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:	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)

Lecture 9: Diffusion

- Phenomenology of diffusion: describing diffusion in terms of diffusion flux
- Microscopic diffusion mechanisms
- Sb diffusion as a function of temperature as stress in Si/SiGe heterostructures

Lecture 9: Diffusion

- **Phenomenology of diffusion: describing diffusion in terms of diffusion flux**
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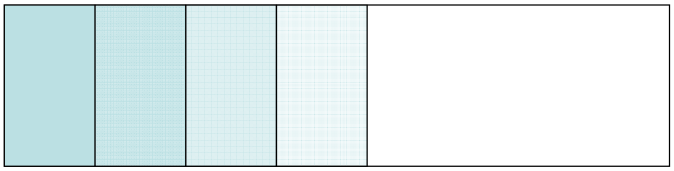
Diffusion

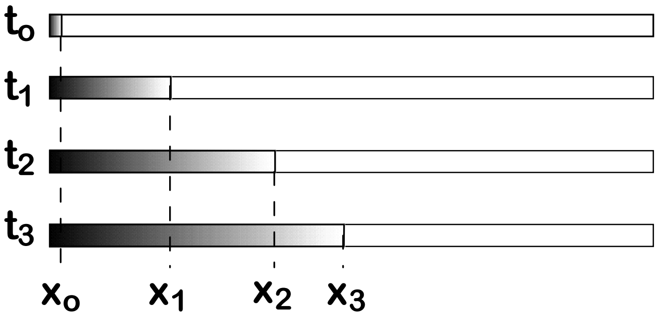
Phenomenon of material transport by atomic or particle transport from region of high to low concentration

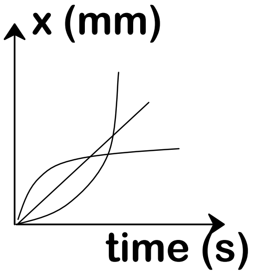


- What forces the particles to go from left to right?
- Does each particle “know” its local concentration?
- Every particle is equally likely to go left or right!
- At the interfaces in the above picture, there are **more** particles going right than left ➔ this causes an average “flux” of particles to the right!
- Largely determined by probability & statistics

Diffusion

- Glass tube filled with water.
- At time t = 0, add some drops of ink to one end of the tube.
- Measure the diffusion distance, x, over some time.



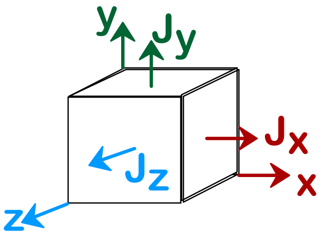


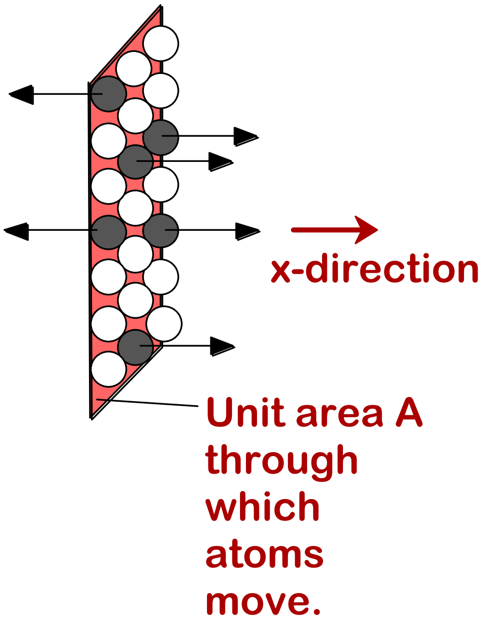
Describing diffusion in terms of diffusion flux

- Flux: amount of material or atoms moving past a unit area in unit time
  Flux, J = ΔM/(A Δt)

$$J = \frac{1}{A}\frac{dM}{dt} \Rightarrow \left[\frac{kg}{m^2 s}\right] \text{ or } \left[\frac{atoms}{m^2 s}\right]$$

- Directional Quantity

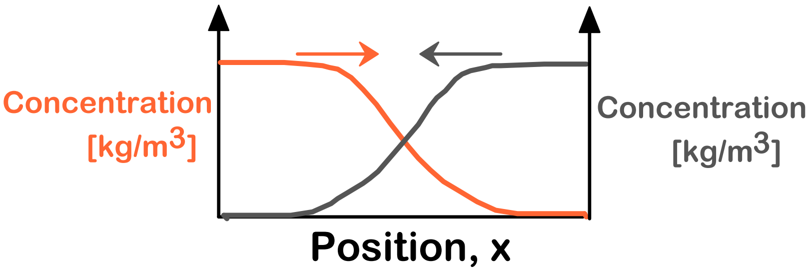




- Flux can be measured for:
  - --vacancies
  - --host (A) atoms
  - --impurity (B) atoms

