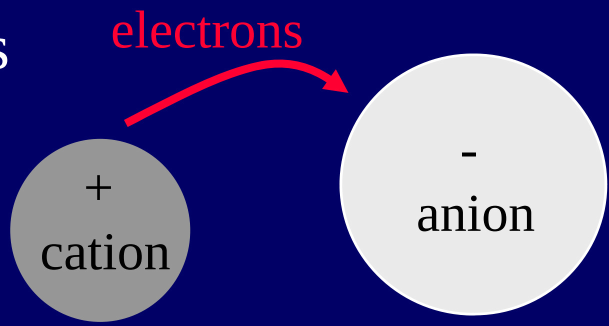
Ceramics

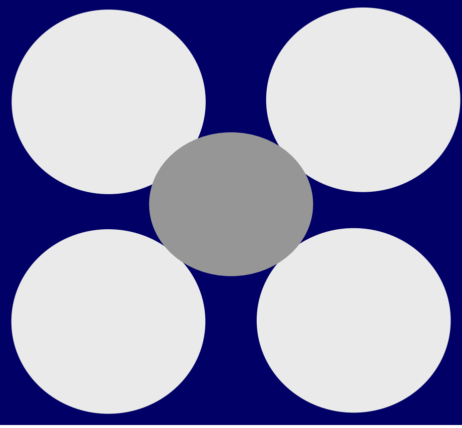
Ceramics

inorganic – non-metallic materials
- china/dishes
- cement/concrete
- functional ceramics
- structural ceramics

ionic – covalent bonding of at least 2 atoms
(e.g. Al_2O_3: 63% ionic, SiC: 12% ionic)



structures depending on a) electrical charge
b) atomic radii (r_C/r_A)

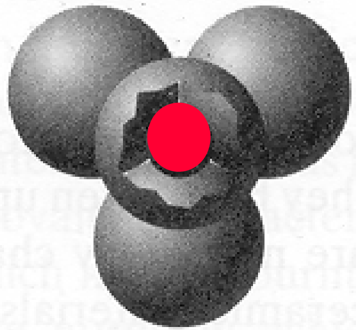


stable – cations are in contact with surrounded anion

Structure of Ceramics

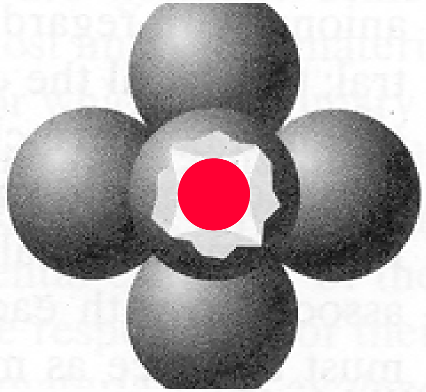
coordination number 4 r_C/r_{A}:

0.225–0.414



coordination number 6 r_C/r_{A}:

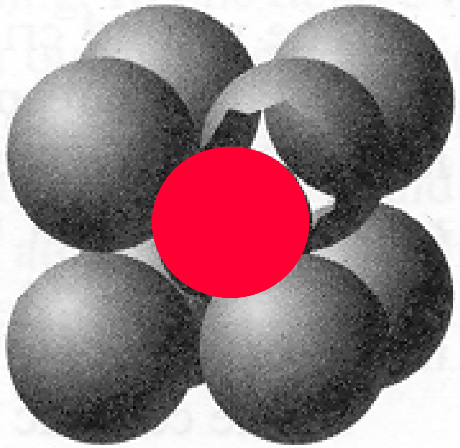
0.414–0.732



e.g.: Al_2O_3:
Al^{3+}: r_C=0.053nm, O^{2-}: r_A=0.140nm

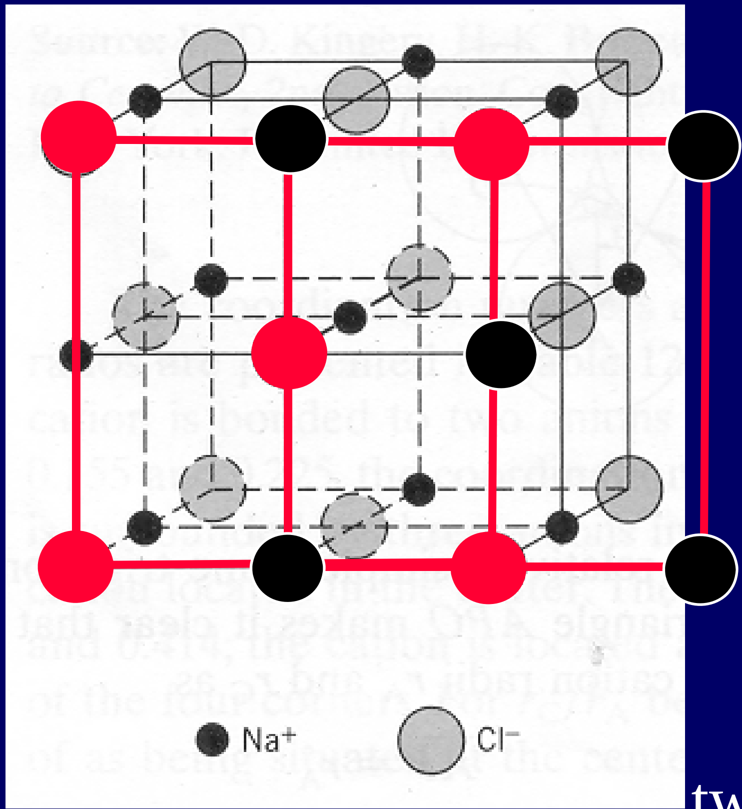
coordination number 8 r_C/r_{A}:

0.732–1.0



AX Structures

e.g. NaCl



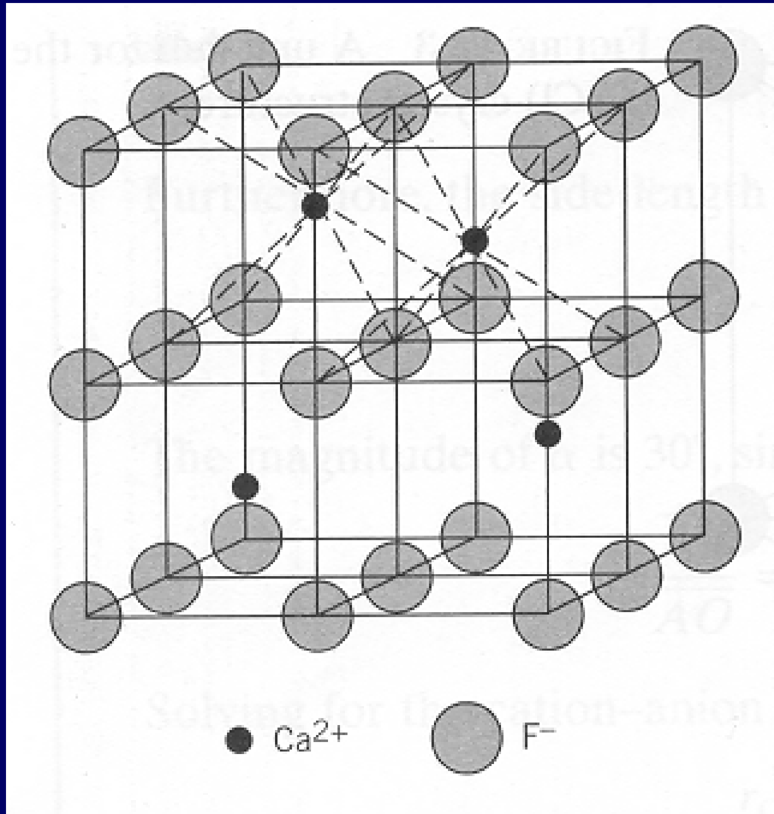
fcc anionic (Cl^-) lattice

fcc cationic (Na^+) lattice

two interpenetrating fcc lattices:
e.g. MgO, MnS, FeO
(coordination number 6)

A_mX_p Structures

e.g. CaF_2
$r_C/r_A=0.8$
coord. 8



center cube positions
only half-filled

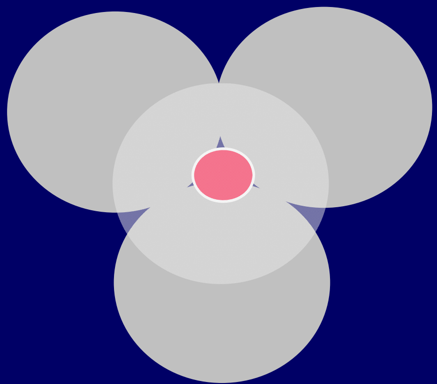
(CsCl completely-filled)

