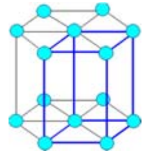
Physical bases of dental material science

Irén Bárdos-Nagy

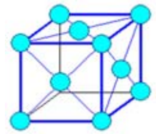
Submicroscopic structure of metals



hexagonal

Ti, Cd, Co, Zn

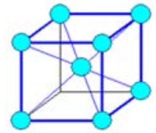
Space filling factor 74 %



face-centered cubic

Ag, Au, Pd, Pt, Al, Cu, Ni

Space filling factor 74 %

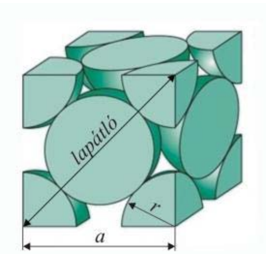


body-centered cubic

Fe, Cr

Space filling factor 68 %

The Ni has face centered cubic crystal structure. Calculate the space filling factor for this metal. How large is the density of the Ni, if the atomic mass is 58.7 and the atomic radius is 0.125nm?



In one unit cell there are 6 *1/2 atoms and 8* 1/8 atoms

⇩

4 atoms

$$V_a = \frac{4}{3} r^3 \cdot \pi$$

$$a \cdot \sqrt{2} = 4r \rightarrow a = 2 \cdot r \cdot \sqrt{2}$$

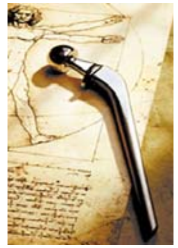
$$V_{cell} = 8 \cdot \sqrt{8} \cdot r^3$$

$$\frac{4 \cdot V_a}{V_{cell}} = \frac{4 \cdot \frac{4}{3} \cdot r^3 \cdot \pi}{8 \cdot \sqrt{8} \cdot r^3} = 0{,}74$$

$$\rho = \frac{m}{V} = \frac{4 \cdot \frac{M}{N_A}}{V_{cell}} = \frac{4 \cdot \frac{58{,}7}{6 \cdot 10^{23}}}{8 \cdot \sqrt{8} \cdot \left(0{,}125 \cdot 10^{-7}\right)^3} = 8{,}85 \left(\frac{g}{cm^3}\right)$$

Alloyes

partial or complete solid solutions of one or more elements in a metallic matrix



metal + metal (Fe+Cr+Ni, Au+Cu)

metal + non metal (Fe+C)

The aim: to modify (to improve) the properties

- hardness and rigidity (Au + Cu)
- tensile strength
- shear strength
- to avoide or reduce the corrosion (Fe, Co, Ni, + Cr)
- to increase the adhesion on metal-ceramic surfaces (precious metal+Fe, Sn, In)

Determination of composition

weight % : $$c_{m1} = \frac{m_1}{m_1 + m_2} \cdot 100(\%)$$

properties!!

molar % : $$c_{\nu 1} = \frac{\nu_1}{\nu_1 + \nu_2} \cdot 100(\%)$$

$$c_{\nu 1} = \frac{\frac{m_1}{M_1}}{\frac{m_1}{M_1} + \frac{m_2}{M_2}} \cdot 100 = \frac{\nu_1}{\nu_1 + \nu_2} \cdot 100 = \frac{m_1 \cdot M_2}{m_1 \cdot M_2 + m_2 \cdot M_1} \cdot 100(\%)$$

$$c_{m1} = \frac{m_1}{m_1 + m_2} \cdot 100 = \frac{\nu_1 \cdot M_1}{\nu_1 \cdot M_1 + \nu_2 \cdot M_2} \cdot 100 = \frac{c_{\nu 1} \cdot M_1}{c_{\nu 1} \cdot M_1 + c_{\nu 2} \cdot M_2} \cdot 100(\%)$$

The molar ratio in a gold – silver alloy is 2. How large is the molar percent? How large is the mass percent of the two components in this metal?

$$M_{Au} = 197g \qquad M_{Ag} = 108g$$

$$c_{\nu Ag} = \frac{1}{1+2} \cdot 100(\%) = 33{,}3\%$$

$$c_{\nu Au} = \frac{2}{1+2} \cdot 100(\%) = 66{,}7\%$$

$$c_{mAg} = \frac{m_{Ag}}{m_{Ag} + m_{Au}} \cdot 100(\%) = \frac{0{,}333 \cdot 108}{0{,}333 \cdot 108 + 0{,}667 \cdot 197} \cdot 100 = 21{,}5\%$$

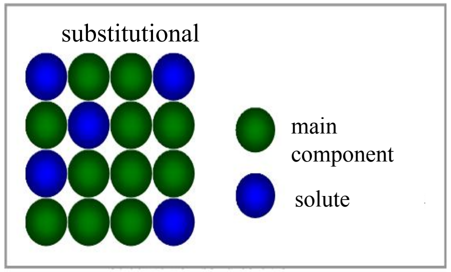
$$c_{mAu} = \frac{m_{Au}}{m_{Ag} + m_{Au}} \cdot 100(\%) = \frac{0{,}667 \cdot 197}{0{,}333 \cdot 108 + 0{,}667 \cdot 197} \cdot 100 = 78{,}5\%$$

