus
- policy, self study and literature
- overview: from discrete energy levels in isolated atoms to quasi-continuous energy bands in crystals

Description & Aim

This module describes the basic physical properties (structural, optical, electrical) of semiconductor materials used in the electronic and opto-electronic industries, and in semiconductor based research.

The aim is to equip the students with a comprehensive background understanding of the physical, structural, optical, electronic properties of semiconductor materials used in modern electronic and opto-electronic devices so they understand their design.

Objectives

- understand role and use of different semiconductors in different devices
- understand relevant crystal structures in real and in reciprocal space
- have knowledge of the role of the crystal structure in defining the thermal, optical, and electrical properties of the semiconductor, and describe the role of defects and doping on these properties
- understand how band-structure defines electronic & optical properties
- understand different optical transitions, carrier relaxation processes, excitonic effects and the role of free carriers on the band-structure
- understand electrical conduction processes for intrinsic and doped materials and the formation of p-n junctions
- understand characteristics of diodes, transistors and solar cells
- understand the effects of quantum confinement
- demonstrate practical knowledge of the characterization of quantum wells by XRD and PL

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Syllabus & Running Order 2015

L1	Intro and overview…	TW	12.10.
L2,3	Crystal structures, symmetry	TW	14.& 19.10.
	no lecture due to Careers Day		21.10
T2,3	Tutorials to L1, L2 & L3	TW	26. & 28.10.
L4	Reciprocal lattice	TW	2.11.
T4	Tutorial to L4	TW	4.11.
L5	Electron Diffraction	TW	9.11.
T5	Tutorial to L5	TW	11.11.
L6	Defects, dislocations	TW	16.11.
T6	Tutorial to L6	TW	18.11.
L7	X-ray diffraction	TW	23.11.
T7	Tutorial to L7	TW	25.11.
L8	Phonons	TW	30.11.
T8	Tutorial to L8	TW	2.12.

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Syllabus & Running Order

L9	Doping	TW	7.12
T9	Tutorial to L9	TW	9.12
L10	Electronic band structure & DOS	TW	14.12.
T10	Tutorial to L10 (brief) and	TW	16.12.
L11	Assignment description and scheduling	IF	16.12.

Practical Lab, further lectures and tutorials by IF in 2016 on:

- optical transitions
- excitons, free carrier effects
- carrier lifetime and recombination
- conductivity
- pn-junction, diodes and transistors
- photo-detectors
- gain and lasing
- quantum mechanics
- DOS – lasers, LEDs
- Nano –technologies

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Policy

- spare handouts will be thrown away after each lecture – we will not keep copies if you miss the lecture
- tutorials – attend having made effort beforehand
- work out what you don't understand, don't be shocked if we say "have you looked it up in a book"
- we are happy if you make appointments for individual questions by email
- no queues outside our offices the last day before the exam please!

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What is a 15 Credit Module?

The University requires that it is ~150 hours of work!

- Lectures & Tutorials = 36
- Practical Write Up = 4
- Exam = 2
- **Total Contact Time = 42**

so that results in...

~100 hours of study on your own

Books

- Ashcroft & Mermin: "Solid State Physics" Brooks/Cole
- Kittel: "Introduction to Solid State Physics", Wiley
- Fox: "Optical Properties of Solids", OUP
- Kelly: "Low Dimensional Semiconductors", OUP
- Sze: "Physics of Semiconductor Devices", Wiley
- Phillips: "Crystals, Defects & Microstructures", CUP

- But read around the subject – use the library!
- Almost all solid state physics textbooks contain chapters on semiconductors.

Self Study

- **When:**

  try to spread background reading over a large time period – a few hours per week during term time, following the points introduced in the lectures

- **How:**

  do problem sheets, read books, weba

  try the relevant tutorial questions ***well before*** the tutorial sessions

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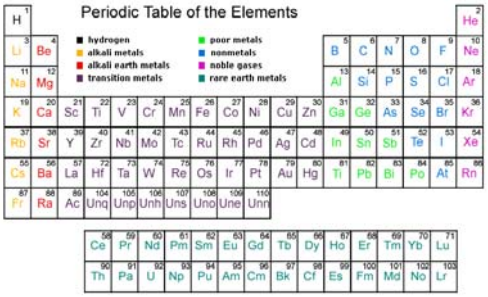
Atoms