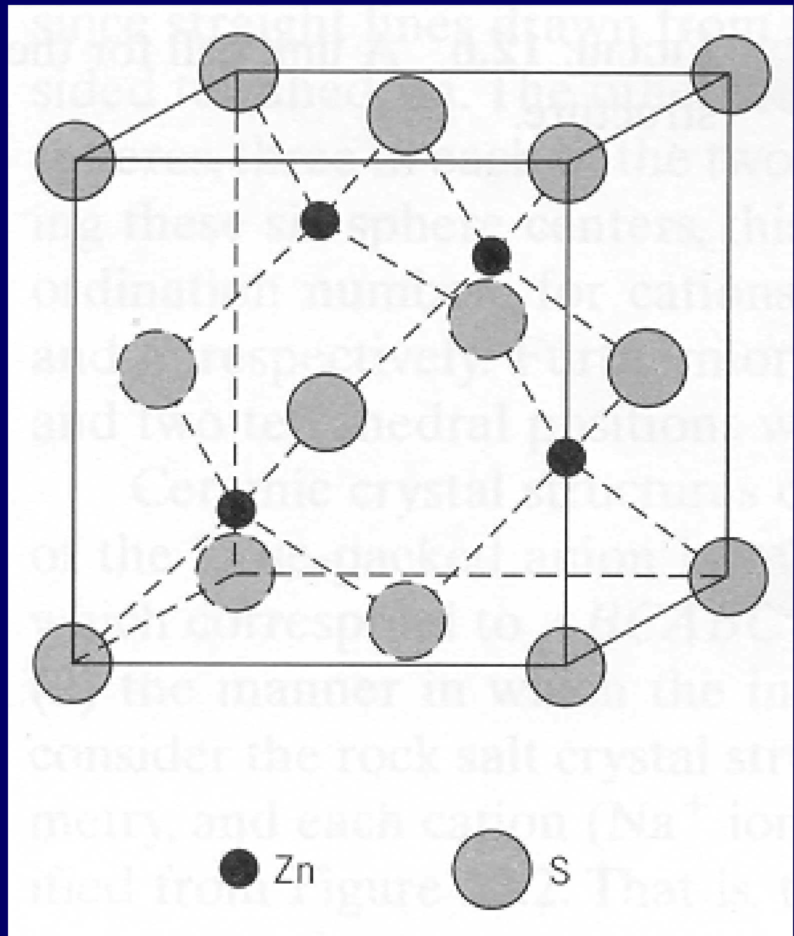
$A_mB_nX_p$ Structures

e.g. $BaTiO_3$

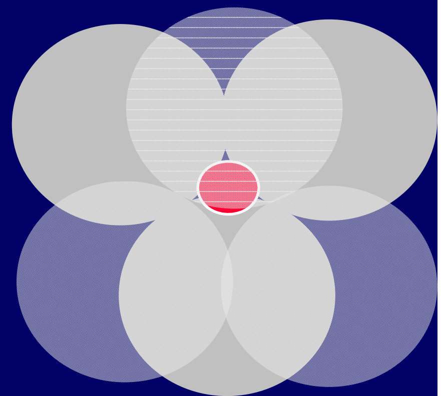
Close Packing of Anions

e.g. ZnS
$\Rightarrow$Zn anions in
tetrahedral
interstitial positions





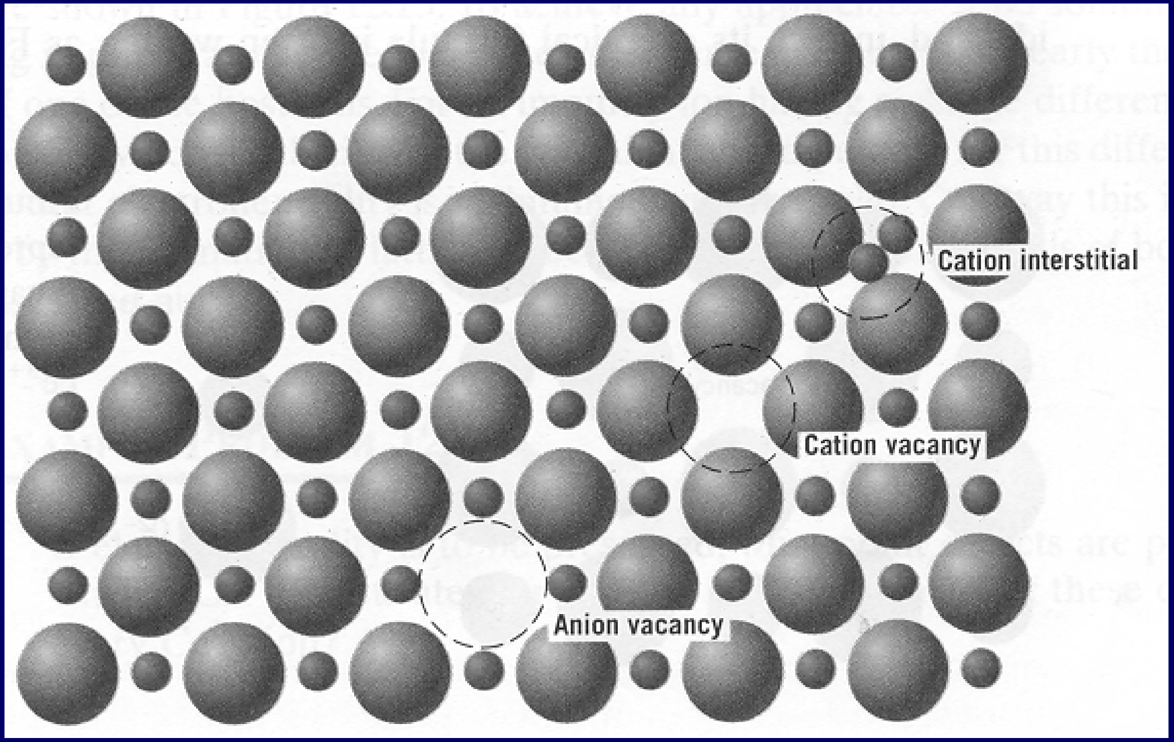
octahedral
interstitial positions



spinel structures, e.g. $MgAl_2O_4$: O^{2-} fcc lattice, Mg^{2+} tetrahedral, Al^{3+} octrahedral

Imperfections in Ceramics

defects:

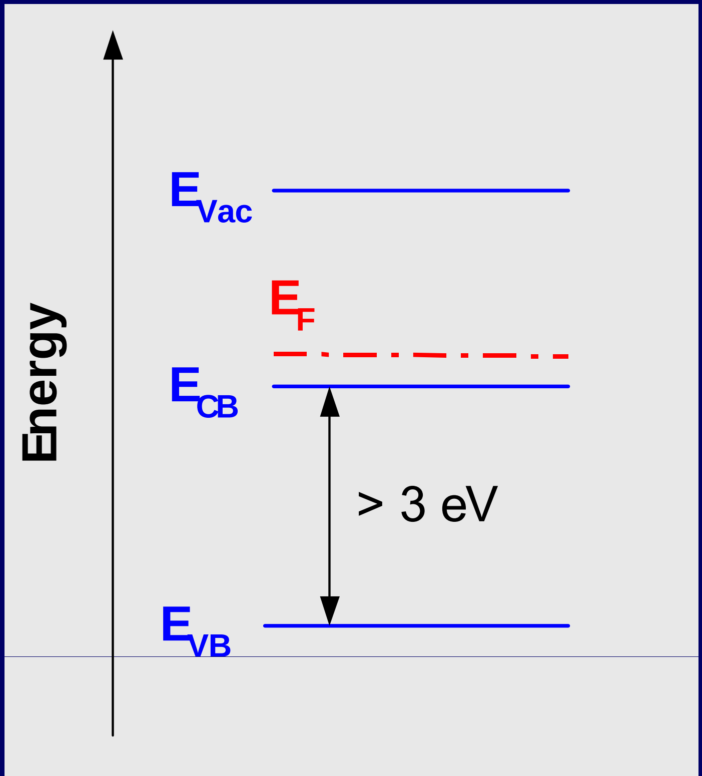


electroneutrality: Schottky pair defect: cation and anion vacancy
Frenkel pair defect: cation vacancy+interstitial

non-stoichimetry: e.g. $Fe_{1-x}O$, 2 Fe^{3+} ions – 1 Fe^{2+} vacancy, impurities

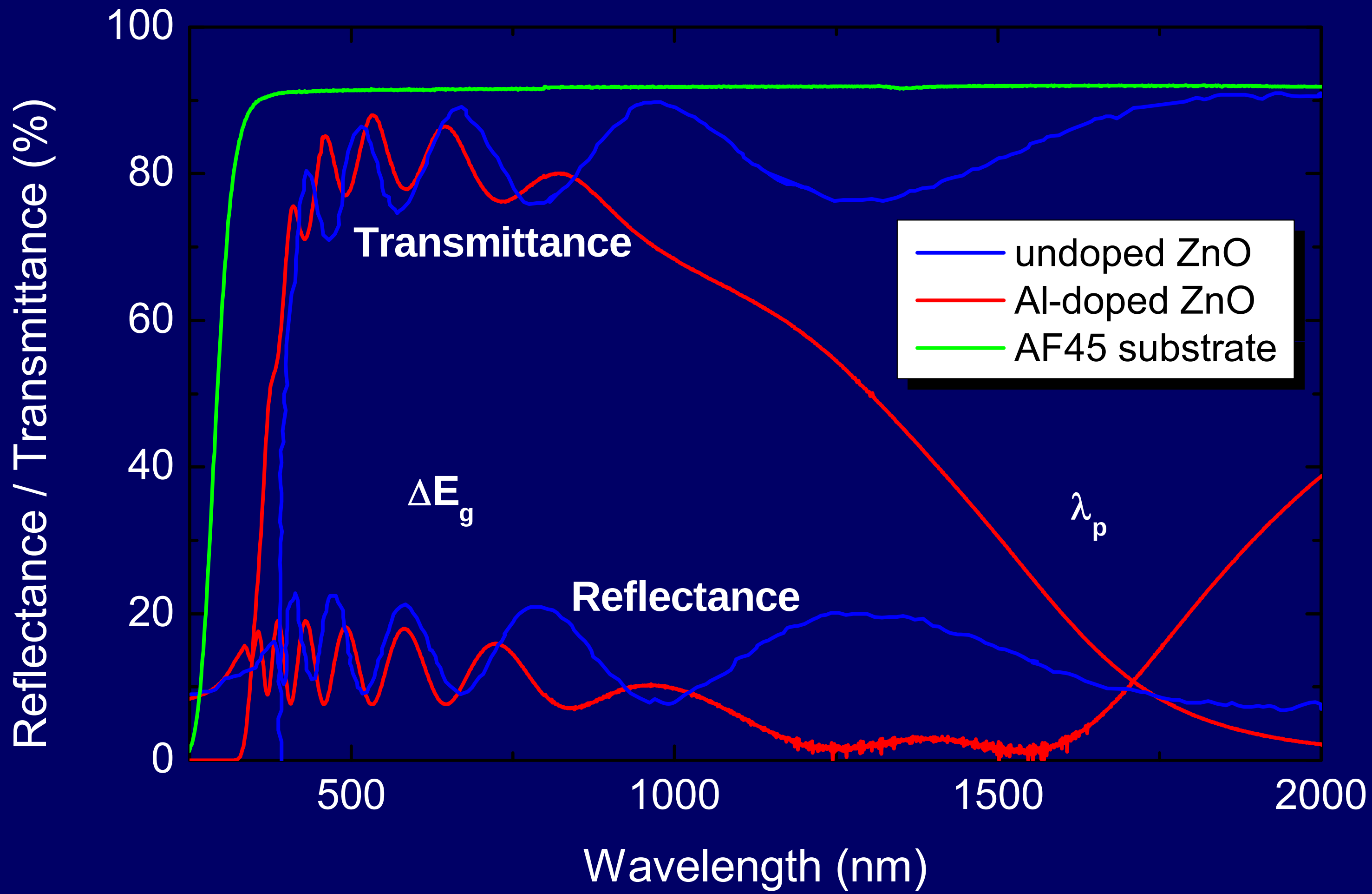
→ diffusion/electrical conduction

Transparent Conductive Oxides (TCOs)



- Wide band gap oxide semiconductors (ZnO, SnO_2, In_2O_3 and mixed systems)
- High doping level (non-stoichiometry, substitution)
- Electron degeneracy, resulting in
  - High electrical conductivity (n-type)
  - High transmittance in the visible spectral range
  - High infrared reflectivity

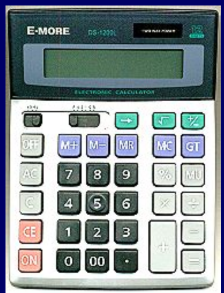
Properties of undoped and Al-doped ZnO films



Applications of TCO thin films

Solar cells & solar control:

- Transparent front contacts for thin film photovoltaics

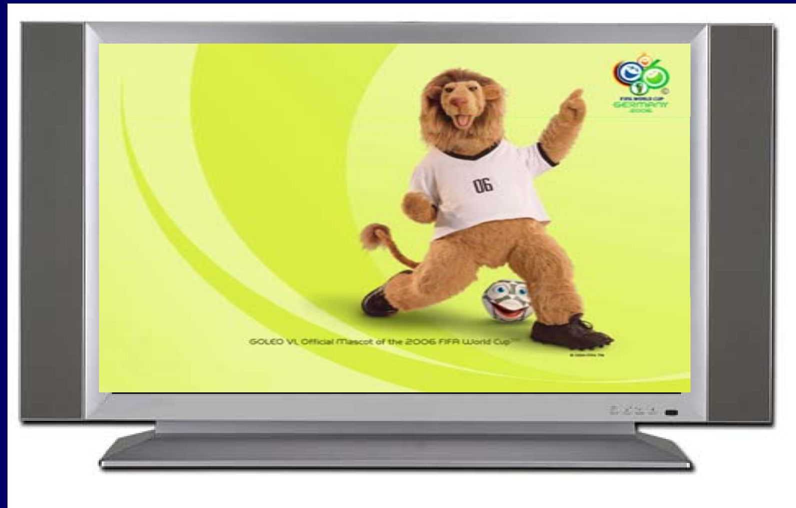


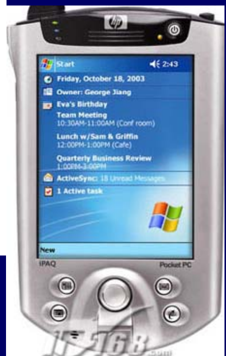
Solar cells

solar control

Displays

- LCD (Liquid crystal display)
- FPD (Flat panel display)
- PDP (Plasma display panel)
- Flexible display
- PLED (Polymer light emitting device)
- OLED (Organic light emitting device)

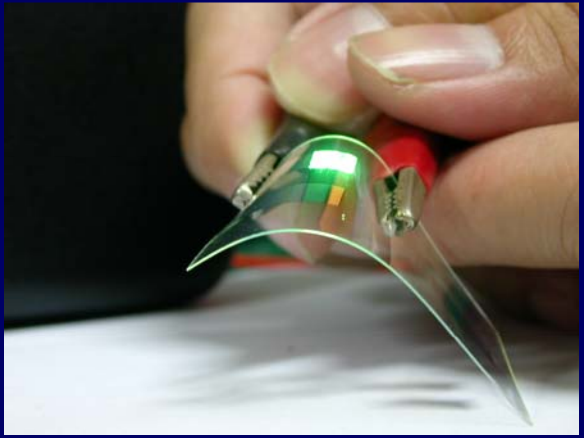


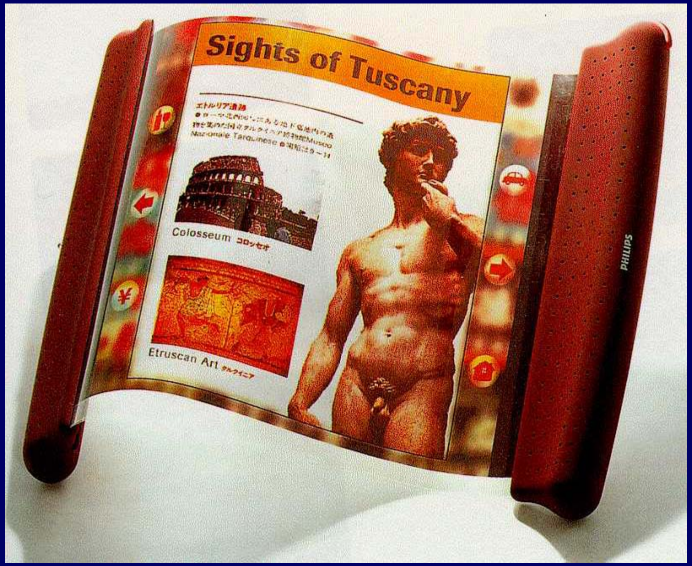


Flexible displays:

Intrinsic shortcomings of LCDs:

- Viewing angle dependency,
- Low contrast and high power consumption





Artist's impression of the display of the future.

