

Università degli Studi di Trieste
Dipartimento di Ingegneria e Architettura
A.A. 2021-2022

Scienza e Tecnologia dei Materiali Ceramici

Modulo: Materiali Nanostrutturati

- Lezione 1 -


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Università degli Studi di Trieste

5 μm

The background of the slide is a grayscale scanning electron microscope (SEM) image of a nanostructured ceramic surface. The surface is covered with a dense array of small, rounded, interconnected particles or grains. A white horizontal scale bar is located in the bottom right corner, with the text "5 μm" positioned above it.

Informazioni generali

Il corso si struttura su due moduli:

- Modulo 1: nanomateriali e nanostrutture (prof. Lughi) – 4 CFU
- Modulo 2: modellazione di nanomateriali (prof. Posocco) – 2 CFU

Esame:

- Modulo 1: lavoro di gruppo + ricerca
- Modulo 2: progetto di modellazione

Informazioni generali

- Presentazione, contatti e ricevimento
 - Vanni Lughi
 - St. 48, 1° piano edificio B
 - 040-558-3769
 - vlughi@units.it
 - Ricevimento: Martedì 9.00-10.00 in ufficio
Per appuntamento
Dopo lezione
- Orario e luogo del corso

Obiettivi del Modulo 1

- Saper rispondere alle seguenti domande:
 - Fondamenti di proprietà elettriche ed elettroniche dei materiali
 - Cosa sono e perché vogliamo usare materiali nanostrutturati?
 - Come facciamo il design di materiali nanostrutturati affinché servano alla funzione che ci interessa?
 - Come fabbrichiamo materiali nanostrutturati?
 - Come caratterizziamo materiali nanostrutturati?
 - Come applichiamo i materiali nanostrutturati?
- Acquisire familiarità con la letteratura in ambito nanotecnologico
- Acquisire un minimo grado di pratica in alcuni aspetti sperimentali esemplificativi

Materiale per il Modulo 1

- Slides (inglese)
- Moodle
- Testi consigliati:
 - Introduction to nanotechnology (Poole, Owens) – **in biblioteca**
 - Introduction to Nanoscience (Tibbals)
 - Fundamentals of Nanotechnology (Gabor, Hornyak, Moore)
 - **Introduction to Nanoscience (Lindsay) – in biblioteca**
 - Nanostructured materials: Processing, Properties, and Applications (C. Koch)
 - Nanophysics and nanotechnology: an introduction to modern concepts in nanoscience (Wolf)
 - Nanostructured Materials for Solar Energy Conversion (Soga)
 - **Nanostructures and Nanomaterials (Cao, Wang)– in biblioteca**
 - Handbook of Nanostructured Materials and Nanotechnology, Five-Volume Set (Hardcover)
 - Grain Boundary Diffusion and Properties of Nanostructured Materials (AAVV, Cambridge Publ.)
 - Bulk Nanostructured Materials (Zehetbauer, Zhu)
 - Nanoparticle technology handbook (Hosokawa et al.)– **in biblioteca**
 - Springer Encyclopedia of Nanotechnology (Bhushan)

Esame e criteri di valutazione (mod. 1)

Modalità d'esame e criteri di valutazione

- Ricerca bibliografica su argomento a scelta
- Homework
- Valutazione finale:
 - Presentazione e discussione della ricerca bibliografica (10 punti)
 - Partecipazione e homework (5 punti)
 - Domanda a scelta dello studente (5)
 - Domanda a scelta del docente (10 punti)

Appelli

- Ufficiali (previa conferma)
- **Su appuntamento (collettivo)**

Calendario del corso

Mercoledì (3h)	Giovedì (2h)
18 sep	19 sep
25 sep	26 sep
2 ott*	3 ott*
9 ott	10 ott
16 ott	17 ott
23 ott	24 ott
30 ott	31 ott
6 nov	7 nov
13 nov	14 nov
20 nov	21 nov
27 nov	28 nov
4 dic	5 dic
11 dic	12 dic
18 dic	19 dic

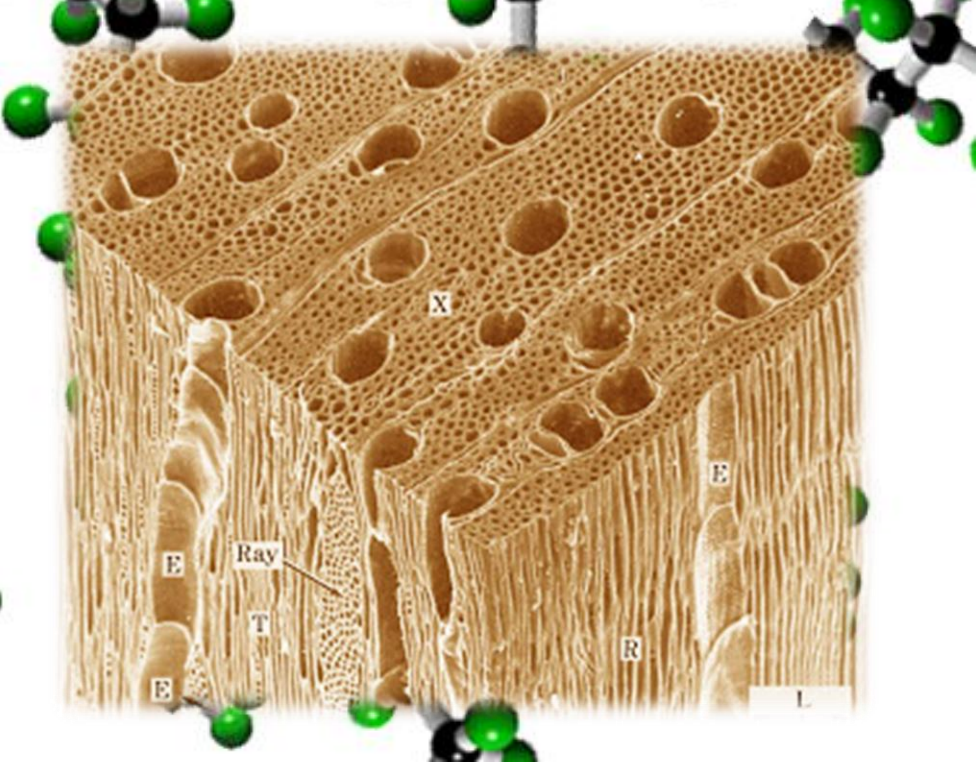
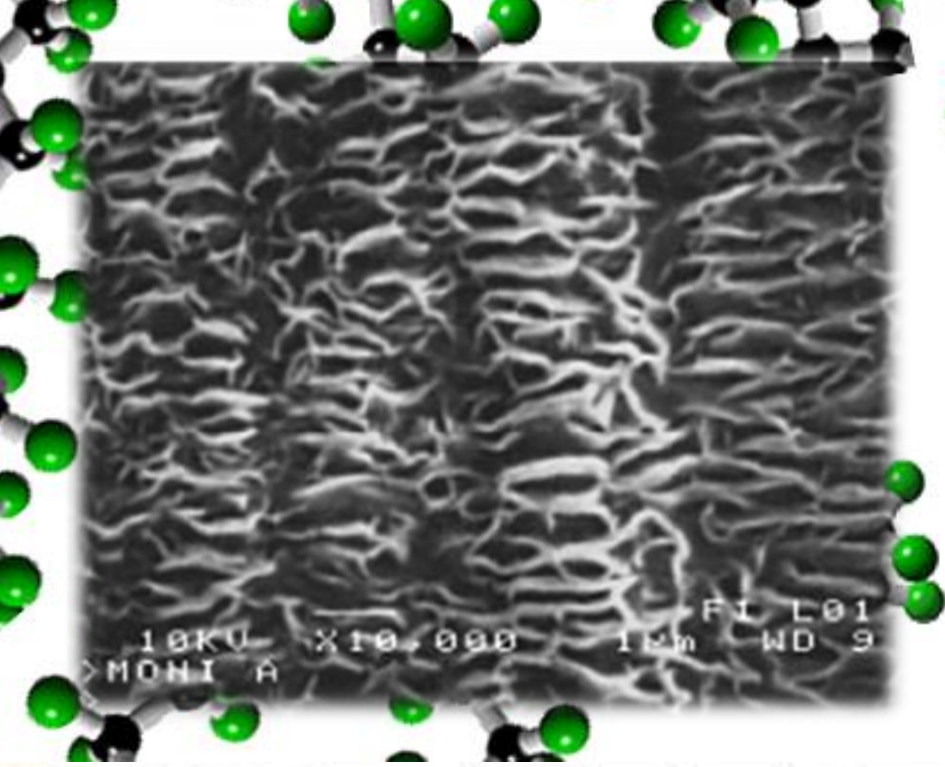
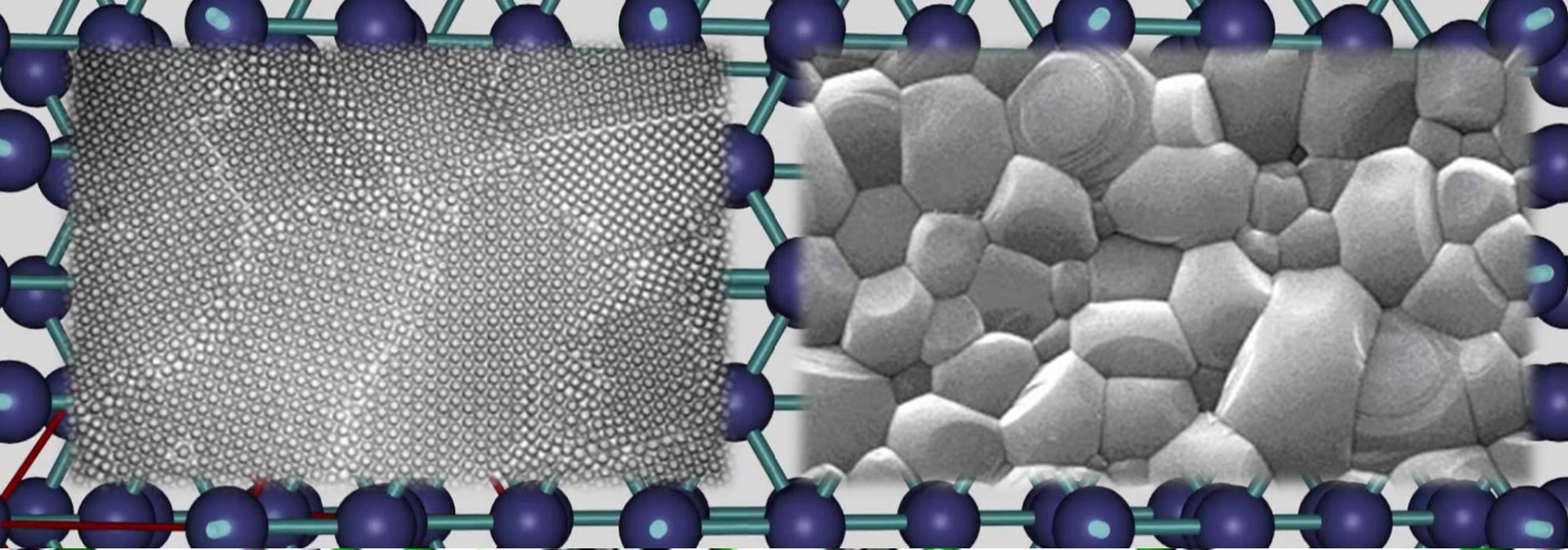