Describing diffusion in terms of diffusion flux

- Concentration Profile, C(x): [kg/m^3]



- Fick's First Law:

$$J_x = -D\frac{dC}{dx}$$

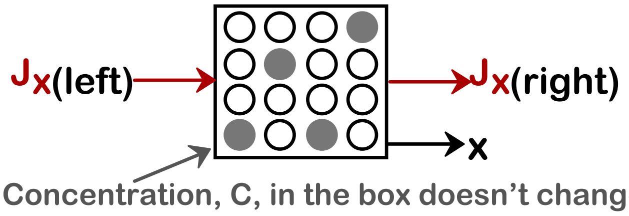
flux in x-dir. [kg/m^2-s]

Diffusion coefficient [m^2/s]

concentration gradient [kg/m^4]

Describing diffusion in terms of diffusion flux

- Steady State: Steady rate of diffusion from one end to the other. Implies that the concentration profile doesn't change with time. Why?



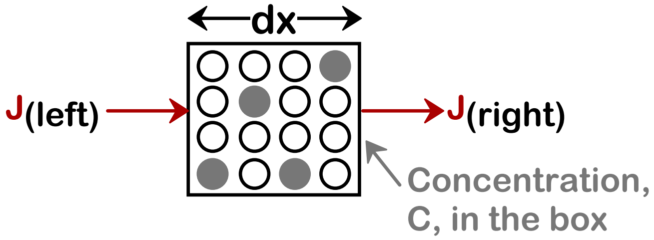
Steady State:

J_x(left) = J_x(right)

- Apply Fick's First Law: $J_x = -D\frac{dC}{dx}$
- If $J_x)_{left} = J_x)_{right}$, then $\left(\frac{dC}{dx}\right)_{left} = \left(\frac{dC}{dx}\right)_{right}$
- Result: the slope, dC/dx, must be constant (i.e., slope doesn't vary with position)!

Describing diffusion in terms of diffusion flux

- Concentration profile, C(x), changes w/ time.



- To conserve matter:

$$\boxed{\frac{J(\text{right}) - J(\text{left})}{dx}} = -\frac{dC}{dt}$$

$$\boxed{\frac{dJ}{dx}} = -\frac{dC}{dt}$$

- Fick's First Law:

$$J = -D\frac{dC}{dx}$$

$$\boxed{\frac{dJ}{dx}} = -D\frac{d^2C}{dx^2}$$ (if D does not vary with x)

equate

- Governing Eqn.:

$$\boxed{\frac{dC}{dt} = D\frac{d^2C}{dx^2}}$$ Fick's second law

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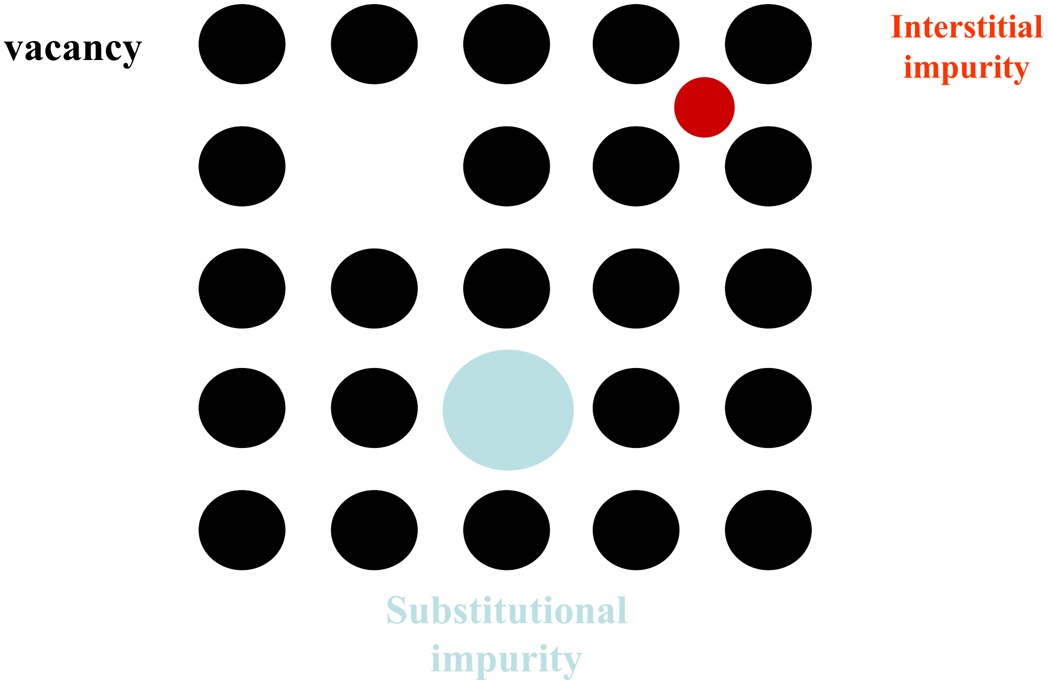
Lecture 9: Diffusion