Classification:

- according the application (inlay, corona of teeth)
- on the base of the main component (Au, Pd, Pt, Fe)
- on the base of the number of components (biner, terner, quaterner)
- on the base of the main 3 components (Au-Pd-Ag, Ni-Cr-Be)
- on the base of the phase diagram (solid solution, eutectic alloy, peritectic alloy, metal compound)

Solid solutions

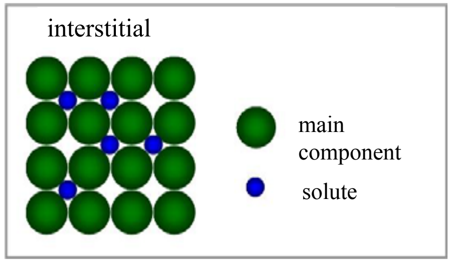
homogeneous structure



examples: Cu-Ni, Pd-Ag, Au-Cu, ...

criteries of formation

similar atomic radii (less then 15% diff.)
same crystal structure
similar electronegativities
similar valency



examples: Fe-C, CP Ti (O, C, N, H), ...

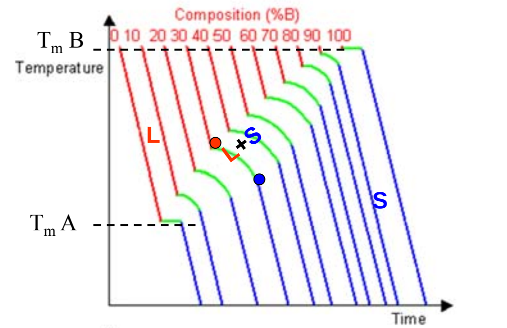
the atomic radius of the solute is smaller
the amount of the solute is less than 10%

properties of solid solutions

- flexibility changes
- strength increases
- hardness increases
- ductility changes
- plasticity decreases

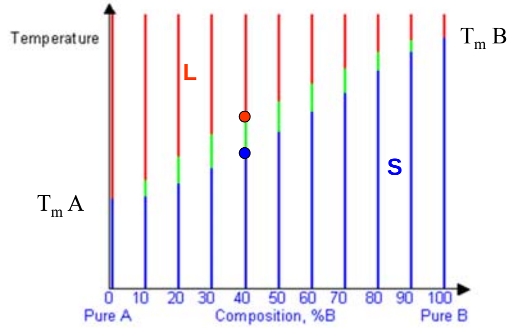
metal	atomic radius (nm)	lattice	electro-negativity
Au	0,2882	fcc	2,4
Pt	0,2775	fcc	2,2
Pd	0,2750	fcc	2,2
Ag	0,2888	fcc	1,9
Cu	0,2556	fcc	1,9
Ni	0,25	fcc	1,8
Sn	0,3016	tetragonal	1,8

cooling curve of solid solutions

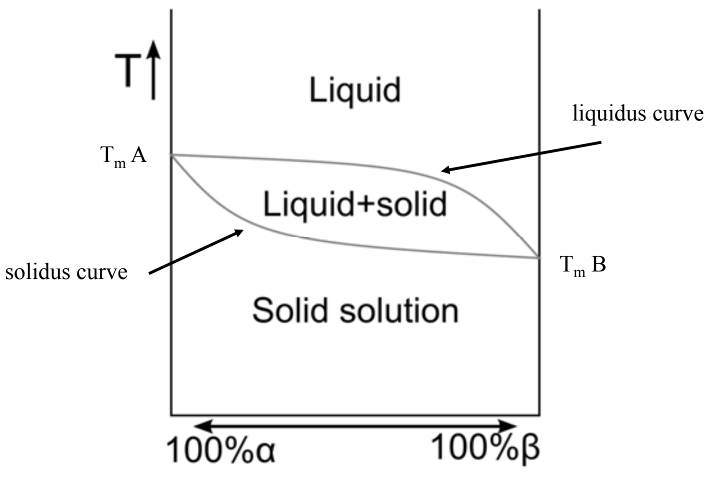


phase diagram of solid solutions

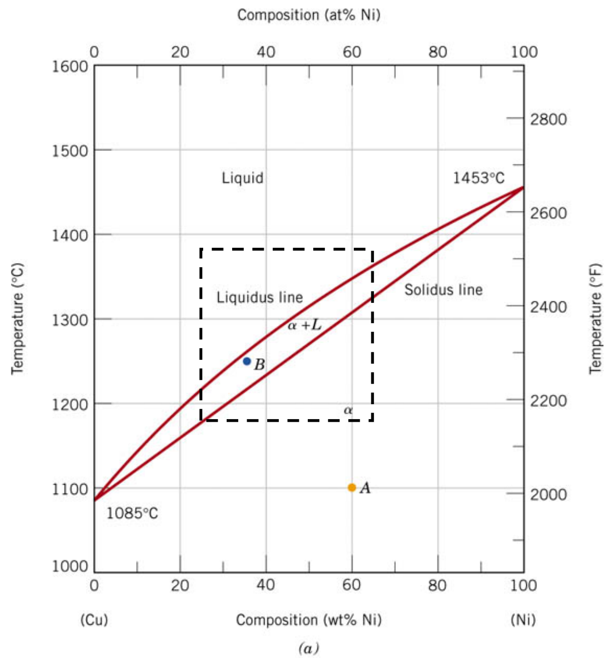
equilibrium !!