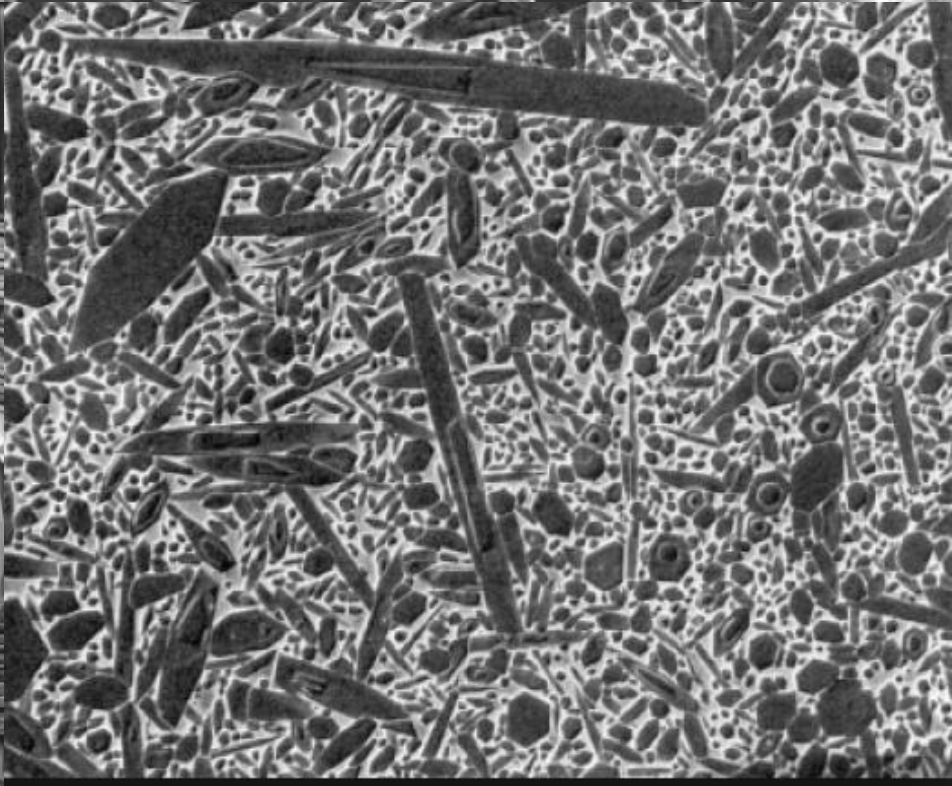
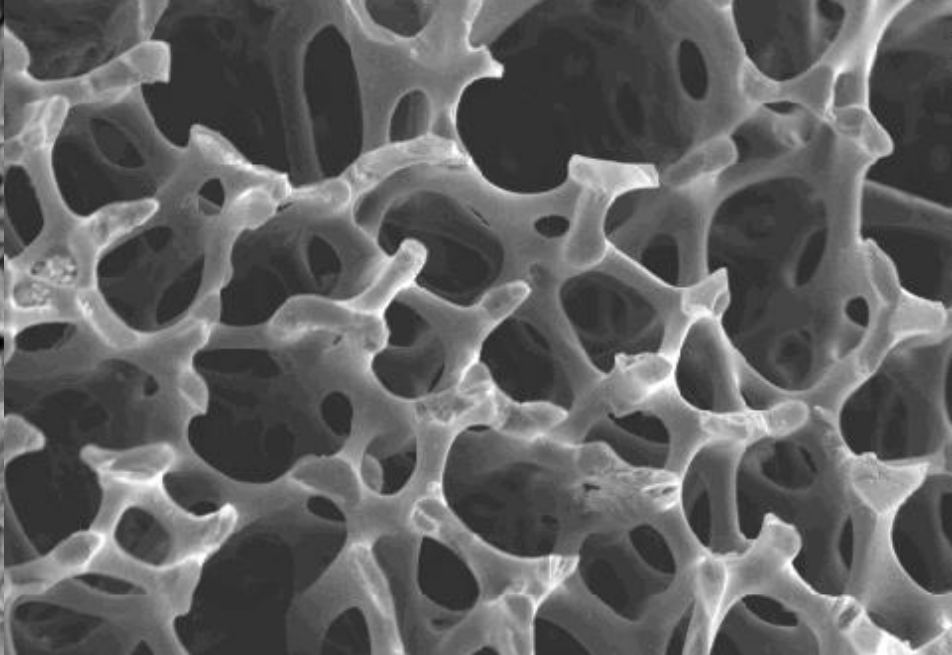
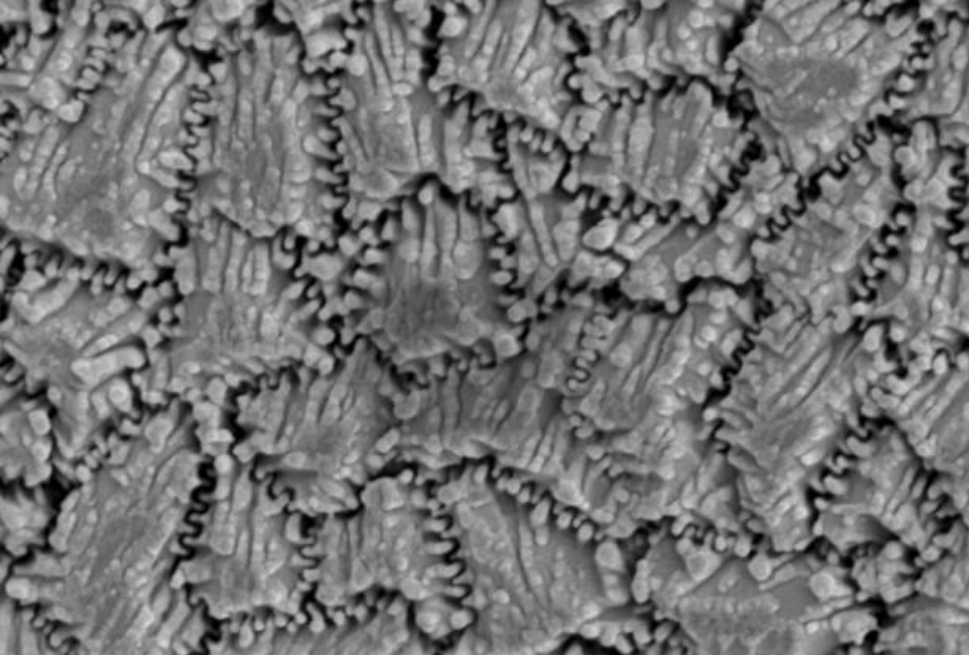
Assignment #1

- In class: group up and research and read at least 3 different sources about Nanoscience, Nanotechnology, Nanomaterials (15 minutes)
- In class: discussion (15 minutes)

Discussion

- What is nano? What is nanotechnology? What is nanoscience? What are nanomaterials?
- Brainstorming: which topics are “hottest” in the “nano” world?

