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
- Crystal binding, elastic strain and waves
- Imperfections in crystals: point defects and diffusion
- 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:	Brillouin Zones. Interpretation of a diffraction experiment	1h
M/01/2/2010:	Crystal binding, elastic strain and waves	2h
W/03/2/2010:	Elastic waves in cubic crystals; defects in crystals	1h
M/08/2/2010:	Defects in crystals; case study - vacancies	2h
W/10/2/2010:	Diffusion	1h
M/15/2/2010:	Crystal vibrations and phonons	2h
W/17/2/2010:	Crystal vibrations and phonons	1h
M/22/2/2010:	Lattice heat capacity: Dulong-Petit and Einstein models	2h
W/24/2/2010:	Phonon density of states (DOS) and Debye model	1h
M/01/3/2010:	General result for DOS; role of anharmonic interactions	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 and thermal conductivity of FEFG	2h
W/17/3/2010:	Repetition	1h
22/3/2010:	Mid-term exam	

M/12/4/2010:	Drude model and the idea of energy bands	2h
W/14/4/2010:	Nearly free electron model; Kronig - Penny model	2h
M/19/4/2010:	no lectures	
W/21/4/2010:	Empty lattice approximation; number of orbitals in a band	2h
M/26/4/2010:	Semiconductors, effective mass method, intrinsic carriers	2h
W/28/4/2010:	Impurity states in semiconductors and carrier statistics	2h
M/03/5/2010:	p-n junctions and heterojunctions	2h
W/05/5/2010:	surface structure, surface states, Schottky contacts	1h
M/10/5/2010:	Metals and Fermi surfaces	2h
W/12/5/2010:	no lectures	
W/19/5/2010:	no lectures	
W26/5/2010:	Repetition	2h
27-28/5/2010:	Final Exam (sensor: Prof. Arne Nylandsted Larsen at the Aarhus University, Denmark, http://person.au.dk/en/anl@phys.au.dk)	

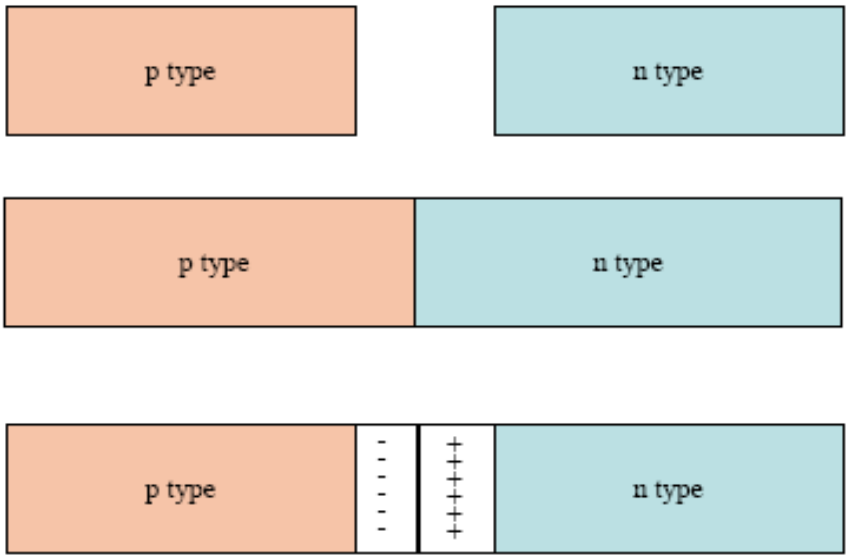
Lecture 25: surface structure, surface states, Schottky contacts

- Repetion: p-n junctions in equilibrium and applied bias
- Surface structure
- Surface states
- Schottky diodes