equilibrium

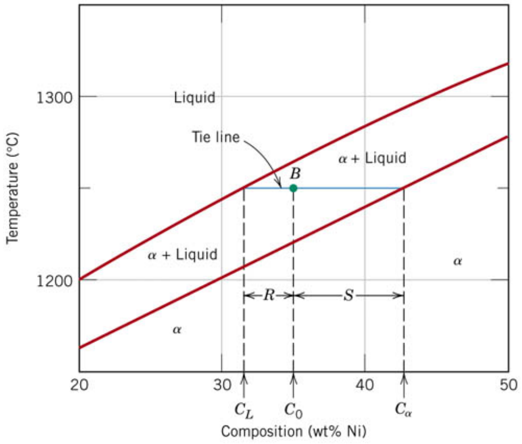


example:
Cu + Ni



Calculation of the composition and the ratio of the different phases

what is the composition at the B point



Liquid phase composition:

31,5 wt % Ni + 68,5 wt % Cu

Solid phase composition:

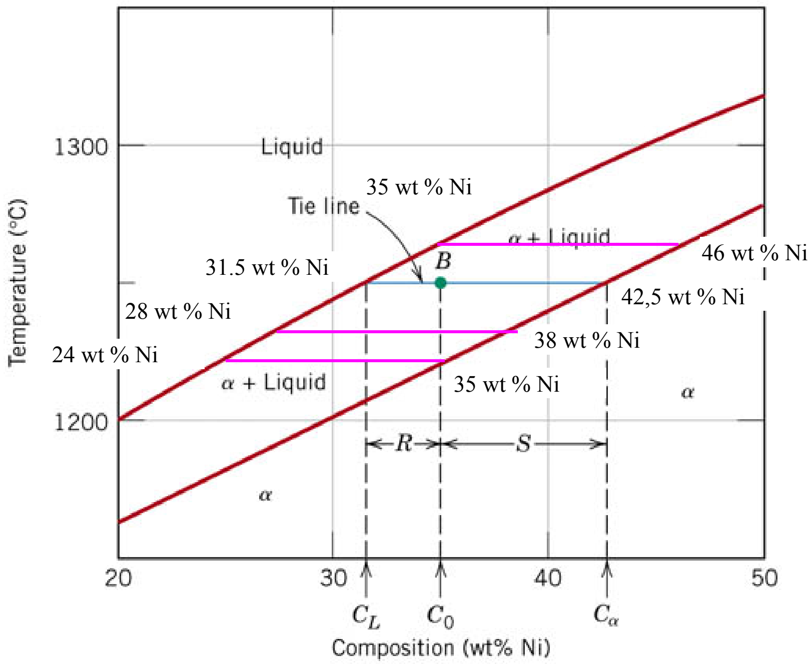
42,5 wt % Ni + 57,5 wt % Cu

Liquid phase ratio:

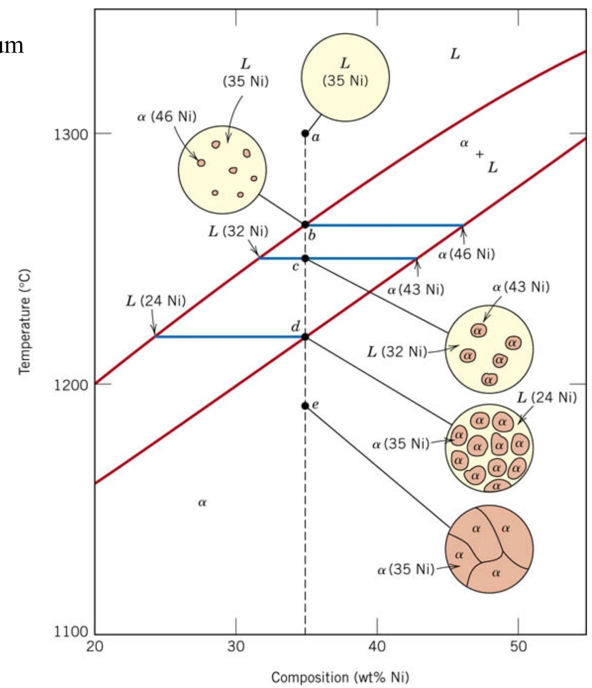
$$\frac{S}{R+S} = 68\%$$

Solid phase ratio:

