Inorganic Materials Chemistry C7780

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Course grading:

- 3 graded homeworks during semester
- Short presentations on a selected topic concerning materials chemistry
- Written final exam (100 pts, minimum 50 pts to pass)

Grading weights: final test 75%, homeworks 15%, presentation 10%.

Recommended Literature

SCHUBERT, U. a N. HÜSING. Synthesis of Inorganic Materials. Weinheim: Wiley-VCH

CALLISTER, W.D.J. Materials Science and Engineering, An Introduction. John Wiley and Sons

SMART, L. a E. MOORE. Solid state chemistry : an introduction. 2nd ed. London: Chapman & Hall

Plinio Innocenzi, The Sol to Gel Transition, Springer International Publishing

Mary Anne White, Physical Properties of Materials, 2nd Edition, CRC Press

Ulrich Muller , Inorganic Structural Chemistry, 2nd Edition, Wiley

Materials in Human History

Historical perspective:

New materials bring advancement to societies

- **Stone age**
- **Bronze age**
- **Iron age**
- **Silicon age**

Crescent Axes. The top Syrian, the bottom Egyptian.
about 1900 BC

Materials in Human History

50 000 B.C.	Iron oxide pigments Lascaux, Altamira
24 000 B.C.	Ceramics – fat, bone ash, clay
3 500 B.C.	Cu metallurgy
	Glass, Egypt and Mesopotamia
3 200 B.C.	Bronze
1 600 B.C.	Iron metallurgy, Hittites
1 300 B.C.	Steel
1 000 B.C.	Glass production, Greece, Syria
105 B.C.	Paper, China
590 A.D.	Gun powder, China
700 A.D.	Porcelain, China

This is a Hittite dagger-sword made of iron about 1100 B.C. Much of it has turned to rust over the past three thousand years.

Materials in Human History - Metals

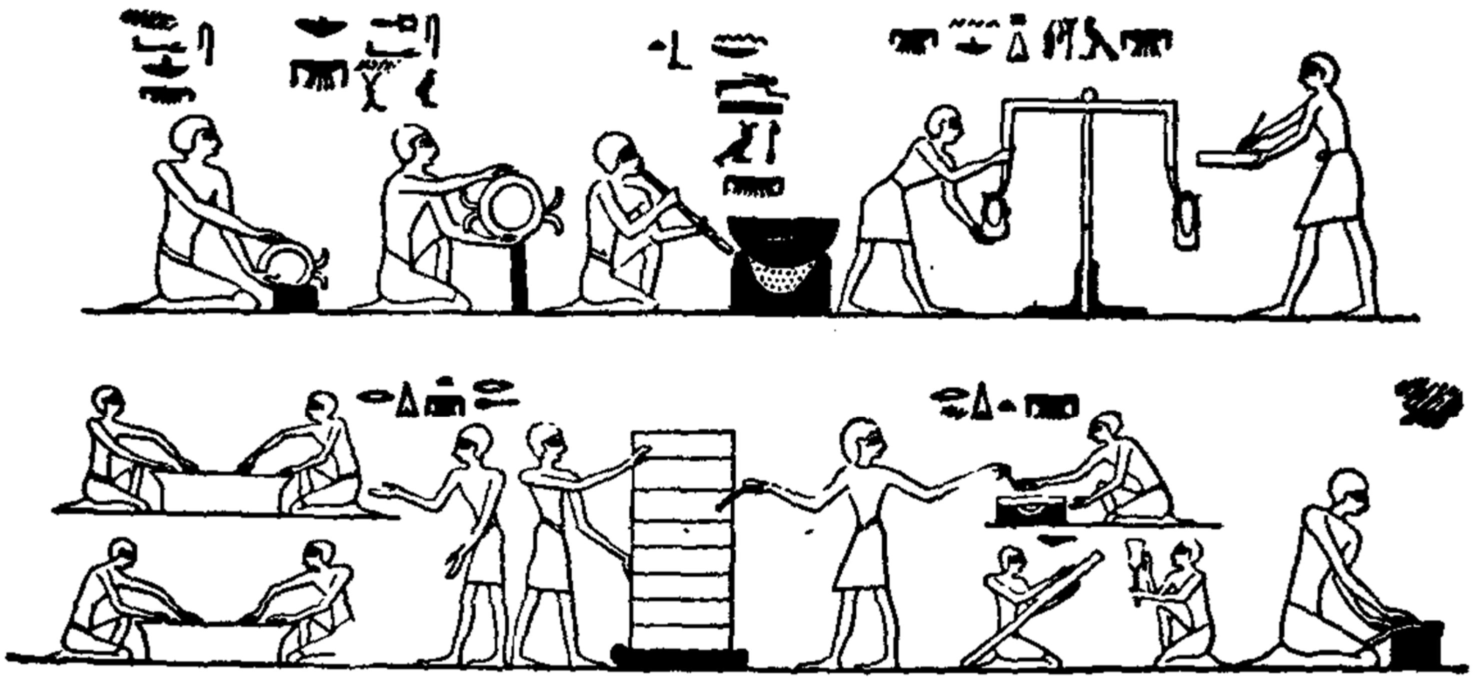


FIG. 11.—EGYPTIAN GOLDSMITHS WASHING, MELTING AND WEIGHING GOLD.
BENI HASAN, 1900 B.C.