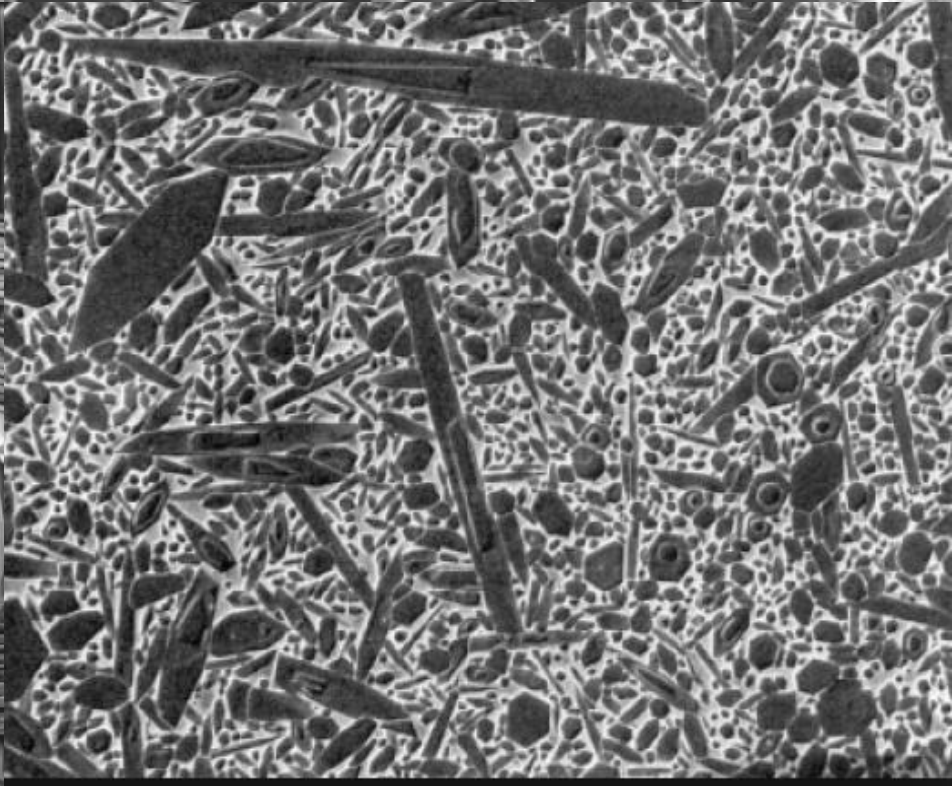
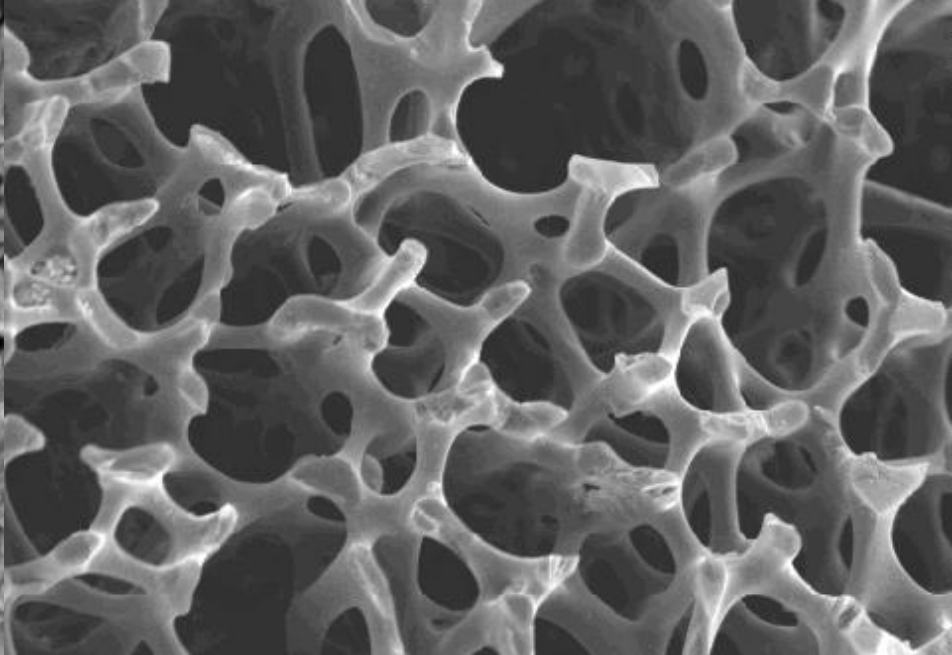
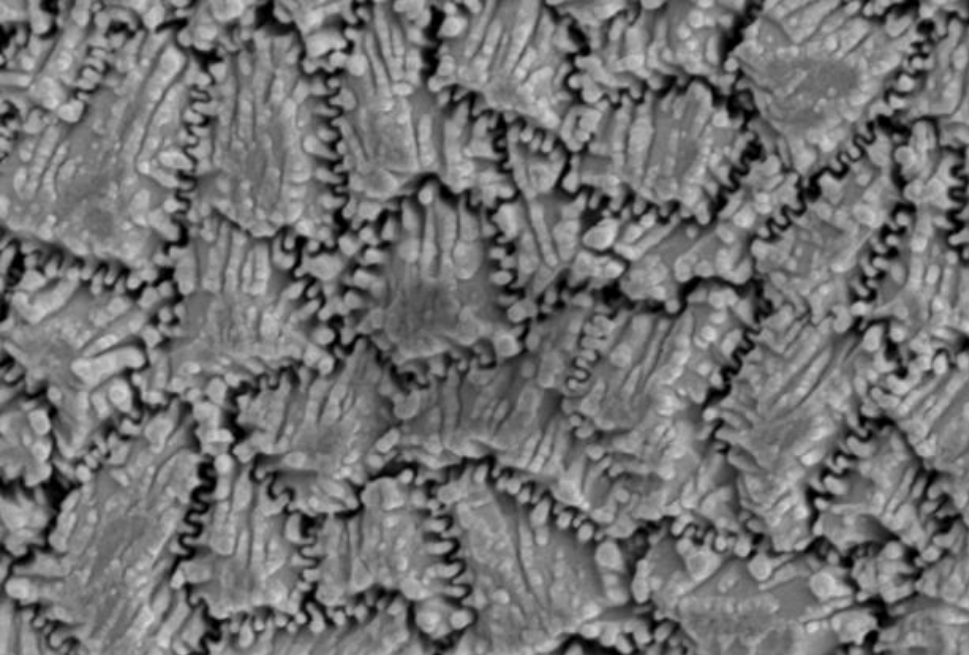