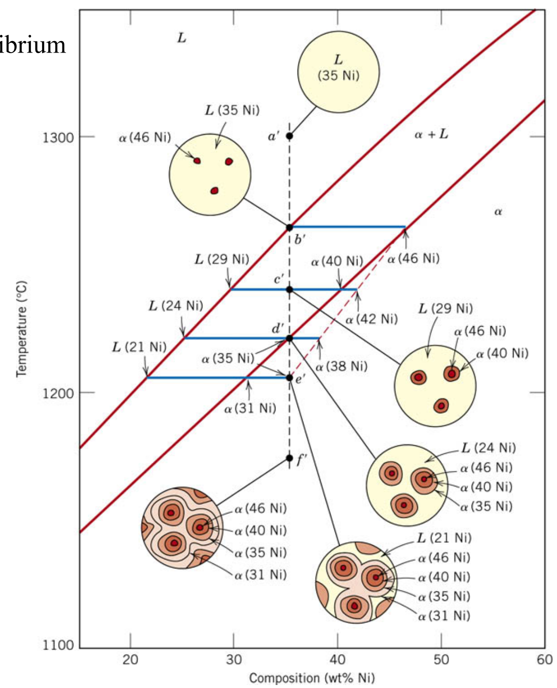
$$\frac{R}{R+S} = 32\%$$



equilibrium



non equilibrium cooling



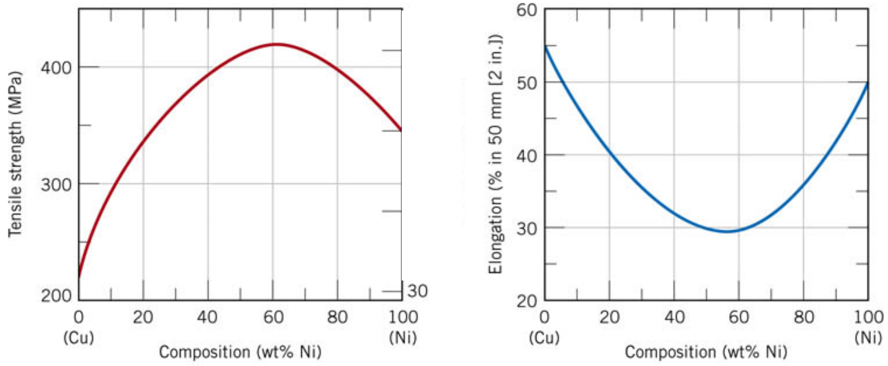
segregation

seedy structure

heterogeneous

homogenization

Influence of the solute material on different physical properties of alloyes

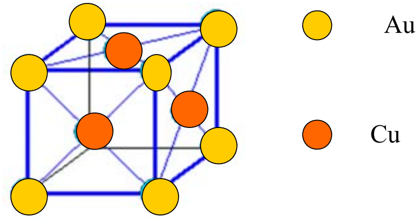


(a) (b)

