FYS3410 - Vår 2010 (Kondenserte fasers fysikk)

http://www.uio.no/studier/emner/matnat/fys/FYS3410/index-eng.xml

Based on Introduction to Solid State Physics by Kittel

Course content

- Periodic structures, understanding of diffraction experiment and reciprocal lattice
- Imperfections in crystals: diffusion, point defects, dislocations
- Crystal vibrations: phonon heat capacity and thermal conductivity
- Free electron Fermi gas: density of states, Fermi level, and electrical conductivity
- Electrons in periodic potential: energy bands theory classification of metals, semiconductors and insulators
- Semiconductors: band gap, effective masses, charge carrier distributions, doping, pn-junctions
- Metals: Fermi surfaces, temperature dependence of electrical conductivity

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FYS3410 lecture schedule and exams: Spring 2010

M/18/1/2010:	Introduction and motivation. Periodicity and lattices	2h
W/20/1/2010:	Index system for crystal planes. Crystal structures	1h
M/25/1/2010:	Reciprocal space, Laue condition and Ewald construction	2h
W/27/1/2010:	Interpretation of a diffraction experiment	1h
M/01/2/2010:	Crystal binding and introduction to elastic strain	2h
W/03/2/2010:	Point defects, case study – vacancies	1h
M/08/2/2010:	Point defects and atomic diffusion	2h
W/10/2/2010:	Diffusion (continuation); dislocations	1h
M/15/2/2010:	Crystal vibrations and phonons	2h
W/17/2/2010:	Crystal vibrations and phonons	1h
M/22/2/2010:	Planck distribution and density of states	2h
W/24/2/2010:	Debye model	1h
M/01/3/2010:	Einstein model and general result for density of states	2h
W/03/3/2010:	Thermal conductivity	1h
M/08/3/2010:	Free electron Fermi gas in 1D and 3D – ground state	2h
W/10/3/2010:	Density of states, effect of temperature – FD distribution	1h
M/15/3/2010:	Heat capacity of FEFG	2h
W/17/3/2010:	Repetition	1h
22/3/2010:	Mid-term exam	

M/14/4/2010:	Electrical and thermal conductivity in metals	2h
W/12/4/2010:	Bragg reflection of electron waves at the boundary of BZ	1h
M/19/4/2010:	Energy bands, Kronig - Penny model	2h
W/21/4/2010:	Empty lattice approximation; number of orbitals in a band	1h
M/26/4/2010:	Semiconductors, effective mass method, intrinsic carriers	2h
W/28/4/2010:	Impurity states in semiconductors and carrier statistics	1h
M/03/5/2010:	p-n junctions and heterojunctions	2h
W/05/5/2010:	surface structure, surface states, Schottky contacts	2h
M/10/5/2010:	no lectures	
W/12/5/2010:	no lectures	
W/19/5/2010:	Repetition	2h
W26/5/2010:	Repetition	2h

28/5/2010: Final Exam (sensor: Prof. Arne Nylandsted Larsen at the Århus University, Denmark, http://person.au.dk/en/anl@phys.au.dk)

Introduction and motivation. Periodicity and lattices

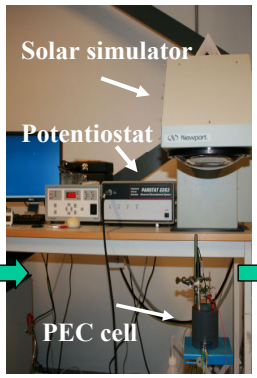
- examples of on-going research at the MiNaLab and how the progress is supported by understanding of condenced matter physics (slides);
- importance of periodicity illustrated by wave diffraction in crystalls (blackboard)
- assuming the motivation to study periodical structures is established, basic symmetry deffinitions are introduced (slides & blackboard)

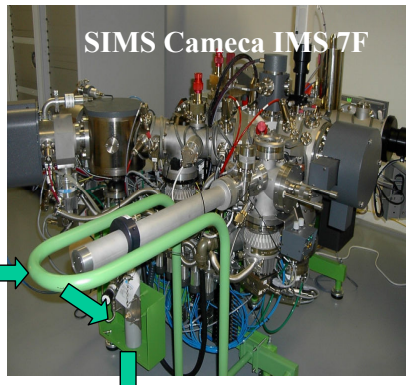
MiNaLab-UiO

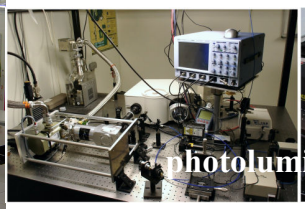
Micro- and Nanotechnology Laboratory (MiNaLab) includes 1400 m^2 clean room area in total of which UiO dispose 400 m^2.