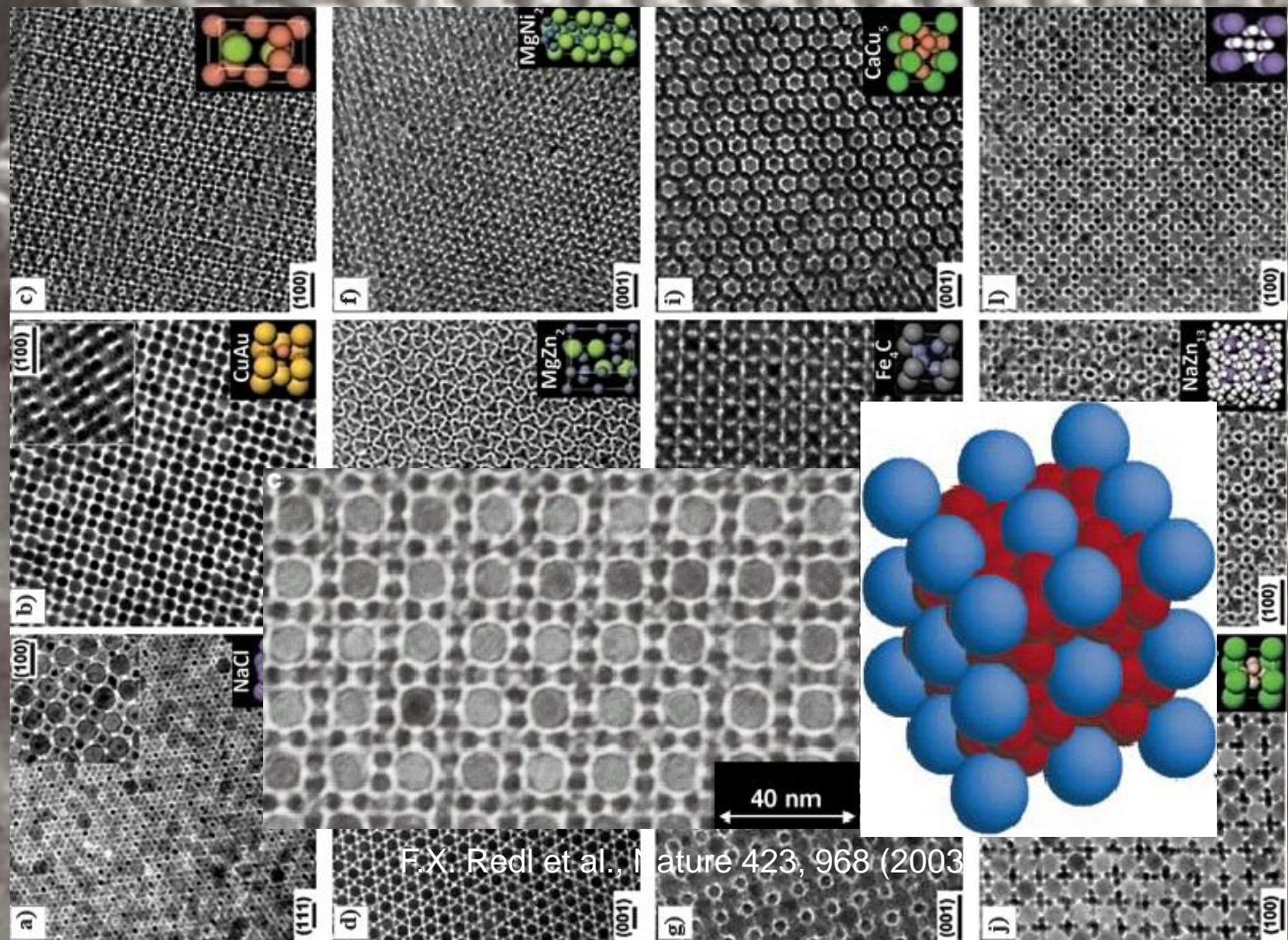
gettyimages
BIOPHOTO ASSOCIATES



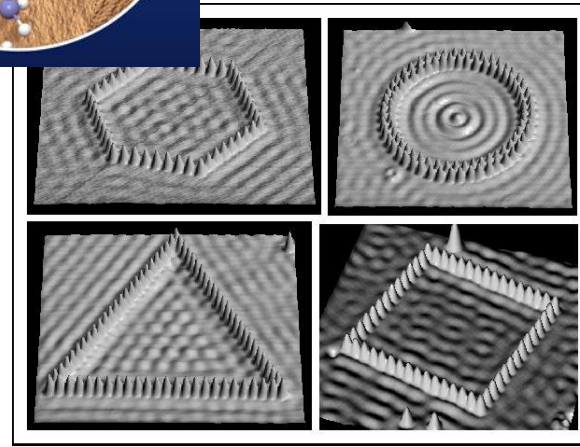
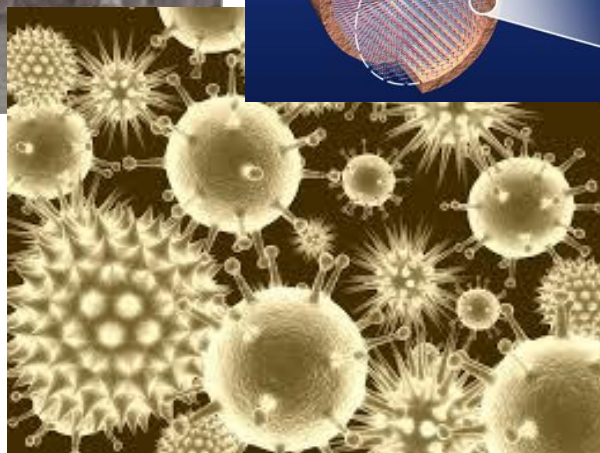
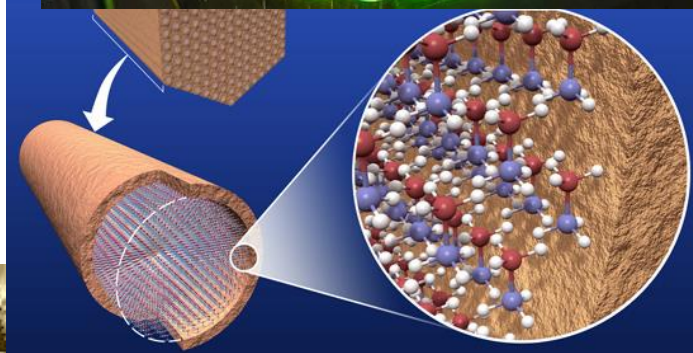
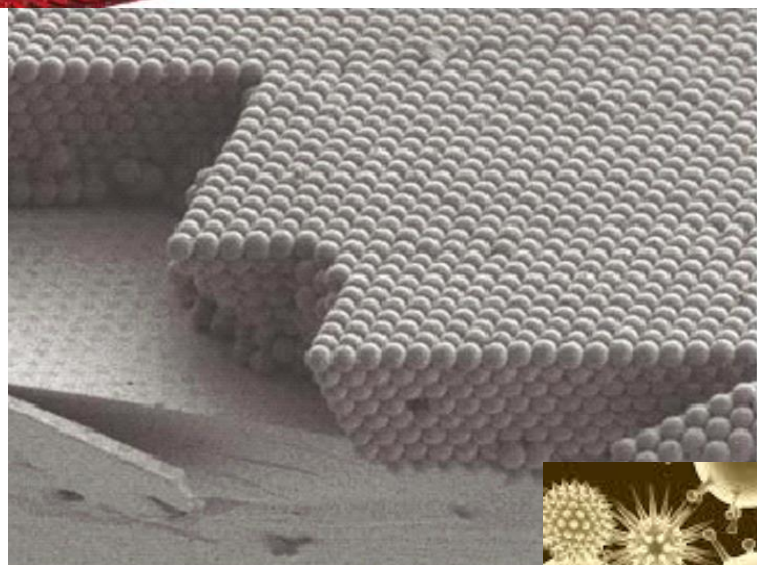
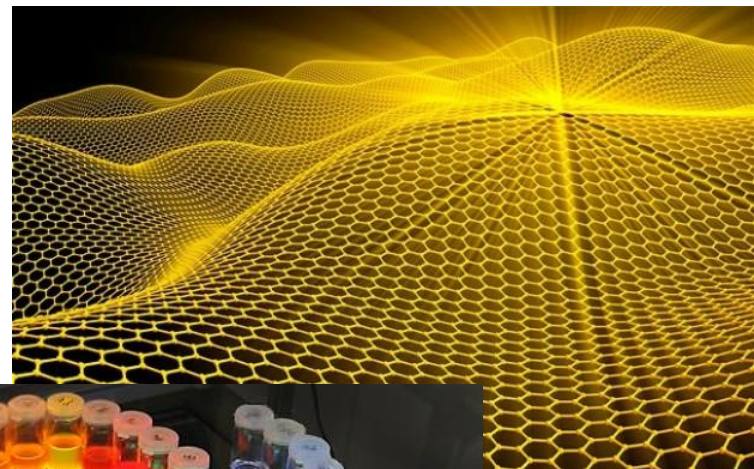
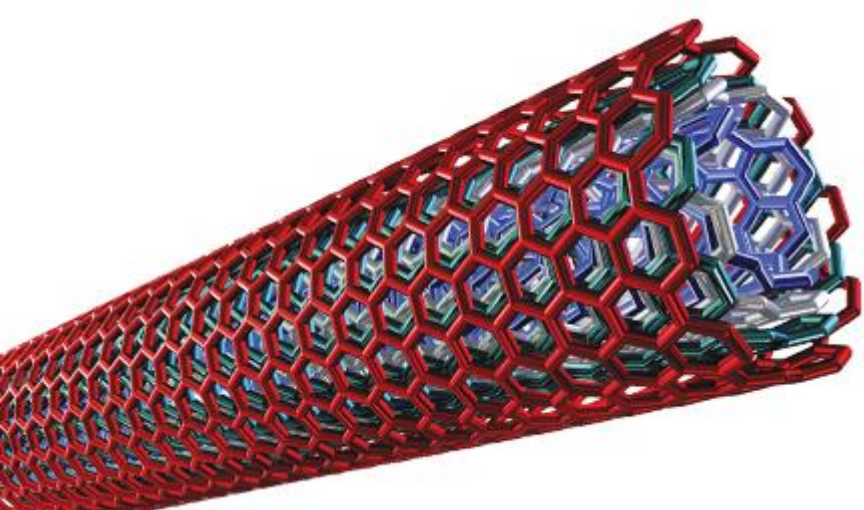




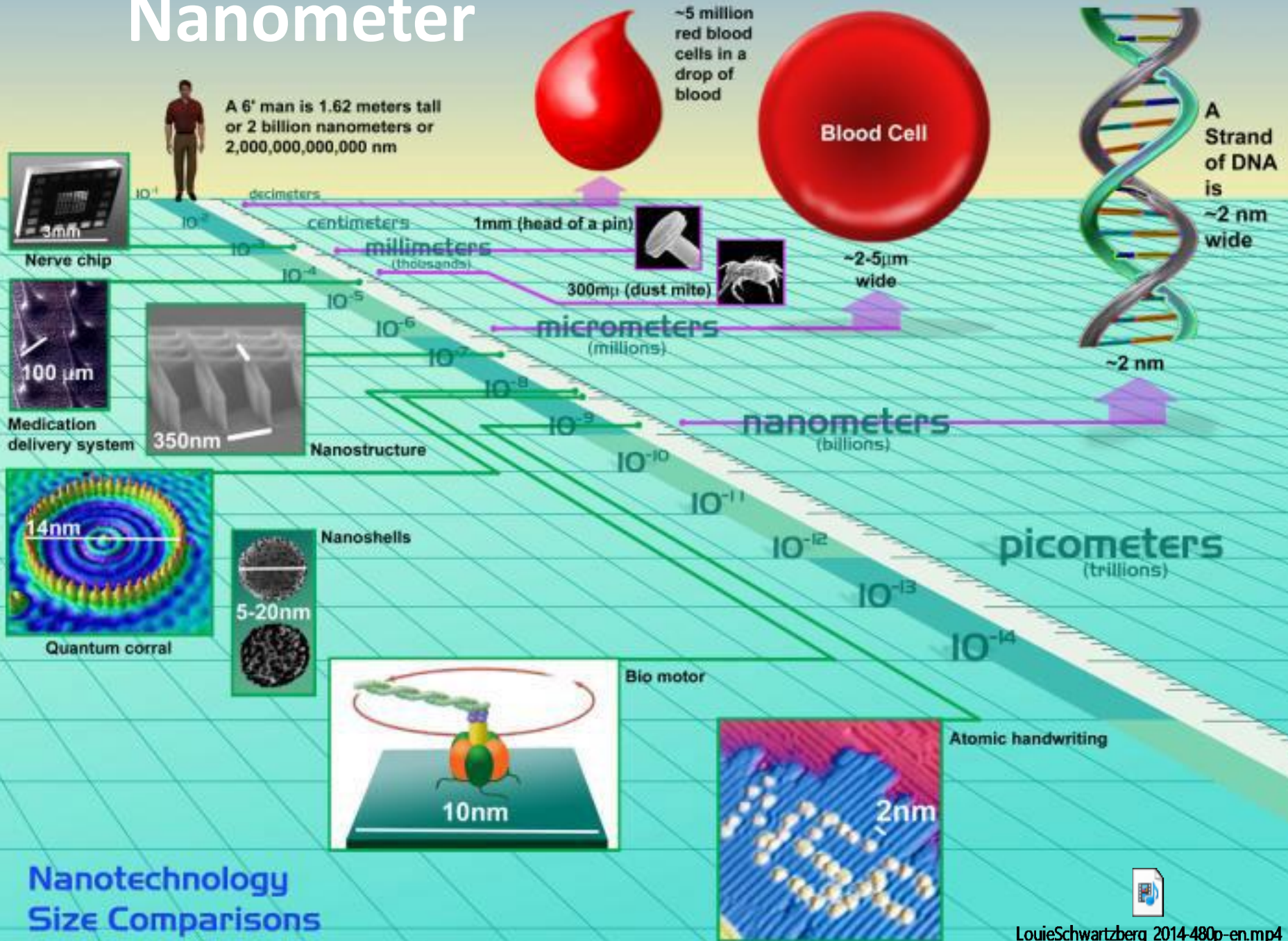
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F.X. Redl et al., Nature 423, 968 (2003)