- Phenomenology of diffusion: describing diffusion in terms of diffusion flux
- Microscopic diffusion mechanisms
- Sb diffusion as a function of temperature as stress in Si/SiGe heterostructures

Type of point defects



Diffusion mechanisms

Diffusion at the atomic level is a step-wise migration of atoms from lattice site to lattice site

Conditions for diffusion:

- there must be an adjacent empty site
- atom must have sufficient energy to break bonds with its neighbors and migrate to adjacent site (“activation” energy)

Higher the temperature, higher is the probability that an atom will have sufficient energy

➔ hence, diffusion rates increase with temperature

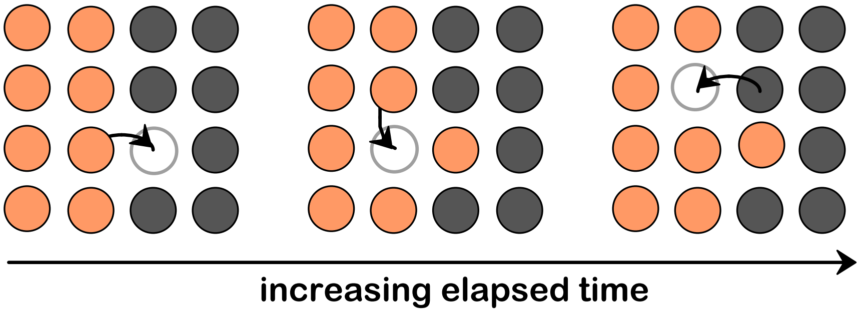
Types of atomic diffusion mechanisms:

- substitutional (through vacancies)
- interstitial

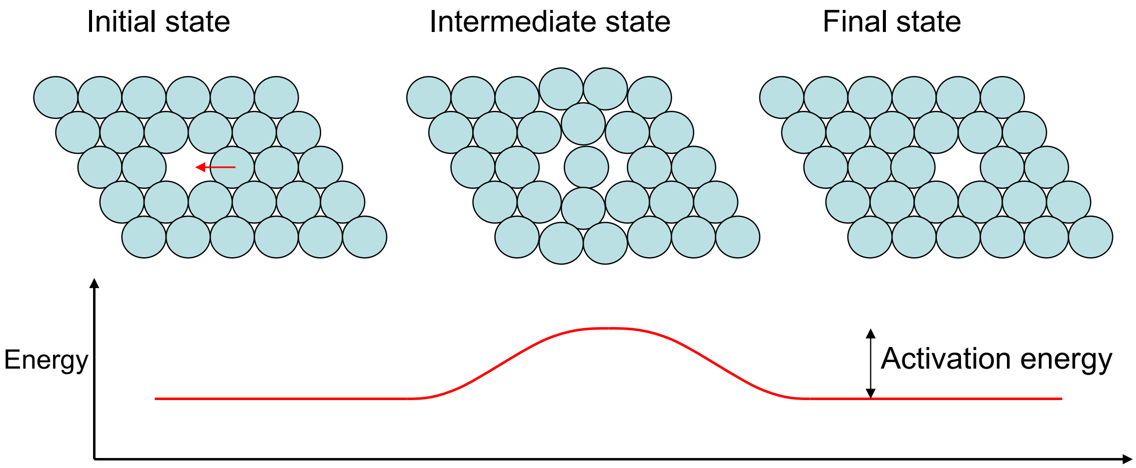
Diffusion mechanisms

Substitutional Diffusion:

- applies to substitutional impurities
- atoms exchange with vacancies
- rate depends on:
  -- number of vacancies
  -- temperature
  -- activation energy to exchange.