Advantages of PLED:

- Excellent viewing angle, contrast and low power consumption

Applications of flexible PLED:

- Electronic paper, smart cards, wearable devices

OLEDs

Organic Light Emitting Device (OLED) technology is emerging as a leading next generation technology for electronic displays and lighting. OLEDs can provide desirable advantages over today's liquid crystal displays (LCDs), as well as benefits to product designers and end users.

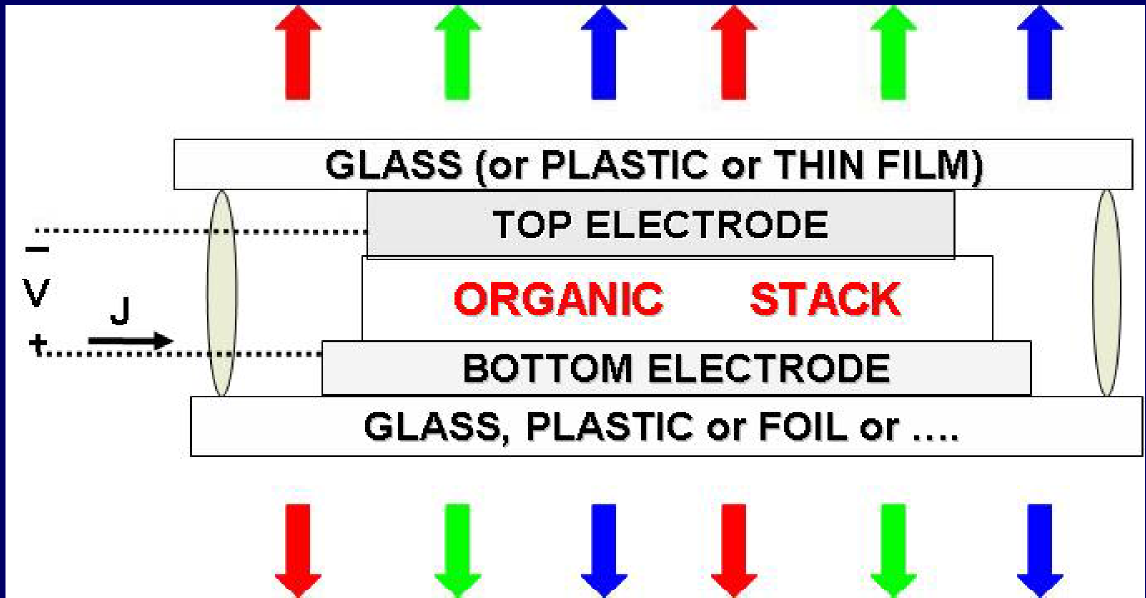
OLEDs features:

- **Vibrant colors**
- **High contrast**
- **Excellent grayscale**
- **Full-motion video**
- **Wide viewing angles from all directions**
- **A wide range of pixel sizes**
- **Low power consumption**
- **Low operating voltages**
- **Wide operating temperature range**
- **Long operating lifetime**
- **A thin and lightweight form factor**
- **Cost-effective manufacturability**

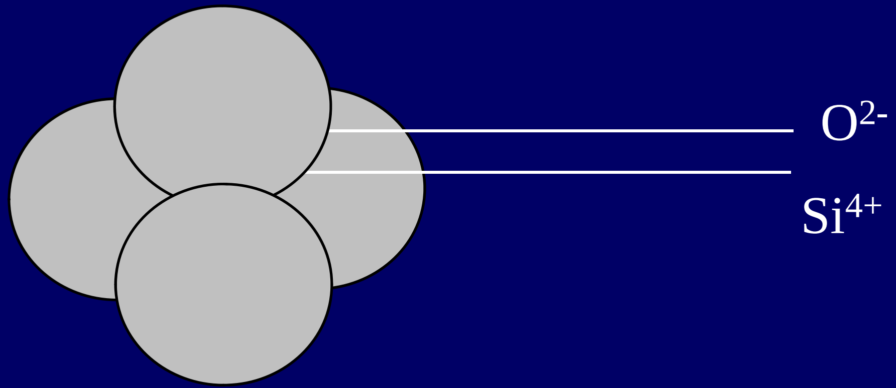
http://www.universaldisplay.com/tech.htm

Structure of OLEDs

As this schematic shows, an OLED is a monolithic, solid-state device that typically consists of a series of organic thin films sandwiched between two thin-film conductive electrodes. The choice of organic materials and the layer structure determine the device's performance features: emitted color, operating lifetime and power efficiency.



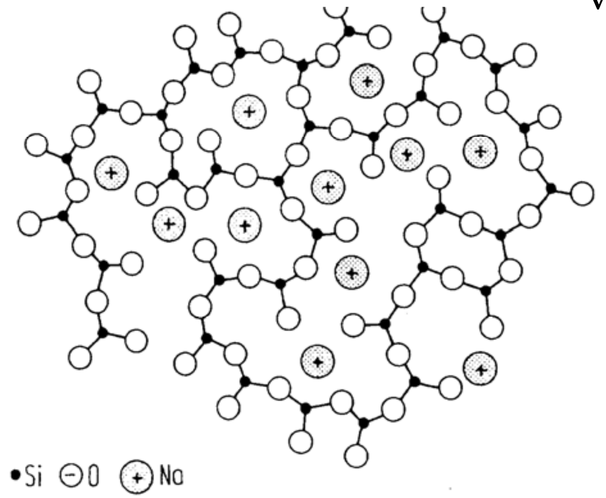
Silicate Ceramics

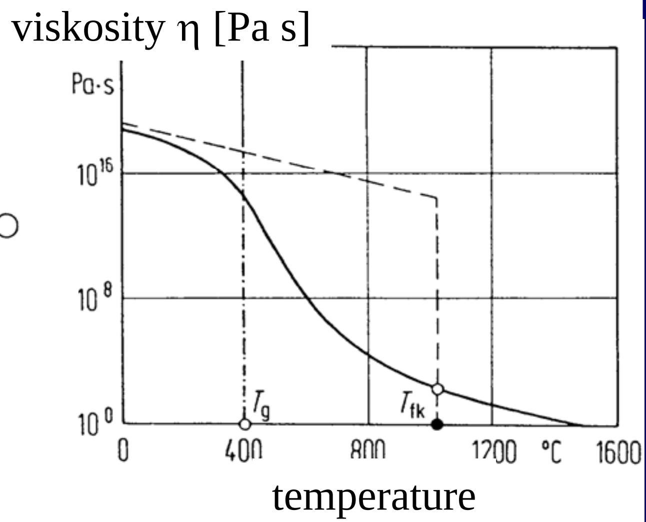


basic unit:
SiO_4^{4-} tetrahedron

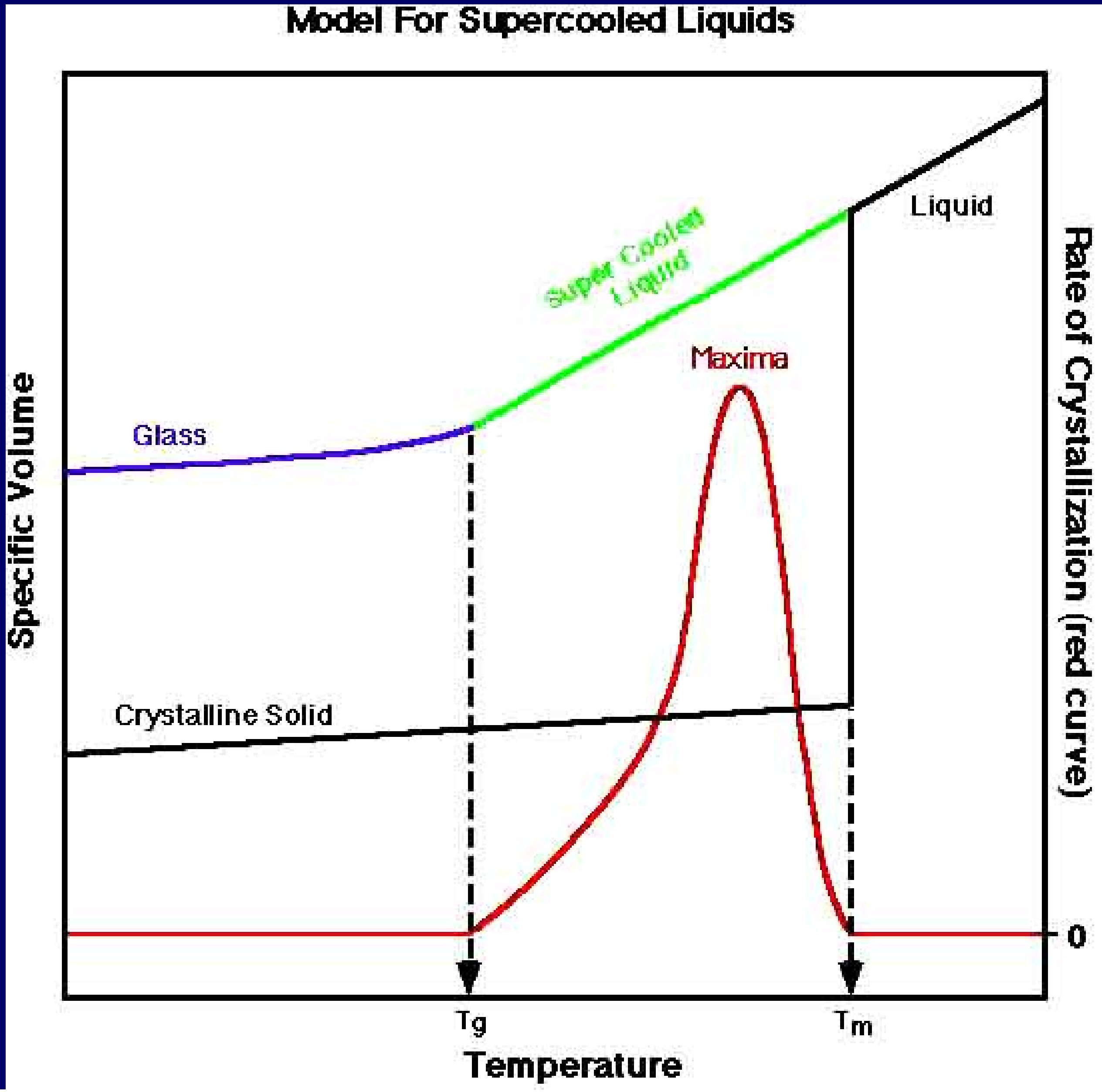
crystalline: SiO_2 (silica, high strength, relatively high Tm: 1710°C)

non-crystalline: SiO_2 (addition of CaO, Na_2O-network modifier – random networks)
glass