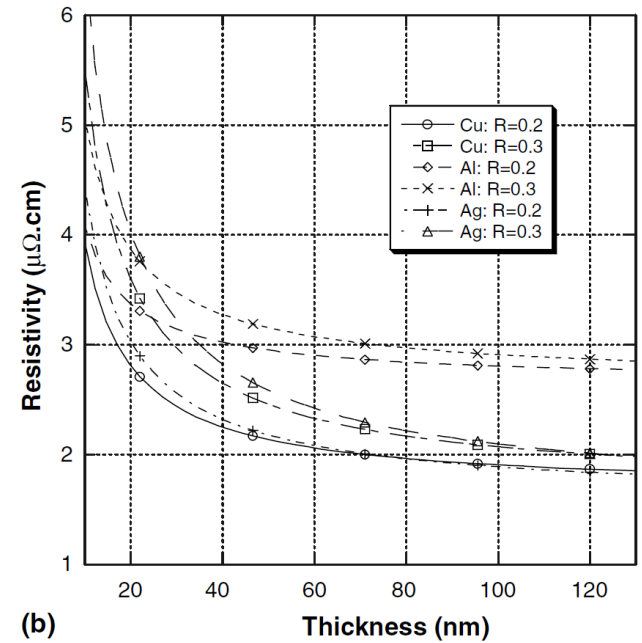
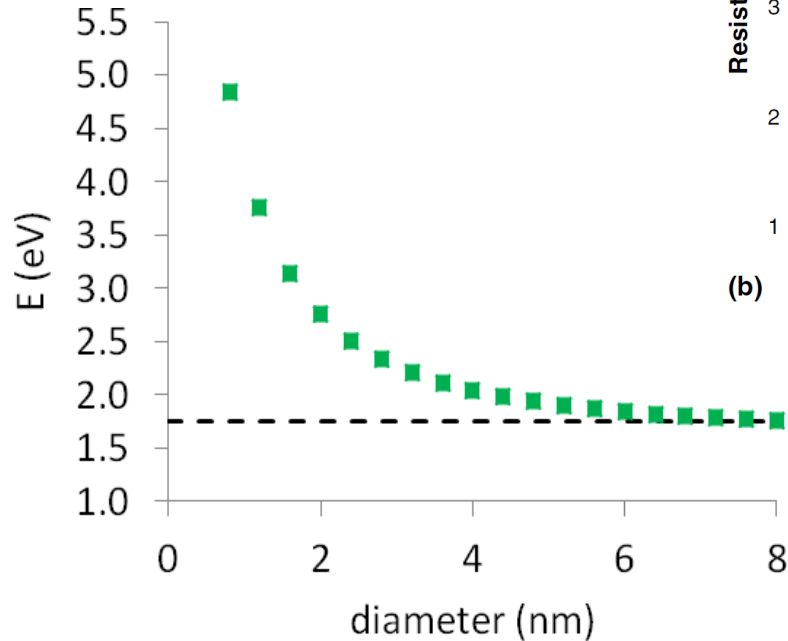
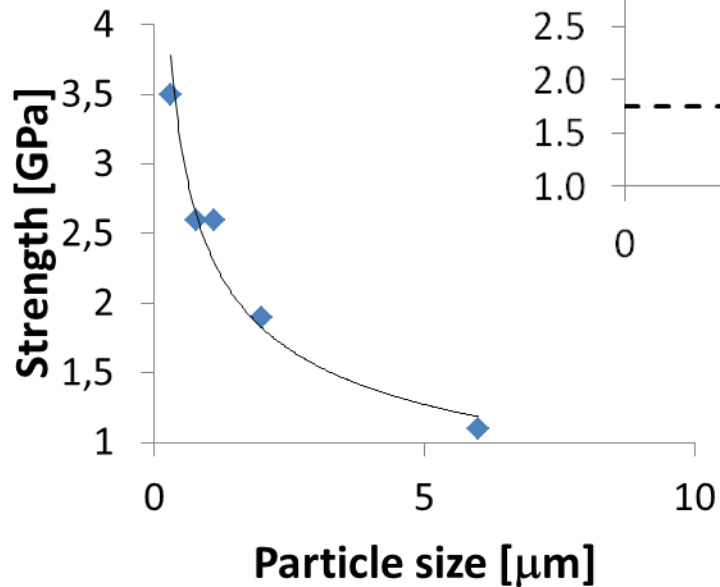