Metal compounds

Definite stochiometry

example: Au-Cu



50 wt %Au-50 wt %Cu

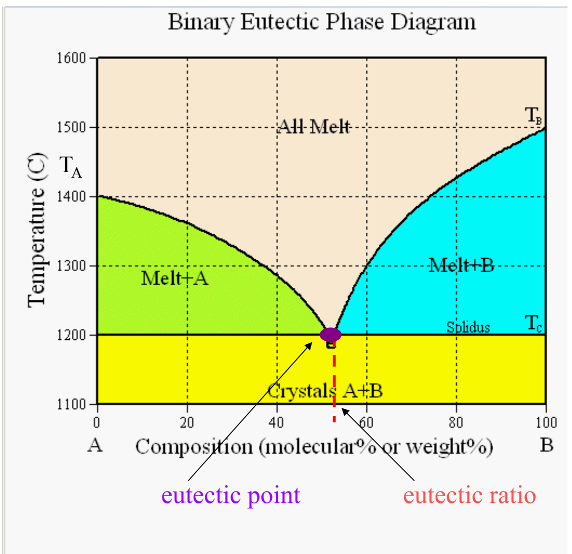
< 400 C

$AuCu_3$

in the amalgam: Ag_3Sn

Cu_6Sn_5

Eutectic alloys



insolubility in the solid phase

↓

pure metal crystallites

↓

heterogenious structure

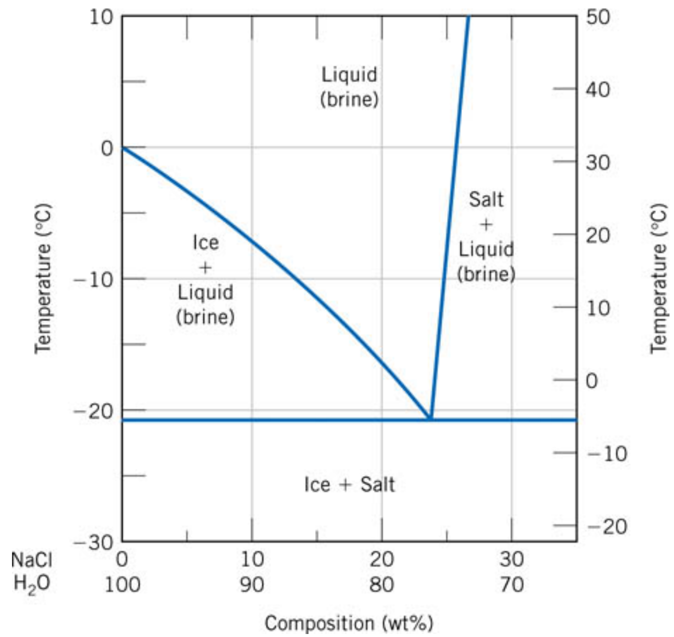
examples

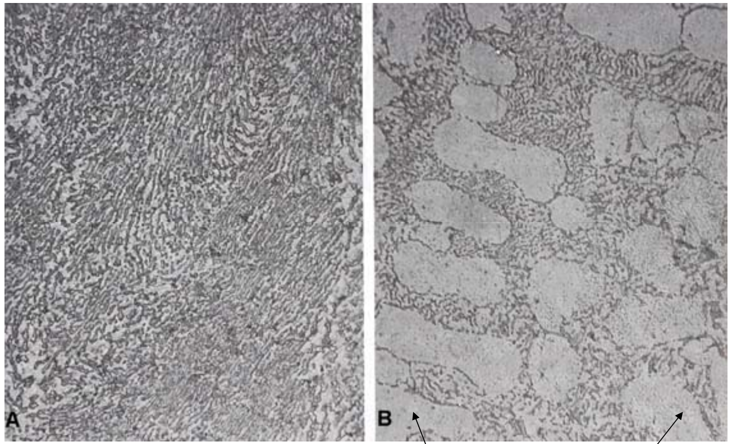
77% H_2O+23 % NaCl

$T_E = -21°C$

Wood-metal (Bi-Pb-Cd-Sn)

$T_E = 68°C$



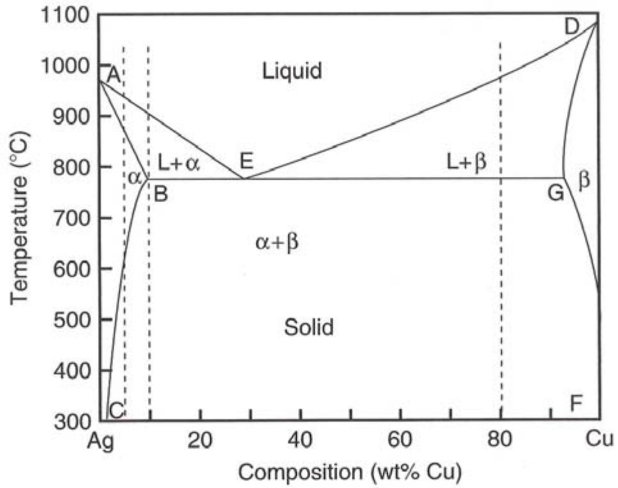


62%Sn-38%Pb

eutectic alloy

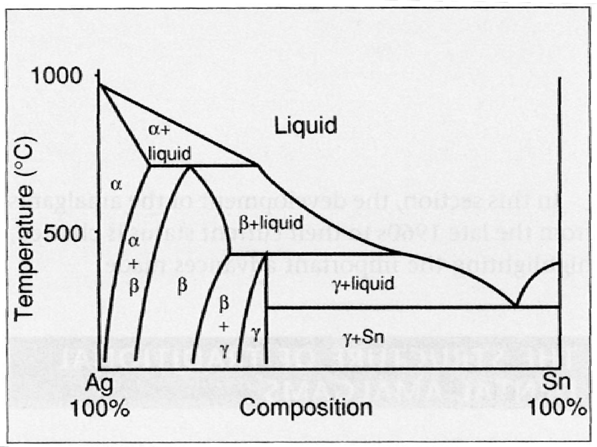
75%Sn-25%Pb

(Sn rich islands)



dental amalgam

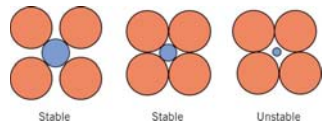
composition	
metal	**% (wt/wt)**
Hg	50
Ag	34
Sn	13
Cu	2
Zn	1

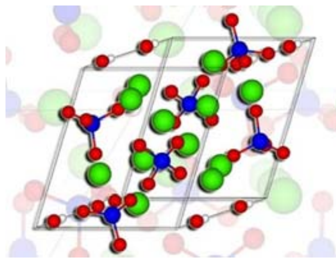


γ phase: Ag_3Sn

Ceramics: compounds of metal and non-metal elements

- mainly ionic bond between the components
- the + ions are smaller
- crystalline or amorphous structure
- phase diagram like in the case of metals