Glass general



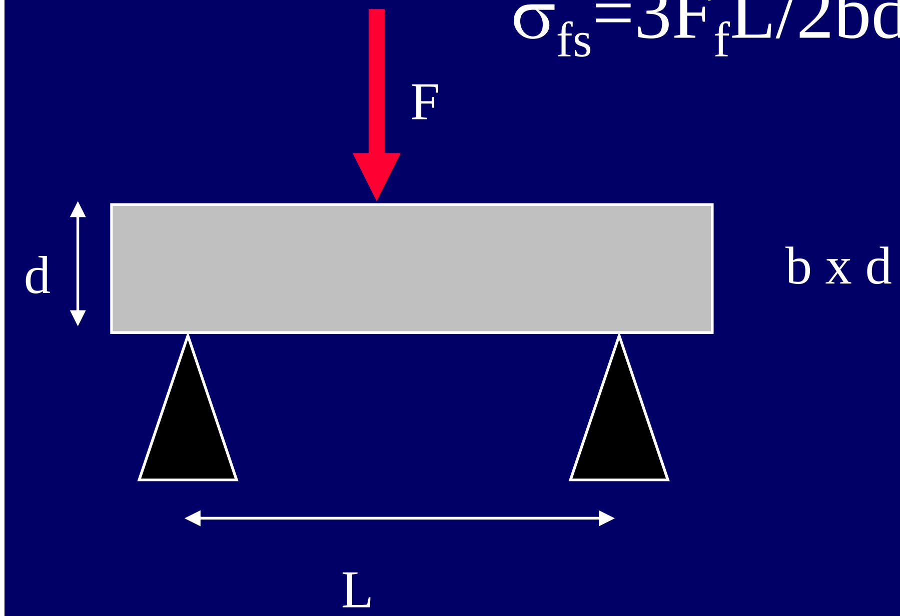
Mechanical Properties of Ceramics/glasses

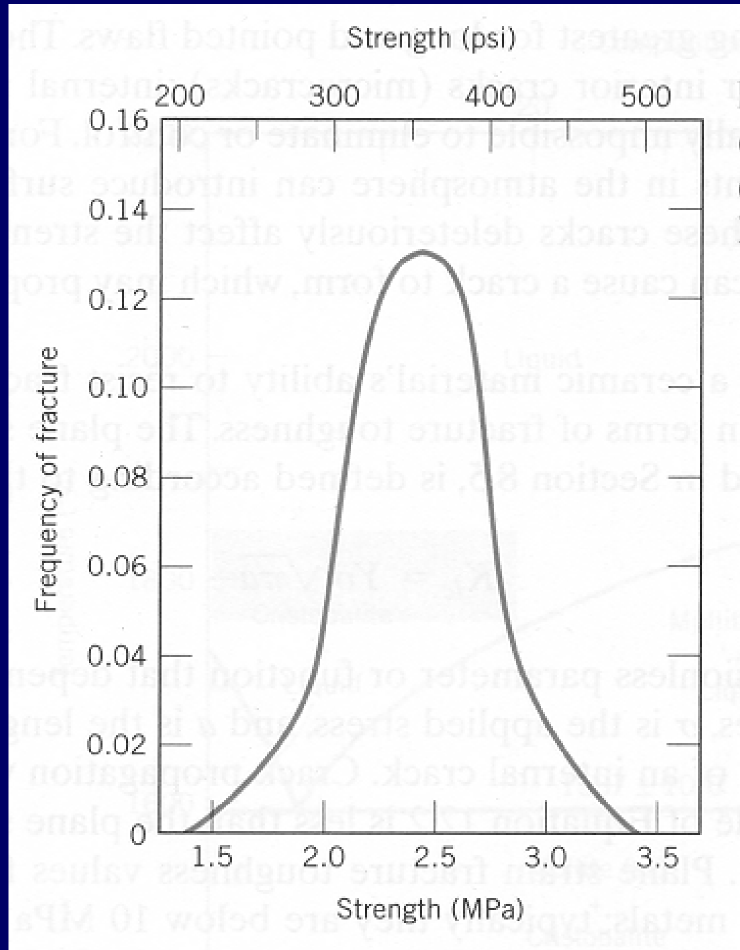
brittle, no plastic deformation

lower fracture strength than theoretical value
-flaws (stress raisers)

flexural strength/fracture strength:
3pt bending

$$\sigma_{fs}=3F_fL/2bd^2$$

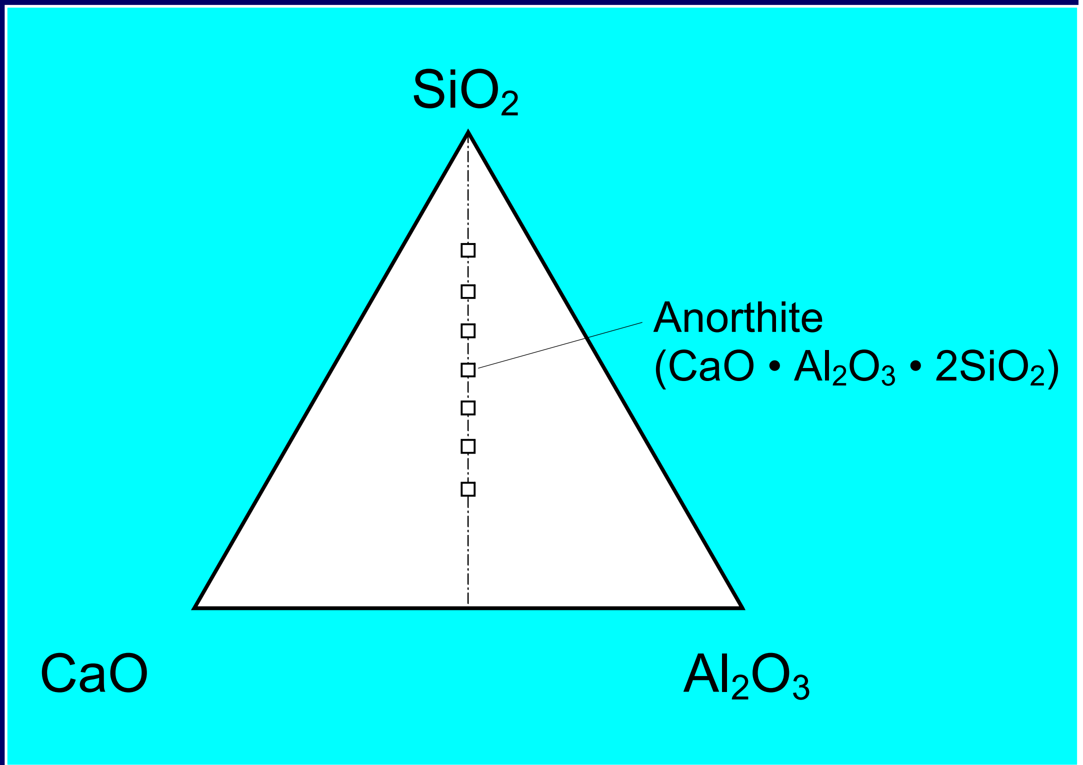




=> statistical approach!!

Example: Investigated glass samples

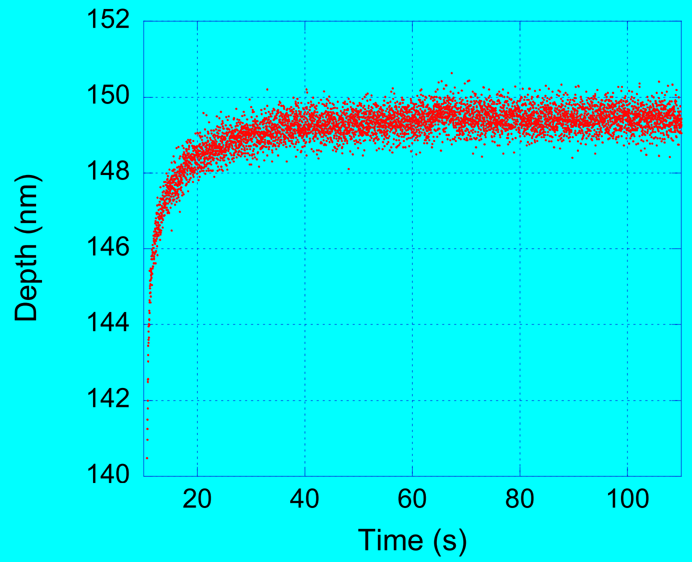
- Model-System
  - $CaO / Al_2O_3 / SiO_2$
- Glass Sheets:
  - as received ($10\times10\times1$ mm^3)
- Cross-section:
  - Crack induced by three-point-bending
  - All indents taken within 20min after cracking



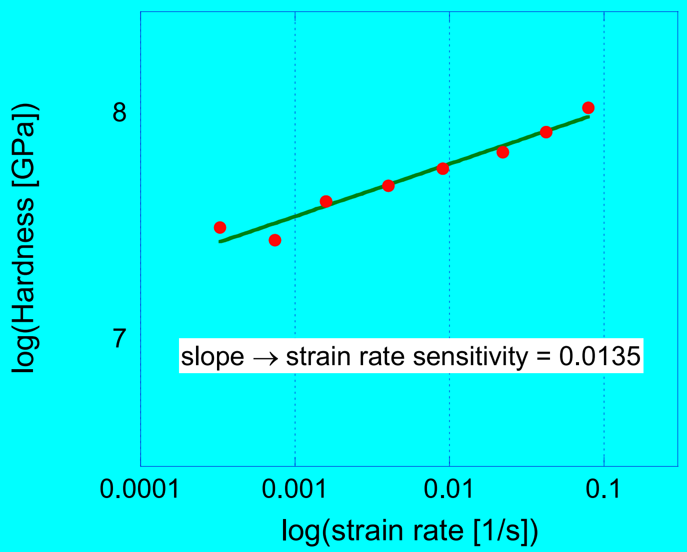
Time dependent behavior under constant load: Strain Rate Sensitivity

- Relaxation processes under constant load
- strain rate sensitivity (m) describes this behavior: $\boxed{\sigma \propto \dot{\varepsilon}^m}$

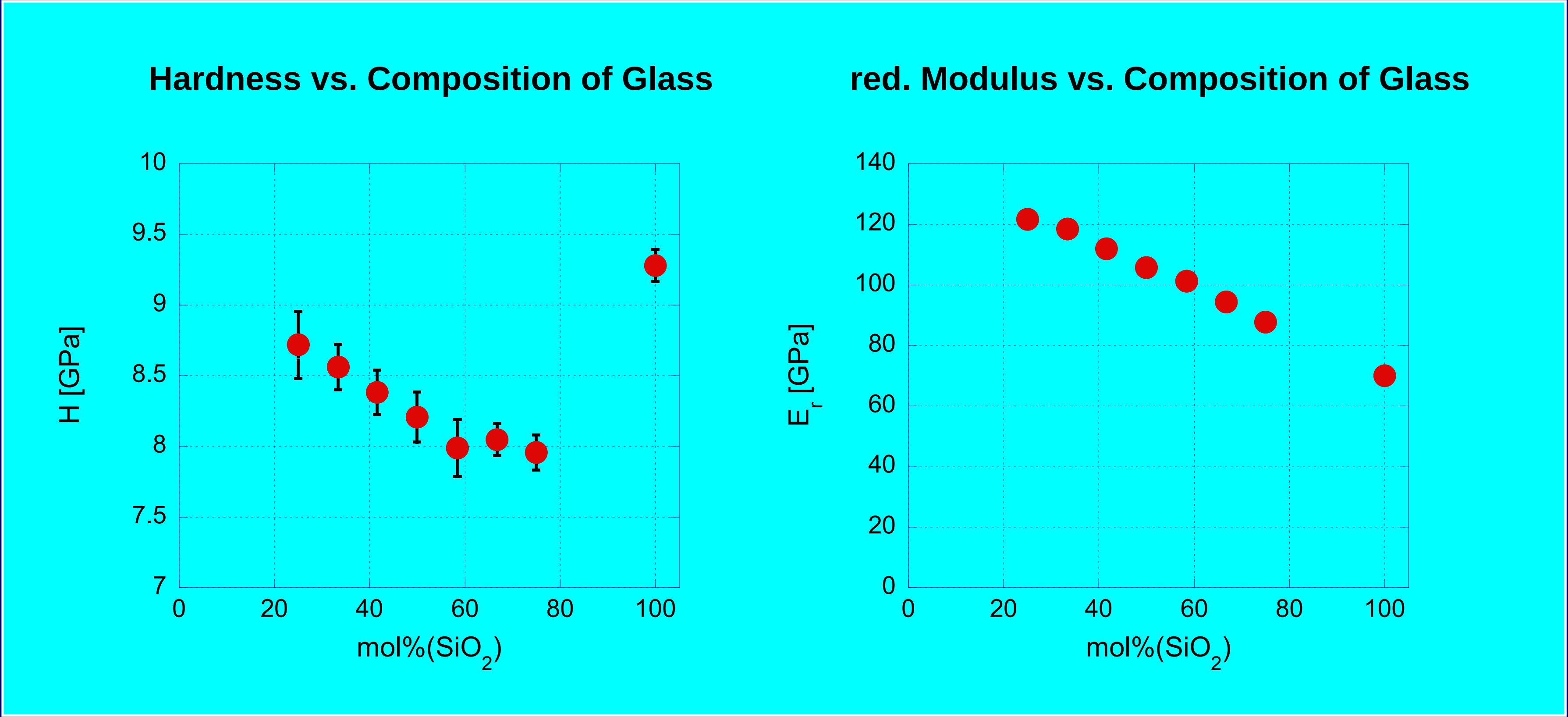
Example of time dependent behavior (glass) holding segment - constant load



