



Physical Bases of Dental Material science

4.

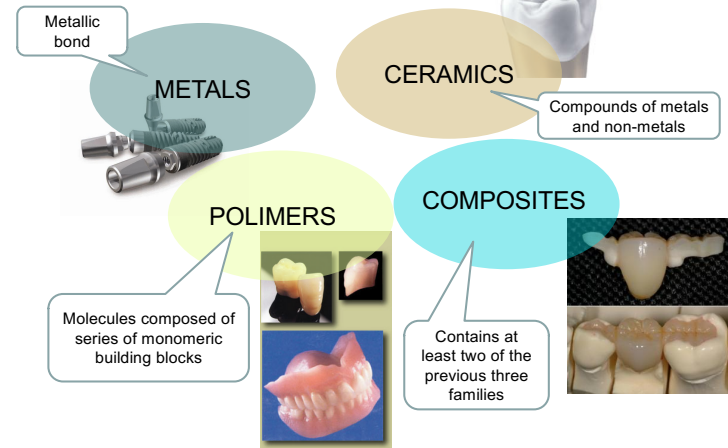
Crystallisation. Metals, alloys, ceramics.

E-book
Chapters:
9-11

Homework:
Chapter 3.:
3-5, 8, 10, 12, 14,
18

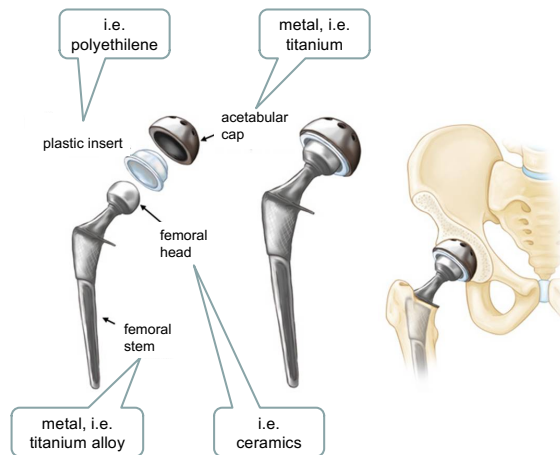
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Types of dental materials

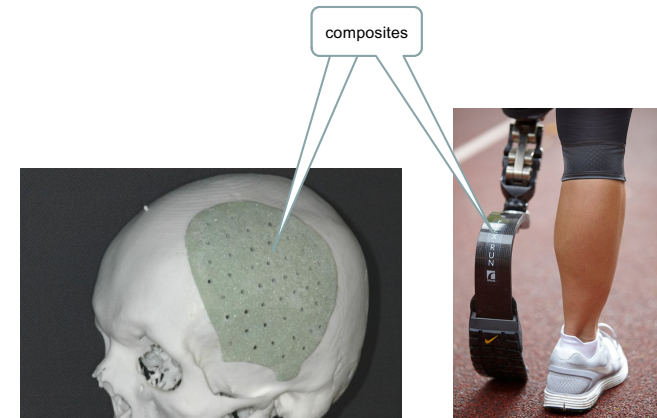


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Medical examples

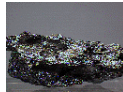


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Metals



Properties:

- common material; diverse properties
- relatively large density
- solid at room temperature (except for Ga and Hg)
- relatively large toughness and strength
- relatively good deformability
- tendency to corrode (except for precious metals)
- properties can be influenced by alloying
- good heat and electric conductivity
- metallic color
- mostly not biocompatible



amorphous
metallic
glass!

Structure:

- metallic bond
- Atoms with identical size in pure metals
- crystalline (typically hexagonal or cubic)*
- polycrystalline**

examples for application:

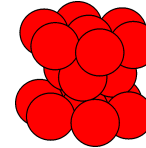
- crown, bridge
- implants
- filling
- orthodontics

Production: melting, casting

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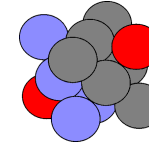
*Why is the hexagonal and cubic lattice common among metals?

close packing of equal spheres!