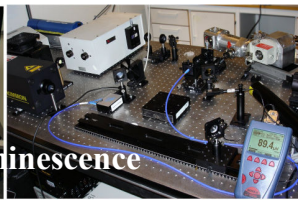
UiO clean room area

Labs







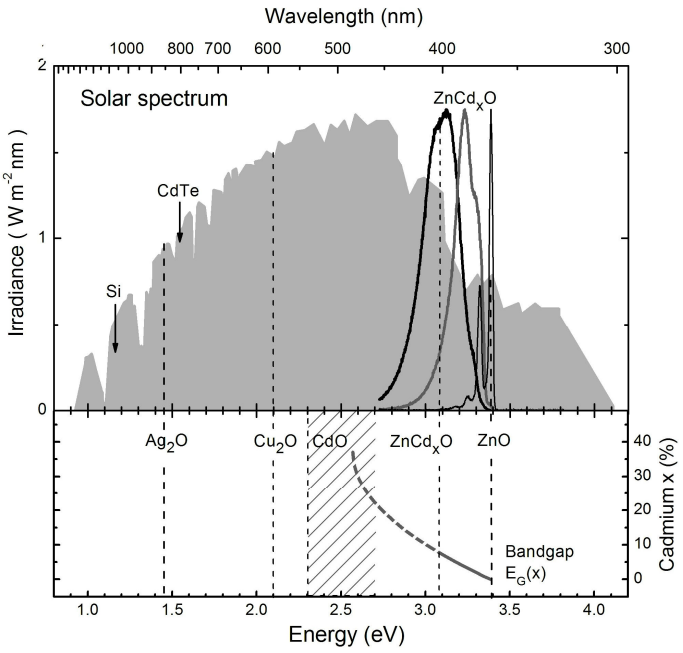


Single-photon sensitive time-resolved imaging-spectroscopy

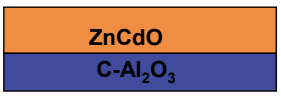
Conventional lock-in low-temperature spectroscopy

capacitance spectroscopy (DLTS, TSCAP,…), CV/IV measurements, AFM, FTIR, life-time tester, etc.

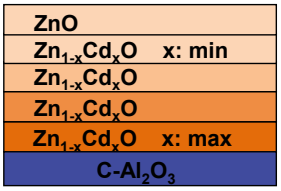
Mastering semiconductor multi-junctions to improve the efficiency of solar cells