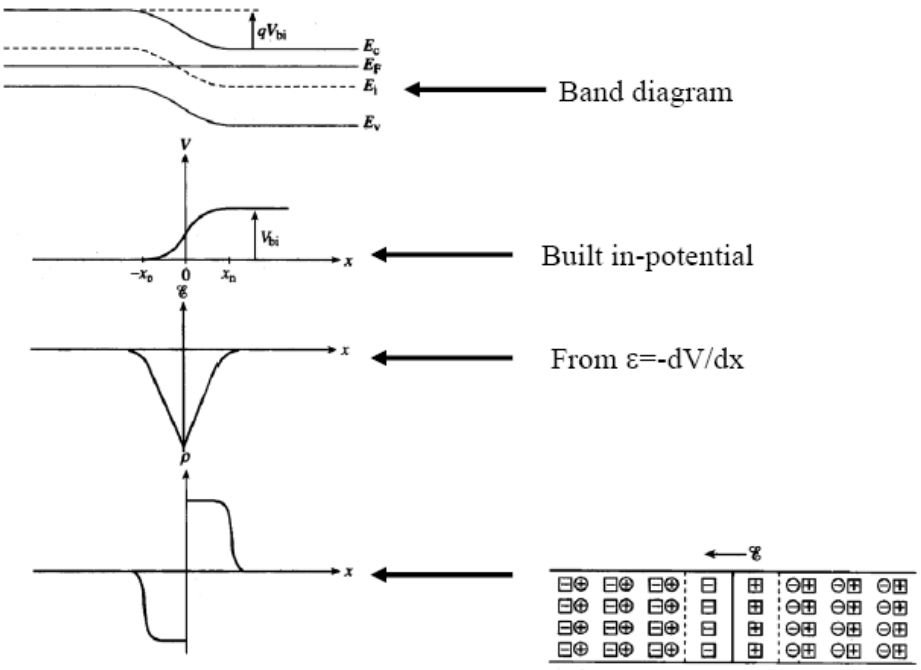
Lecture 25: surface structure, surface states, Schottky contacts

- **Repetion: p-n junctions in equilibrium and applied bias**
- **Surface structure**
- **Surface states**
- **Schottky diodes**

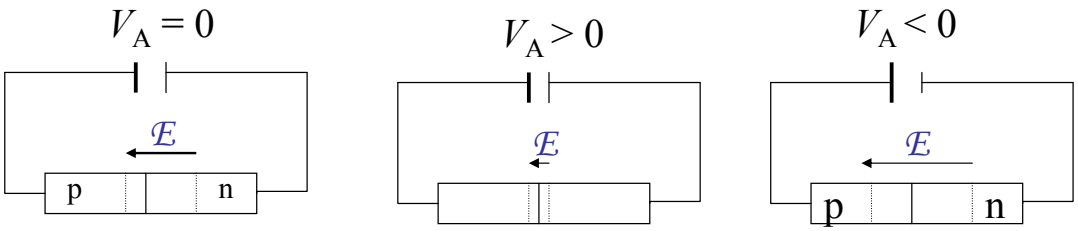
p-n junctions: two identical materials having different movable charge particle on each side