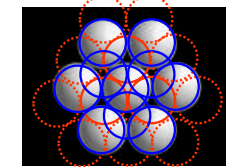
hexagonal close packed
(hcp)

pl. Ti, Cd, Co, Zn, ...



face centered cubic
(fcc)

pl. Ag, Au, Pt, Al, Cu, Ni, ...



less packed body
centered cubic
(bcc)

pl. Fe, Cr, ...

space filling: 74 %

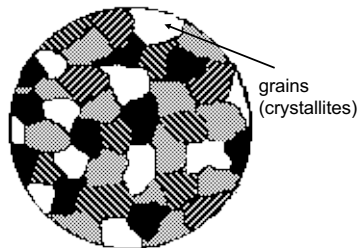
74 %

68 %

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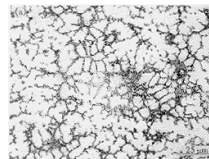
**Polycrystalline structure

Microstructure:

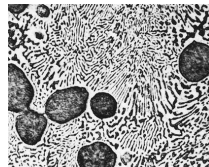


grains
(crystallites)

homogenous microstructure



heterogeneous microstructure



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Metal microscope (for samples that are not transparent)

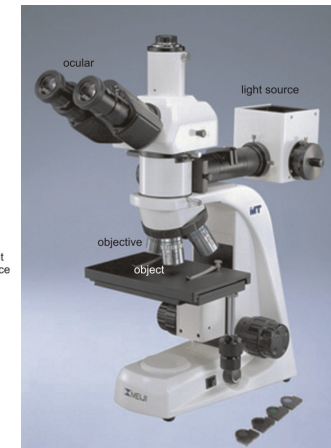
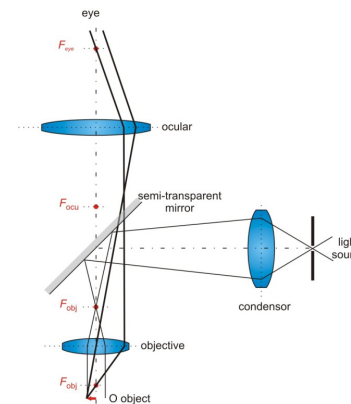
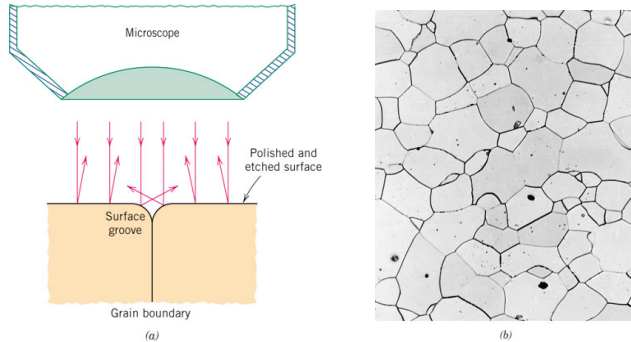
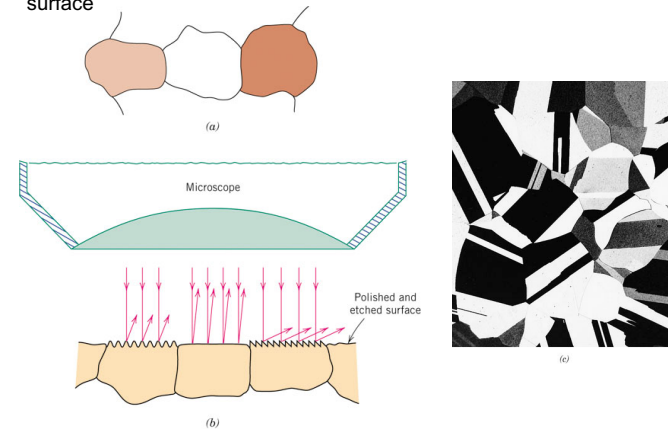


Image formation of a light microscope from a polished reflecting surface



The microscopic image of a partly polished reflecting surface



Metal alloys

Aim: to improve properties, for example:

- increase corrosion resistance, i.e. Fe, Ni, Co, ...+Cr
- increase hardness, stiffness, i.e. Au+Cu
- to improve metal-ceramic adhesion, i.e. precious metals +Fe, Sn, In

Classification:

- metal+metal, i.e. Fe+Cr
- metal+non-metal, i.e. Fe+C
- usage (i.e. inlay, crown, ...)
- base element (gold or palladium based, ...)
- number of components (biner, terner, kvaterner,...)
- 3 main element (i.e. Au-Pd-Ag, Ni-Cr-Be, ...)
- type of phase diagram
 - solid solution
 - eutectic alloy
 - peritectic alloy
 - metal alloy