Example of determination of strain rate sensitivity



Hardness and Moduli of the samples surfaces

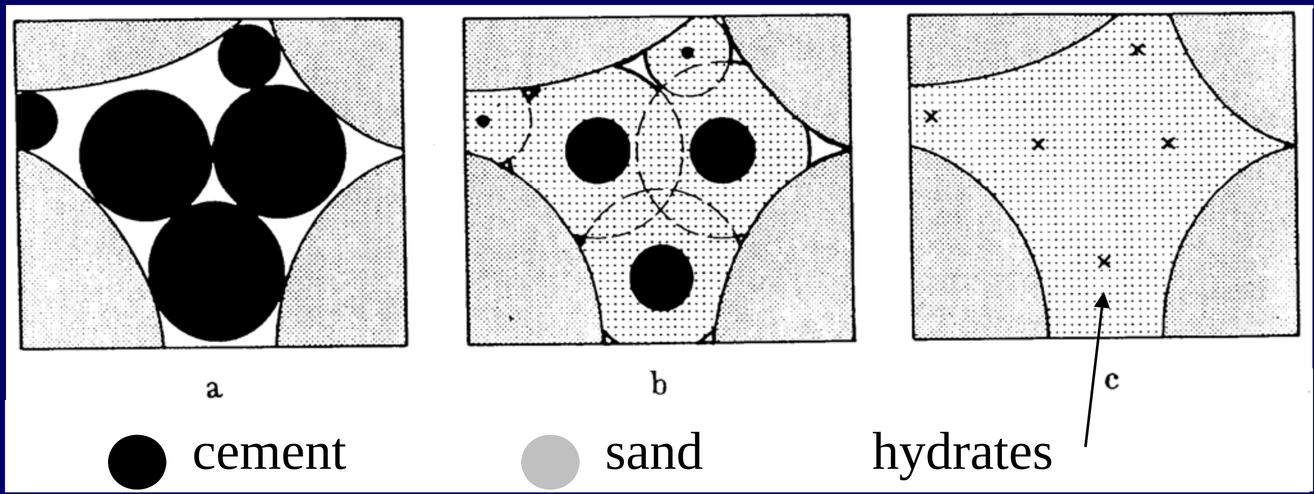


- Berkovich indenter / 10mN / 10s holding
- significant influence of composition

Hydrated Silicates - Concrete

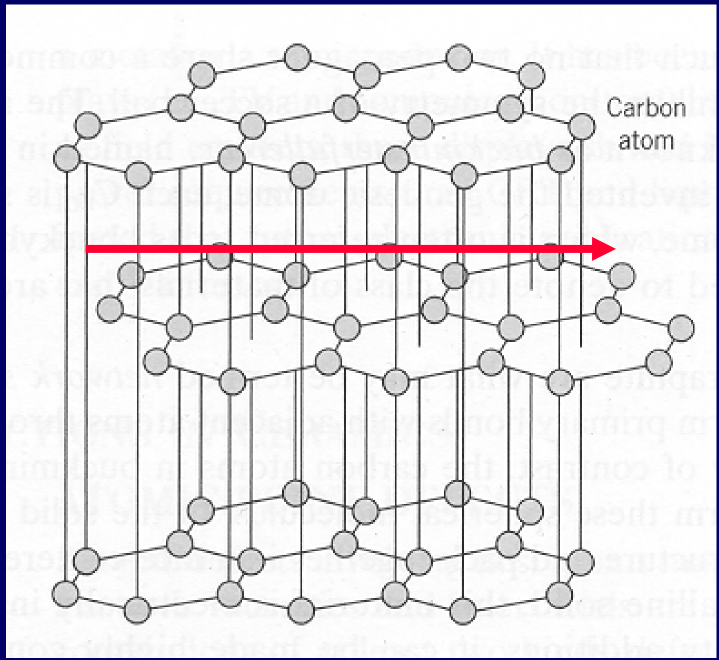
Portland Cement Concrete: sand + gravel (about 60% packing) + cement

Hydratation (simplified): $2(2CaO \cdot SiO_2)+4H_2O \Rightarrow 3CaO \cdot SiO_2 \cdot 3H_2O+Ca(OH)_2$



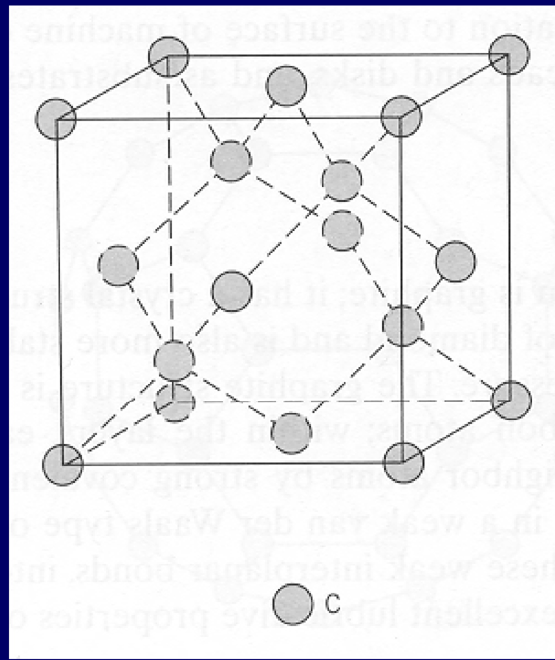
Polymorphic Forms of Carbon

graphite



layers of hexagonally arranged C
covalent bond (3C)
between layers
weak van der Waals bond
⇒good chemical stability/strength
electric conductivity (electrodes/contacts)

diamond



very strong bond (cubic diamond structure)
each C bonds to 4 neighbours (ZnS structure)
=> hard,
low electric/high thermal conductivity
synthetic diamonds/thin films (tool surfaces)

Intrinsic properties of Diamond and its applications

Hardness	**About 100 GPa**	Wear-protection coatings
Chemical resistivity	**All chemicals**	Electrodes in aggressive chemical environment
Thermal conductivity	**20 W/cmK**	Insulating heat-sink in the context of laser diodes
Disruptive strength E_s	**10^7 V/cm**	
Transparent	**UV-, VIS, IR**	Optical windows (UV- to IR-regime)
Index of refraction n	**2,42**	
Absorption edge	**200 nm**	
Band gap E_g	**5,45 eV**	High-temperature semiconductors and sensors (up to 600°C, compared to 120°C for Si)
Carrier mobility μ, Electrons	**2200 cm^2/Vs**	
Holes	**1600 cm^2/Vs**	

CVD-Diamond deposition

(M. Frenklach et al., 1991)

Gas inlet

$H_2 + CH_4$

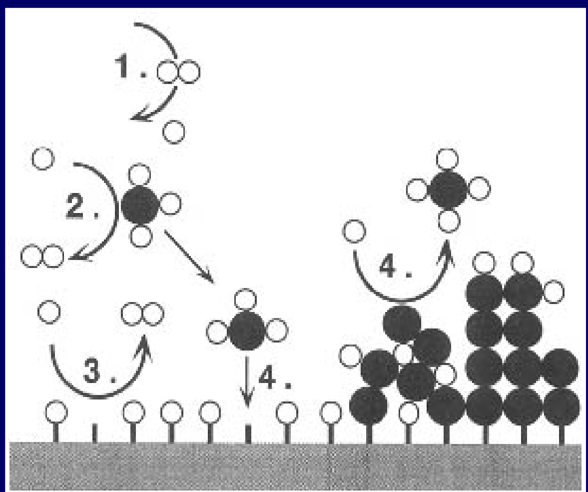
Thermal or electric activation (HF, Flame, MWP, DC, ...)

Hydrogen-dissociation

(1) $H_2 = 2H$

(2) $CH_4 + H = CH_3 + H_2$

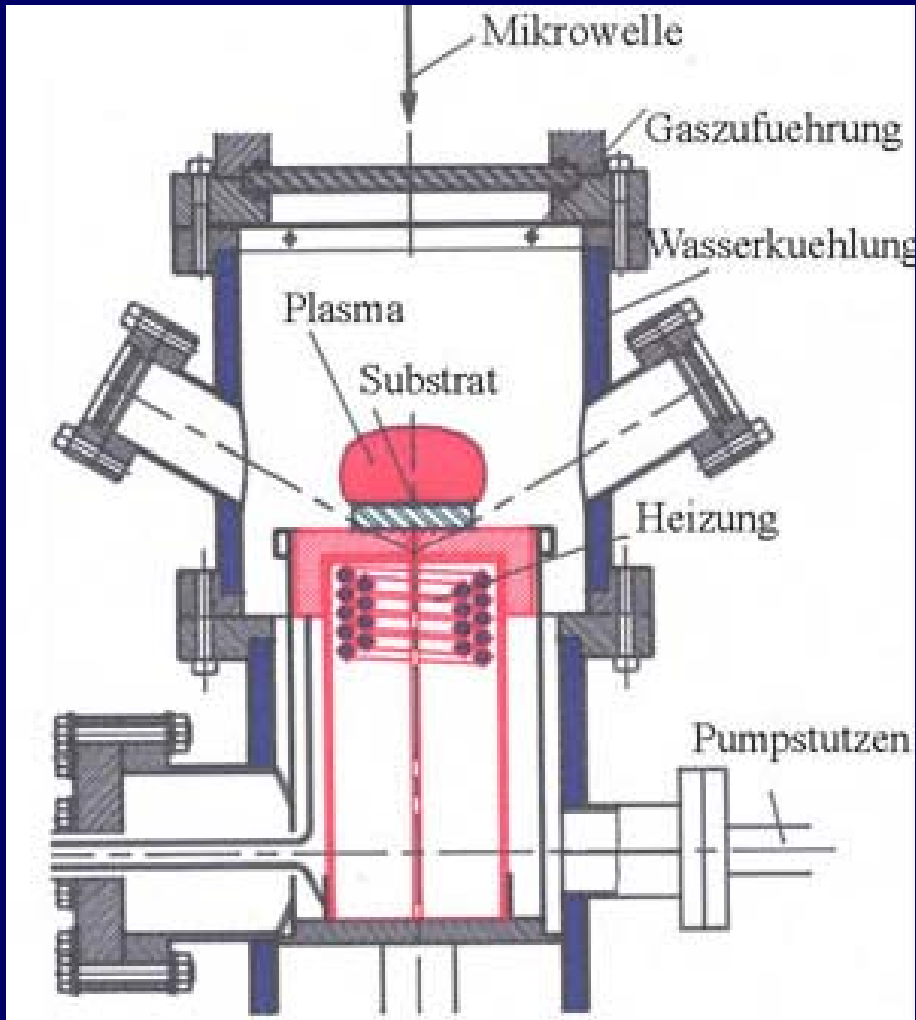
Reactions in the gas-phase
Kinetics, transport, surface-reactions, and carbon-incorporation



