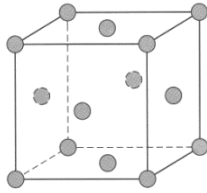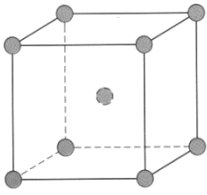# Answers to MMK073 (2017-12-20)

1. Crystal structure and crystal geometry (6 P)
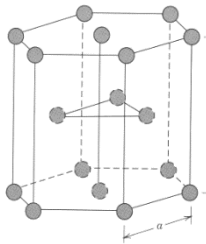
a)

Number of atoms in fcc unit cell: 4
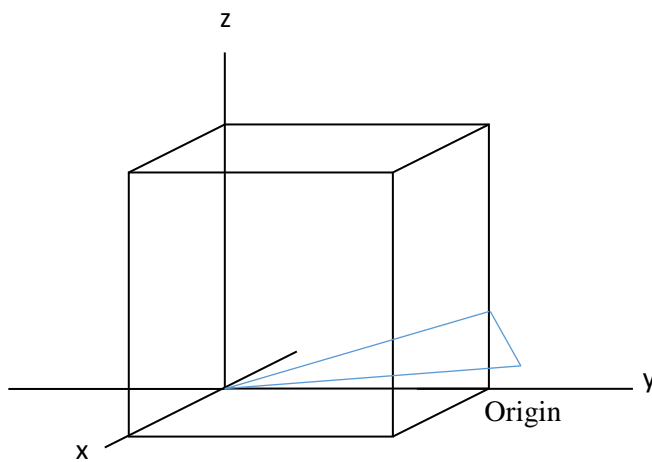

Number of atoms in bcc unit cell: 2

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)
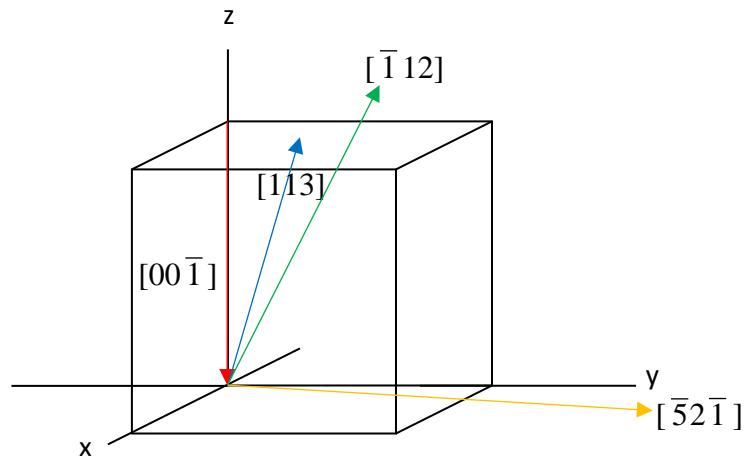
b)

(1 P)

c)

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

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


2. Defects (7 P)

a)   Magnitude and direction of a lattice distortion associated with a dislocation is expressed by the Burgers vector. Hence, by making a Burgers circuit (loop in around the dislocation and same loop (same step size) in the perfect crystal, the Burgers vector can be determined. For an edge dislocation, the Burgers vector is perpendicular to the dislocation line, whereas for a screw dislocation, the Burgers vector is parallel to the dislocation line.   (2 P)

b)   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)

c)   Same crystal structure preferred
     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.
     Substantial difference in electronegativity should be avoided.
     A solute with higher valence would be preferred.   (2 P)

d)   Solution, grain boundary and deformation hardening can be achieved.   (2 P)

3. Mechanical properties (5 P)

a)
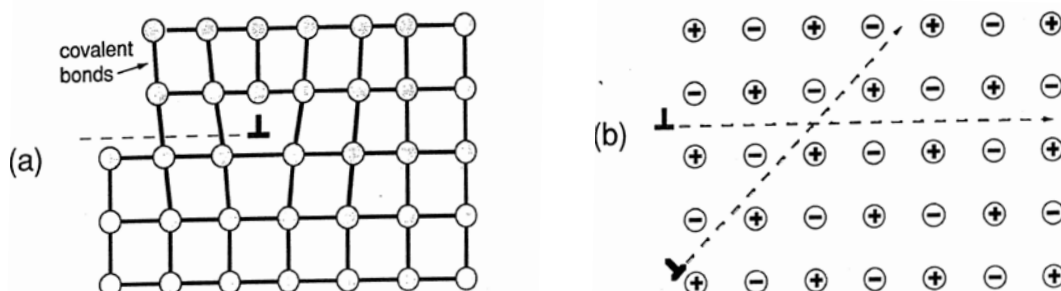
Copper is a metal and comes in fcc structure. A dislocation can move in specific crystallographic planes and specific crystallographic directions (glide systems) as seen in (a); there are many such combinations of planes/directions (in fact 12). This is not the case in a ceramic material like MgO. Here, the ionic structure is not allowing many of the crystallographic planes/directions because ions of same charge would be placed next to each other (strong repulsive (Coulomb) forces, leading to fracture of the material. Hence, there is a limited amount of glide systems in ceramic materials which makes deformation more difficult.