Schematic of the structures studied



single layer



multilayer

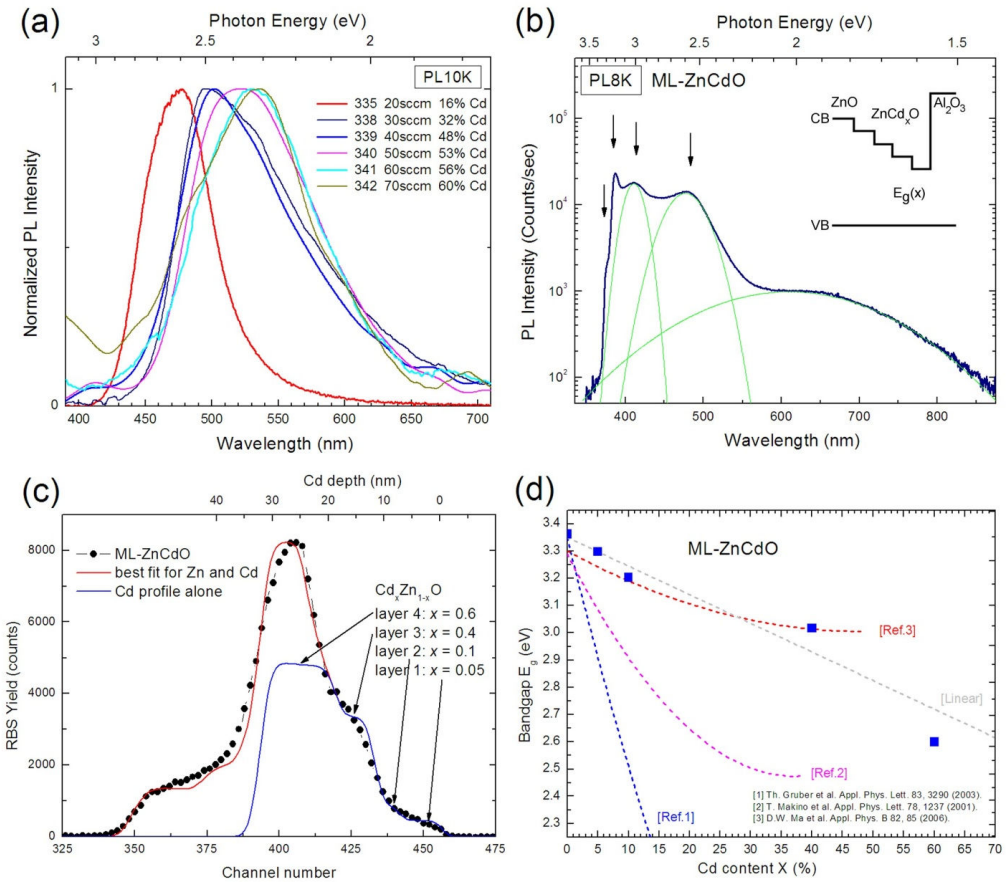
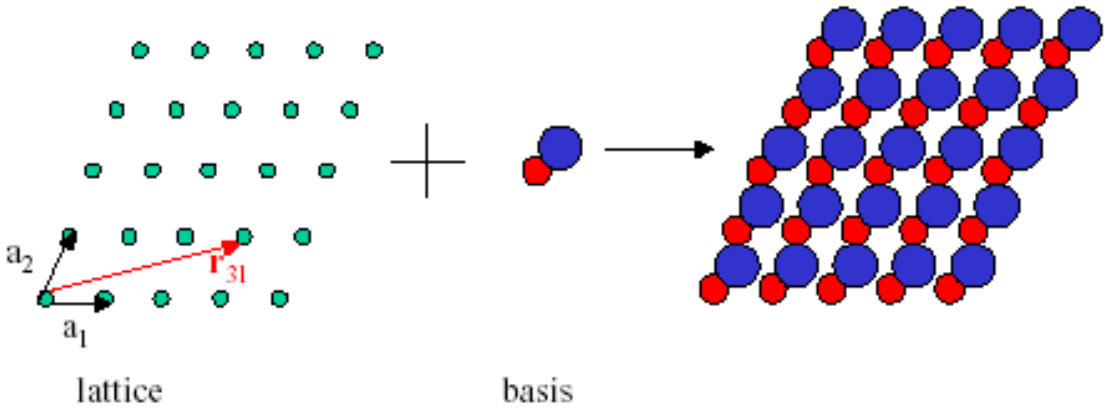


FIG.1. (a) Typical photoluminescence (PL) spectra from ZnCdO films as a function of Cd content; (b) PL spectrum of a ML-structure as recorded at 8K with a schematics of the band gap in the inset; (c) Cd profile through ML-structure as measured by RBS; (c) our results in the context of literature.

Crystal structure I

- In bulk, many solids are crystalline.
- Have discrete translational and rotational symmetries.
- Real-space structure is periodic - repetitions of a single *unit cell*.
- Smallest unit cell that gives full structure: *primitive unit cell*
- Can describe structure by a *lattice* and a *basis*.



Ideal Crystal

- An ideal crystal is a periodic array of structural units, such as atoms or molecules.
- It can be constructed by the *infinite repetition* of these identical structural units in space.
- Structure can be described in terms of a *lattice*, with a group of atoms attached to each lattice point. The group of atoms is the basis.

