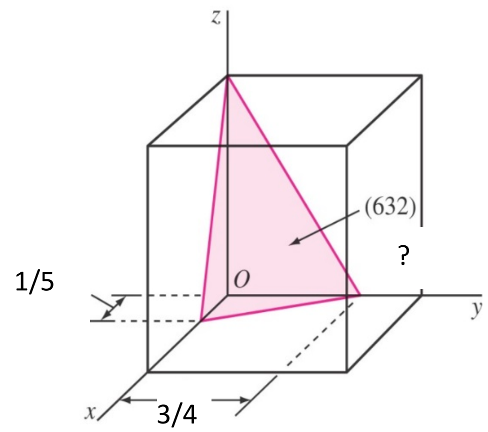
# Answers to exam in Materialteknik Z (2019-10-30)

## 1. Interatomic bonding and Miller indices (6 P)

a) Ceramics do ionic bonding and semiconductors covalent bonding. For details see course book. (2 P)

b) Miller indices, for
   (i) a specific crystallographic plane (hkl)
   (ii) a specific crystallographic direction [uvw]
   (iii) a family of planes {hkl}
   (iv) a family of directions <uvw> (1 P)

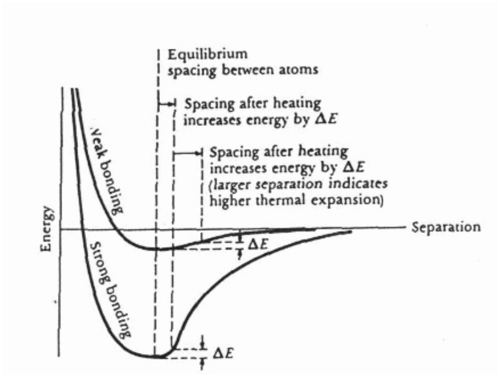
d) Give the Miller indices of the plane sketched below: (1 P)




| | x | y | z |
|---|---|---|---|
| Intercepts in terms of lattice parameters | 1/5 | 3/4 | 1 |
| Reciprocals | 5 | 4/3 | 1 |
| Reduction | 15 | 4 | 3 |

Enclosure (Miller indices): (15 4 3)

e) Potential energy-versus-interatomic separation curve for strongly and weakly bonded material:

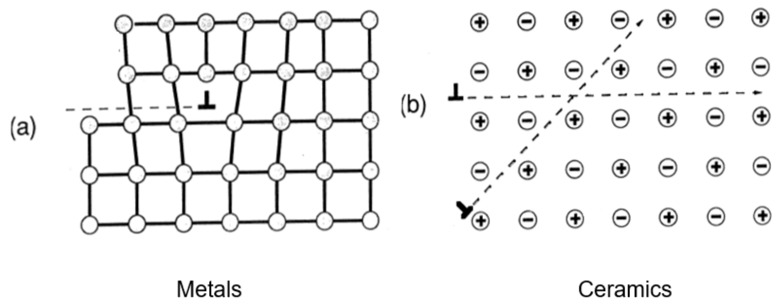



(2 P)

## 2. Mechanical properties (7 P)

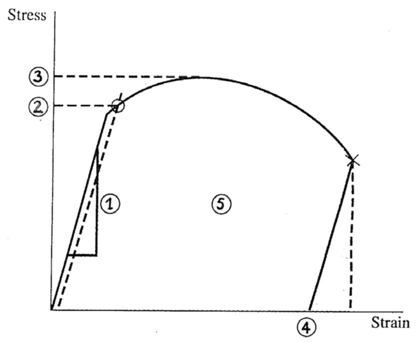
a) Strengthening mechanisms: Grain size strengthening, Precipitation strengthening, Solid solution strengthening, work hardening. Explanation see textbook/slides. (2 P)

b) Copper is a metal (metallic bonding) and dislocations can move in high-atomic-density planes and in high-atomic-density directions. In contrast, MgO is an oxide and is bonded by ionic bonding. Charge neutrality requires that dislocations can only move in certain crystallographic planes/directions (not left to right but rather from bottom upwards in the example), otherwise the strong Coulomb forces between ions of the same type will lead to failure, i.e. the crystal will break up.