nucleus (neutrons + protons) surrounded by electrons

physical understanding – continued debate Thomson, Rutherford, Bohr, etc,

in atomic physics – consider isolated atoms

in solid state physics – consider atoms in crystal lattices

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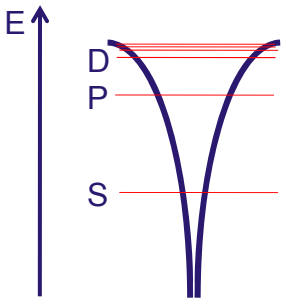
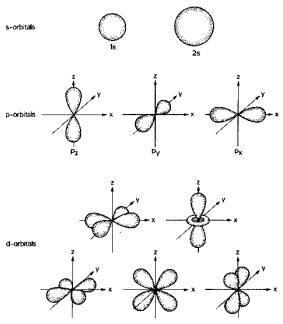
Electronic States



S - 2 electrons 1 orbital
P- 6 electrons 3 orbitals
D- 10 electrons 5 orbitals
F- 14 electrons 7 orbitals



Quantum mechanics →discrete energy levels arranged in shells & orbitals – chemical properties governed by empty shells

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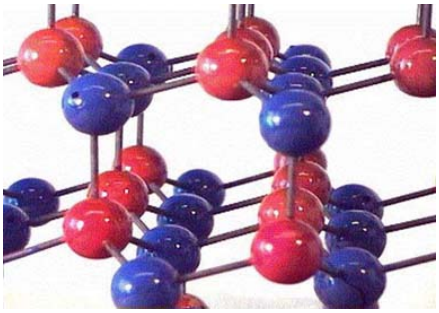
Crystals



Covalent bonds can be formed between atoms – shared electrons to fill shells

Treating the system as isolated atoms no longer valid:

bond lengths of 0.1-0.2nm yield lattice constants of ~0.3-0.5nm

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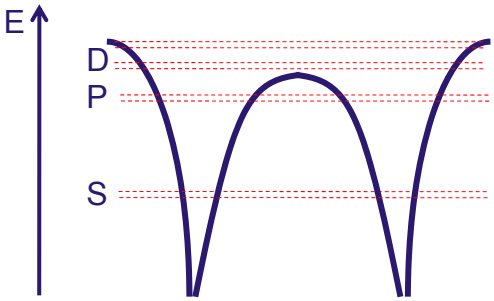
Two atoms interacting



Quantum mechanics (Pauli exclusion principle) does not allow identical states

→the two states split

How about in a crystal?

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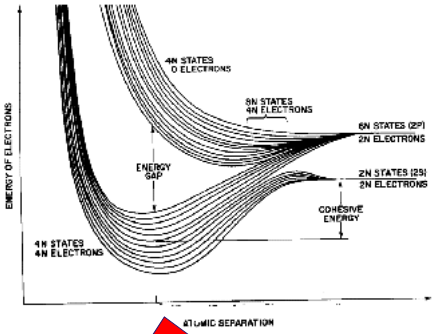
Formation of Energy Bands



Transition from

discrete energy levels in isolated atomic levels

to

quasi-continuous energy bands of a crystal

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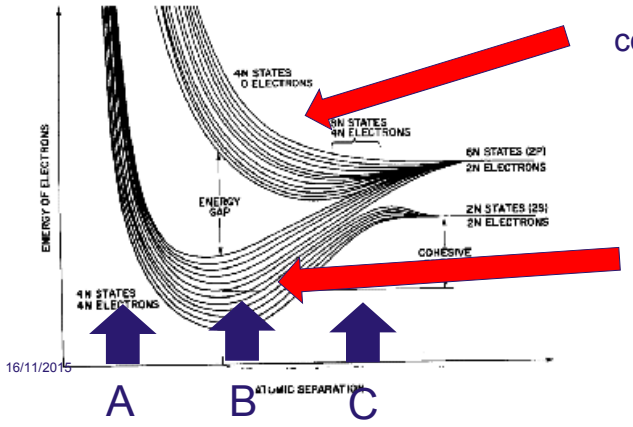
Energy Bands – Regimes