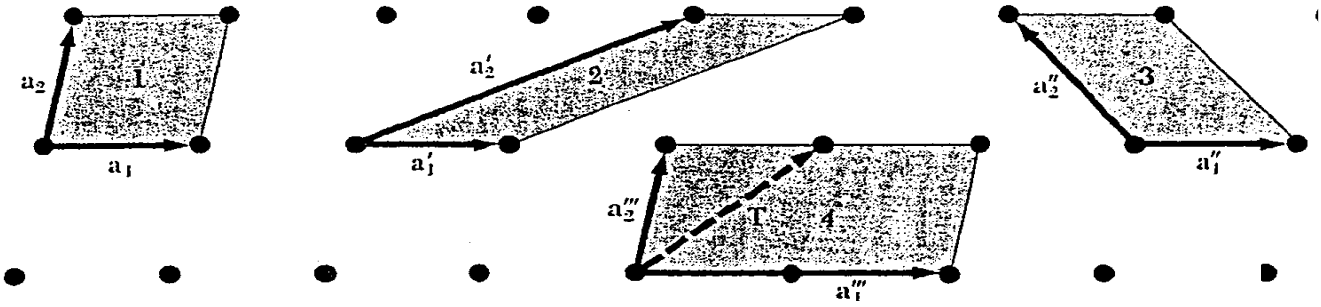
Bravais Lattice

- An infinite array of discrete points with an arrangement and orientation that appears exactly the same, from any of the points the array is viewed from.
- A three dimensional Bravais lattice consists of all points with position vectors R that can be written as a linear combination of *primitive vectors.* The expansion coefficients must be *integers*.

Primitive Unit Cell

- A *primitive cell* or primitive unit cell is a volume of space that when translated through all the vectors in a Bravais lattice just fills all of space without either overlapping itself or leaving voids.
- A primitive cell must contain precisely one lattice point.

Crystal structure II



Primitive (a_1,a_2) and not primi $_2$''') translation vectors

Wigner-Seitz Primitive Cell: Full symmetry of Bravais Lattice

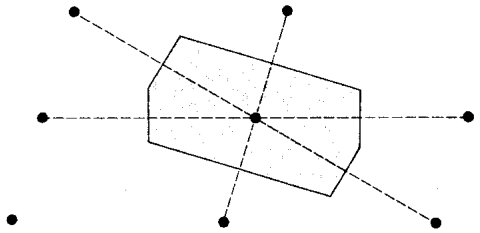
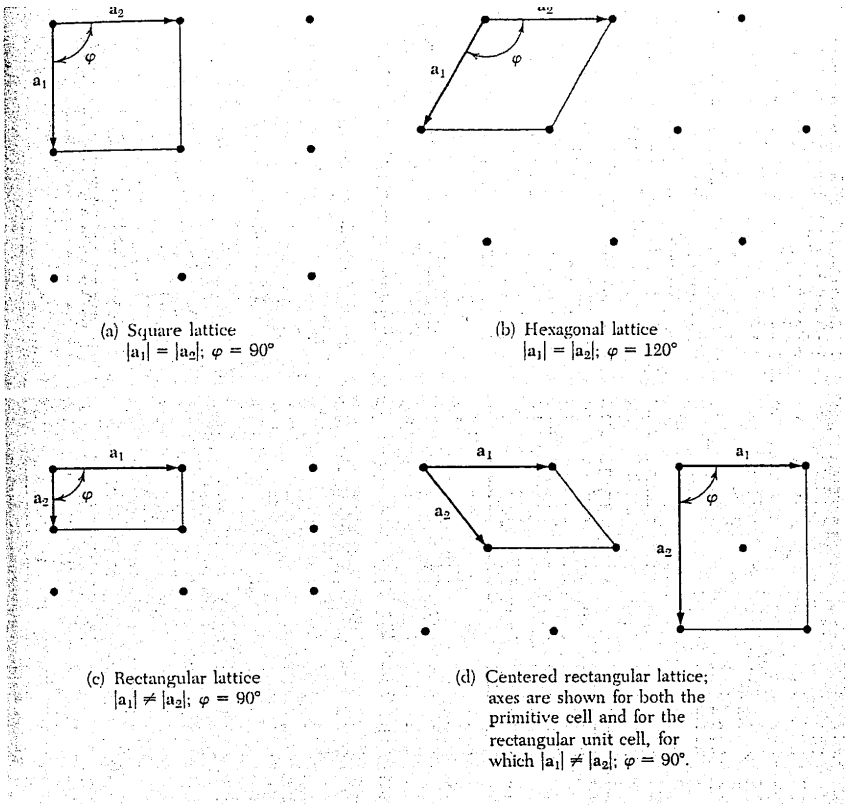
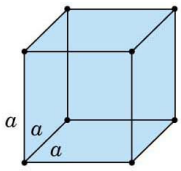


Figure 4.14
The Wigner-Seitz cell for a two-dimensional Bravais lattice. The six sides of the cell bisect the lines joining the central points to its six nearest neighboring points (shown as dashed lines). In two dimensions the Wigner-Seitz cell is always a hexagon unless the lattice is rectangular (see Problem 4a).