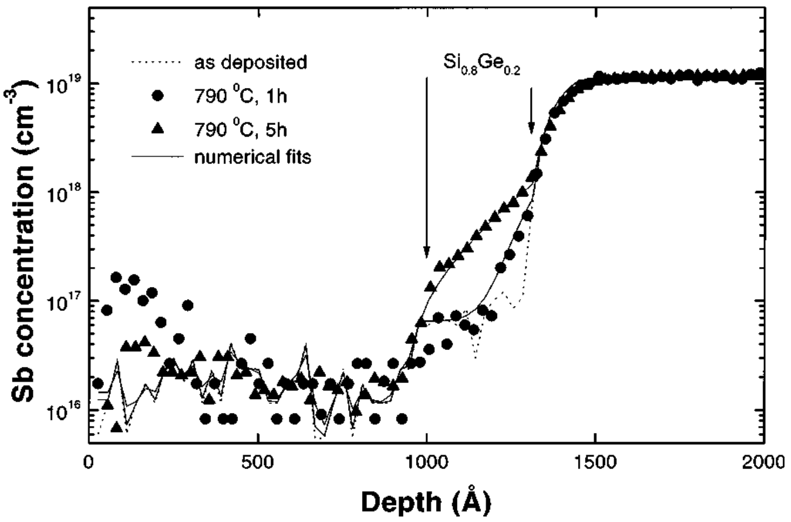
Diffusion mechanisms

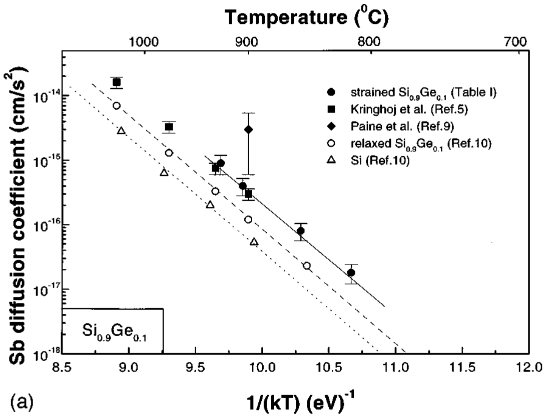


- Also called energy barrier for diffusion

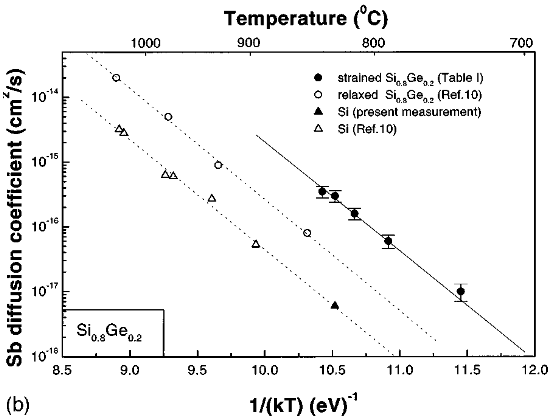
Lecture 8: Diffusion

- Phenomenology of diffusion: describing diffusion in terms of diffusion flux
- Microscopic diffusion mechanism
- **Sb diffusion as a function of temperature as stress in Si/SiGe heterostructures**



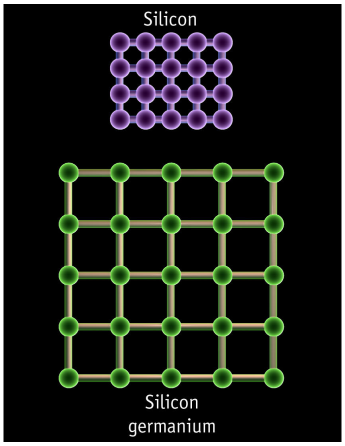


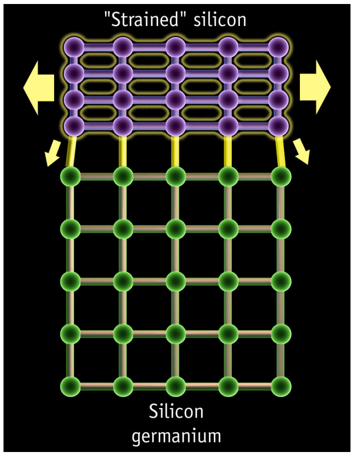
(a)



(b)

Strained silicon





- How does it work?
- Basic idea: Change the lattice constant of material