Materials in Human History - Ceramics

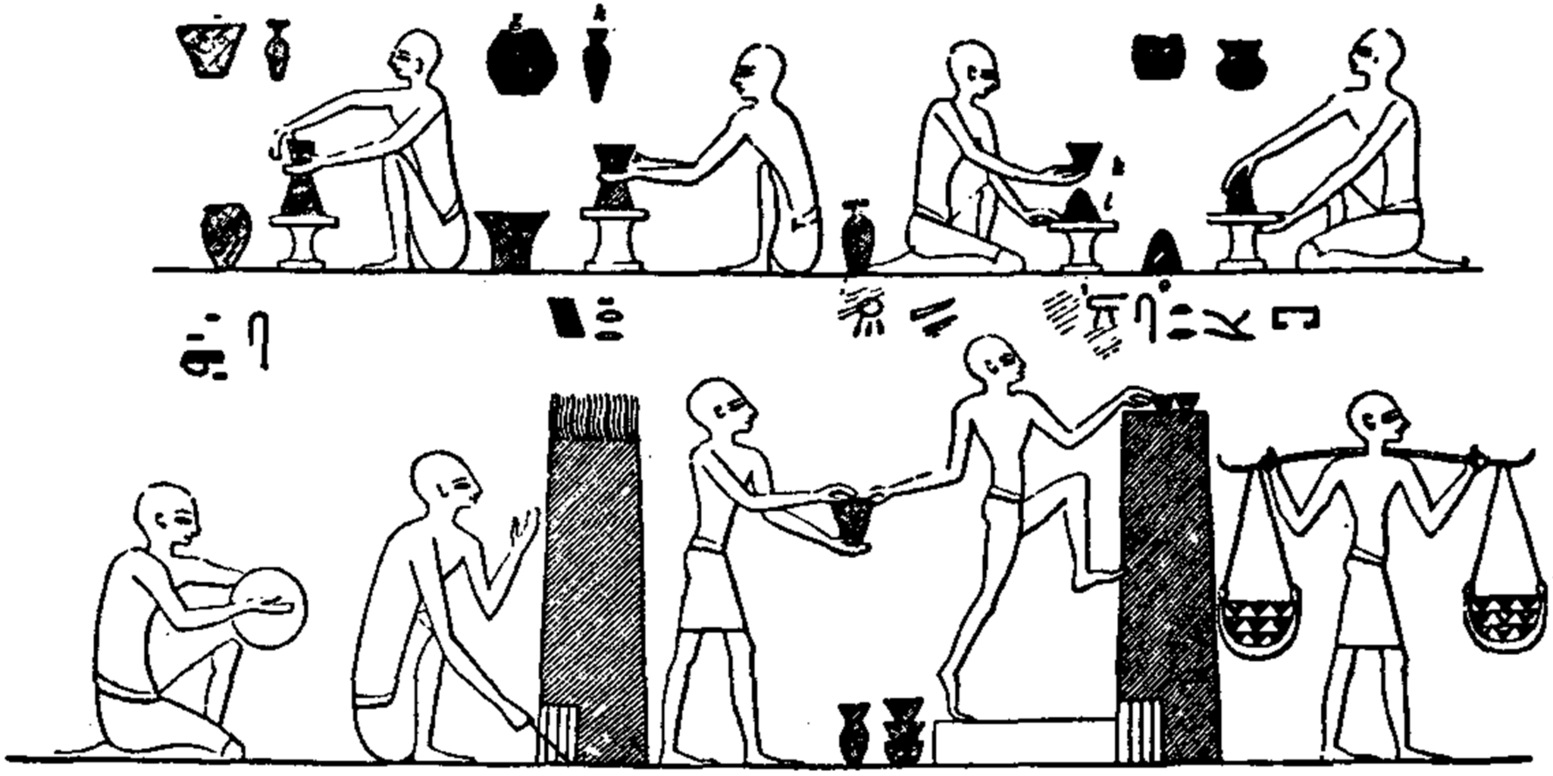
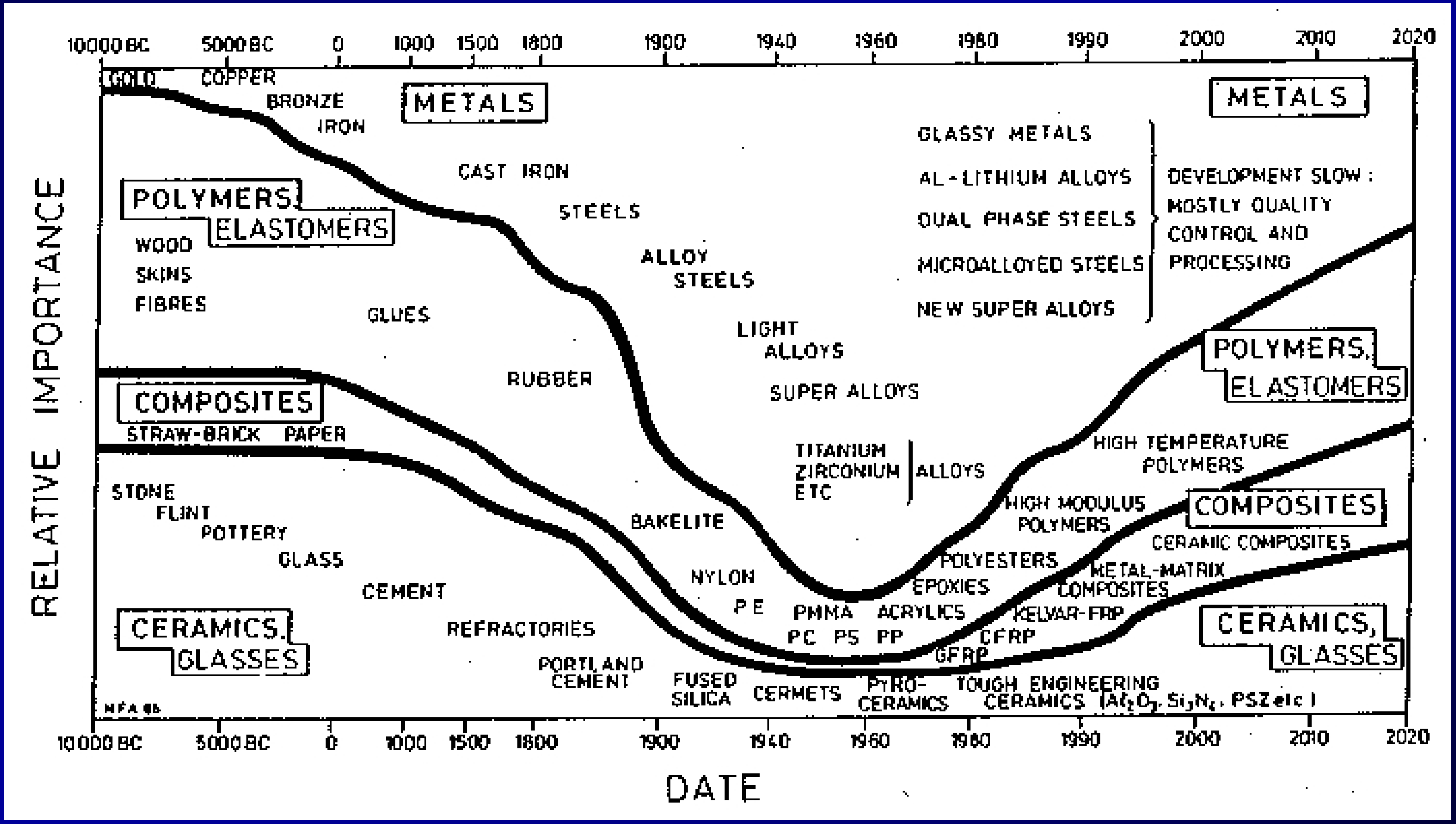


FIG. 12.—EGYPTIANS MAKING POTTERY, WITH FURNACE.
BENI HASAN, 1900 B.C.

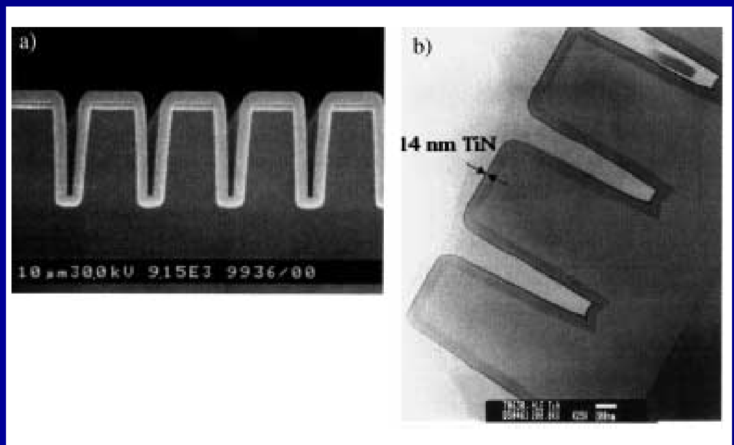
Development of Materials in Human History

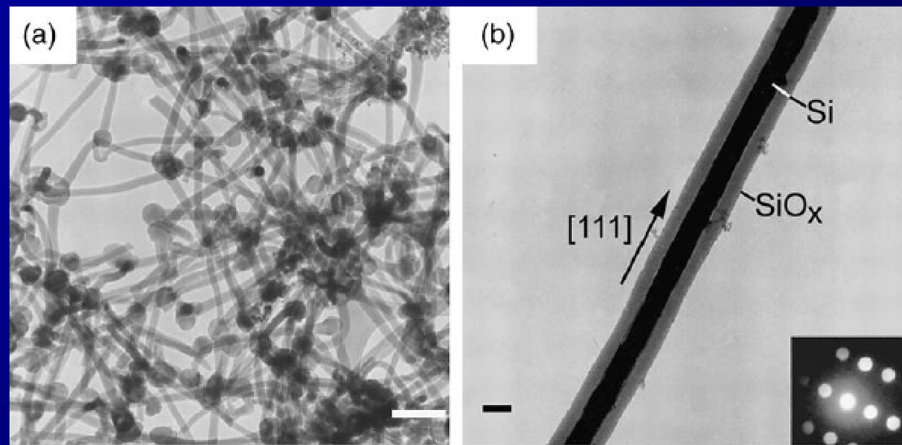


Compounds vs. Materials

* **Chemical compounds**
  single use (pharmaceuticals, fertilizers, fuels)

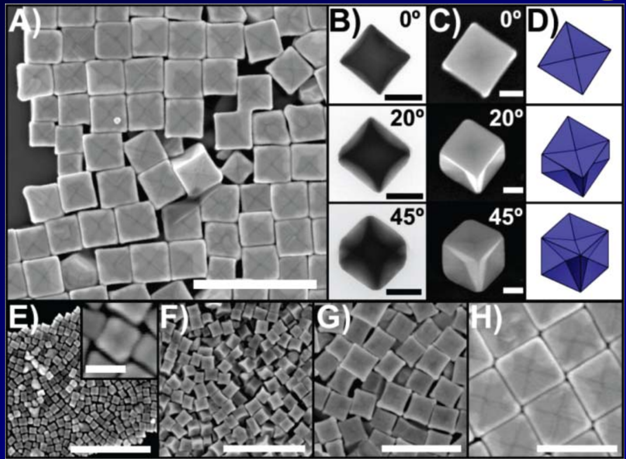
* **Materials** - **repeated or continual use**
  - **shaping**