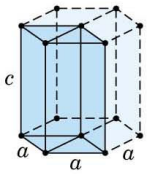


2-D lattices

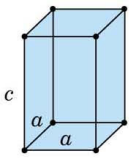
3-D lattices



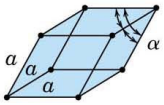
Cubic
a=b=c
α=β=γ=90°



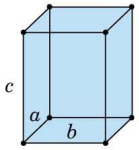
Hexagonal
a=b≠c
α=β= 90° ; γ=120°



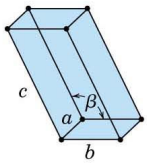
Tetragonal
a=b≠c
α=β=γ=90°



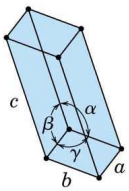
Rhombohedral
a=b=c=
α=β=γ≠90°



Orthorhombic
a≠b≠c
a=b=g=90°



Monoclinic
a≠b≠c
α=γ=90°≠β



Triclinic
a≠b≠c
α≠β≠γ≠90°

Primitive Cell: FCC Lattice

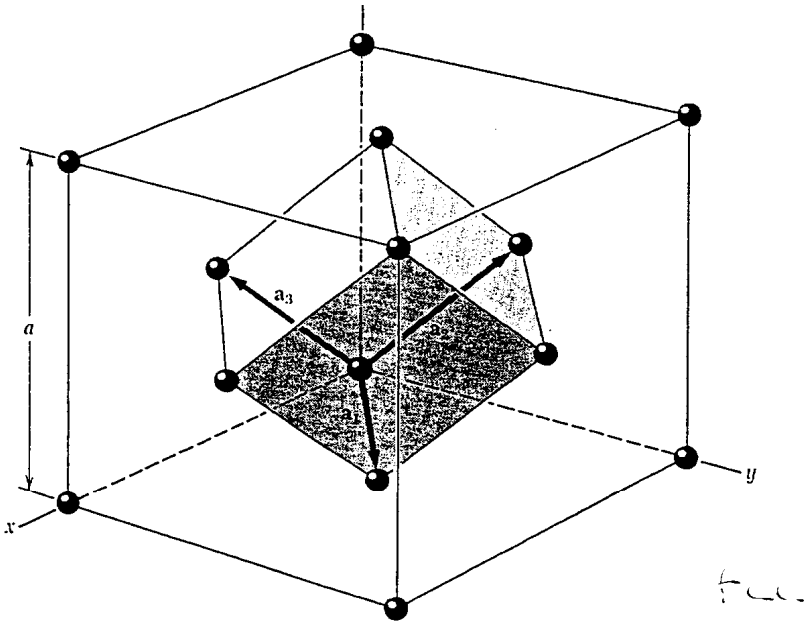


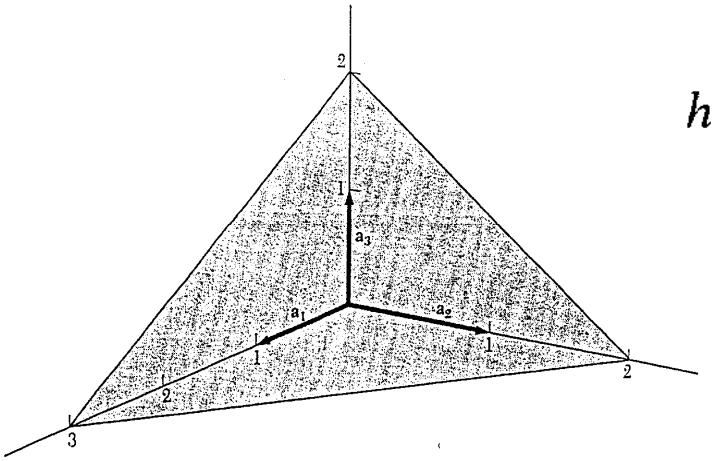
Figure 13 The rhombohedral primitive cell of the face-centered cubic crystal. The primitive translation vectors $\mathbf{a}_1$, $\mathbf{a}_2$, $\mathbf{a}_3$ connect the lattice point at the origin with lattice points at the face centers. As drawn, the primitive vectors are:

$$\mathbf{a}_1 = \tfrac{1}{2}a(\hat{\mathbf{x}} + \hat{\mathbf{y}}) \; ; \qquad \mathbf{a}_2 = \tfrac{1}{2}a(\hat{\mathbf{y}} + \hat{\mathbf{z}}) \; ; \qquad \mathbf{a}_3 = \tfrac{1}{2}a(\hat{\mathbf{z}} + \hat{\mathbf{x}}) \; .$$

The angles between the axes are 60°. Here $\hat{\mathbf{x}}$, $\hat{\mathbf{y}}$, $\hat{\mathbf{z}}$ are the Cartesian unit vectors.

Miller indices of lattice planes

- **The indices of a crystal plane (h,k,l) are defined to be a set of integers with no common factors, inversely proportional to the intercepts of the crystal plane along the crystal axes:**



$$h:k:l = \frac{1}{x_1} : \frac{1}{x_2} : \frac{1}{x_3}$$

Figure 15 This plane intercepts the a_1, a_2, a_3 axes at $3a_1$, $2a_2$, $2a_3$. The reciprocals of these numbers are $\frac{1}{3}$, $\frac{1}{2}$, $\frac{1}{2}$. The smallest three integers having the same ratio are 2, 3, 3, and thus the indices of the plane are (233).

Indices of Planes: Cubic Crystal

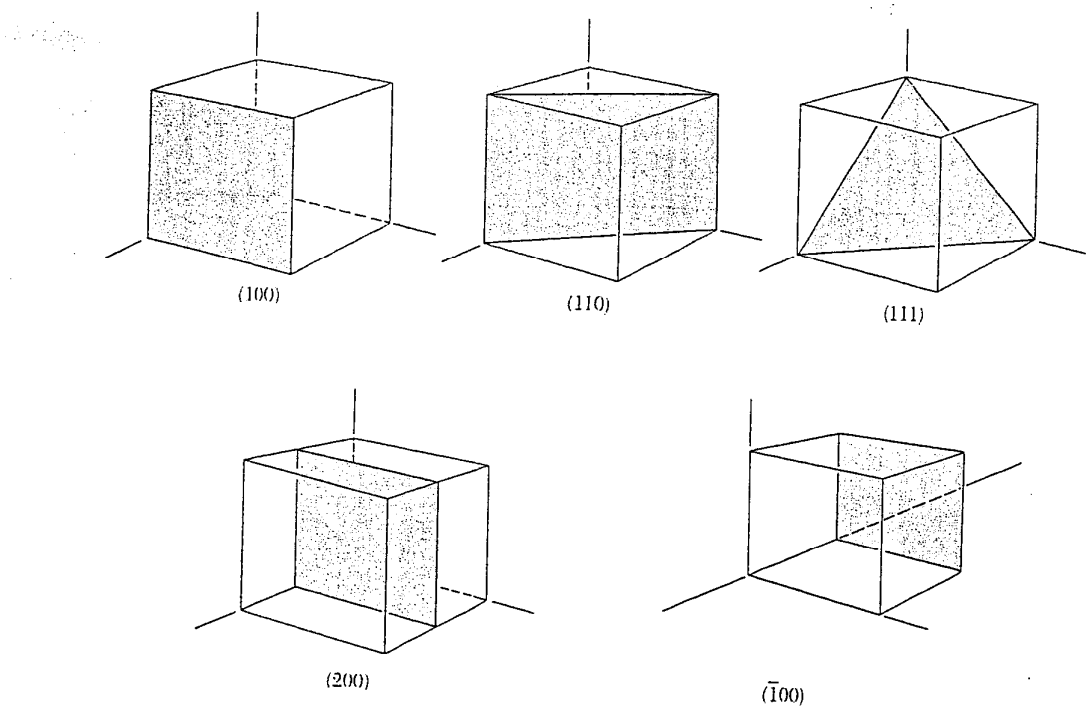


Figure 16 Indices of important planes in a cubic crystal. The plane (200) is parallel to (100) and to (1̄00).