p-n junctions: electrostatics



p-n junctions: forward/reverse bias



Hole diffusion current

Hole drift current

Electron diffusion current

Electron drift current

Hole diffusion current

Hole drift current

Electron diffusion current

Electron drift current

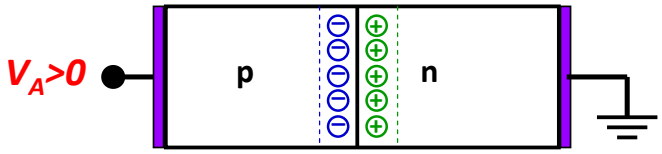
Hole diffusion current

Hole drift current

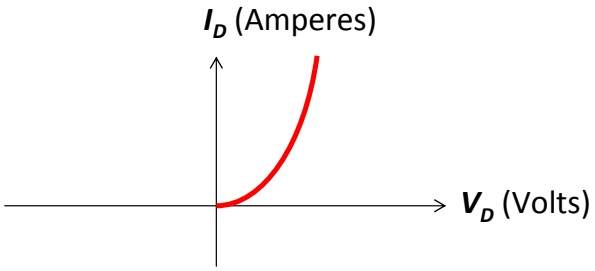
Electron diffusion current

Electron drift current

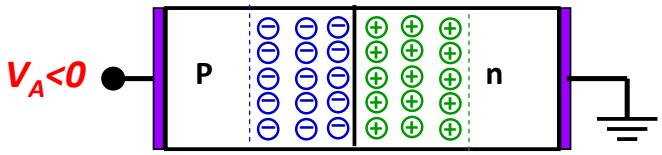
p-n junctions: forward bias



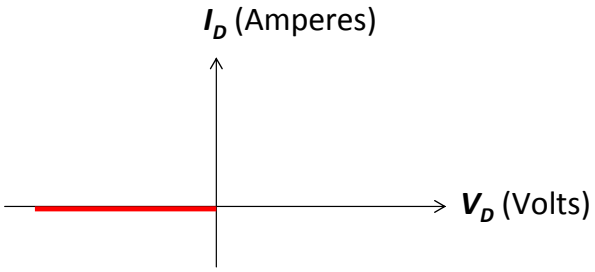
$$\frac{p_{\mathrm{p}}}{p_{\mathrm{n}}} = \mathrm{e}^{\frac{q(V_0 - V_{\mathrm{A}})}{kT}}$$



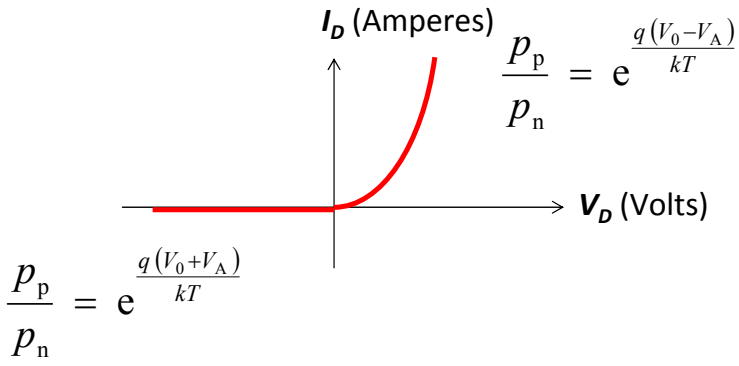
p-n junctions: reverse bias



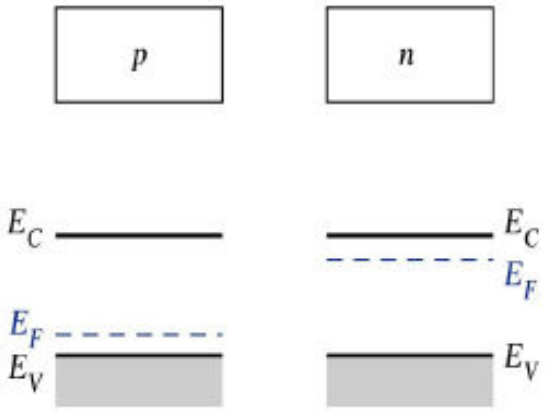
$$\frac{p_{\mathrm{p}}}{p_{\mathrm{n}}} = \mathrm{e}^{\frac{q(V_0 + V_{\mathrm{A}})}{kT}}$$



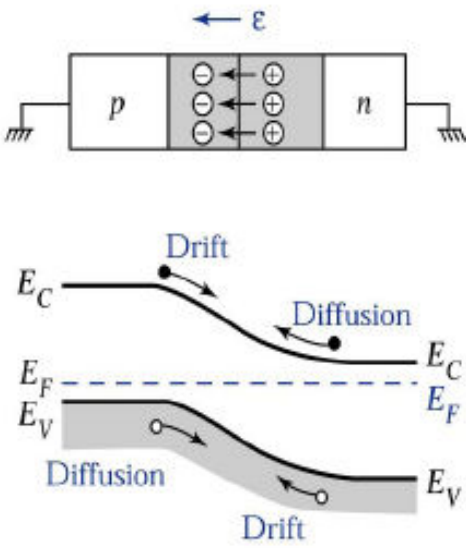
p-n junctions: rectification



p-n junctions: summary



Uniformly doped p-type and n-type semiconductors before the junction is formed.