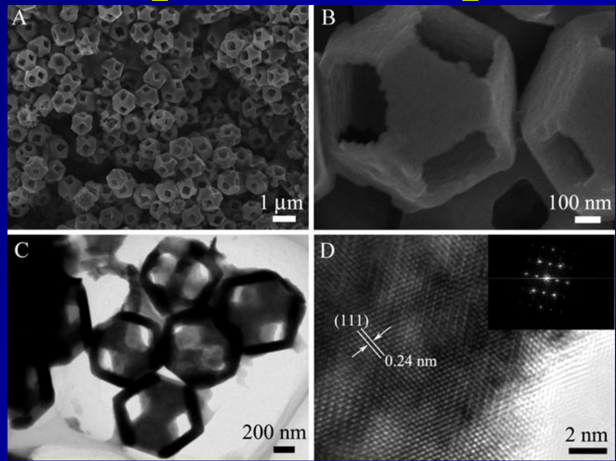


Shaping of Materials

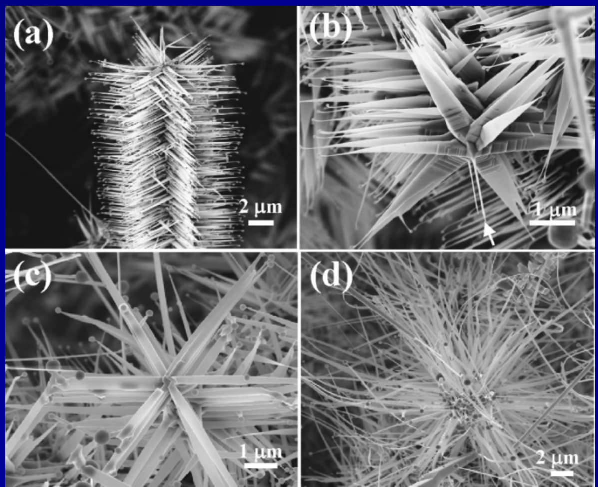
Shaping of (Nano)Materials



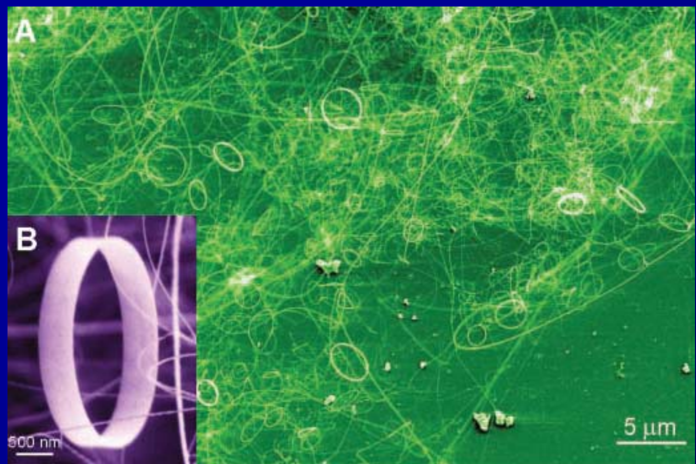
Au concave cubes



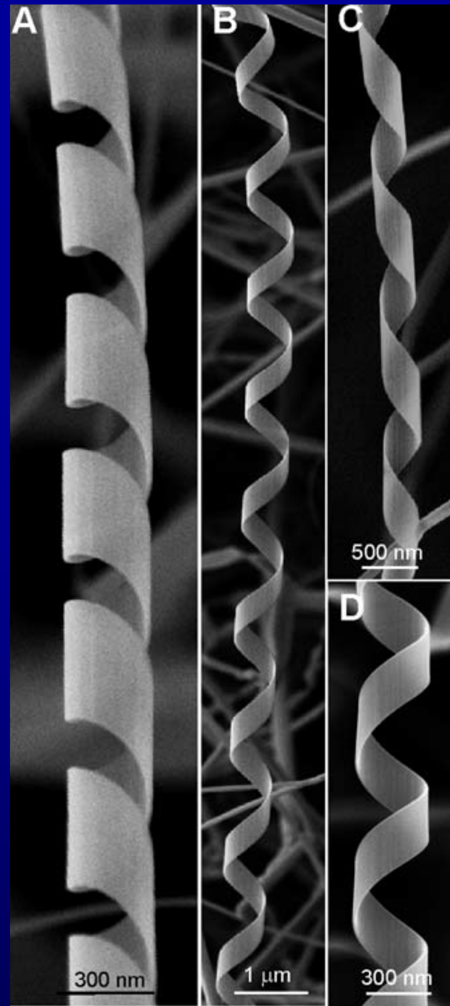
Cu_2O nanoframes



ZnO nanopropellers

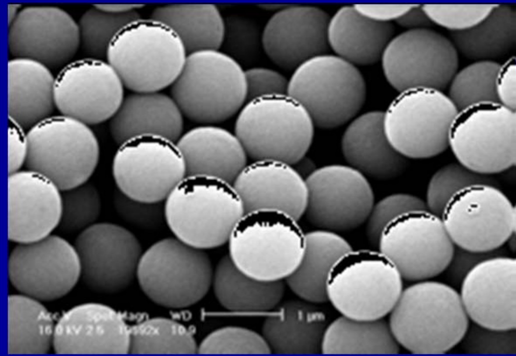


ZnO nanorings



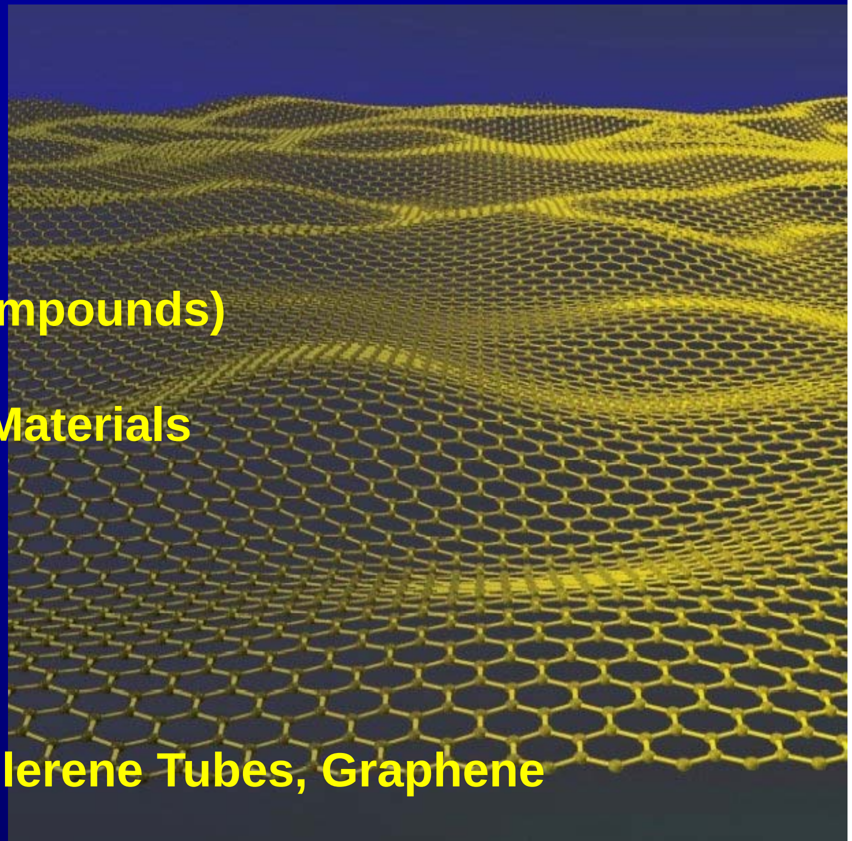
ZnO nanobelts

Materials



Ceramics (oxides, carbides, nitrides, borides)

Glasses (oxides, fluorides, chalcogenides, metallic)



Metals, Alloys, Intermetallics

Polymers - inorganic, organic, hybrid

Semiconductors (Si, Ge, 13/15, 12/16 compounds)

Composites, Inorganic-Organic Hybrid Materials

Zeolites, Layer and Inclusion Materials

Biomimetic Materials, hydroxyapatite

Carbon-based Materials: Fullerenes, Fullerene Tubes, Graphene

Properties of Materials

A property = a material trait, the kind and magnitude of response to a specific stimulus

Properties

- Mechanical
- Electrical
- Thermal
- Magnetic
- Optical
- Deteriorative (corrosion)
- Catalytic
- Biocompatibility

Metals	Ceramics	Polymers
Strong	Strong	Usually not strong
Ductile	Brittle	Very ductile
Electrical Conductor	Electrical Insulator	Electrical Insulator
Heat Conductor	Thermal Insulator	Thermal Insulator
Not transparent	May be transparent	Not transparent
Shiny	Heat Resistant	Low Densities

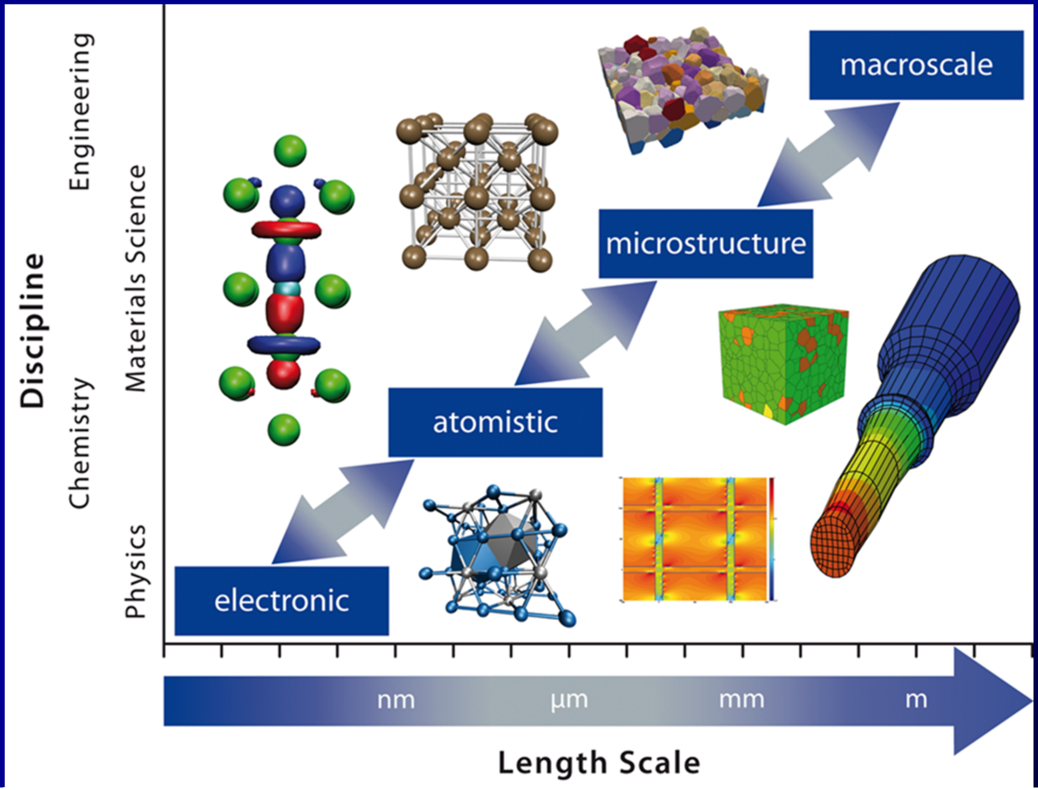
Materials Science:

Studies relationships between the structure and properties of materials

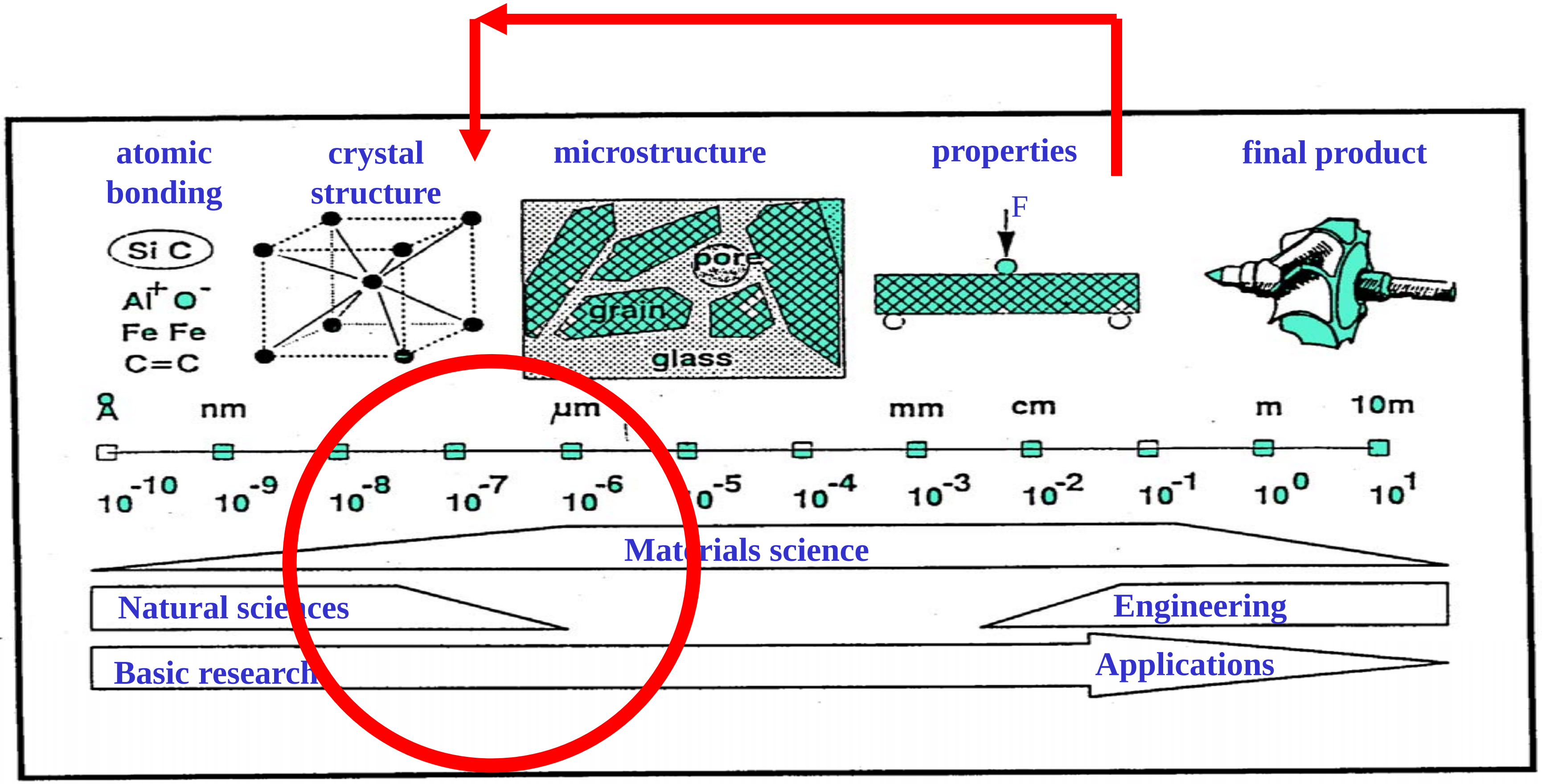
Materials Engineering:

Designing and engineering the structure of a material to produce a predetermined set of properties

Processing Structure Properties Function



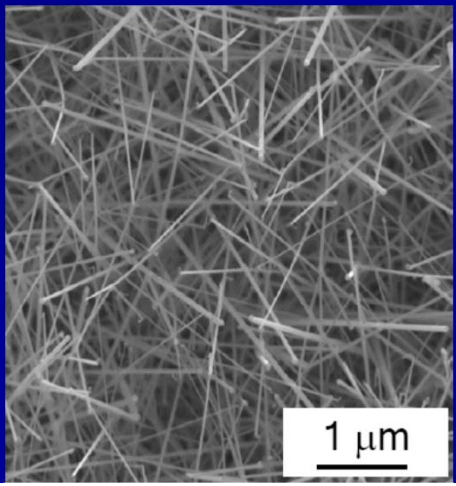
Materials Chemistry among Natural and Technical Sciences

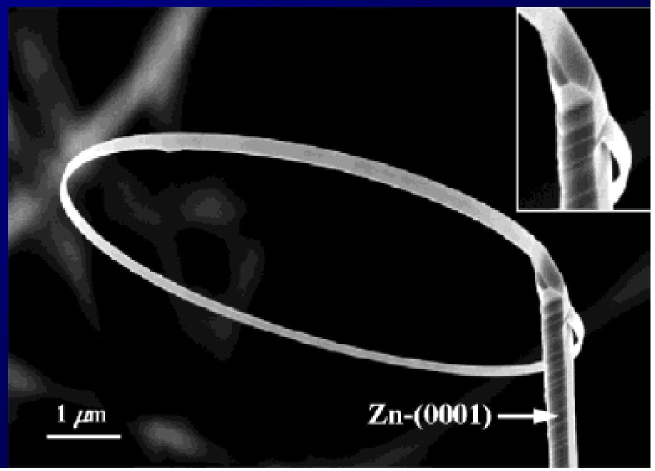


Materials Chemistry

Role of Materials Chemistry

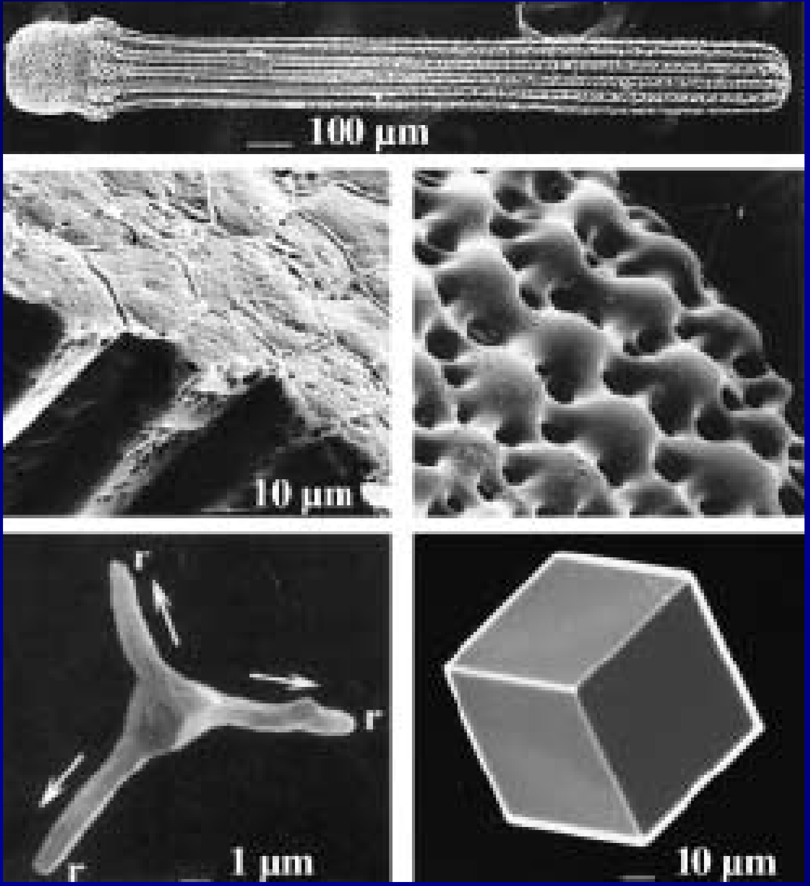
- Synthesis of new materials – new atom architecture
- Preparation of high purity materials
- Fabrication techniques for tailored morphologies (shapes and sizes)
- Fabrication of functional materials



