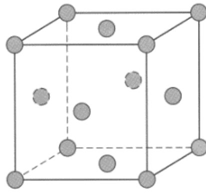
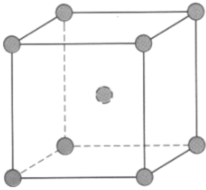
Answers to MMK073 (2017-10-26)

1. Crystal structure and crystal geometry (5 P)

a)



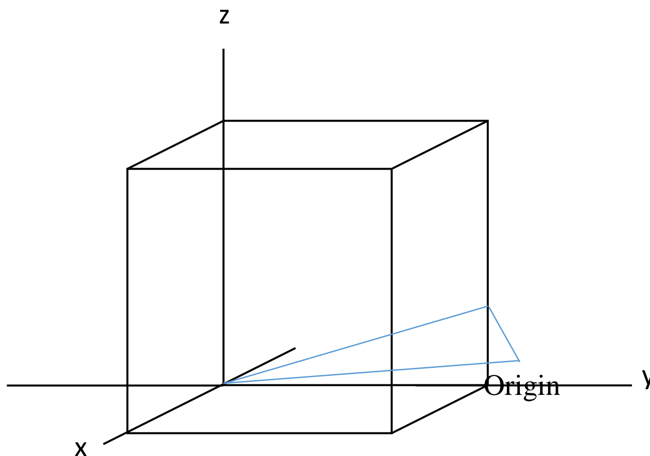
Number of atoms in fcc unit cell: 4



Number of atoms in bcc unit cell: 2

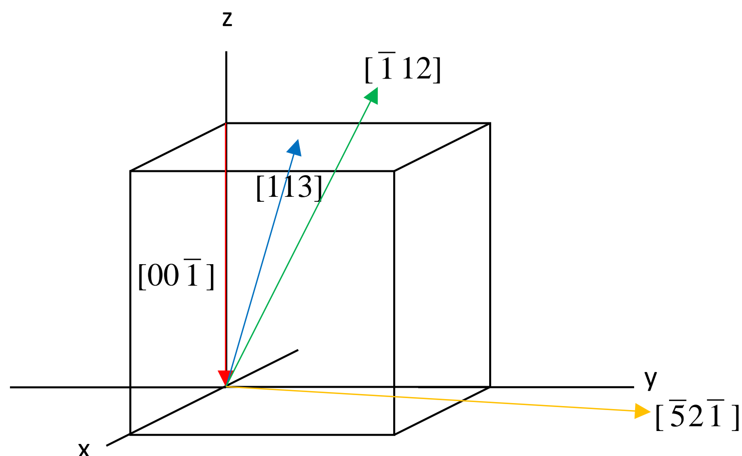
The atomic packaging factor of the fcc structure is 0.74 and of the bcc structure is 0.68. Hence, the fcc structure has a higher density. (1 P)

b)



Sketch of ($\bar{6}\bar{2}6$ plane). (1 P)

c) Direction vectors: [$00\bar{1}$], [113], [$\bar{1}12$], [$\bar{5}2\bar{1}$]. (2 P)



d) Cubic faces: (100), (010), (001), ($\bar{1}$00), (0$\bar{1}$0), (00$\bar{1}$) (1 P)

2. Mechanical properties (6 P)

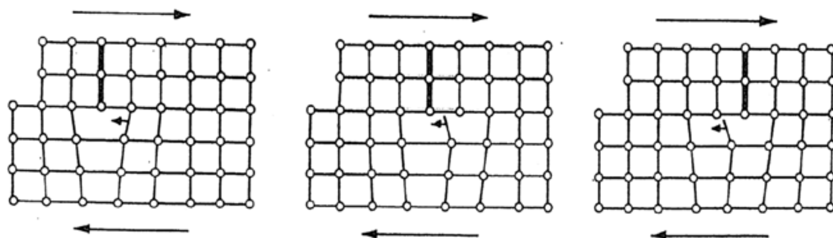
a) When the material is exposed to higher temperatures, first, recovery sets in and at even higher temperatures (ca 0.4 x Tm) recrystallization occurs. New, dislocation-free grains nucleate and start to grow. After recrystallization a new microstructure has formed that has consumed the deformation microstructure. As a result, the tensile strength and yield strength go down and the ductility (here expressed as % elongation) increases. Yield strength is defined as the intersection of the deformation curve with a straight line parallel to the elastic portion and offset 0.2 % on the strain axis. It describes the transition from elastic to plastic behavior. (3 P)