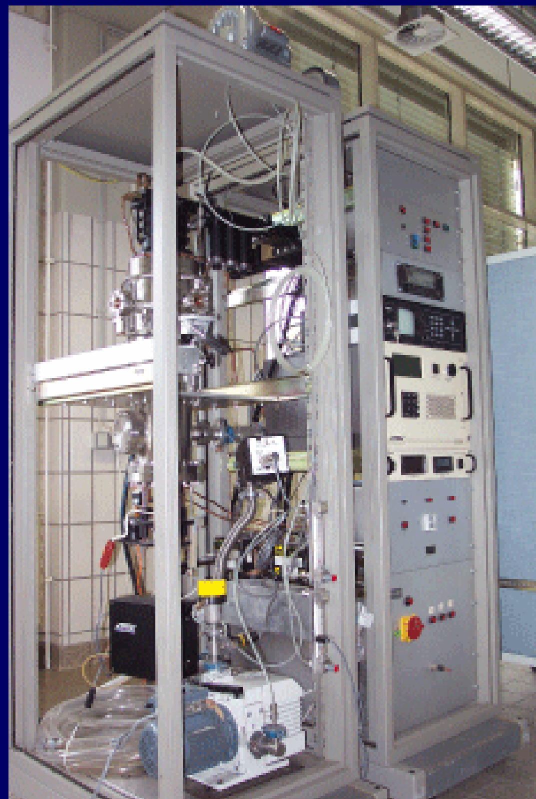
(3) $CH\ (s) + H = C\ (s) + H_2$
(4) $C\ (s) + CH_3 = C_2H_3\ (s)$

Substrate

Microwave Plasma CVD

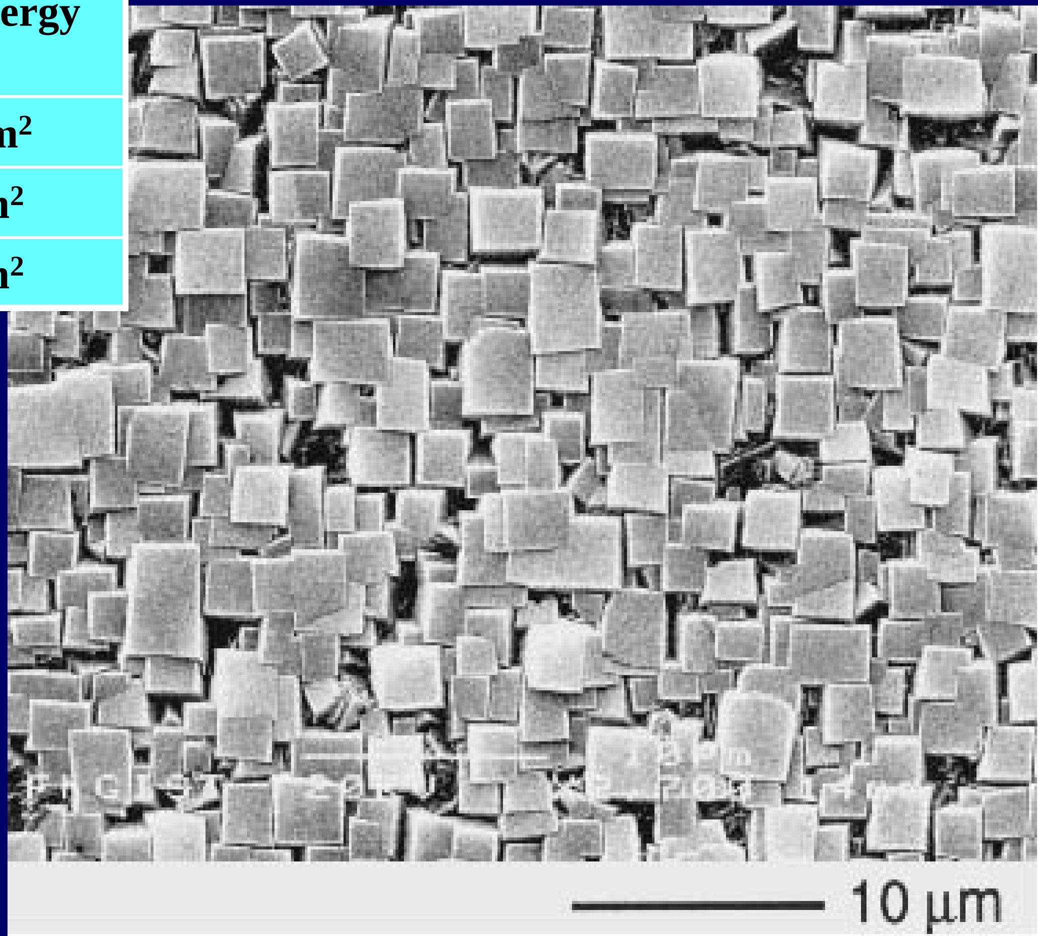


T_S = 500 – 1100°C,
CH_4/H_2 = 0,5 - 2%,
Pressure = 10 - 40 mbar
P = 300 - 1500 W



Hetero-epitaxy of Diamond on Si

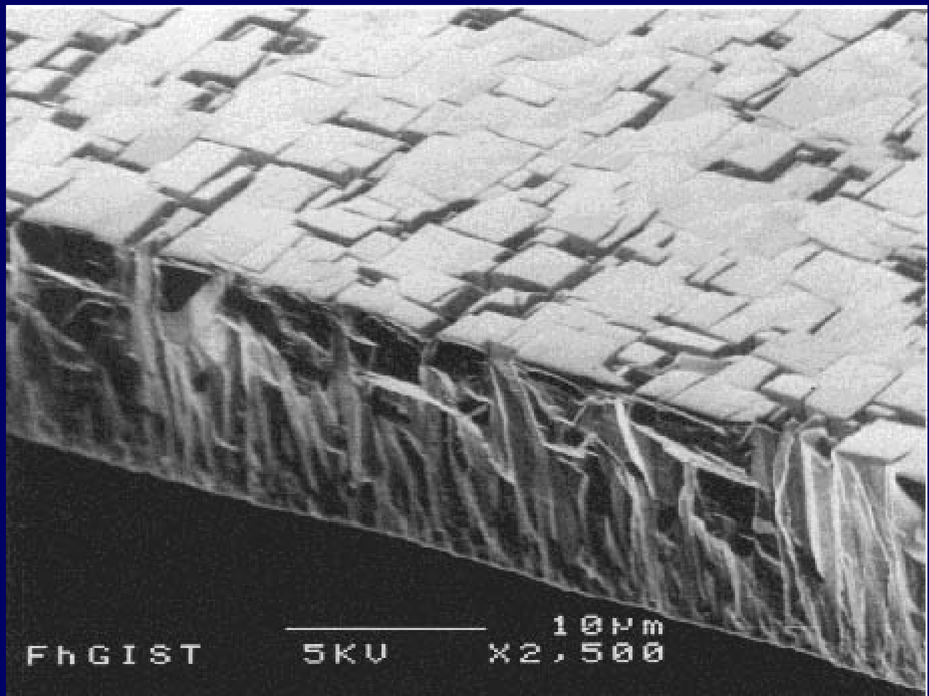
Material	Lattice-constants	Surface-energy
Diamond	3,5667 Å	ca. 6,0 J/m^2
c-BN	3,612 Å	4,8 J/m^2
Si	5,4388 Å	1,5 J/m^2



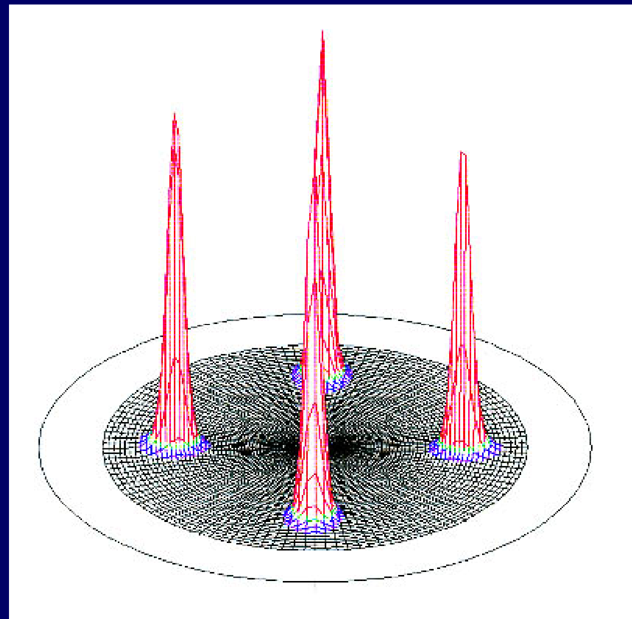
SEM

Jiang & Klages, Appl. Phys. Lett. 62, 3438 (1993)

Hetero-epitactic Diamond-films on Si(001)