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Alloying ratios:

• **mass%**
$$c_{m,1} = \frac{m_1}{m_1 + m_2} (\cdot 100\%)$$

• **mole%**
$$c_{v,1} = \frac{V_1}{V_1 + V_2} (\cdot 100\%) \rightarrow \text{properties!}$$

(i.e. Ni-Cr-Mo-Be alloy: Be 1,8 mass% \leftrightarrow 11 mole%)

Conversion:

$$c_{v,1} = \frac{c_{m,1} \cdot M_2}{c_{m,1} \cdot M_2 + c_{m,2} \cdot M_1} (\cdot 100\%) \quad c_{m,1} = \frac{c_{v,1} \cdot M_1}{c_{v,1} \cdot M_1 + c_{v,2} \cdot M_2} (\cdot 100\%)$$

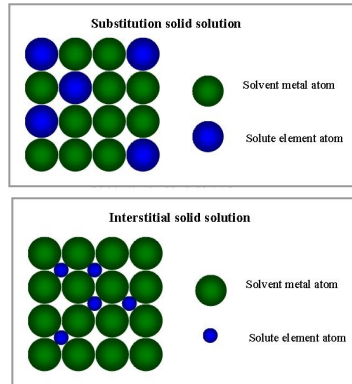
Mean density:
$$\bar{\rho} = \frac{\rho_1 \cdot \rho_2}{c_{m,1} \cdot \rho_2 + c_{m,2} \cdot \rho_1}$$

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Solid solution

Good solubility in both liquid and **solid phases**.

homogenous microstructure



i.e. Cu-Ni, Pd-Ag, Au-Cu, ...

i.e. Fe-C, CP Ti (O, C, N, H), ...

(CP: Commercial Purity)

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Criteria of solubility for substitution solid solutions:

- difference between size of atoms is small ($< 15\%$)
- same crystal lattice type
- similar electronegativity
- same valence, or the valance of „solvent“ is greater

metal	atomic diameter (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

Criteria of solubility for interstitial solid solutions:

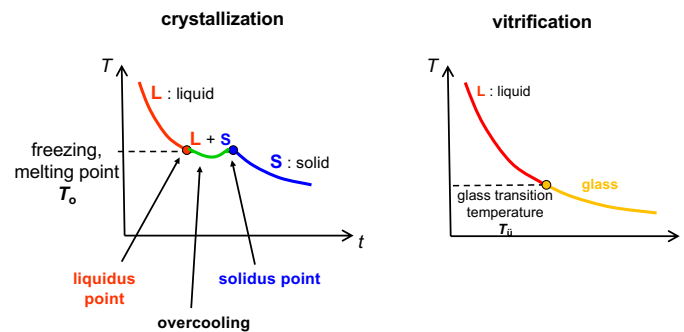
- size of „solute“ atom is much smaller
- amount of „solute“ is low ($< 10\%$)

Properties f solid solution:

elastic limit, strength, hardness increases
plasticity decreases, i.e. Au-Cu (5 mass%)

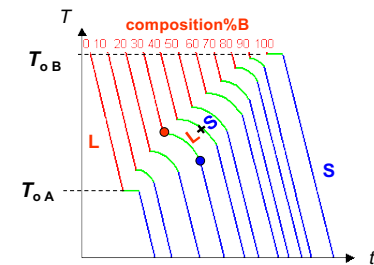
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Cooling of pure melted metal