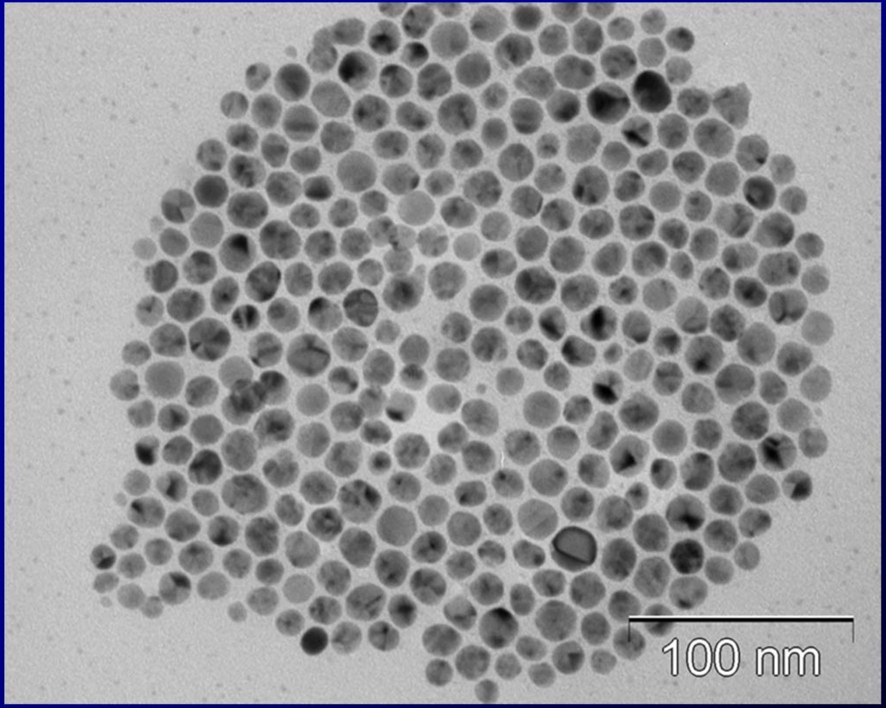


Shapes of Natural and Synthetic Single Crystals

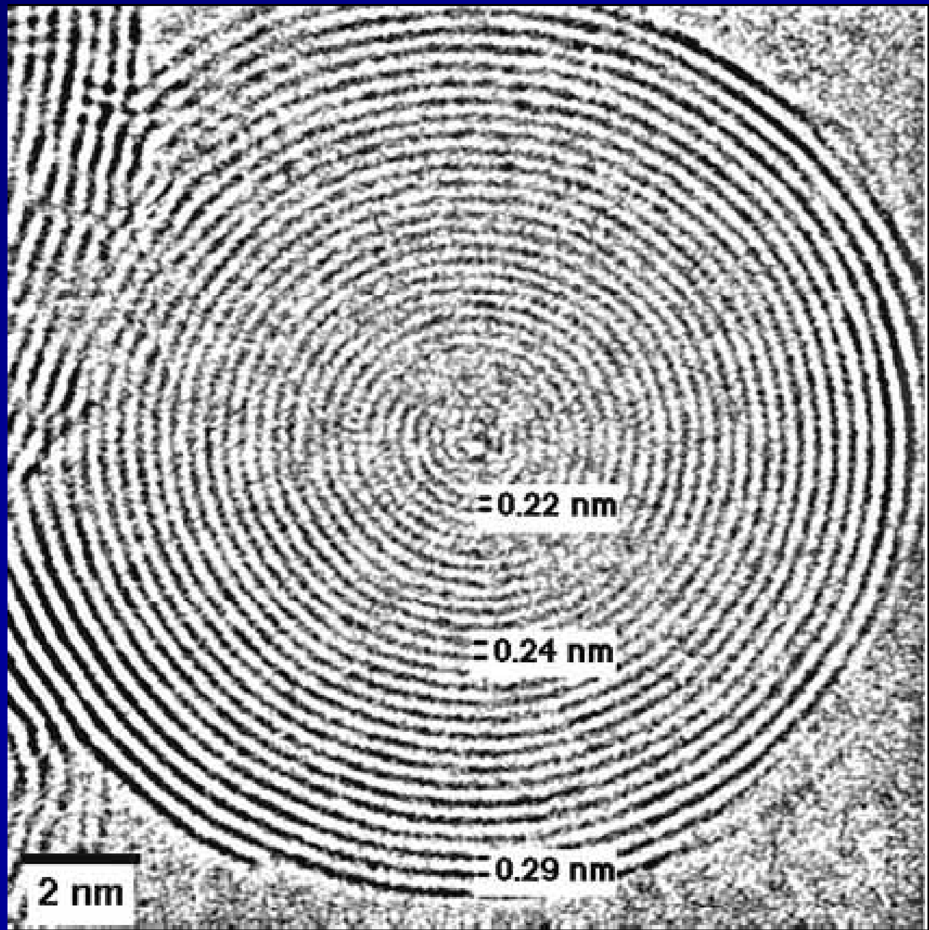
Calcite $CaCO_3$



Cu-Ag nanoalloy



Onion-Like Graphitic Particles



Functional Materials

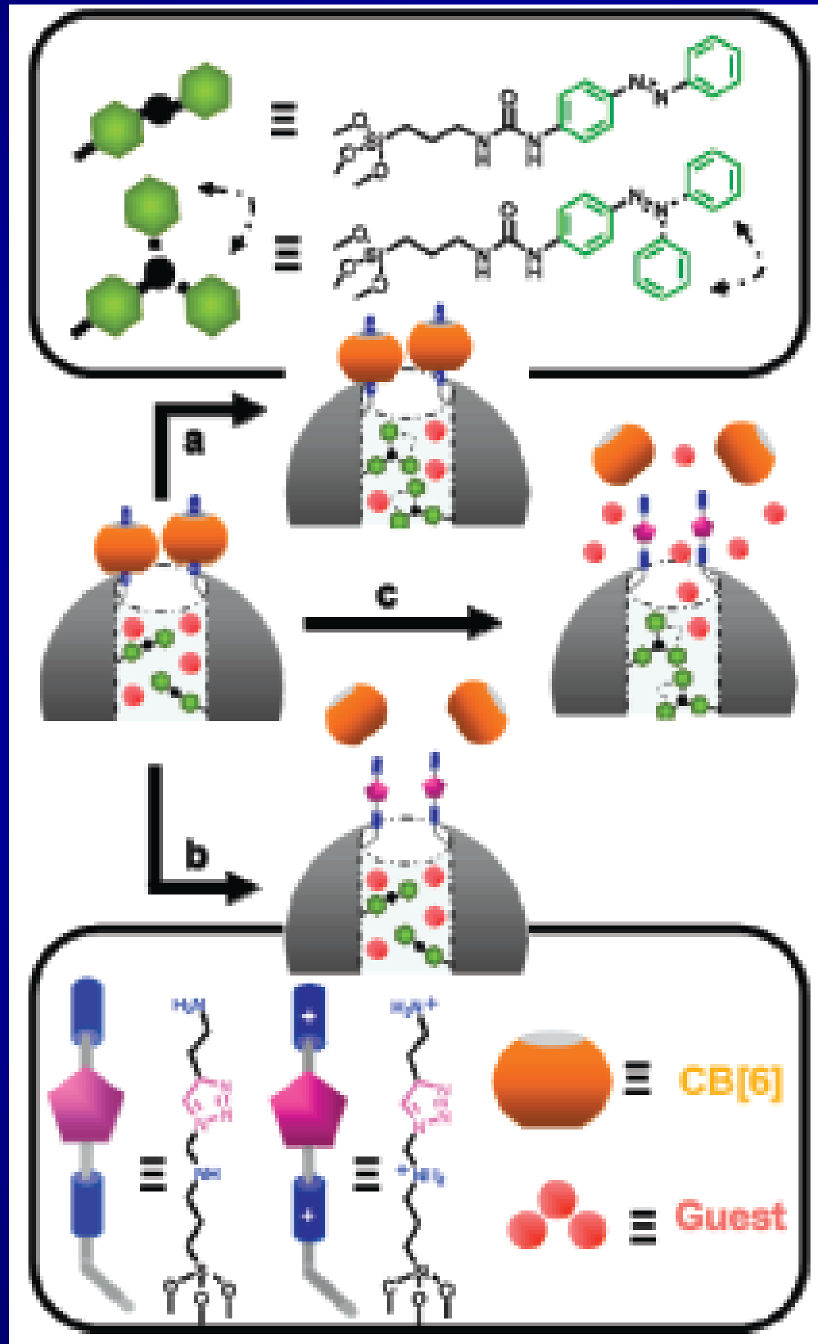
Dual-controlled nanoparticles exhibit AND logic function