b) Strengthening methods for metals:
Precipitation strengthening, solute strengthening, grain size strengthening and work hardening. (2 P)

c) You can strengthen a polymeric materials by adding fibres or particles. (1 P)

3. Defects and diffusion (9 P)

a) When stress is applied on an edge dislocation, the dislocation can glide (breaking of bonds and establishing of new bonds along the glide plane bring the dislocation one atomic step forward) (1 P)



b) For diffusion to happen, you have to have energy (high temperature) and space available (displacement and in case of substitutional diffusion the formation of vacancies). (1 P)

c) Self-diffusion occurs via interchange of an atom and a vacancy on normal lattice positions (substitutional/vacancy diffusion) while C-diffusion occurs via migration on interstitial positions. There are by far more vacant interstitial positions available, also is the distortion involved much smaller. Hence C-diffusion is much faster than self-diffusion.(1 P)

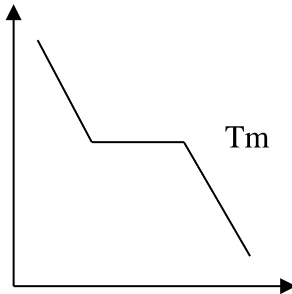
d) During carburization, carbon atoms are supposed to diffuse into a material, e.g. steel. Carbon is an interstitial atom and harden the surface (solute strengthening) (2 P)

e) The diameter of the atoms of the elements must not differ more than 8% to achieve full solubility. Between 8% and 15% partial solubility occurs.
Same crystal structure preferred
Substantial difference in electronegativity should be avoided.
A solute with higher valence would be preferred. (2 P)

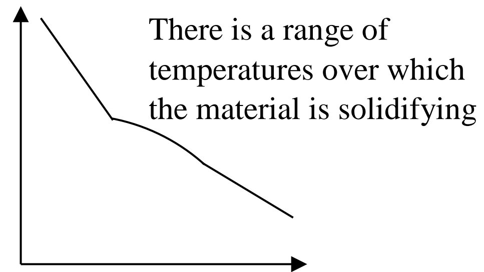
f) Solute, grain boundary and deformation hardening can be achieved. (2 P)

4. Phase diagram (4 P)

a) single component system



binary system



(2 P)

b)

(i) The microstructure is eutectic ($\alpha + \beta$) containing primary α (distributed). (1 P)

(ii) The first liquid forms at 183ºC (0.25 P)

(iii) The first liquid consists of about 62% Sn and 38% Pb (0.25 P)

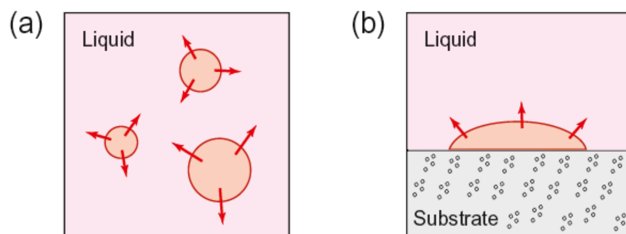
(iv) Complete melting occurs at ~252ºC. (0.25 P)

(v) The last solid prior to complete melting consists of 13% Sn and 87% Pb. (0.25 P)

5. Phase transformations (4 P)

a) The martensitic transformation is a diffusion-less transformation which occurs by a sudden re-orientation of C and Fe atoms from the FCC solid solution (γ-Fe) to a body-centered tetragonal structure (bct, martensite). As martensite is a metastable phase, you cannot find it in an (equilibrium) phase diagram. (1 P)

b) Homogeneous nucleation occurs in liquid while heterogeneous nucleation occurs at a surface (mold). Heterogeneous nucleation is advantageous as a part of the surface energy which has to be brought up can be saved.