Nanometer



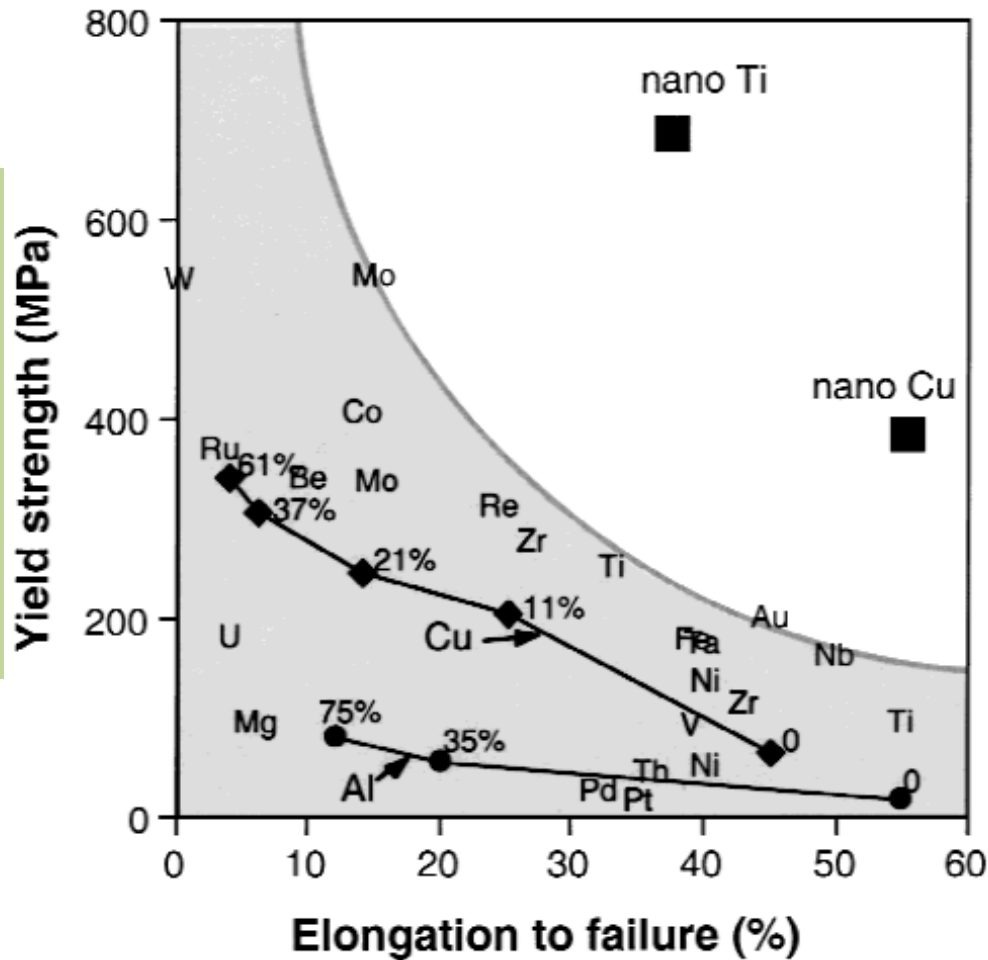
Nanotechnology
Size Comparisons

Properties of materials change at the nanoscale



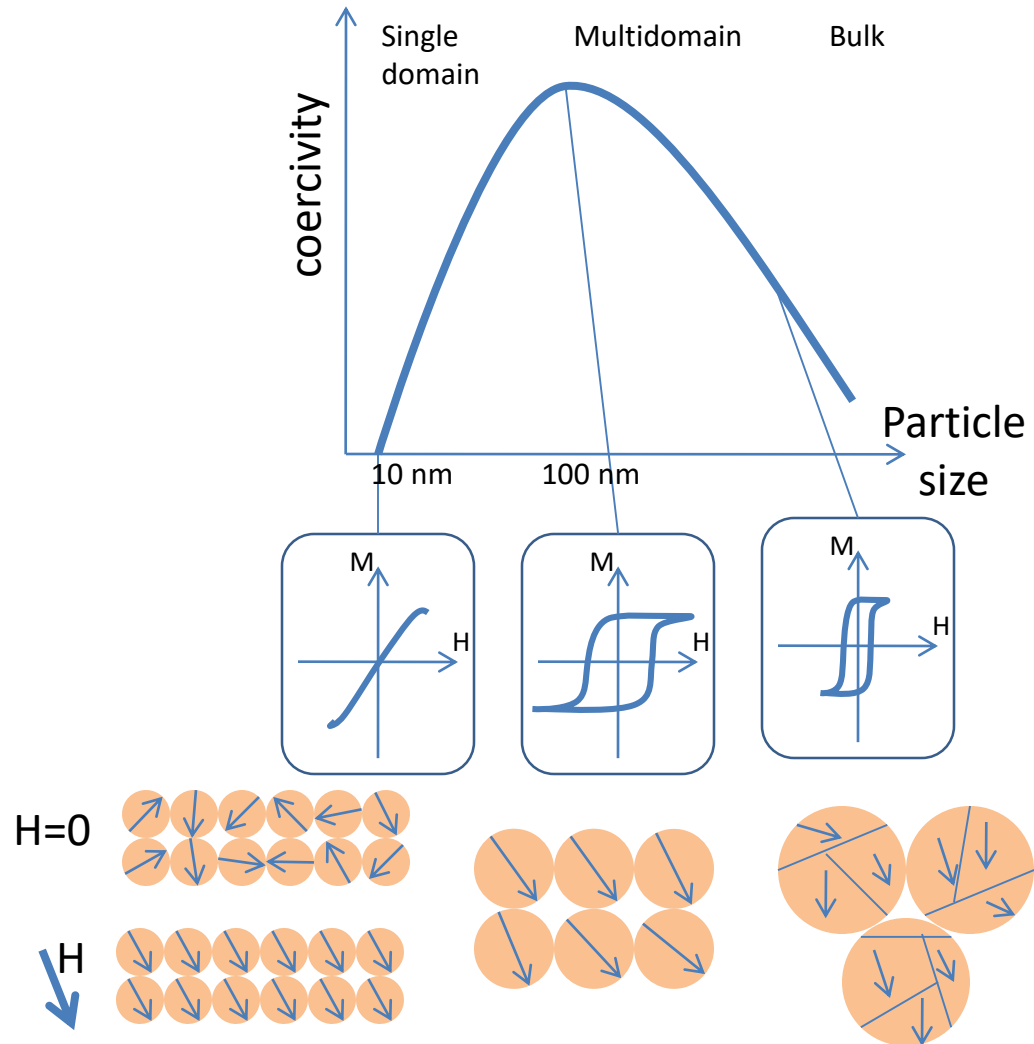
Properties of materials change at the nanoscale

Resistance



Ductility

Super-paramagnetism



“Nanodefinitions”

- **Nanostructured Materials or Nanomaterials**
Materials with a peculiar structure at the nanoscale (nanostructure), leading to peculiar material properties
- **Nanosciences**
The study of the relationship between nanoscale structure of a material and its properties
- **Nanotechnology**
Techniques and instruments for the manipulation or characterization of objects at the nanoscale

Yes, it's fascinating. But... Why bother working at the nanoscale?

«There's plenty of room at the bottom»

Richard P. Feynman, 1959

Controlling the structure of a material at the nanoscale opens up the opportunity for **a new level of engineering and tailoring of the materials properties**

E.g.: Phenomena at the nanoscale are governed by the laws of quantum mechanics

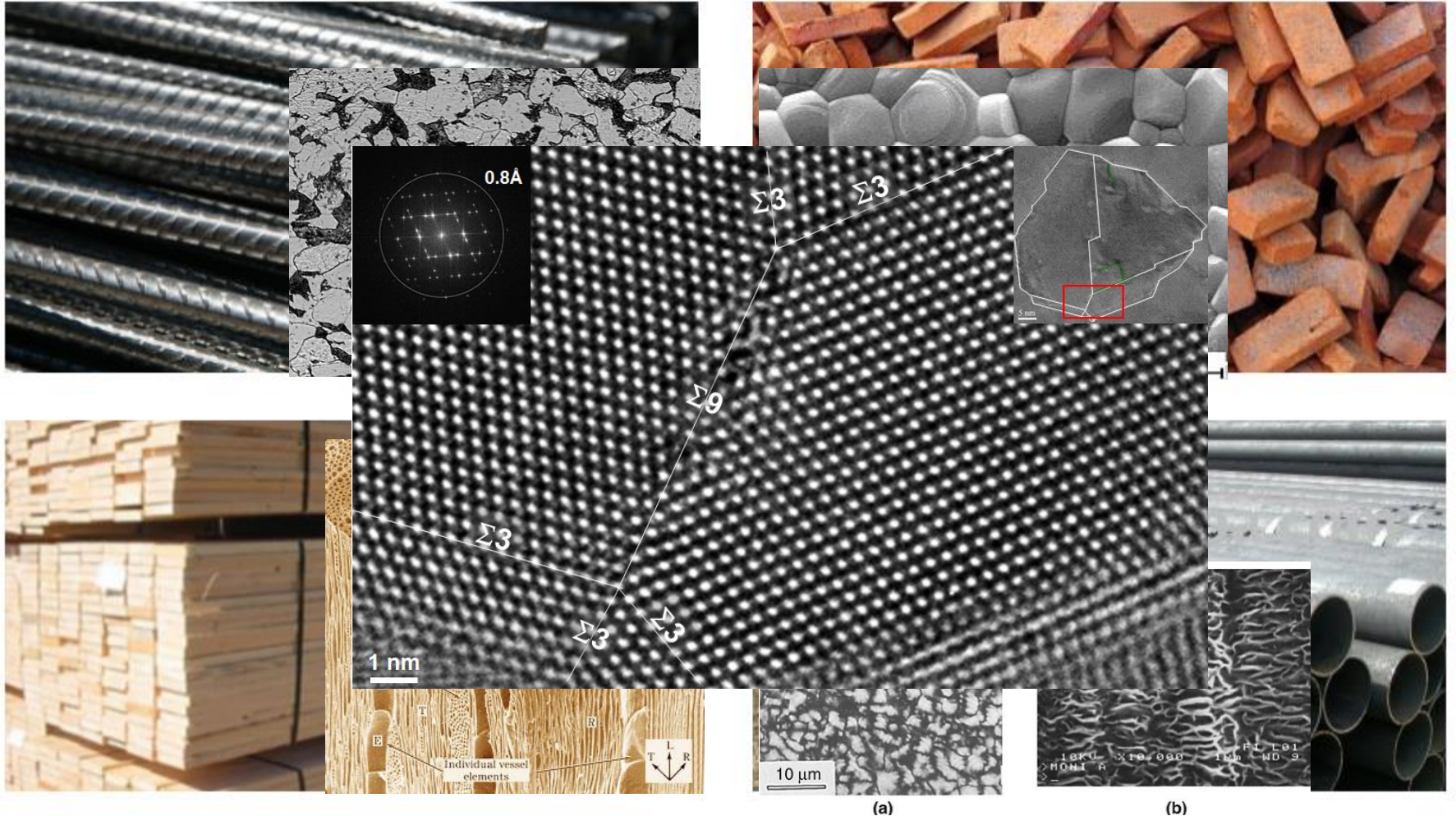


New opportunities for controlling material properties at the macroscale ("untapped physics")

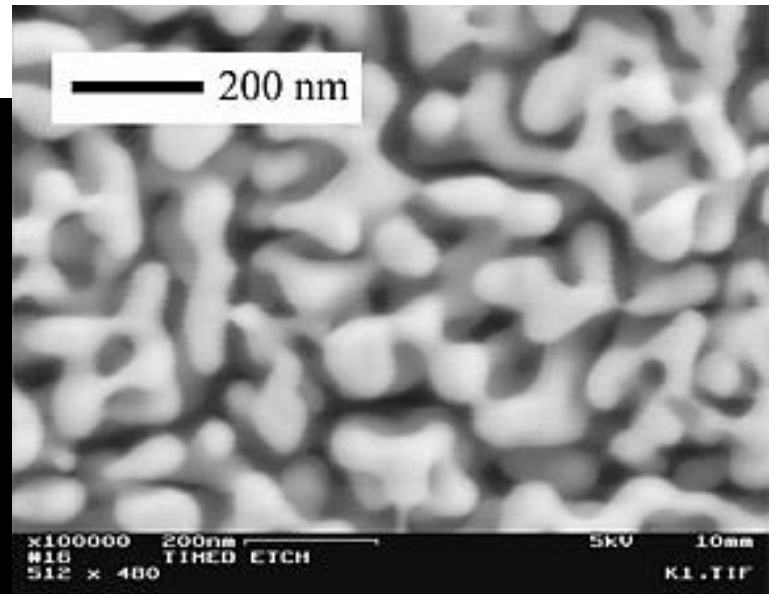
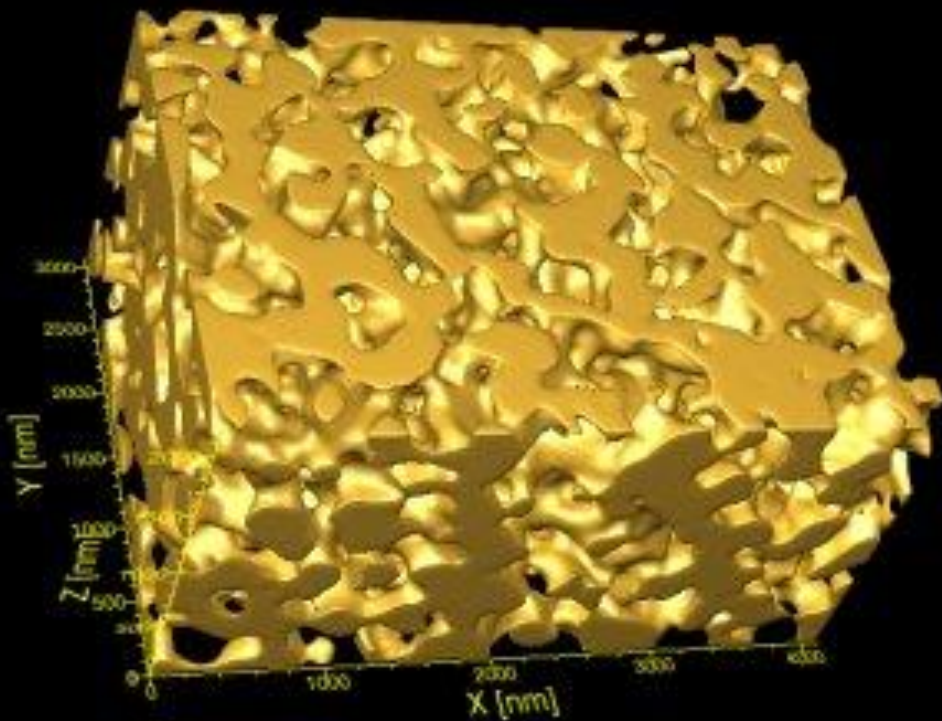
Nanostructures

nanomaterials (3D nanostructured materials) and their **building blocks** (0-D, 1-D, 2-D nanostructures)