(2 P)

c)

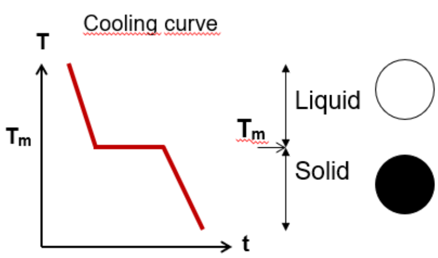



Yield strength (2)
Ductility (4)
Ultimate tensile strength (3)
Regime where necking occurs (between 3 and X). (2 P)

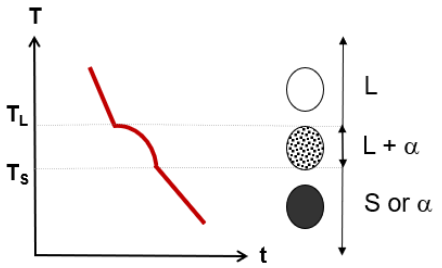
d) A material should be deformed or shaped in the plastic regime between the yield strength and the ultimate tensile strength (otherwise the material or prt gets damaged). (1 P)

## 3. Phase diagrams (6 P)

a) Cooling curve single component system



Cooling curve of a binary system

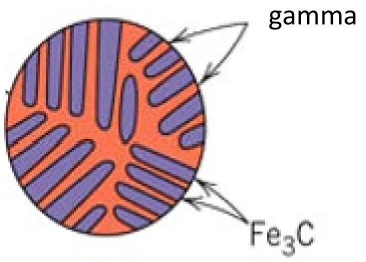



(1 P)

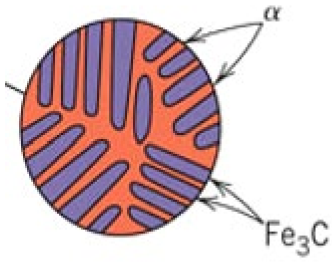
b) Eutectic reaction liquid ↔ alpha + beta
Peritectic reaction liquid + delta ↔ gamma
Eutectoid reaction gamma ↔ alpha + cementite
Congruent reaction liquid ↔ alpha (1 P)

c) For Fe-4.3wt.% C at 1100°C the microstructure is lamellar and contains gamma and cementite; at 720°C, the microstructure is also lamellar and contains alpha and cementite. (In addition, there is primary cementite as well.)

1000°C:

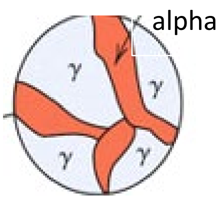



720°C:




(1 P)

d) For Fe-0.5 wt.% C at 728°C determine
(i) the phases present and their composition
Alpha and Gamma are present
Alpha: Fe + 0,022 wt% C; Gamma: Fe + 0.76 wt% C (0.5 P)
(ii) Alpha = (0.76 – 0.5)/(0.76-0.022) = 0,26/0,738 = 0,35
Gamma (0.5 – 0.022)/(0.76-0.022) = 0,478/0,738 = 0.65 (1 P)
(iii) The microstructure contains of gamma-phase with grain boundary alpha.



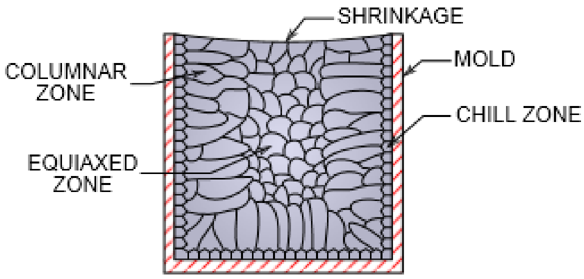

(0.5 P)

e) The difference between an eutectic and a eutectoid reaction is that the eutectoid one only involves solid phases, while in the eutectic one, a liquid is building two solid phases.
Eutectic: liquid ↔ gamma + cementite
Eutectoid: gamma ↔ alpha + cementite (1 P)

## 4. Phase transformations (7 P)

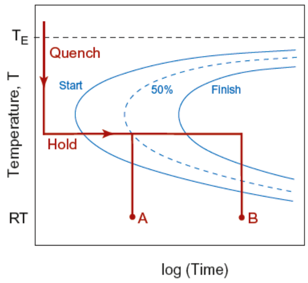
a) Coarse pearlite forms, when the diffusion paths are long (high temperatures), while fine pearlite is formed when the diffusion paths are short (lower temperatures) and the high undercooling leads to a lot of nucleation sites. (2 P)

b) The microstructure of a casting consist of chill zone and the mold wall, columnar zone, and equiaxed zone in the center.