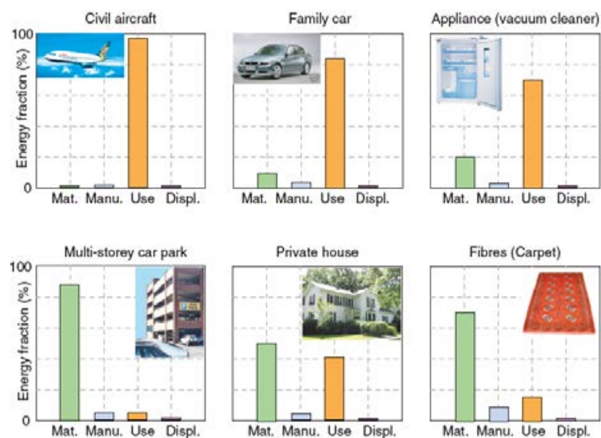
(2 P)

c) The width of the lamellar pearlite tells about the thermal history of the material. When the material solidified at higher temperatures, there are not so many nucleation sites (not too high undercooling) but the atoms can diffuse long distances. This results in coarse structure (wide lamellae). At lower temperatures (higher undercooling), there are more nucleation

sites, but the atoms cannot diffuse so easily any longer. This leads to a finer structure with narrow lamellae width. (1 P)

6. Environment (5 P)

a) The *used energy over life time* of a civil airplane is given below. The used energy over lifetime of a vacuum cleaner is similar to what is given below for a refrigerator ☺. Extremely much fuel will be needed during the life time of an airplane. Hence, the energy during use dominates. For the fridge and other appliances, the energy during use (power for cooling) is still a major part but materials become more important (the energy for use is not as high as for the plane). The vacuum cleaner will be made of polymeric material. Hence, energy from disposal is relatively low. (2 P)

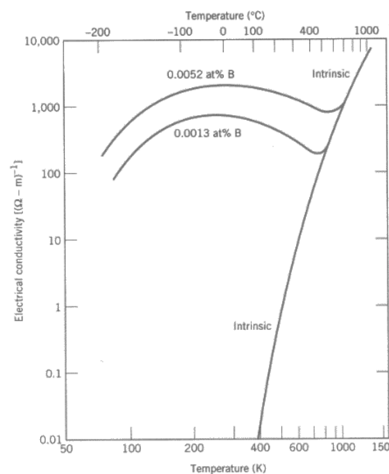


b) Recycling of metals is both economic and makes contributions to the saving of energy (energy committed to produce 1 kg recycled Al is 1/10 of the virgin material; for steel it is 1/3); this is not the case for polymers. Fiber reinforced polymers cannot be recycled, at least not the fibers! (3 P)

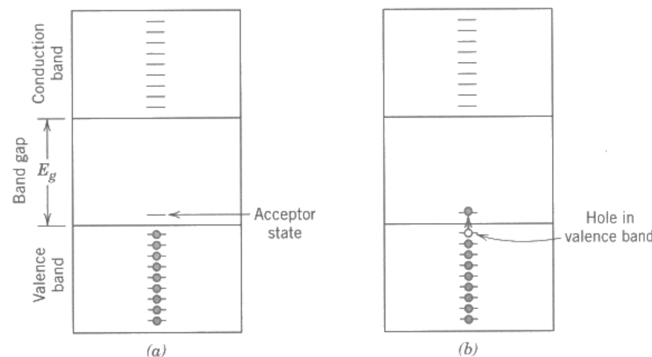
7. Electrical properties (7 P)

a)

An intrinsic semiconductor required high temperatures for obtaining sufficiently high electrical conductivity (one has to overcome the band gap to achieve free electrons). In comparison an extrinsic semiconductor, has the defect level to which electrons can be excited. That requires much less energy; hence a sufficiently high conductivity can be achieved at much lower temperatures. (2 P)



b) The defect level (acceptor state) is situated in the band gap just above the upper end of the valence band. An electron can be excited into the acceptor state and a hole is formed in the valence band which can move in an electrical field → electrical conduction.