Internal electric-field occurs in a depletion region of a p-n junction in thermal equilibrium

Lecture 25: surface structure, surface states, Schottky contacts

- Repetion: p-n junctions in equilibrium and applied bias
- **Surface structure**
- Surface states
- Schottky diodes

Surface structure: some initial ideas

- **surface is where the crystal periodicity is interrupted and chemical bonds are broken**
- **surface affects a few outermost atomic layers of the crystal – surface region**
- **properties of the surface differ significantly from the bulk**
- **energy needed to break the bonds, so energy is needed to create a surface – surface energy**
- **Broken covalent bonds are called dangling bonds**

Surface structure: surface energy

- **Surface energy is always positive, since energy is needed to break bonds**
  - **Surface always tries to minimize its energy, i.e. reduce the number of dangling bonds**
  - **Surface chemically and electrically more active due to dangling bonds**

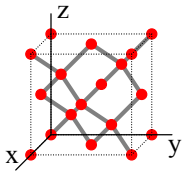
- **Two mechanisms for minimizing surface energy when in ultrahigh vacuum**
  - **Surface relaxation**
  - **Surface reconstruction**

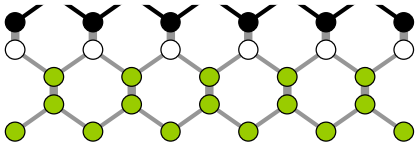
Surface structure: surface relaxation

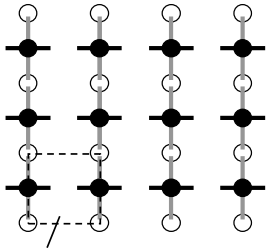
- **Interlayer distance is changed between the 1^{st} and 2^{nd} layers of atoms at the surface**
  - **To minimize surface energy**
  - **The interlayer distance is often reduced**
  - **In a few cases the distance increases**
  - **Advanced theory needed to understand**
  - **Many metals experience surface relaxation**

Surface structure: surface reconstruction

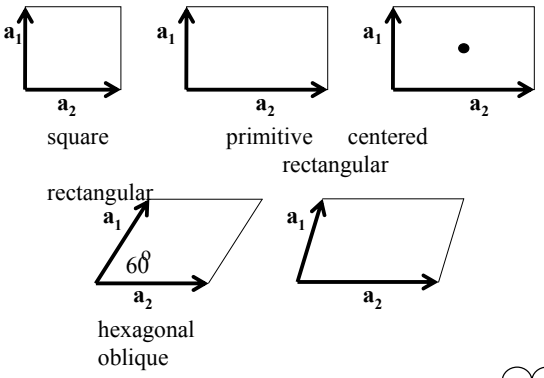
- **Surface atoms form a different structure than the bulk atoms**
  - **The new structure is constrained by the bulk structure**
  - **The unit cell in the new structure is different from the bulk unit cell**
  - **Si(001) as an example**
    - **Diamond structure**
    - **Two dangling bonds per surface atom**
    - **2-D unit cell with lattice constant $(2)^{1/2}a/2$**