conduction band

valence band

16/11/2015

A B C

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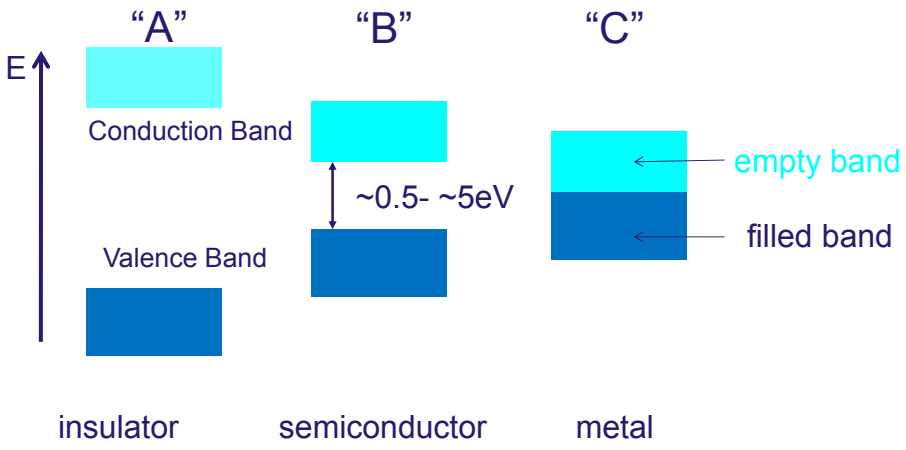
Classification of Solids



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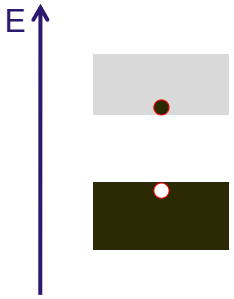
Rough Classification…

material	**resistivity (Ωm)**
Metal	10^{-8}
Semiconductor	variable
Insulator	10^{8}

semiconductors can change conduction properties with temperature, doping, bias…

Intrinsic Semiconductor



- For every electron excited to the conduction band (free electron) there is one free hole → $n=p=n_i$, where n= density free electrons, p=density free holes, n_i
- Total density of free carriers is given by $n+p=2n_i$
- Conductivity $\sigma = n_i q \mu_e + n_i q \mu_h$
- How big is n_i ?

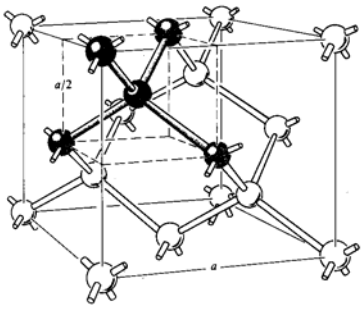
Intrinsic Carrier Density

- For a semiconductor – with no thermal energy (absolute zero: T=0) – no conduction electrons
- For a given electron if it has energy to promote it to the conduction band it can roam the crystal
- Number of free electrons n_i is given by;

$$n_i = C\ T^{3/2} \exp\left(-\frac{E_g}{2k_B T}\right)$$

where E_g is the band-gap energy, k_B is the Boltzmann constant , T is absolute temperature in Kelvin, C= const.

Crystalline Solids



unit cell of lattice constant "a" is the smallest unit which can be repeated to generate the crystal

Most semiconductors have either cubic or hexagonal lattices:
- **diamond lattice** for elemental semiconductors: C, Si, Ge
- **zinc blende** (sometimes also called **sphalerite**) for many cubic compound semiconductors: GaAs, InP etc
- **wurtzite** for hexagonal compounds: GaN etc.

Density ?

- Calculate the atomic number density and density of Si if
  - lattice constant $a=5.4\times10^{-10}$ m
  - diamond lattice
  - atomic weight =28.1
  - Avagadro's number = 6×10^{23}

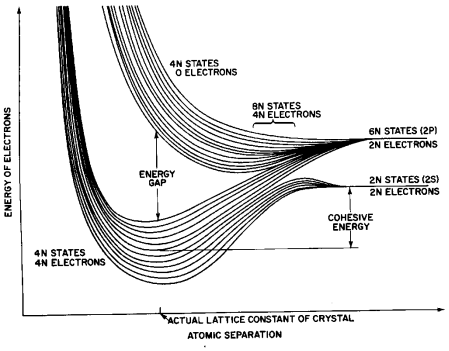
Working Out....