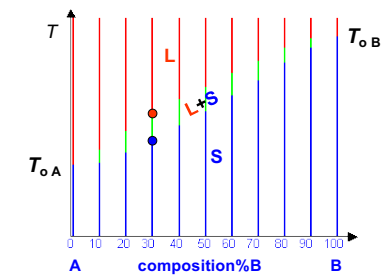


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Cooling of solid solution

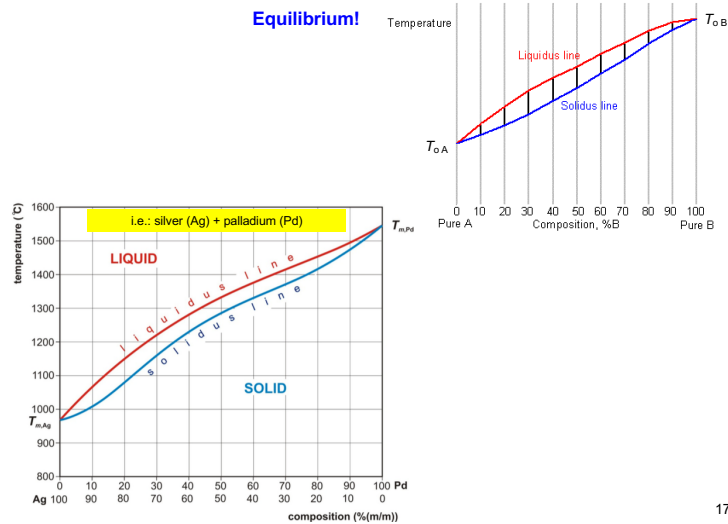


Phase diagram



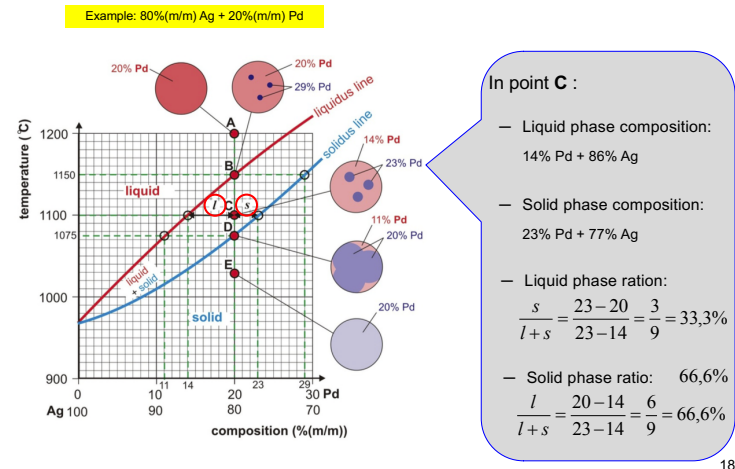
Through equilibrium states! = infinitely slow cooling

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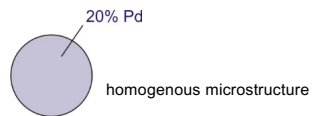
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How to determine phase composition and ratio

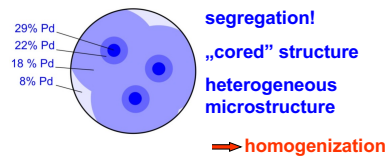


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Through equilibrium states! = infinitely slow cooling

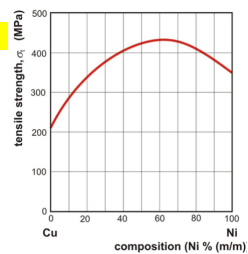


Through non-equilibrium states = reasonable cooling



Alloying determines the properties

example: Cu-Ni

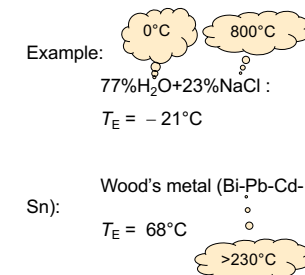
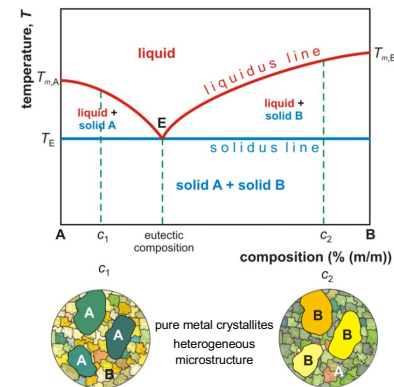


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Eutectic alloys

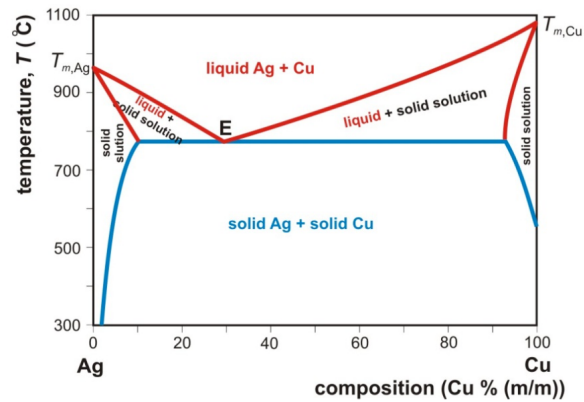
Components do not dissolve in solid phase

The alloys melting temperature is lower than the pure component's.