(2 P)

c) TTT stands for time-temperature (x and y axes) -transformation (shown by an arrow in the diagram). The transformation curves for when the transformation is starting, when it is ending, and when 50% of the material is transformed are included.




(2 P)

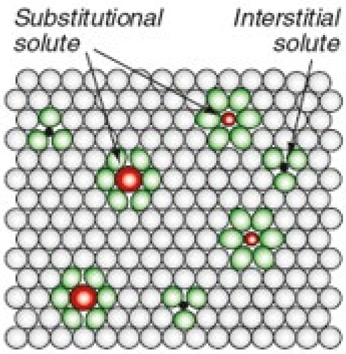
d) Recovery: Strain relief; During recovery, no major microstructural changes occur but dislocations move to lower-energy positions.
Recrystallization: New equiaxed, stress-free grains nucleate at high-stressed areas of the microstructure. Those grains then grow together until they constitute the entire microstructure. (1 P)

## 5. Defects and diffusion (7 P)

a) Explanation of vacancy diffusion and interstitial diffusion – see course book/slides! Interstitial diffusion is faster as no vacancy is needed (there are a lot of interstitial sites for the atom to move to). (2 P)

b) Higher temperature affects substitutional diffusion more, as more vacancies can be formed. However, interstitial diffusion is also at higher temperatures much faster than substitutional diffusion (no vacancies needed, hence temperature only affects the mobility of the interstitial atoms). (2 P)

c) Complete solubility is not possible in an interstitial solid solution as the interstitial is much smaller than the host material. However, full solubility is only achieved if the atomic size factor is below 8%, i.e. the atoms are similar in size. (1 P)

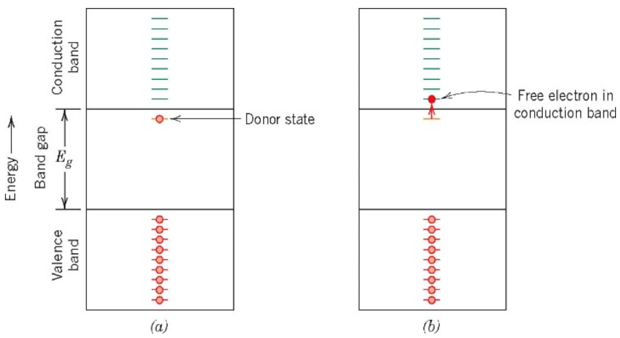
d) 

(1 P)

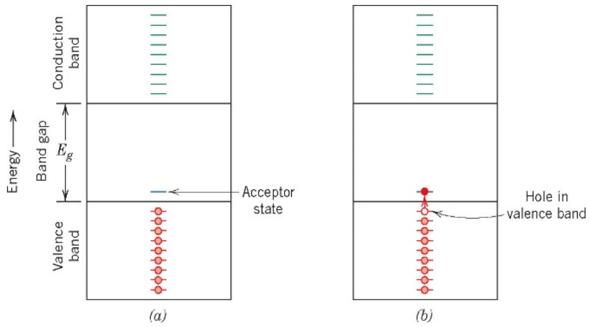
e) Grain boundaries separate grains in a polycrystalline material. The grains will have different orientations and there is an atomic mismatch in the transition from the orientation of one grain to that of an adjacent one:
Orientation mismatch between the grains < 10°: low or small angle grain boundary
Orientation mismatch between the grains > 10°: high or large angle grain boundary
(1 P)

## 6. Electrical and thermal properties (6 P)

a) n-type semiconductor: Exciting of an electron from the donor level into the conduction band (becomes a free electron).




p-type semiconductor: Exciting of an electron into the acceptor level; hole in the valence band is moveable and the charge carrier.