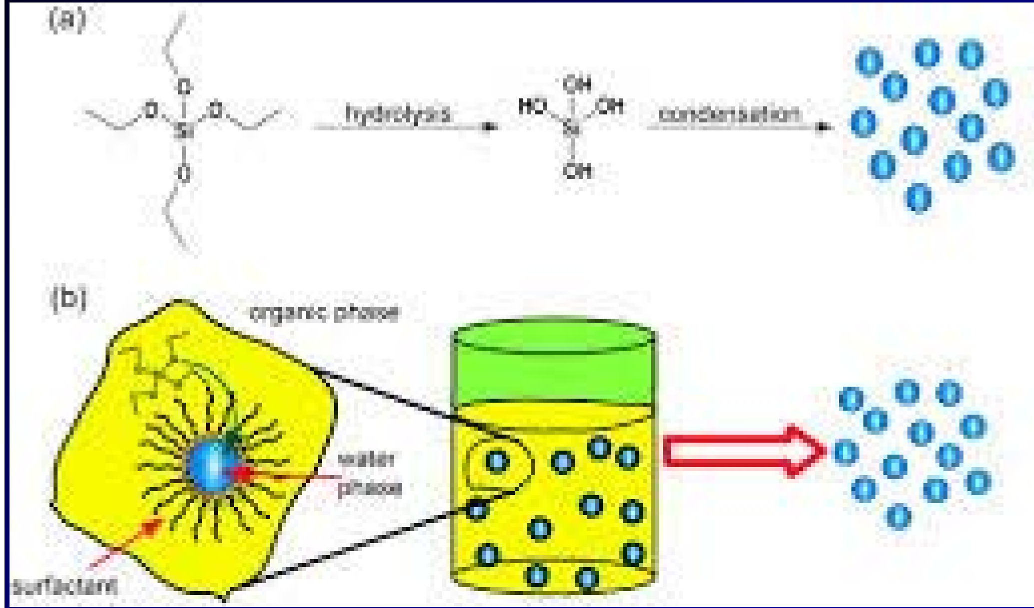
(a) Excitation with 448 nm light induces the dynamic wagging motion of the nanoimpellers, but the nanovalves remain shut and the contents are contained.

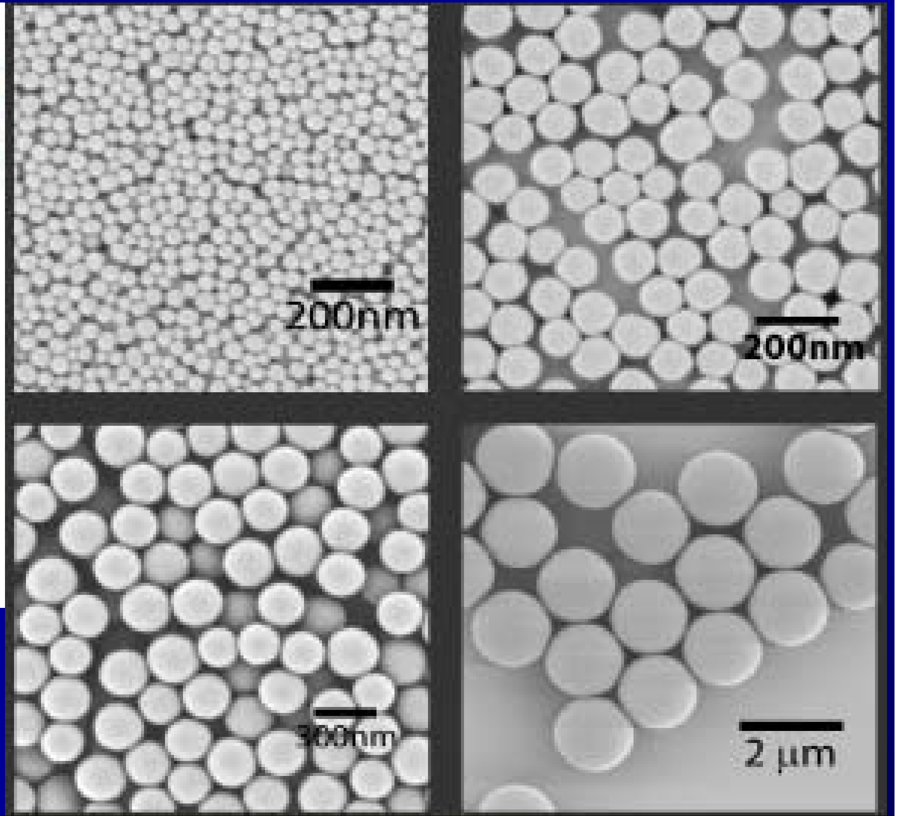
(b) Addition of NaOH opens the nanovalves, but the static nanoimpellers are able to keep the contents contained.

(c) Simultaneous excitation with 448 nm light AND addition of NaOH causes the contents to be released.

CB[6] = cucurbit[6]uril







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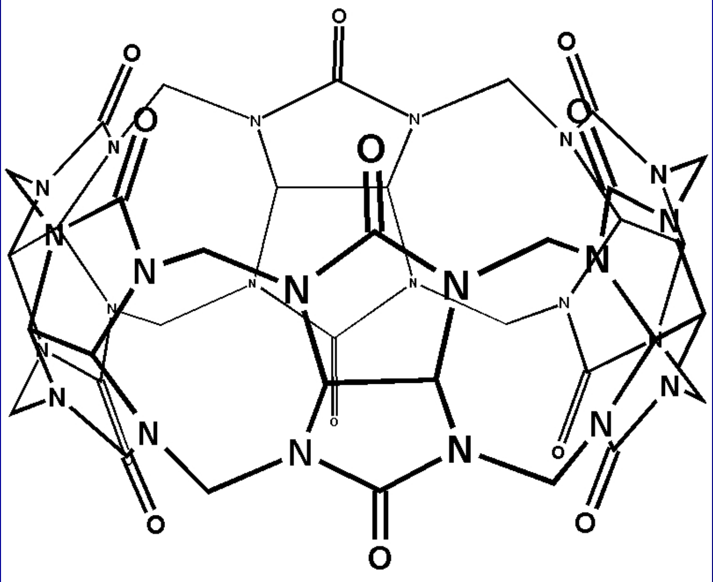


Materials Chemistry

Single crystals, defects, dopants, non-stoichiometry
Monoliths
Coatings
Thin or thick films - singlecrystalline, polycrystalline, amorphous, epitaxial
Fibers, Wires, Tubes
Powders – primary particles, aggregates, agglomerates
polycrystalline, amorphous, nanocrystalline (1-100 nm)
Porous materials
micropores (< 20 Å), mesopores (20-500 Å), macropores (> 500 Å)
Micropatterns
Nanostructures – spheres, hollow spheres, rods, wires, tubes, photonic crystals
Self-assembly – supramolecular chemistry: rotaxenes, catenanes, cavitands, carcerands

Materials Chemistry Tool Box

Direct reactions of solids – „heat-and-beat“

Precursor methods

Chimie douce, soft-chemistry methods, synthesis of novel metastable materials, such as open framework phases

Ion-exchange methods, solution, melt

Intercalation: chemical, electrochemical, pressure, exfoliation-reassembly

Crystallization techniques, solutions, melts, glasses, gels, hydrothermal, molten salt, high P/T

Vapor phase transport, synthesis, purification, crystal growth, doping

Materials Chemistry Tool Box

Electrochemical synthesis, redox preparations, anodic oxidation, oxidative polymerization

Preparation of thin films and superlattices, chemical, electrochemical, physical, self-assembling mono- and multilayers

Growth of single crystals, vapor, liquid, solid phase chemical, electrochemical

High pressure methods, hydrothermal, diamond anvils

Combinatorial materials chemistry, creation and rapid evaluation of gigantic libraries of related materials