b) 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.   (1 P)

Tensile strength is the maximum stress in the stress-strain curve and describes the max stress the material can tolerate before the sample/part is damaged (due to e.g. necking).
                                                                                                                                      (1 P)

By taking a strengthened/deformed material to sufficiently high temperatures, atoms get mobile and the material can be softened and a new microstructure emerges (recrystallization occurs at about 0.4 x melting temperature). When the microstructure starts to change (recovery and recrystallization) upon annealing also the properties change (tensile strength goes down because new dislocation-free grains are formed, ductility increases as dislocations are more movable again).   (1 P)

4. Phase diagram (4 P)

a) single component system   binary system

There is a range of temperatures over which the material is solidifying
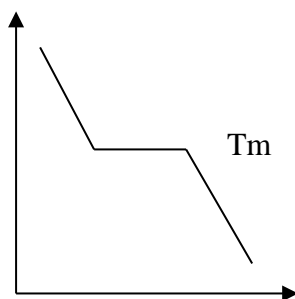
Tm
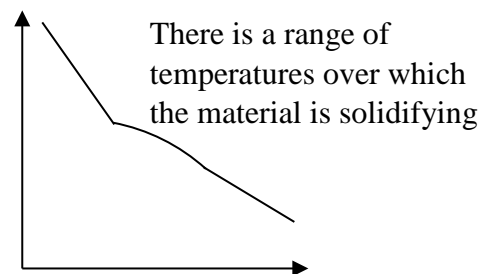
                                                                                                                                      (2 P)

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

    (ii) The first liquid forms at 183°C   (0.25 P)

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

    (iv) Complete melting occurs at ~252°C.   (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.
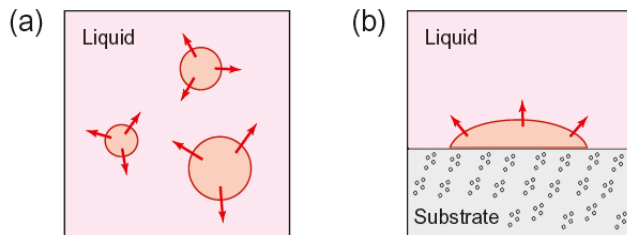

(2 P)

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. Joining and possible failures (5 P)

a) 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!
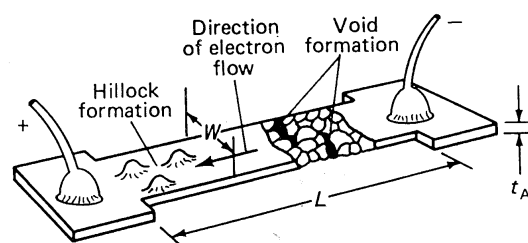
b) Ball bonding:
   Ball bonding is possible for Au-wires only!
   (Al cannot be ball bonded, since Al does not form balls upon melting;
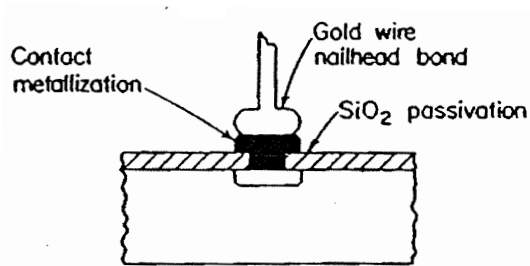   Au has better conductivity, anyhow ☺)

Use of hydrogen flame (heat) → melted wire end forms into a small ball
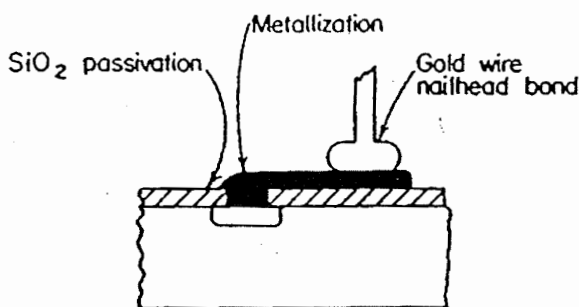(due to high surface tension of Au)
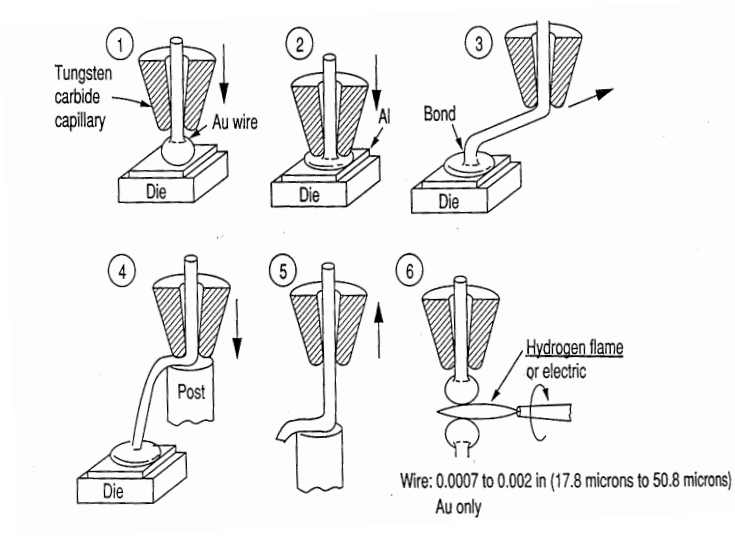
(2 P)