X. Jiang et al. J. Appl. Phys. 83, 2511 (1998)

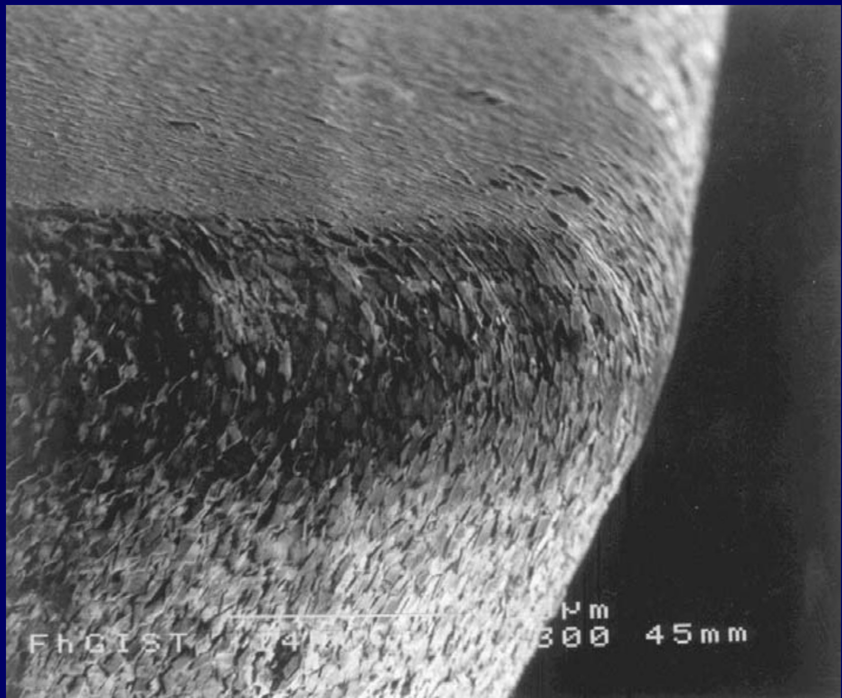


{111}-X-ray Pole-figure

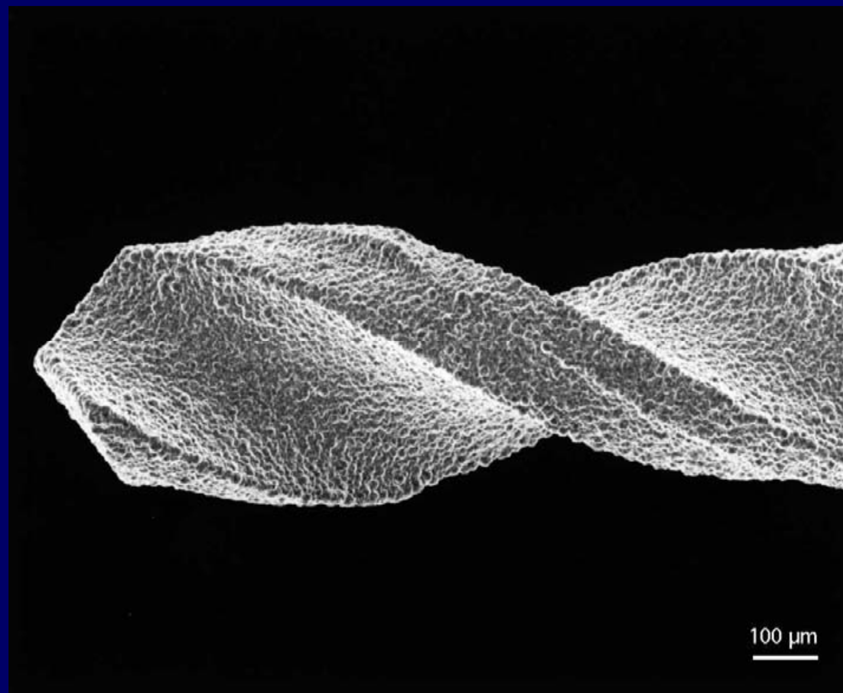
$(001)_{Diamond}$ // $(001)_{Si}$

$[110]_{Diamond}$ // $[110]_{Si}$

Coating of cutting-tools



Edge of a cutting-insert coated
with (100)-diamond



Micro-drill D = 0,15 mm
used to machine circuit-boards

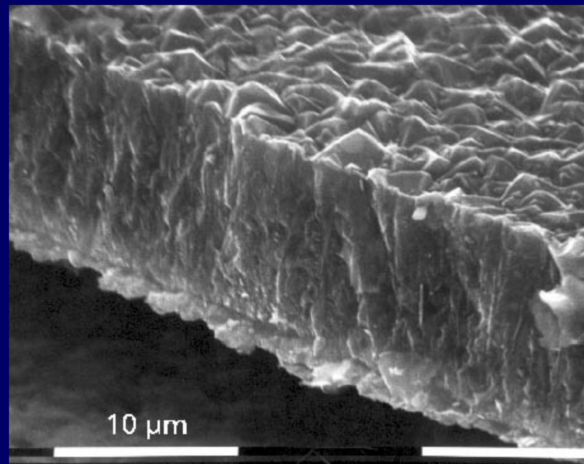
Adhesion issue limits potential applications

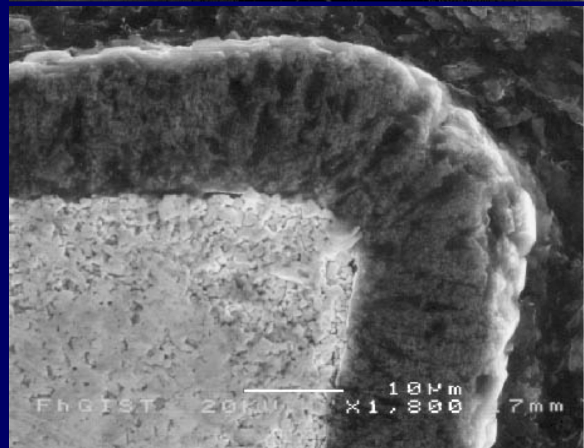
Background: thermal stresses

$$\sigma_f(T) = (\alpha_s - \alpha_f)\Delta T \frac{E_f}{(1-\nu_f)}$$

α_s, α_f : thermal expansion coefficient of substrate and film

E_f, ν_f : Young's modul and Poisson-ratio of film



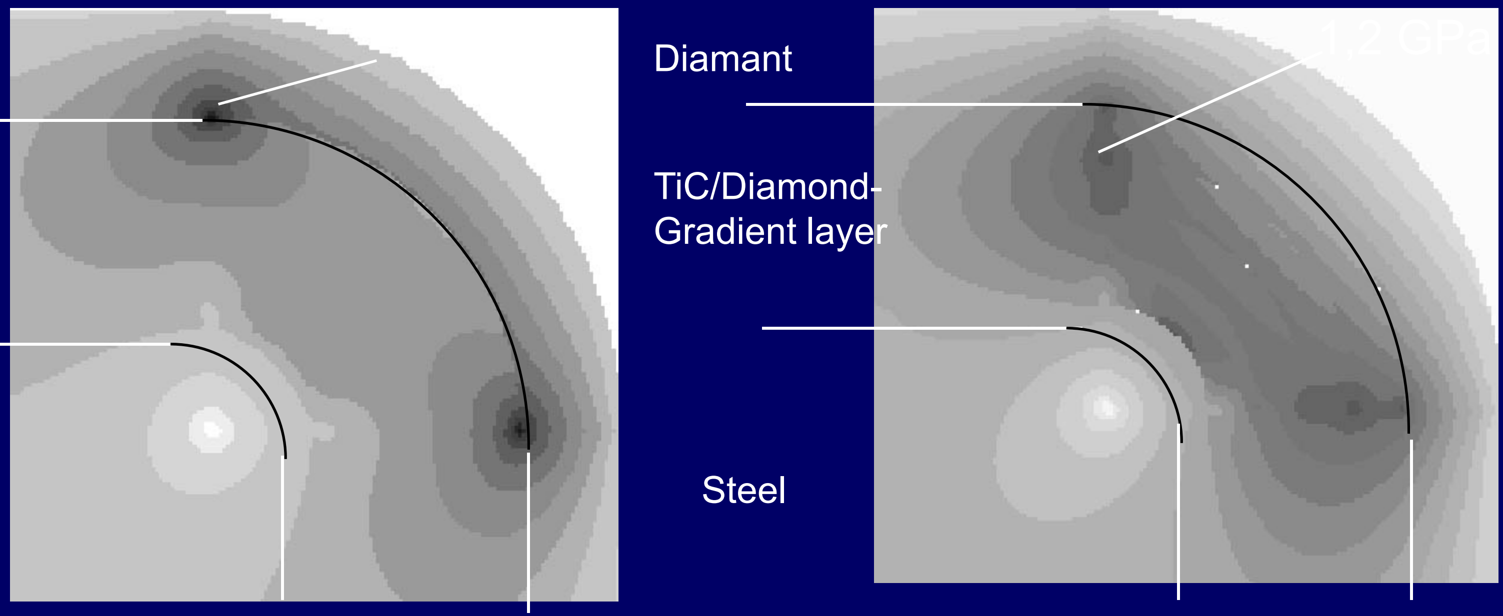


T_s = 800 °C

Material	Diamond	Al_2O_3	Si	ß-SiC	TiC	Steel
α (10^{-6} / K)	**1,2**	**3,3**	**4,0**	**6,6**	**8,3**	**12,0**
σ_f (GPa)	**0,0**	**2,1**	**2,7**	**5,4**	**7,4**	**10,7**

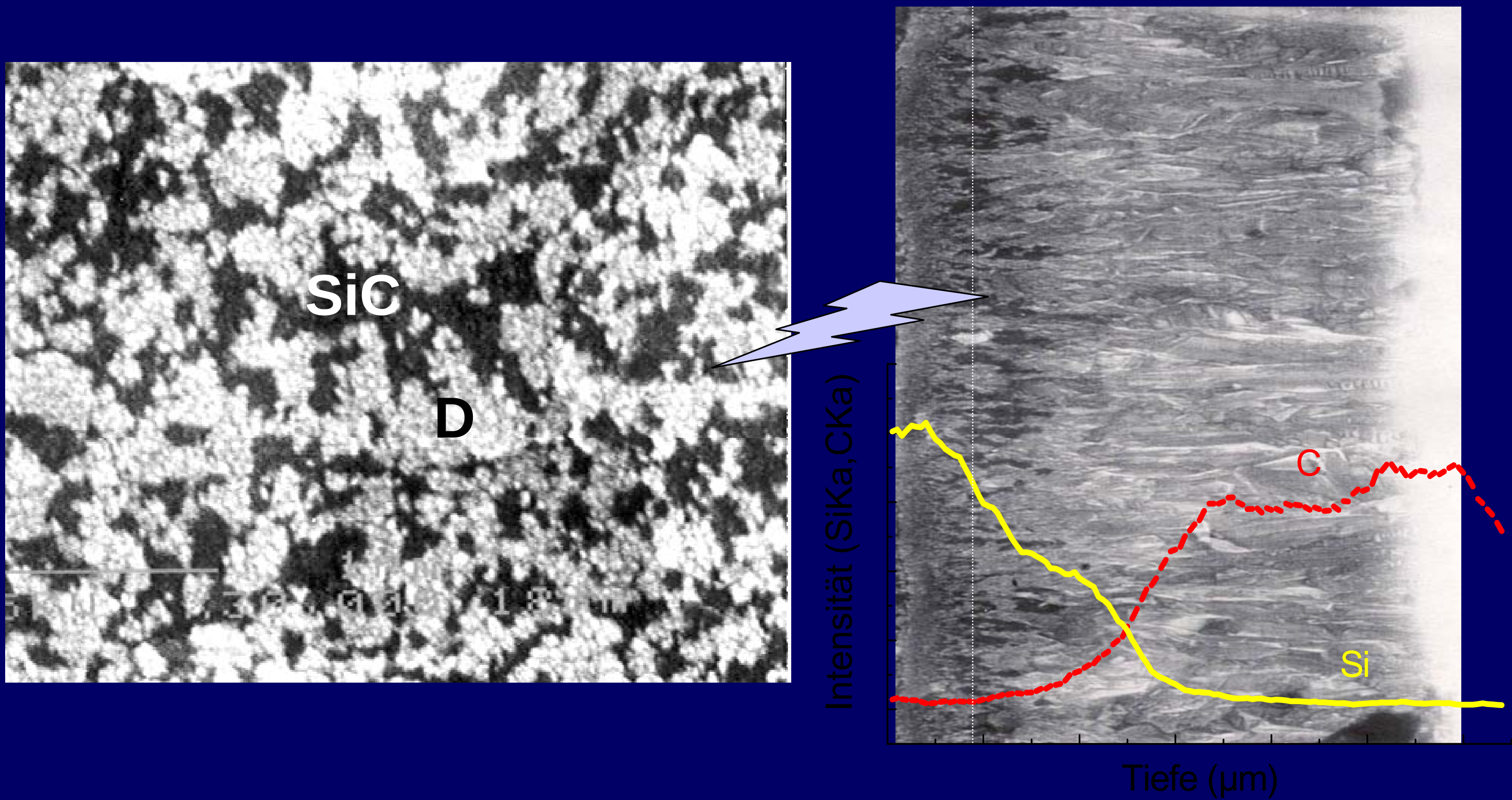
Calculation of thermal stresses by FEM

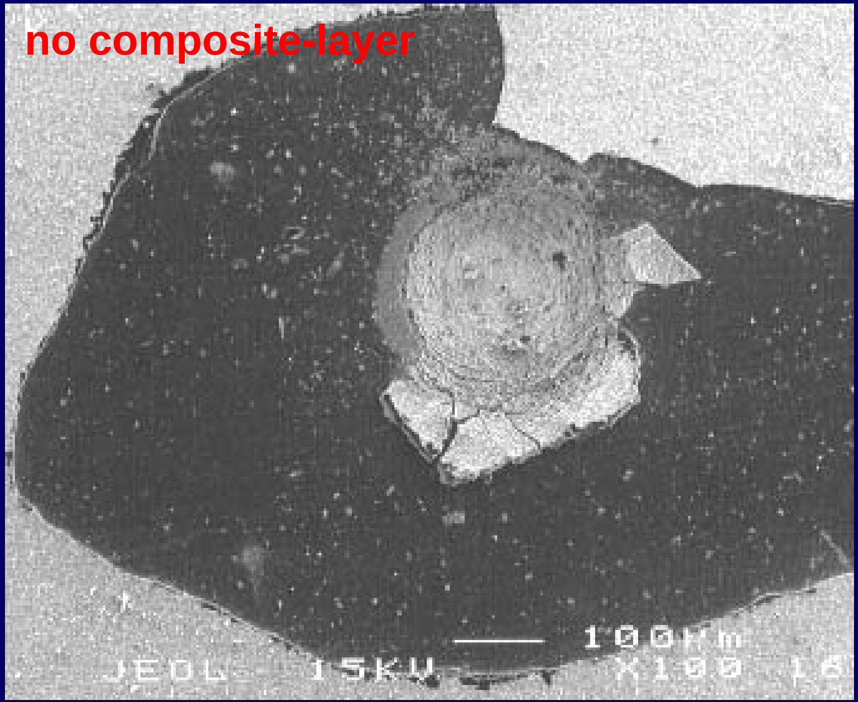
- Inherent good adhesion between Diamond-film and composite
- Good adhesion of carbide-film on metallic substrate
- Reduced maximum stress