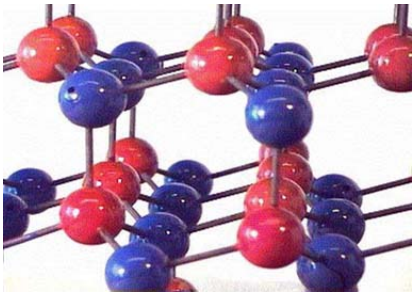
- Number $=8/a^3$ $= 8/(5.4\text{x}10^{-10})^3$

  $=5\text{x}10^{28}$ Atoms/m^3

$$\text{Density} = \frac{\left(\frac{\text{Atoms}}{\text{Vol}}\right)\left(\frac{\text{Kg}}{\text{Mole}}\right)}{\left(\frac{\text{Atoms}}{\text{Mole}}\right)} = \frac{(5\text{x}10^{28})(0.028)}{(6\text{x}10^{23})} = 2.33\text{x}10^{3}\,\text{Kgm}^{-3}$$

Band Structure





Energy distribution of states depends strongly on interatomic distance – Energy dependence with crystallographic direction

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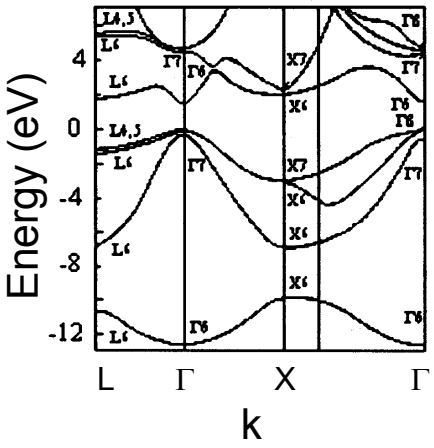
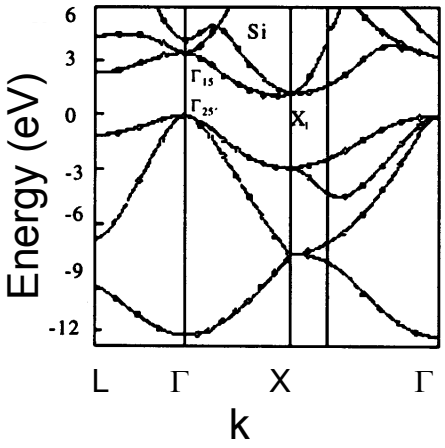
Band Structure (2)

GaAs



Si



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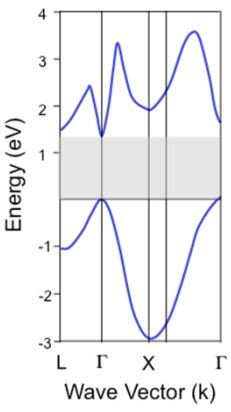
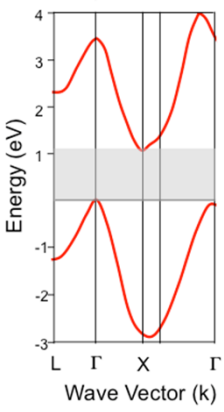
Band Structure (3)

GaAs



Si



Conduction Band

Valence Band

Γ $k_x = k_y = k_z = 0$

L $k_x = k_y = k_z = \pm\pi/a$

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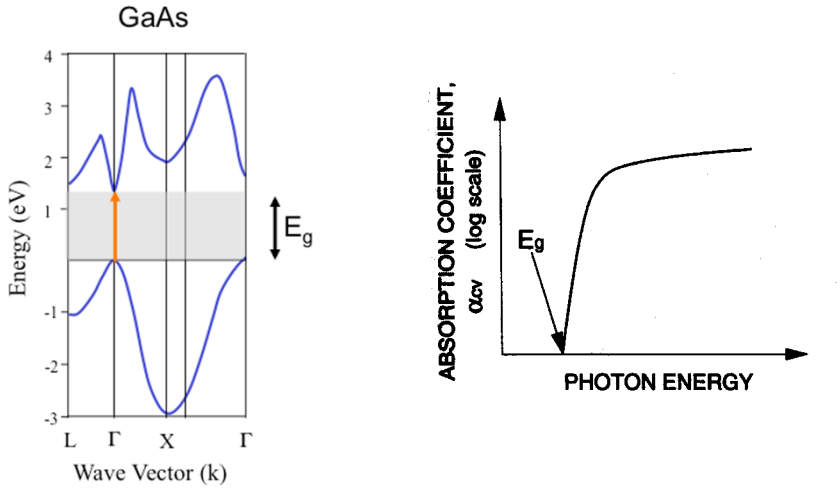
direct band-gap semiconductor