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
Advantage: contact between bare wires and metallization patterns can be avoided

7. 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 fridge ☺. Extremely

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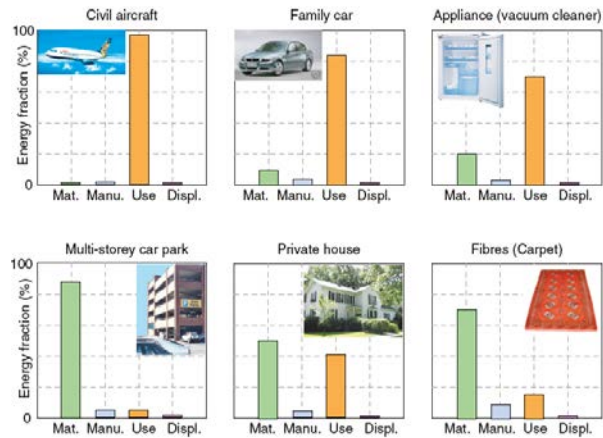
b) Recycling of metals is both economic and makes contributions to the saving of energy (energy committed to produce 1 kg recycled Al is 1/10 of the virgin material; for steel it is 1/3); this is not the case for polymers. Fiber reinforced polymers cannot be recycled, at least not the fibers! (3 P)

8. Thermal properties (7 P)

a) Heat is transported by phonons (travelling lattice waves) and electrons. (2 P)

b) Thermal expansion describes the fact that material is expanding when it gets warmer (and is contracting upon cooling). It occurs because the bonds are stretched when heated (asymmetrical shape of the potential energy versus interatomic distance curve – when energy is increased, the atoms are moving apart). (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. (2 P)

d) The electron energy band structure tells you if you will have free electrons available or not. As heat is transported by phonons and electrons, you know that you have a bad conductor if you have to rely on the phonons for conduction (easily scattered). Whenever the band structure shows the presence of free electrons, you will have a good electrical and thermal conductor. (1 P)

9. Electrical properties (4 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)
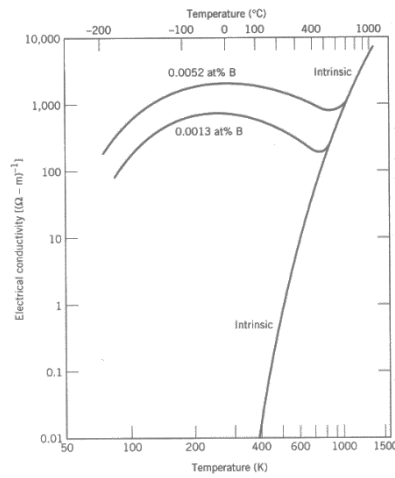
b) The defect level (acceptor state) is situated in the band gap just above the upper end of the valence band. An electron can be excited into the acceptor state and a hole is formed in the valence band which can move in an electrical field → electrical conduction.
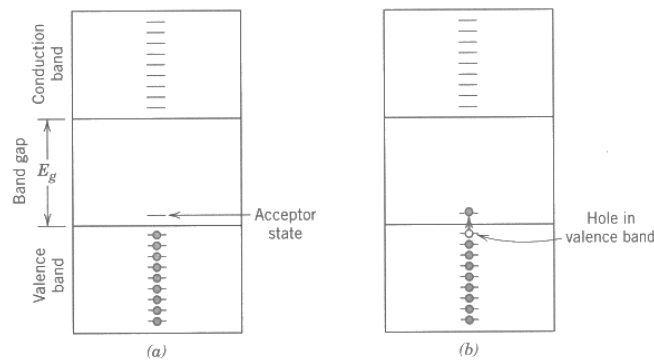
(1 P)

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)

10. Semiconductor devices (4 P)

a) In epitaxial growth, a layer is mimicking the crystal structure of the layers below. (2 P)

b) When joining an n- and p-type semiconductor material, electrons from the n-type will tend to diffuse across the junction into the p-type material. Likewise, holes will tend to diffuse from the p-type to the n-type material. This creates a potential difference between the two types of material, which will act against the diffusion of holes and electrons, pulling them back to where they started. This opposing flow of charge under a potential difference is called drift. (2 P)