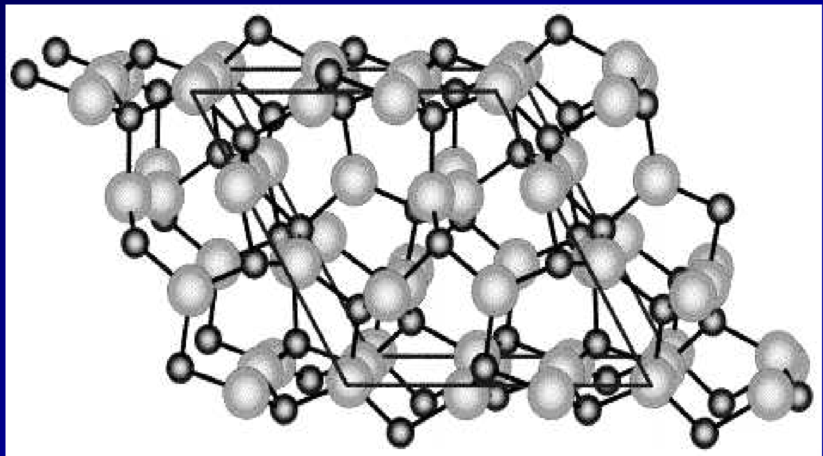
Si_3N_4

Hexagonal

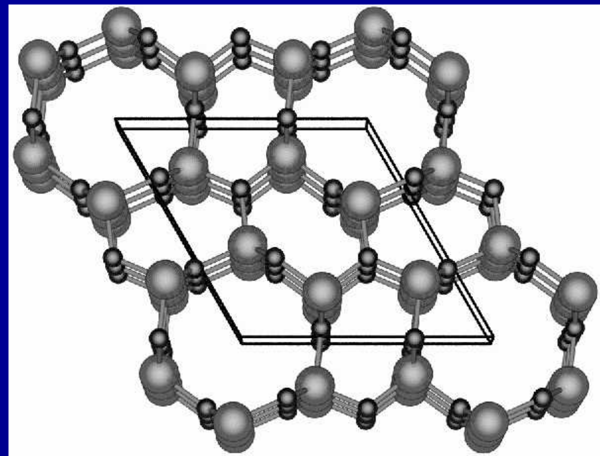
Si

N

a modification

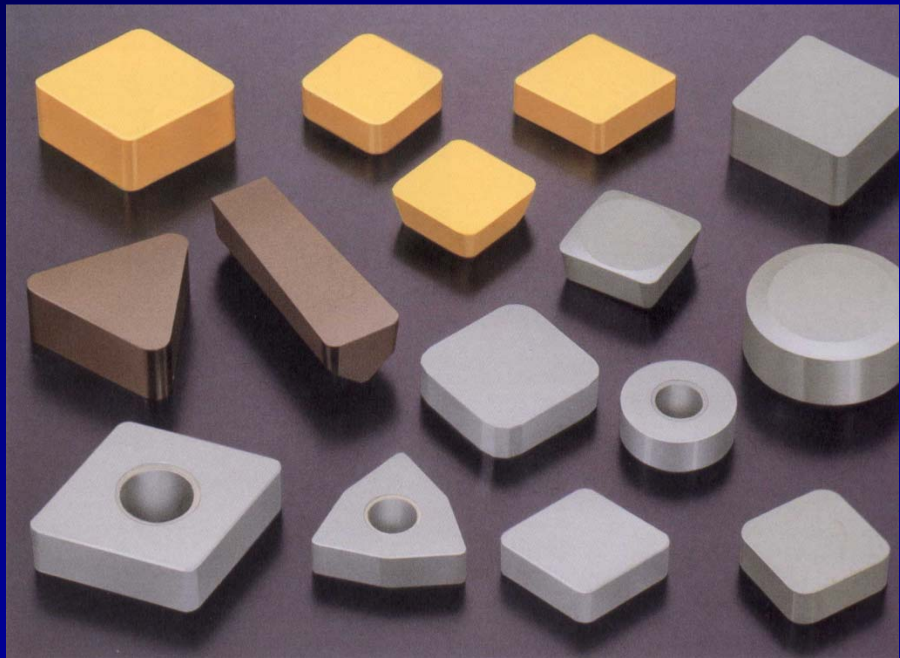


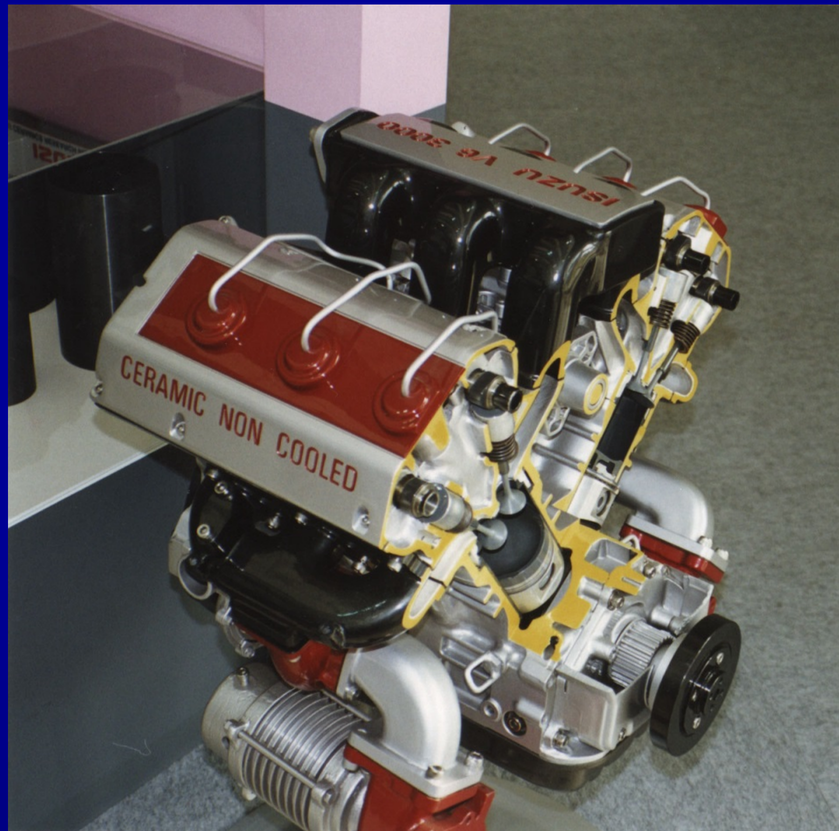
b modification



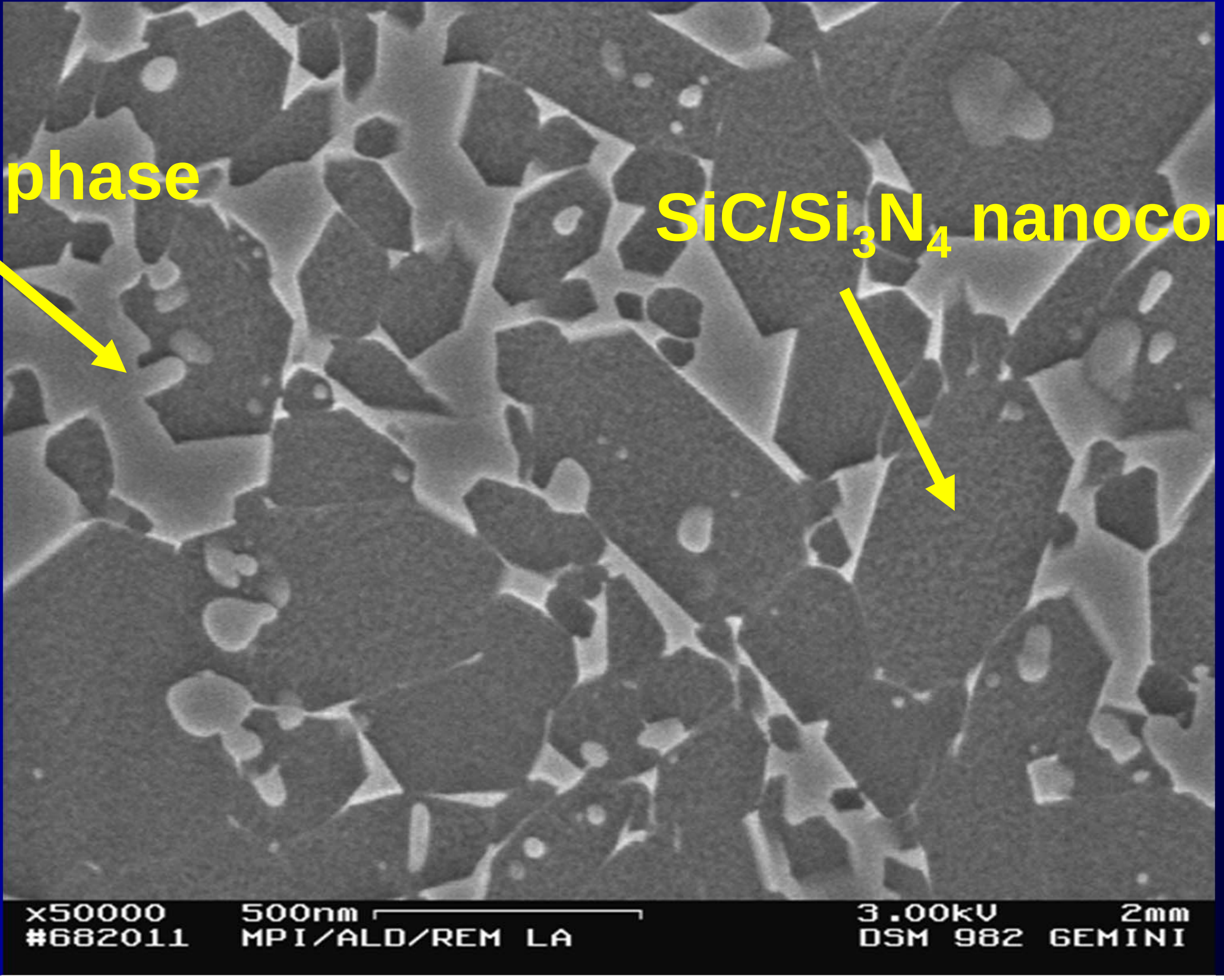
- Strong covalent bond (4.9 eV)
- Hardness (a-monocrystal, Vickers 21 GPa)
- Tensile Strength 1.5 GPa (b-whisker)
- Young modulus 350 GPa
- Decomposition temp. 1840 °C/1 atm N_2
- Density 3.2 g cm^{-3}