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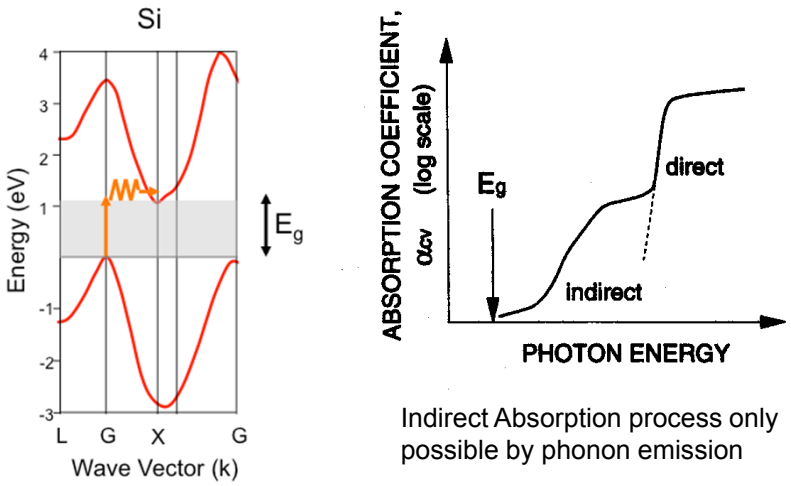
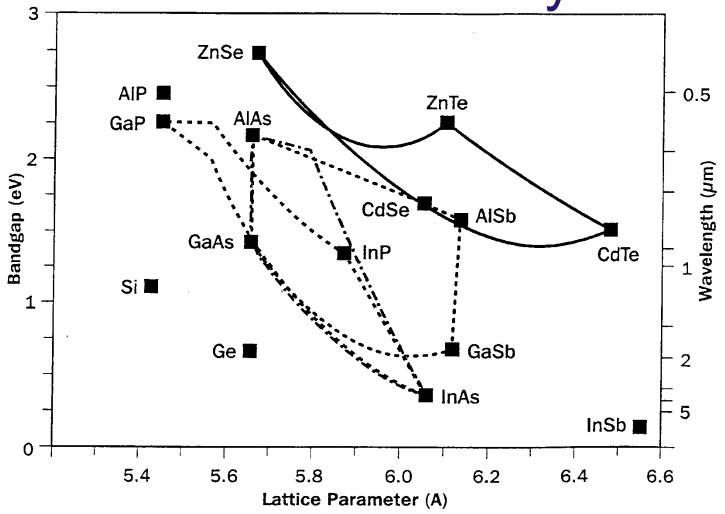
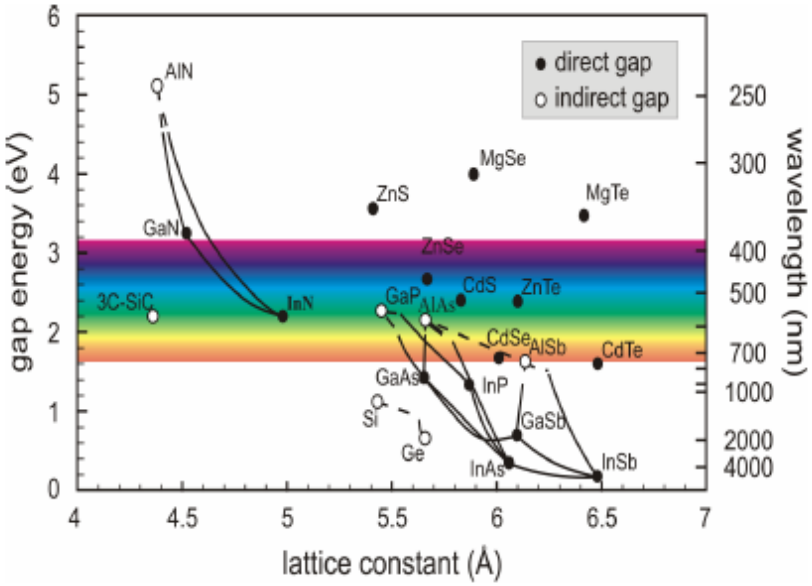
indirect band-gap



Indirect Absorption process only possible by phonon emission

cubic semiconductor crystals





include hexagonal GaN etc

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Summary

- introduced the course, syllabus, running order, policies, etc
- described the formation of a band-gap
- classification of solids – metal insulator, semiconductor
- calculation of atom density and intrinsic carrier density
- band structure, indirect and direct band-gap semiconductors