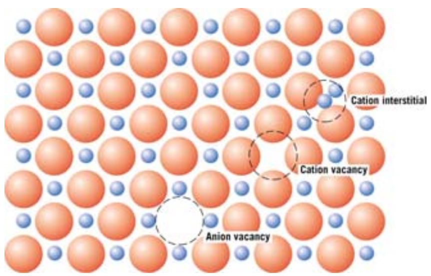


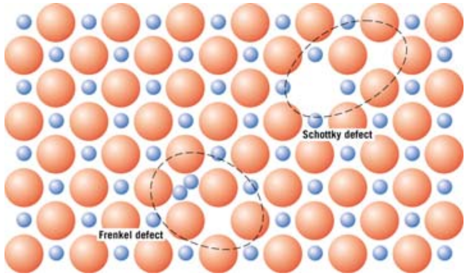


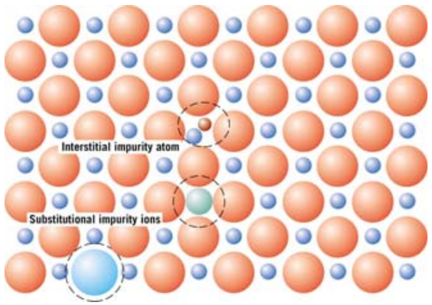
apatite

P^{+5} ● O^{-2} ● Ca^{+2} ● H^{+1} ∘ $Ca_{10}(PO_4)_6(X)_2$

Defects of ceramics







Electroneutrality !!

General properties of ceramics

-solid at room temperature

- fragility

- large hardness and rigidity

- strong in compression

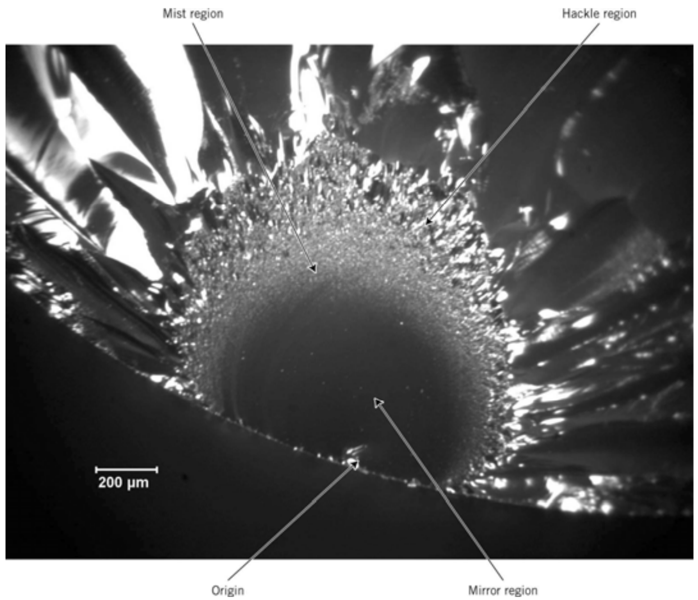
- week in tension and shearing

- pure heat-shock tolerance

- proof against corrosion and heat

- not conduct electric current (insulator)

- biocompatibility



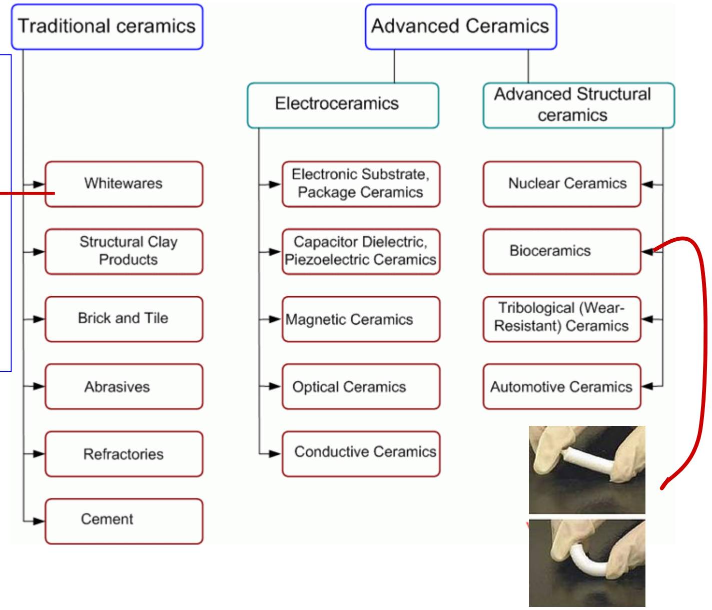
Application base classification of ceramics

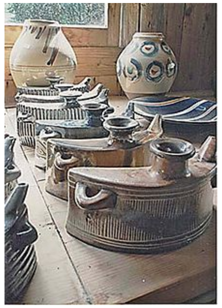
Earthenware (clay, feldspar, quartz)

Stoneware

Porcelain (kaolin)