(1 P)

c) Major charge carriers in
(i) intrinsic semiconductor: electrons and holes
(ii) n-type semiconductor: electrons
(iii) p-type semiconductor: holes
(iv) metal: electrons (1 P)

d) High temperature superconductors are ceramic materials which are usually insulators. But in some ceramic materials and at a critical temperature, the resistivity can suddenly drop to zero (no more losses!), the material becomes a superconductor. Once set in motion, electrical current will flow forever in a closed loop of superconducting material. $YBa_2Cu_3O_7$ was found to have a T_C of 95 K, i.e. the material is superconductive well above the temperature of liquid nitrogen (77 K). (1 P)

e) Matthiesen's rule describes the total resistivity in metals which is the sum of contributions from thermal vibrations (ρ_t), impurities (ρ_i), and plastic deformation (ρ_d):

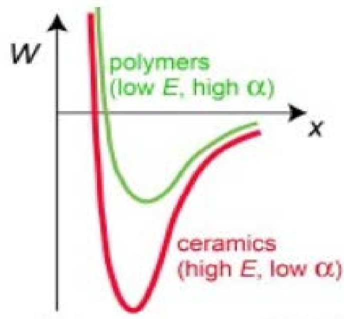
$$\rho_{tot} = \rho_t + \rho_i + \rho_d$$

with ρ_t: temperature effect,
ρ_i: impurity effect
ρ_d: effect due to deformation (2 P)

8. Thermal properties (5 P)

a) Heat is transported by phonons (travelling lattice waves) and electrons. (1 P)

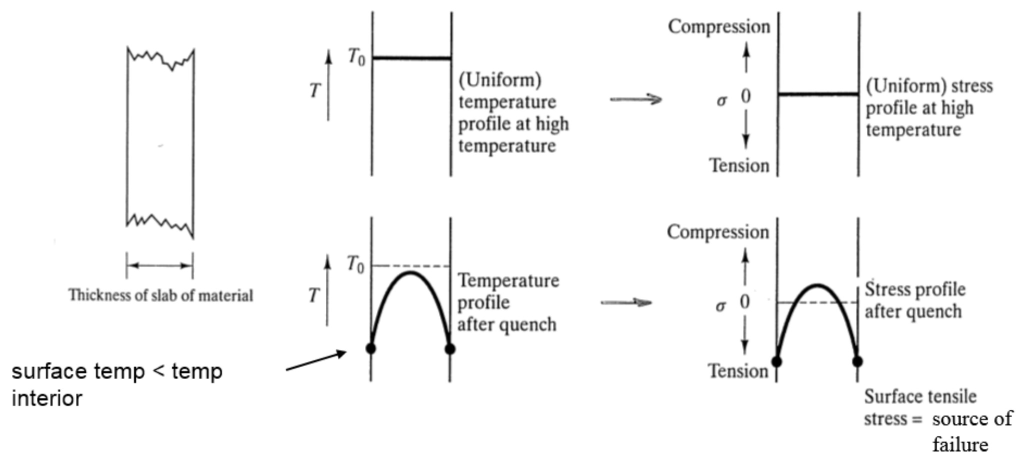
b) Weakly and strongly bonded material (example polymer versus ceramic). The curve for the ceramic is more deep and narrow, while the weaker bonded material (polymer) has a broader and more shallow curve,



(2 P)