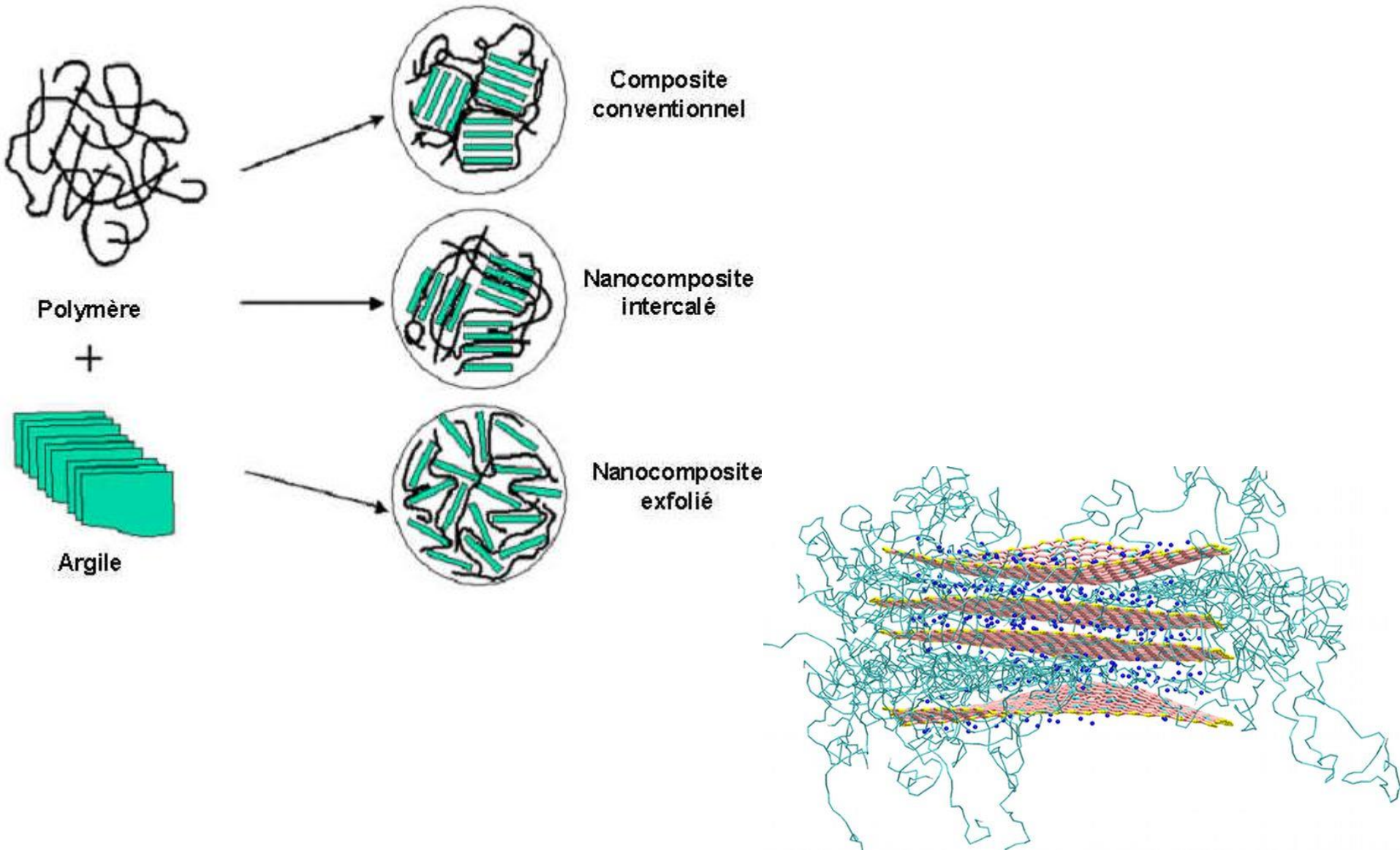
Traditional «bulk» materials (3 dimensions)



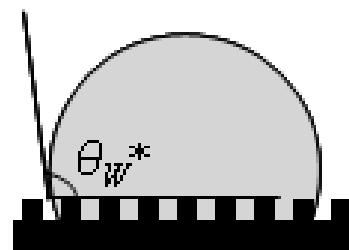
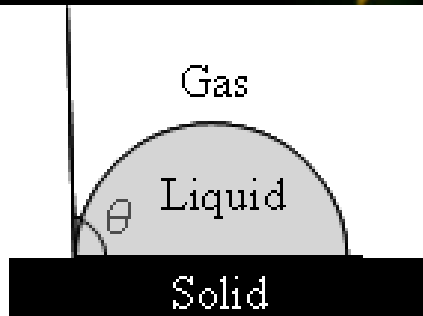
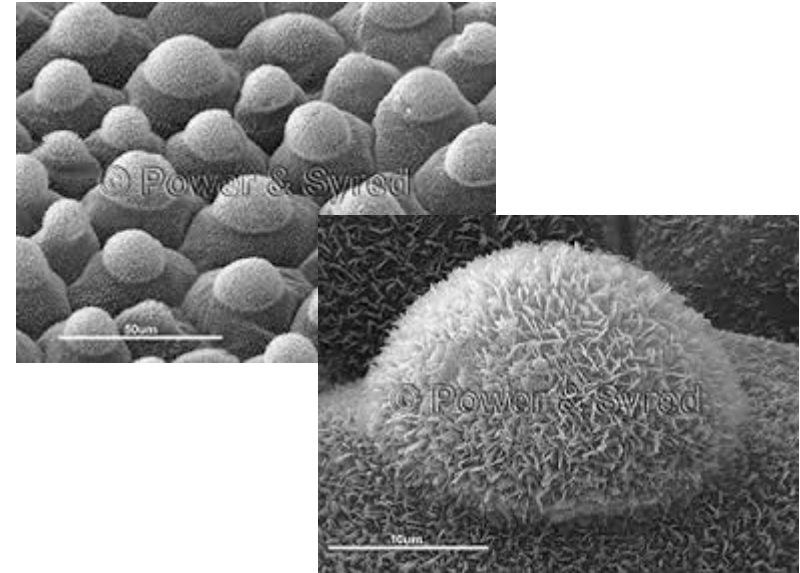
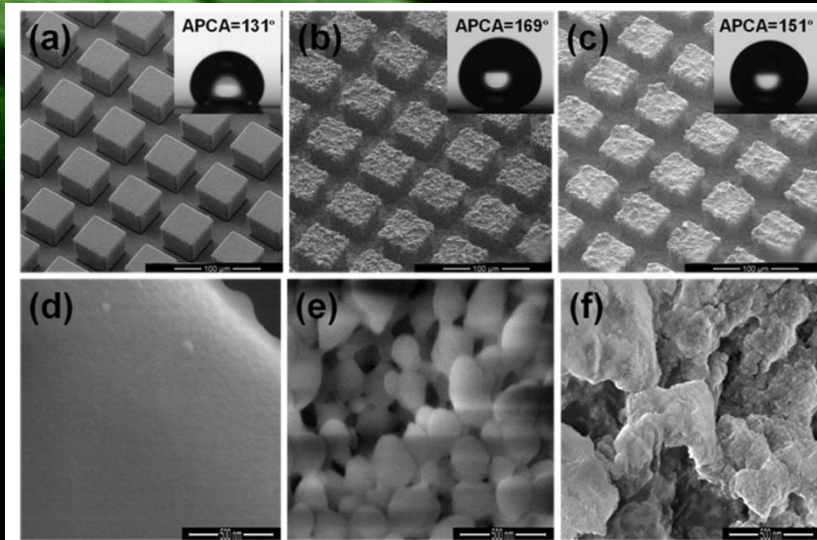
Nanostructured materials (3 dimensions)



Nanocomposites (3 dimensions)



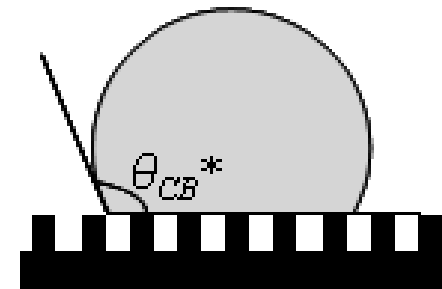
Superhydrophobic nanostructured surfaces ("Lotus" effect)