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Ag-Cu

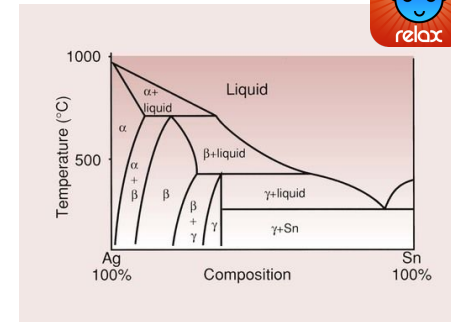


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Amalgam

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

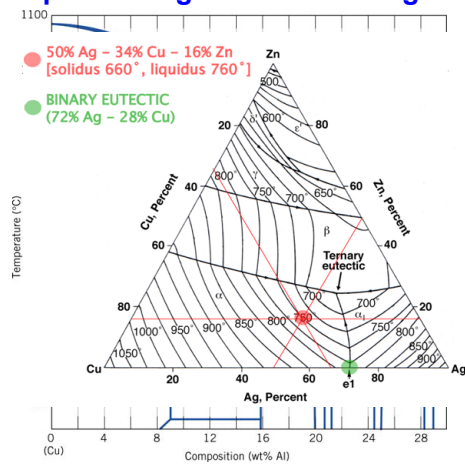
Ag-Sn phase diagram



γ phase: Ag_3Sn

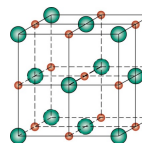
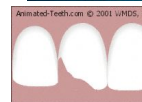
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Eutectic phase diagram can be a nightmare!



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Ceramics



Definition: mixture of metallic and non-metallic elements (there are exemptions!)

Properties:

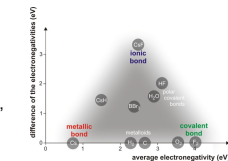
- medium density
- solid at room temperature
- large stiffness, hard, not deformable, brittle
- great heat- and corrosion resistance
- heat shock sensitive
- bad heat- and electric conduction
- diverse optical properties
- biocompatible

Structure:

- mainly ionic bond, less covalent
- ions of different sizes
- crystalline or amorphous or mixed**

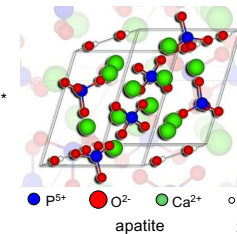
Applications:

- crowns, bridges
- implants
- cements
- polishing materials



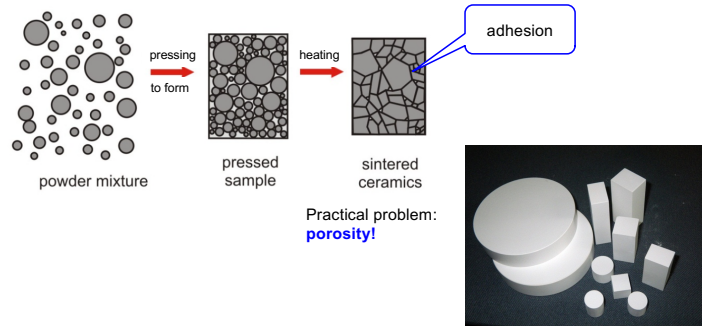
Production:

- melting
- sintering*



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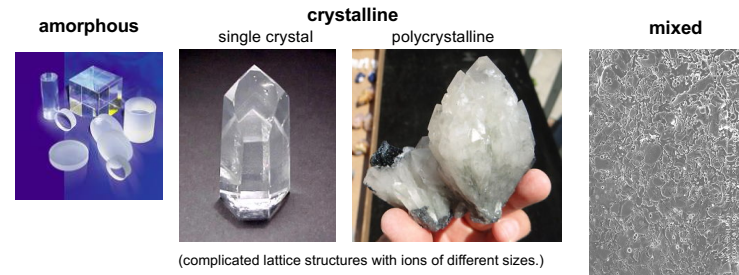
*Sintering