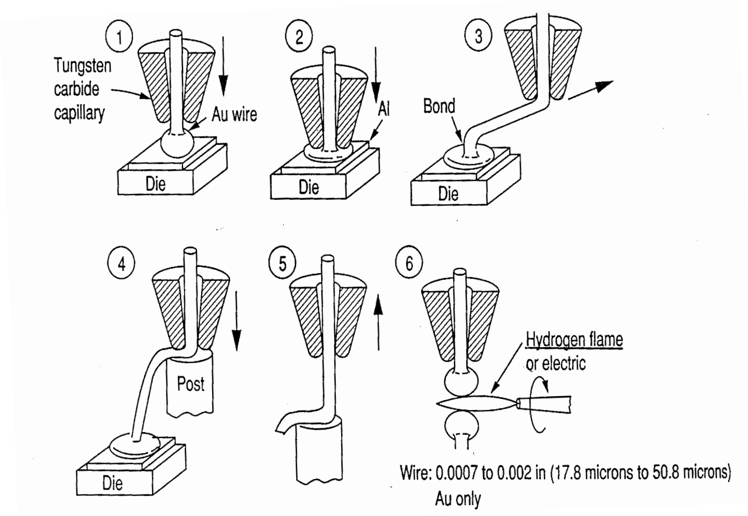
c) The sink is made of stainless steel, i.e. it contains a number of solutes. They are efficient scattering sites for travelling electrons. Heat is not transported so well by phonons, hence, the sink is not getting hot even though the water inside may be hot. (1 P)

d) Ceramics are prone to thermal shock as they have a low thermal conductivity. When you change the external temperature, the material tries to expand. As the thermal conductivity is low, surface of the material will be at a different temperature than the interior. This will lead to stresses and as the material is brittle, this can lead to failure. (1 P)



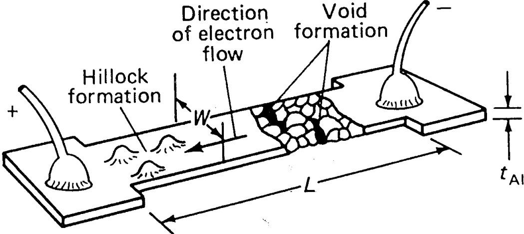
<u>9. Joining and possible failures (5 P)</u>

a) Ball bonding:
Ball bonding is possible for <u>Au-wires only</u>!
(Al cannot be ball bonded, since Al does not form balls upon melting;
Au has better conductivity, anyhow ☺)
Use of hydrogen flame (heat) → melted wire end forms into a small ball
(due to high surface tension of Au)



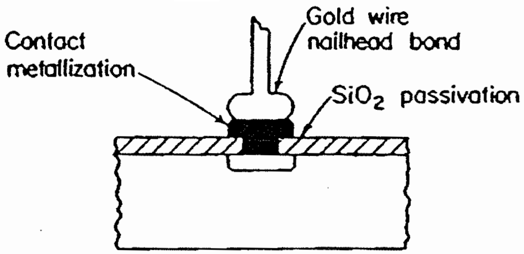
(2 P)

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!

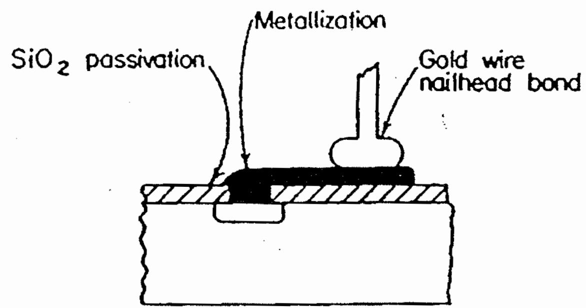


(2 P)

c) Direct and expanded contacts: (1 P)
Metallization direct on Si; wire is directly on top of metallization



(b) Direct contact



(a) Expanded contact

Metallization extended to the chip edge –Bond is at periphery of the chip

<u>Advantage:</u> contact between bare wires and metallization patterns can be avoided