Si_3N_4 Ceramics



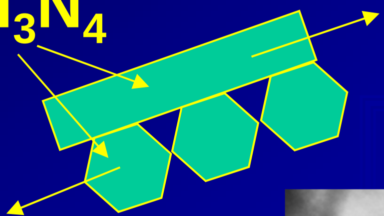


Microstructure of Materials

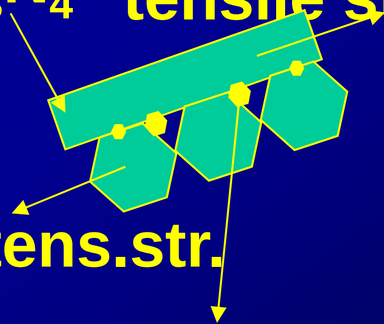


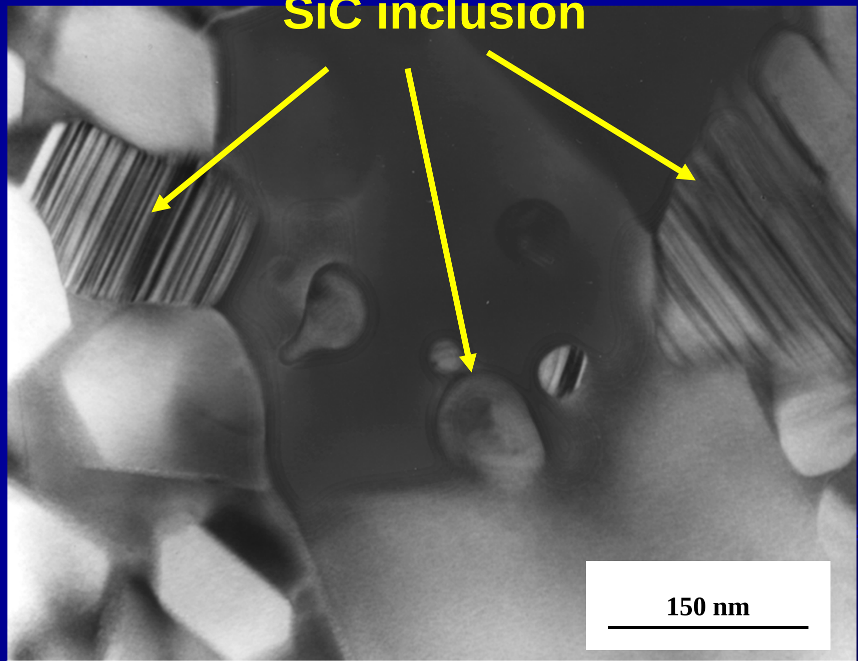
Microstructure vs. Properties

Sliding of grains

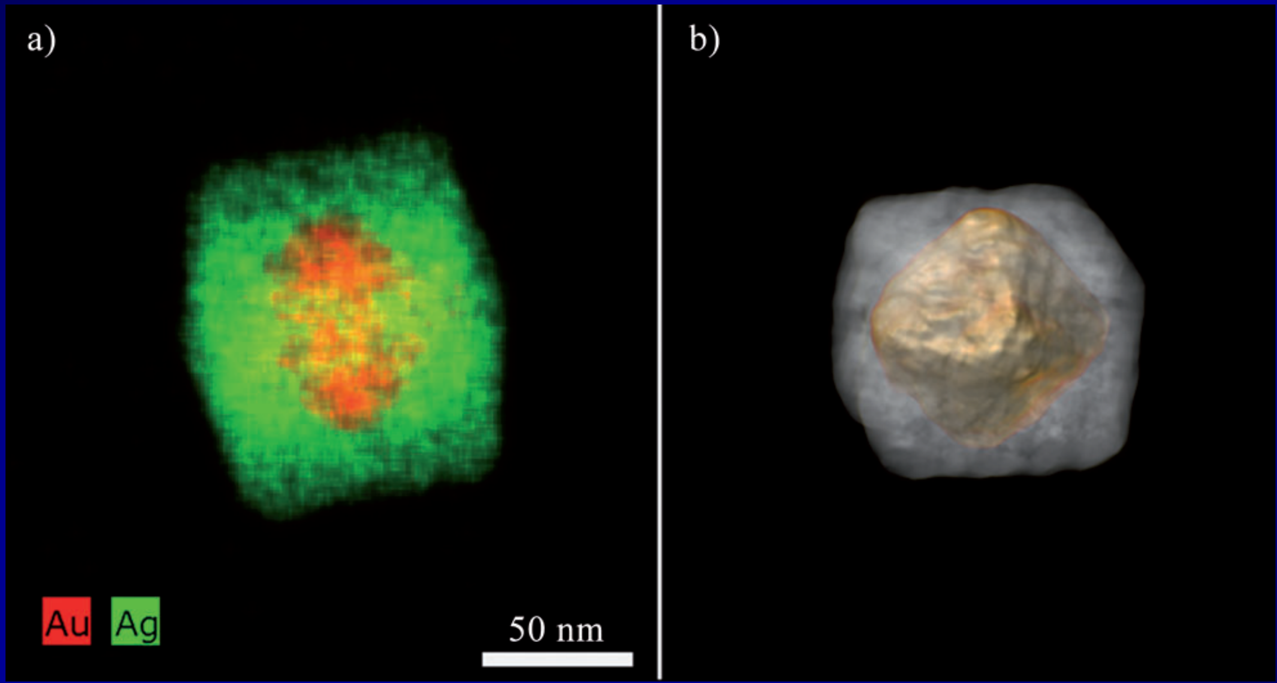


Sliding of grains slowed down improved mechanical properties



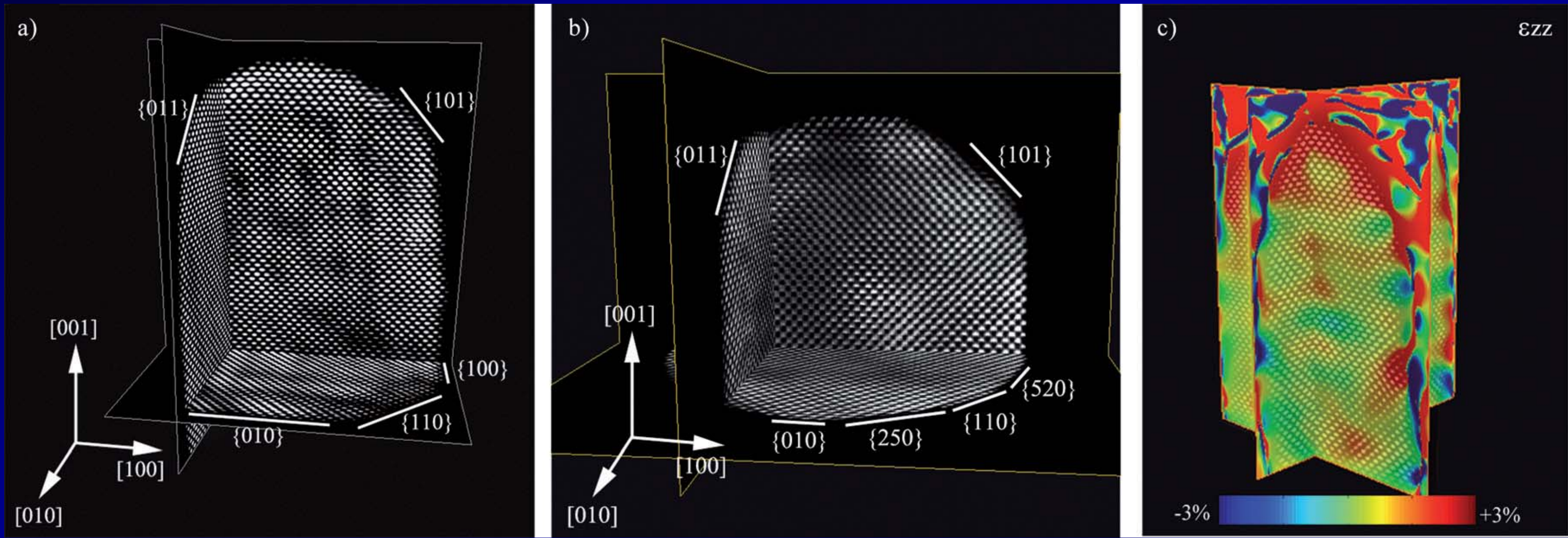


Imaging at Nanoscale



a) 2D EDX map of a Au@Ag nanocube. Based on a tilt series of such 2D EDX maps the 3D reconstruction presented in (b) was obtained. The contrast in the 3D reconstruction is based on differences in chemical composition and it is clear that the core of the particle has an octahedral form.

Atomic Scale Imaging



Atomic scale reconstruction of Au nanorods. a,b) Orthogonal slices through the atomic scale reconstruction of Au nanorods prepared using different surfactants. The side facets of these rods can be clearly recognized. c) Strain measurement along the major axis of the nanorod.