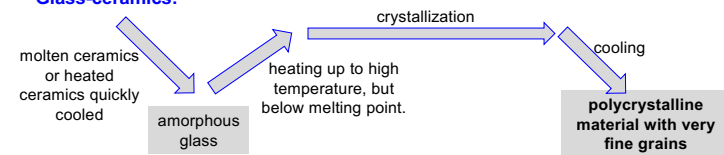
Liquid phase sintering: combination of melting and heating

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**Structure

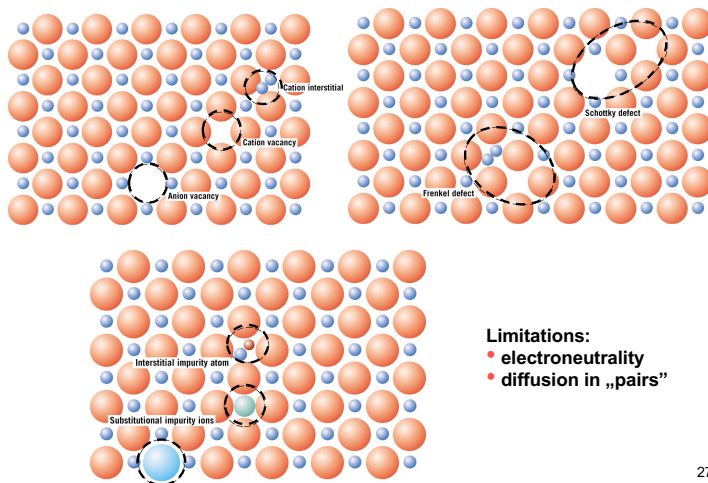


Glass-ceramics:



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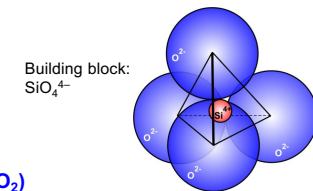
Lattice defects:



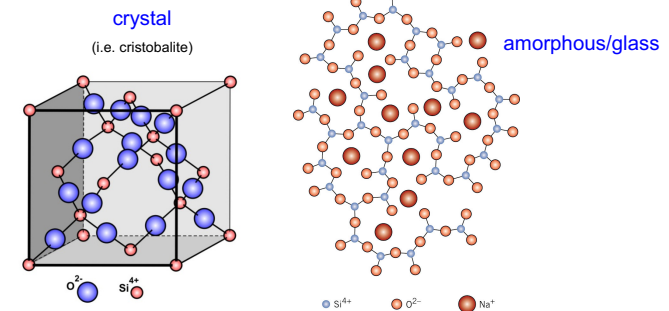
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Silicates

Main elements: Si and O

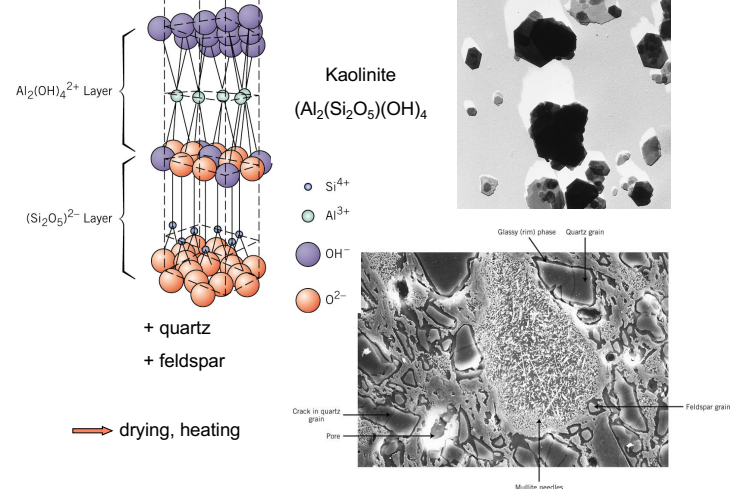


• Silicon-dioxide (SiO₂)