(2 P)

a) Metals are in general good conductors. The conductivity is affected by temperature as the atoms are oscillating more around the lattice site and scatter the moving free electrons. In silicon the conductivity is generally poor. Elevated temperatures are required to excite electrons from the valence band across the band gap into the conduction band. Hence, higher temperatures are in this case beneficial. (2 P)

b) For intrinsic semiconductors, elevated temperatures are required to excite an electron from the valence band across the band gap into the conduction band. Only then, sufficiently high electron concentrations can be reached.
For extrinsic material, the impurities make all the difference. Here, already lower energies are enough to e.g. excite an electron from the donor level into the conduction band. This can already be realized at elevated temperatures. But when temperature is reduced further, also the small energy require for this is not available in form of temperature any more (freeze-out region) and the electron concentration goes down to zero. At high temperatures, also in extrinsic materials the band gap can be overcome, and the behavior is the same as for intrinsic materials. (2 P)

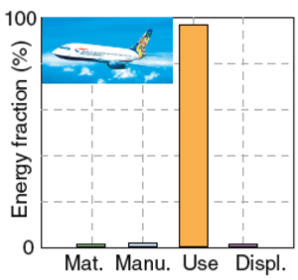
## 7. Environment (5 P)

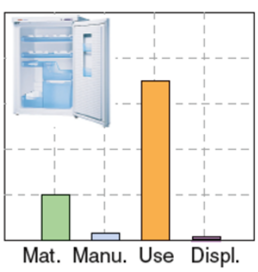
a) The $CO_2$ footprint is the associated release of $CO_2$, in kg/kg, when creating 1 kg of usable material. Energy consumption and $CO_2$ emissions are nearly equivalent when evaluating the eco-impact of a product; the $CO_2$ footprint is easier to determine/handle. (2 P)

b) Environmental stressors are exhaust gases, particulates and toxic waste that are formed in the different steps on a product's life cycle. (1 P)

c)

Like in an airplane, the use energy will be highest for a truck. For a mobile phone, the use energy is also very high and can be compared to a fridge or vacuum cleaner. (More arguments on the other energies should be provided).

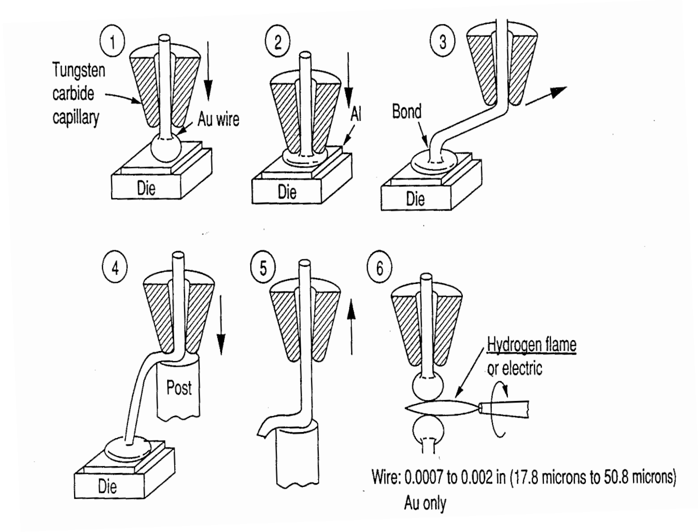



(2 P)

## 8. Joining (4 P)

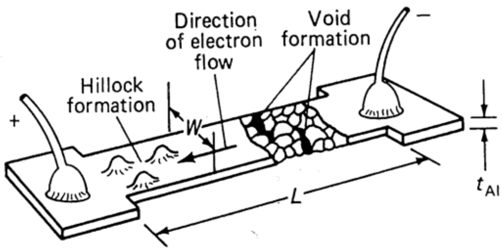
a) Ball bonding: the wire is gold (2 P)




b) Electromigration:

Very high current densities – collisions between electrons and atoms in the metallic film → drift of atoms in the direction of electron flow; due to divergences voids and hillocks or whisker extrusion are formed.

**Failure:** opening and/or shorting.
Higher temperatures accelerate failure!




(2 P)