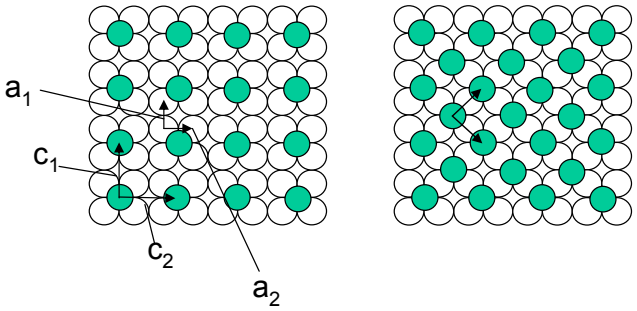
Surface structure: surface crystallography



$$(\frac{c_1}{a_1}\times\frac{c_2}{a_2})R\alpha$$

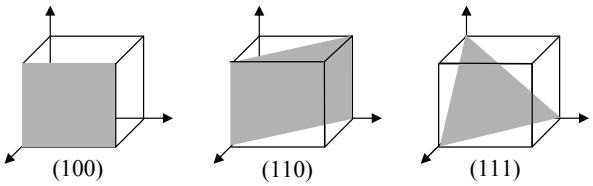
(2x2)

$(\sqrt{2}\times\sqrt{2})R45^\circ$

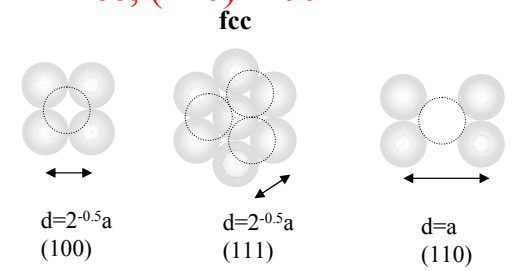


Surface structure: surface crystallography

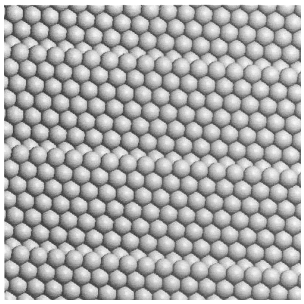
$$\vec{H} = h\vec{x} + k\vec{y} + l\vec{z}$$



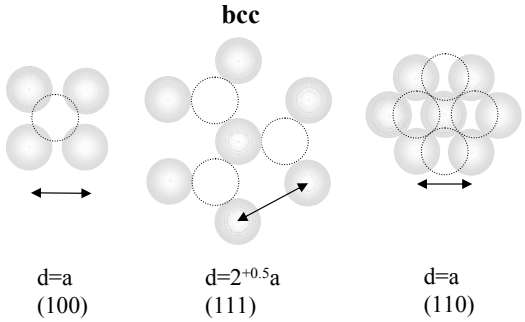
Surface density:
fcc, (111)>100>110
fcc, (110)>100>111



Stepped surfaces



fcc (755)



Surface states: origin

- **There exist electronic states on a semiconductor surface – surface states**
  - **The electronic states are bound to the surface**
  - **Their energy levels are within the band gap of the bulk semiconductor**
- **Dangling bonds are the origin of surface states**
  - **A dangling bond can donate its lone electron or accept another electron**
  - **It is both a donor and an acceptor**
- **Doping the surface region difficult due to compensation**
  - **Surface Fermi level doesn't move when doped – Fermi-level pinning**
  - **surface Fermi level is pinned**
  - **Since the Fermi level is horizontal, the energy bands are bent**

Surface states and Schottky barriers

- When a semiconductor is brought into contact with a metal, a Schottky junction is usually formed
- A n-type semiconductor with no surface states
  - Electrons flow from semiconductor to metal, leaving behind positive charge
  - An electric field is created pointing from semiconductor to metal
  - At interface $\phi_m - \chi$ is fixed

$$\phi_{Bn} = \phi_m - \chi$$

Surface states and Schottky barriers

- A real semiconductor surface has surface states (interface traps), which pin the surface (interface) Fermi level to a fixed point
  - Schottky barrier height less dependent on metal work function

$$\phi_{Bn} \neq \phi_m - \chi$$

- Schottky junction on p-type semiconductor

$$\phi_{Bp} = \chi + E_g - \phi_m$$