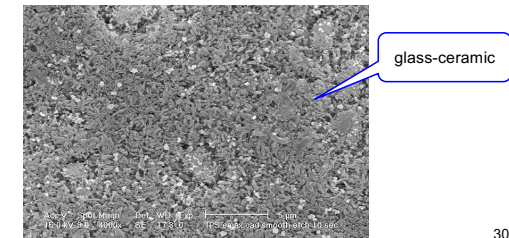
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• Porcelain (traditional)



• Dental silicate ceramics (dental porcelain)

- amorphous glass (alkali feldspars - $\text{NaAlSi}_3\text{O}_8$, KAlSi_3O_8 , SiO_2 , Al_2O_3 , ...)
- amorphous glass with crystalline regions
 - amorphous feldspar glass + few leucite crystals (KAlSi_2O_6)
 - amorphous feldspar glass + 50% leucite crystals (KAlSi_2O_6)
 - Li-silicate glass + 70% Li-disilicate crystals ($\text{Li}_2\text{Si}_2\text{O}_5$)



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Oxide ceramics

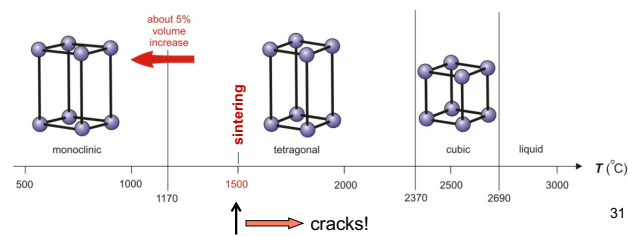
• Zirconium-dioxide (ZrO_2 , zirconia)

Properties (when sintered to compact state):

- white
- density approx. 6 g/cm^3
- great strength, toughness, stiffness, hardness (see later)

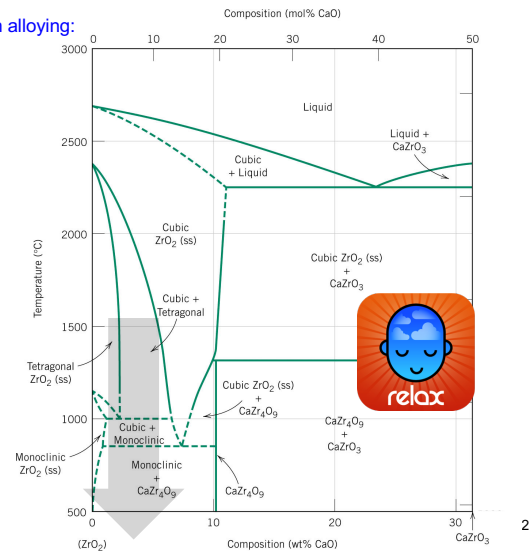
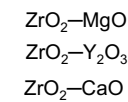
Production:

- from ZrSiO_4
- expensive purification steps, but about 1% of hafnium oxide remains (radioactive $<1 \text{ Bq/g}$)
- cold or hot extrusion, sintering



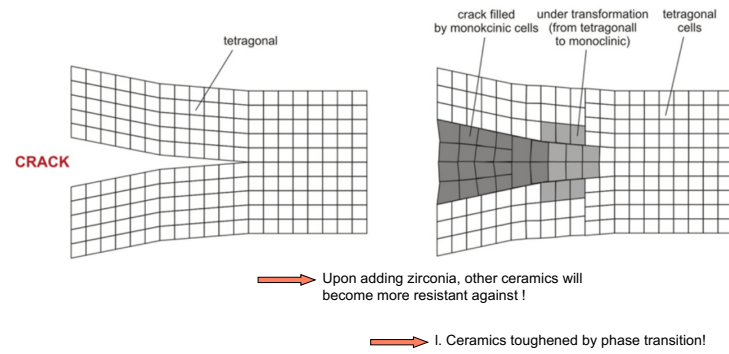
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Stabilizing zirconia with alloying:



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„Self-healing“ property of zirconia:



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• Aluminium-oxide (Al_2O_3)

Properties:

- colorless, white
- melting point 2700°C
- density approx. 4 g/cm^3
- very hard (see later)

Crystalline forms:

corundum

$\text{Al}_2\text{O}_3 + \text{CrO}_2 \rightarrow \text{ruby}$

$\text{Al}_2\text{O}_3 + \text{CoO}_2 \rightarrow \text{sapphire}$



• Oxide ceramics crystal + glass

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