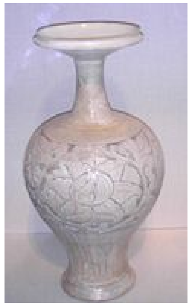
Bone china





Earthenware pottery

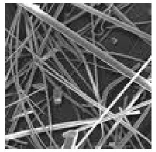
Porcelain

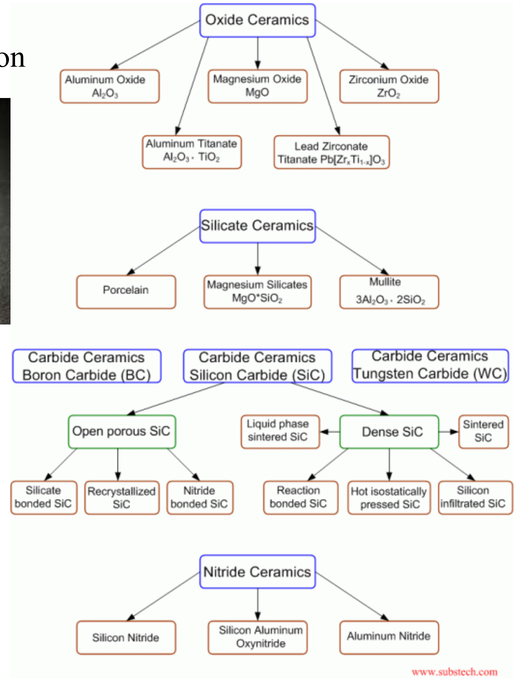


Stoneware vase

Bone china

composition base classification of ceramics

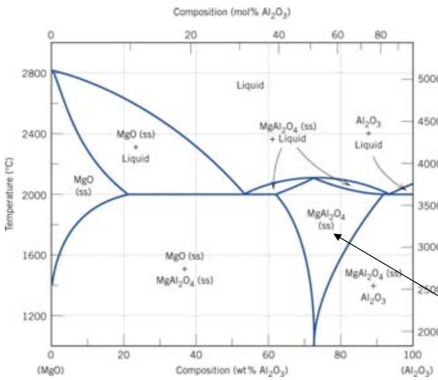


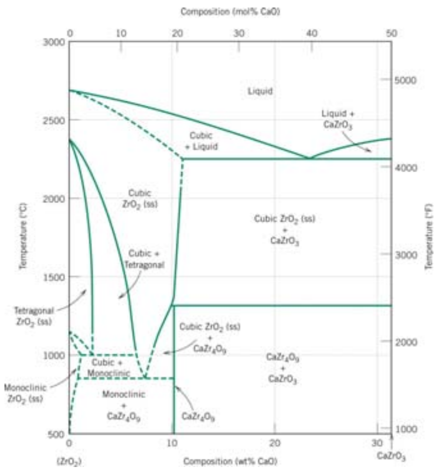


Oxide ceramics

ZrO_2 → ZrO_2 - CaO

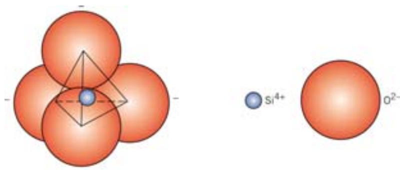
ZrO_2—Y_2O_3



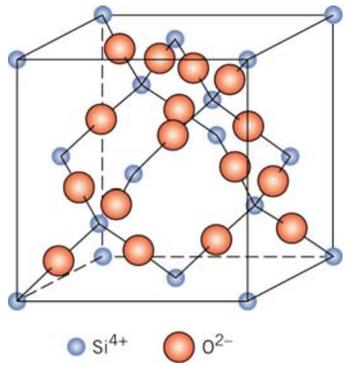


MgO — Al_2O_3 ($MgAl_2O_4$ spinel)