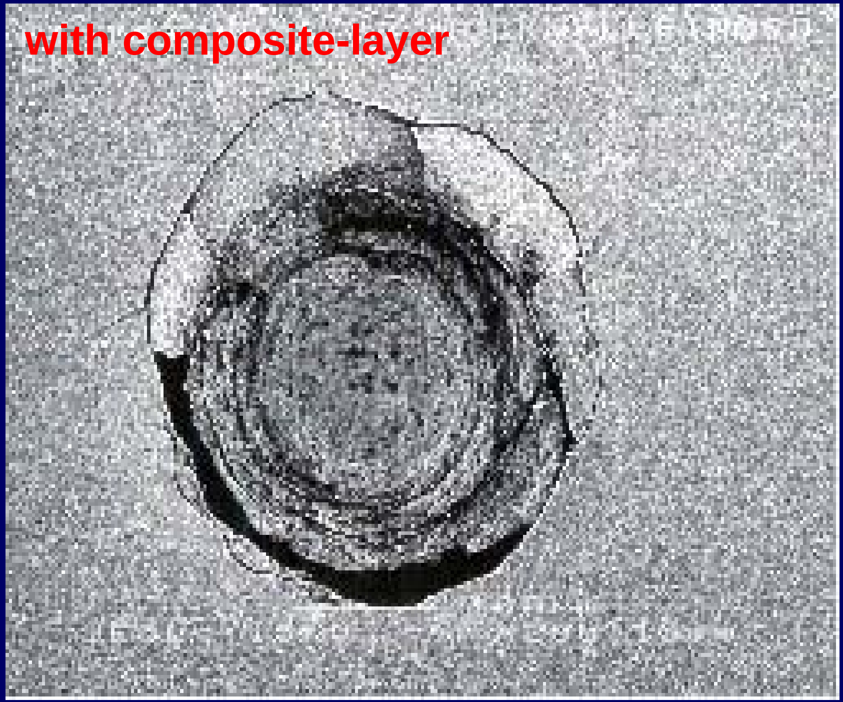


L. Xiang, PhD thesis TU-Braunschweig, 2002

SEM images of a Diamond/ß-SiC-composite-layer as well as its SIMS - depth profile

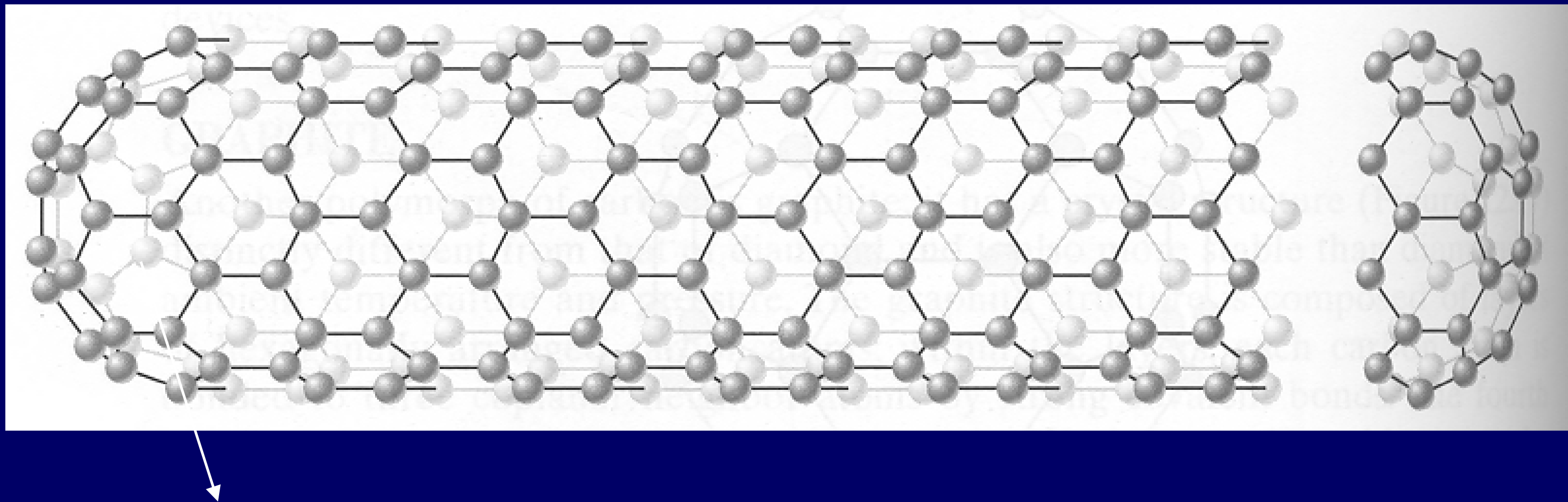



no composite-layer
100µm
JEOL 15KV X100


with composite-layer

Polymorphic Forms of Carbon

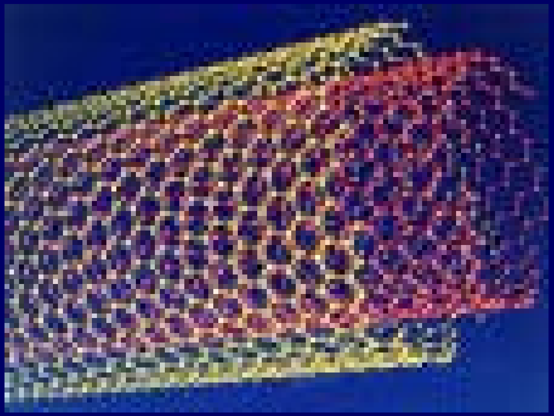
fullerene C_{60} (discovered 1985) => carbon nanotube (C sheet + fullerene)



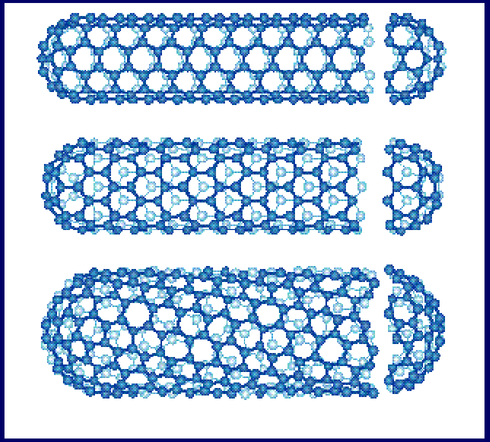
hexagons and pentagons

extremely strong (50-200GPa) stiff (1TPa) and ductile (fracture strain 5-20%)
=> ultimative fiber for composites, unique electric properties (metal/semiconductor)

Carbon nanostructures



Single-wall-C-Nanotube (CNT)

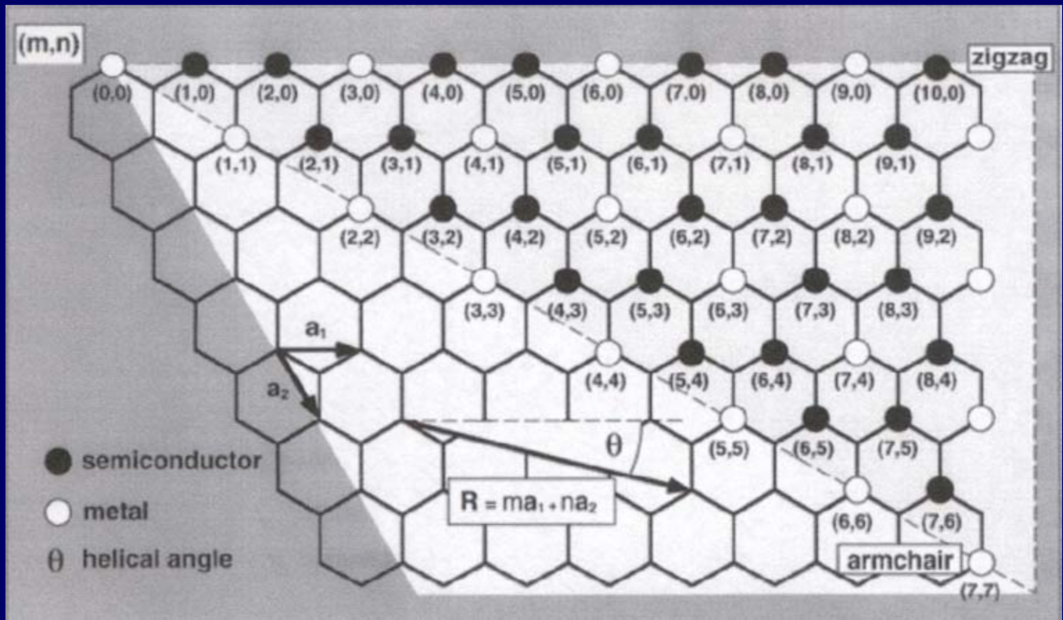


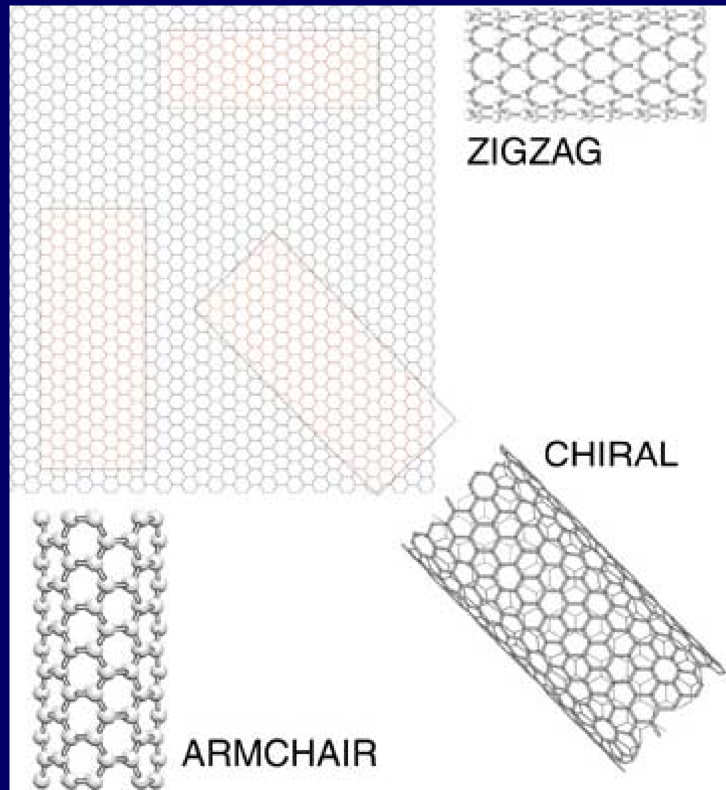
Multi-wall-CNTs:

Van der Waals - bonding between individual layers, layer-spacing D=0,34 nm

Various single-wall CNTs

- C-C bond-length: d=0.1421nm
- Helical angels: θ = 0 – 30°





Production technologies

- Arc-discharge (high quality, low productivity)
- Laser-ablation (same as arc-discharge)
- Chemical Vapor Deposition (CVD)

Pyrolysis
MPCVD
HFCVD

- Catalyst-based (Fe, Co, Ni, Pt, etc) growth
- Orientated CNTs in combination with high productivity

Properties and potential applications

- **Conductivity ranging from metallic to semi-conducting (helical angel, thickness)**
- **Low electric field strength for the onset of electron emission**
- **Ultra high axial mechanical stability: Young's Modul = 5 TPa (single-wall-CNTs)**

- ***Low radial mechanical stability***
- ***Handling issues: grabbing, cutting, welding, and others***

- **Nano-electronics**
- **Scanning probes (AFM)**
- **Electronfieldemission-Sources**
- **Gas- and energy-storage**
- **Biological micro-probes**
- **Composite-material (polymers, concrete, and others)**
- **Nano-cannula for bio- or medical-applications**