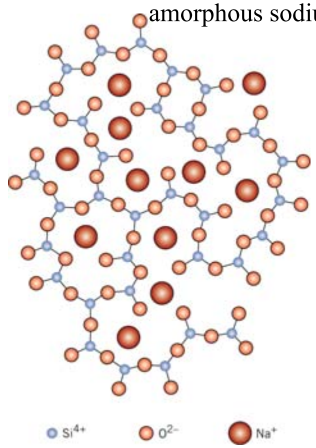
Silicate ceramics



crystal structure of silica

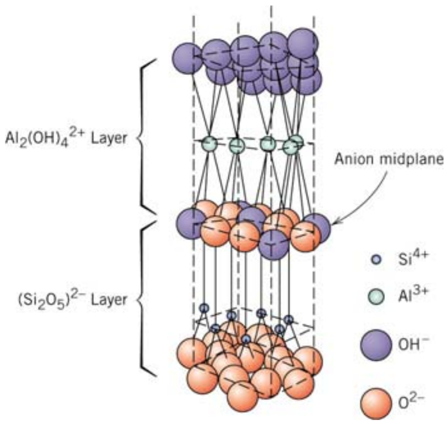


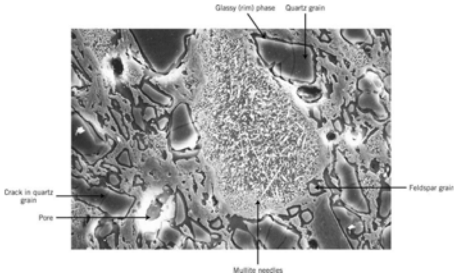
amorphous sodium silicate



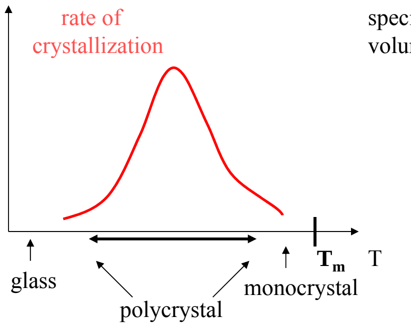
Porcelain

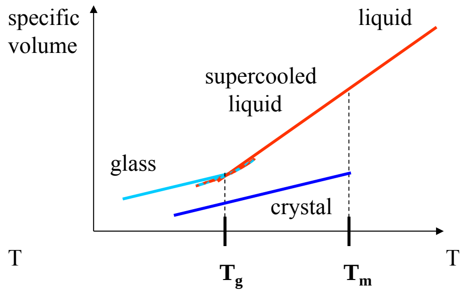
crystal structure of kaolin

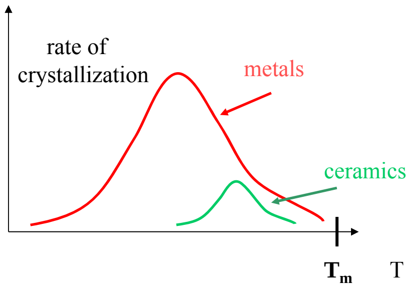




Crystallization ↔ glass formation

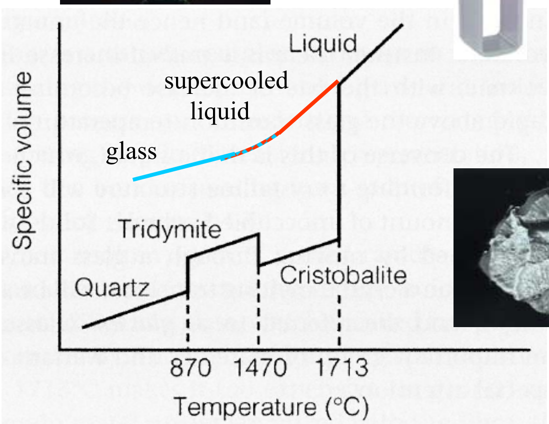


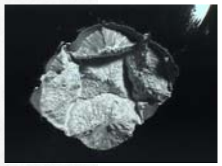




SiO_2

silica glass





Glass ceramic

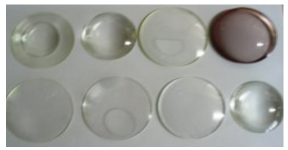
share many properties with both glasses and ceramics

glass ceramics structure:

they have amorphous phase
+ crystalline one (controlled crystallization)

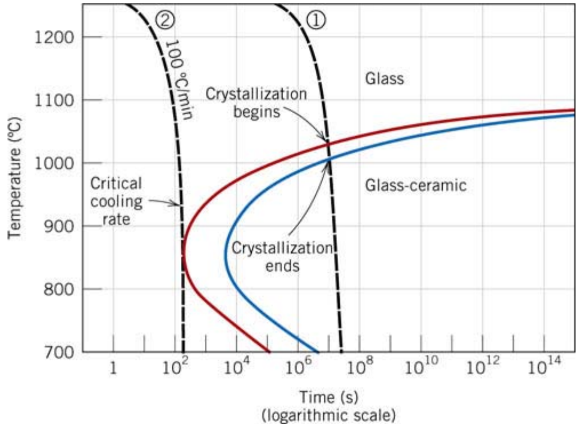
main components:

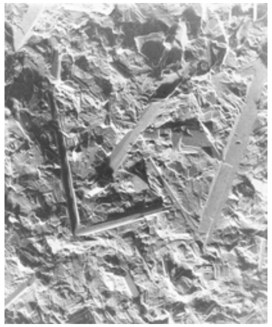
Li_2O – Al2O3 – $nSiO_2$ (LAS-system)
MgO – Al_2O_3 – $nSiO_2$ (MAS-system)
ZnO – Al_2O_3 – $nSiO_2$ (ZAS-system)



properties:
- mechanically strong
- no pores inside the structure
- low heat conduction coefficient
- quick temperature changes (up to 800 -1000 C°)
- coefficient of thermal expansion can vary with phase ratios (it can be negative or even zero)

Formation of glass ceramics





Dental application of ceramics

-crowns, veneers

- bridges

- fillings

- dental implants

- orthodontic brackets

- cements

- polishing materials