Wenzel

$$\cos\theta_W^* = r\cos\theta$$

r : ratio between
actual area and
projected area

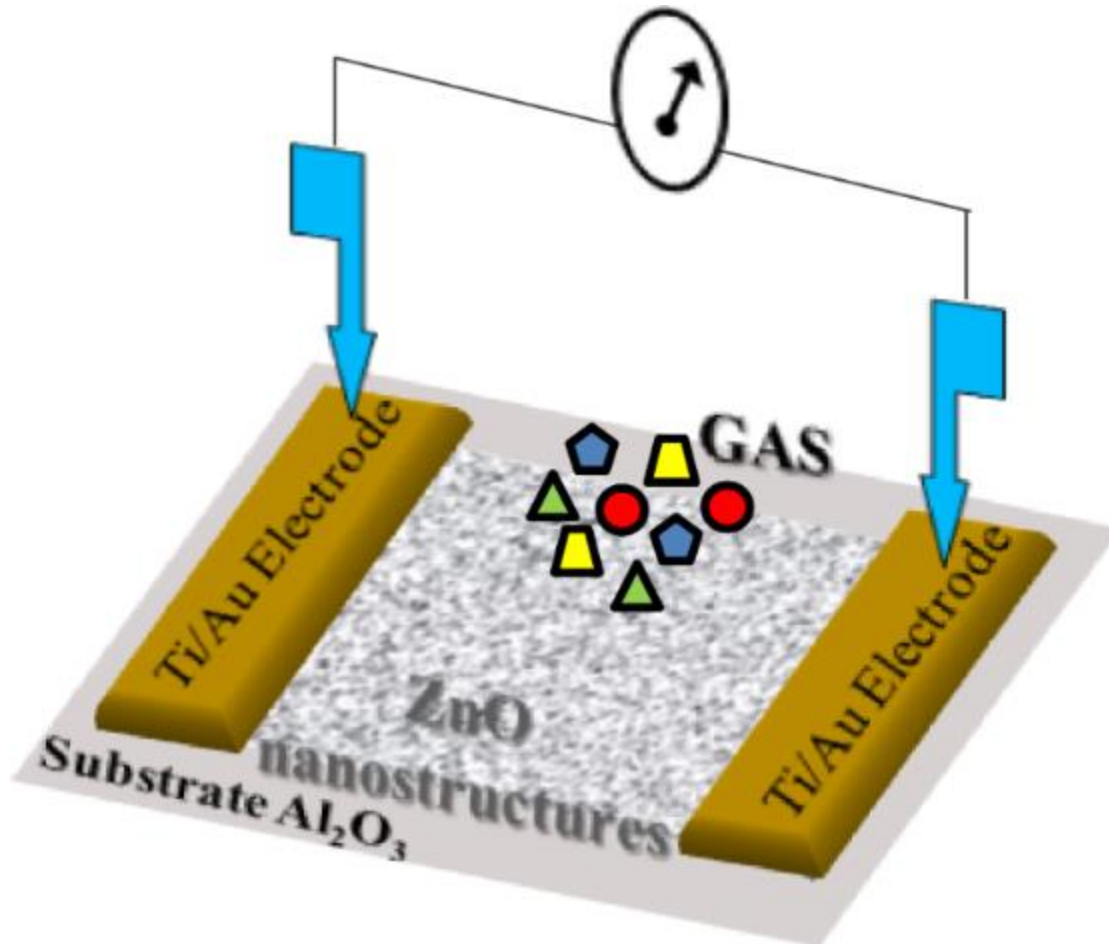


Cassie-Baxter

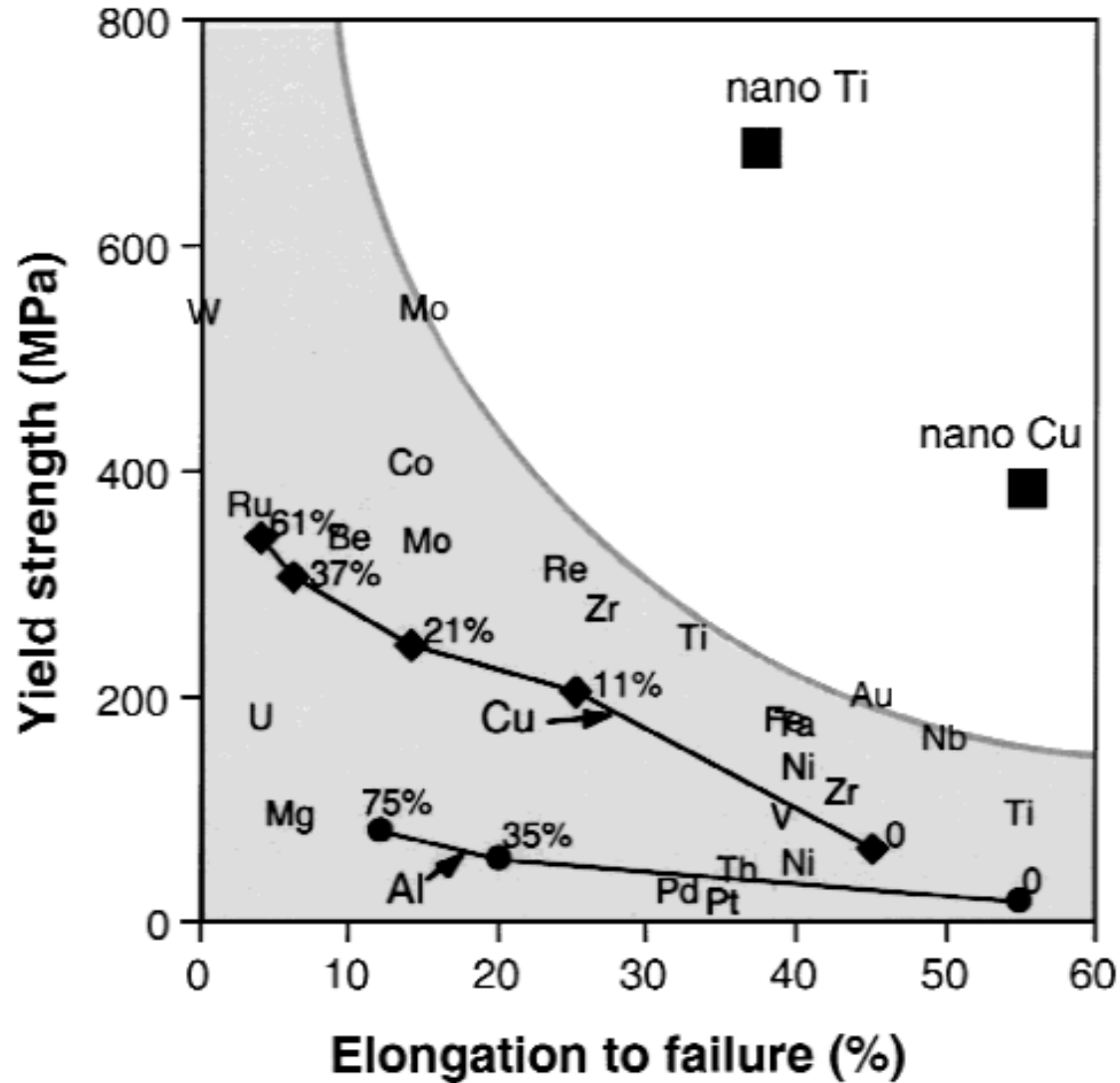
$$\cos\theta_{CB}^* = \phi(\cos\theta + 1) - 1$$

ϕ : fraction of area actually
in contact with the liquid

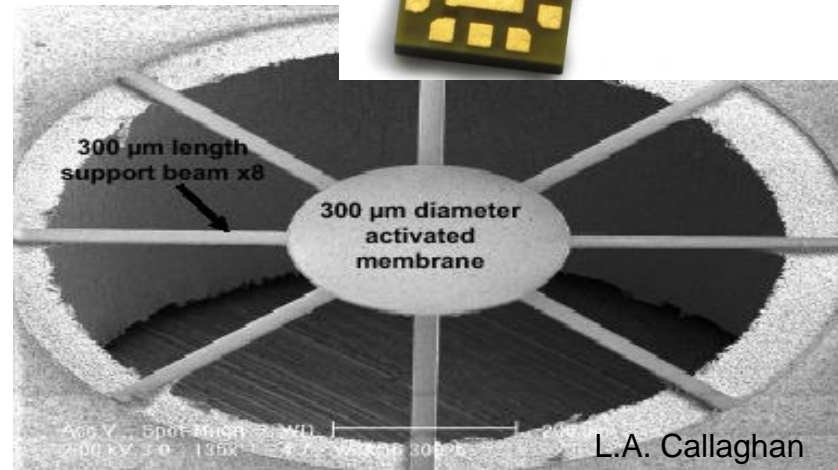
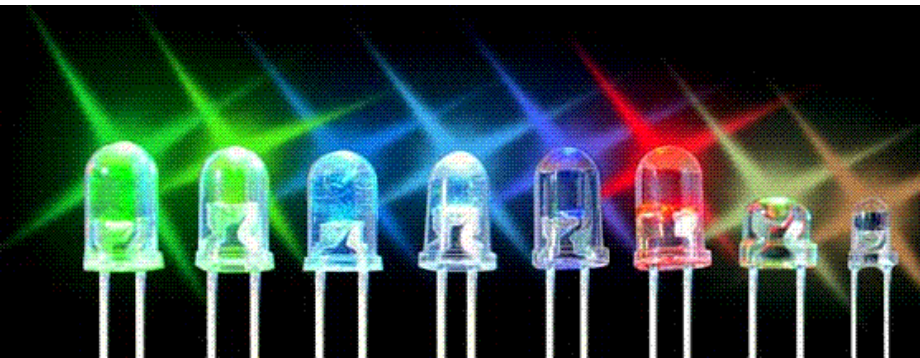
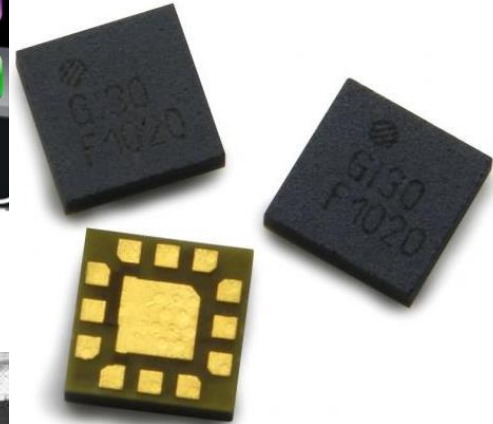
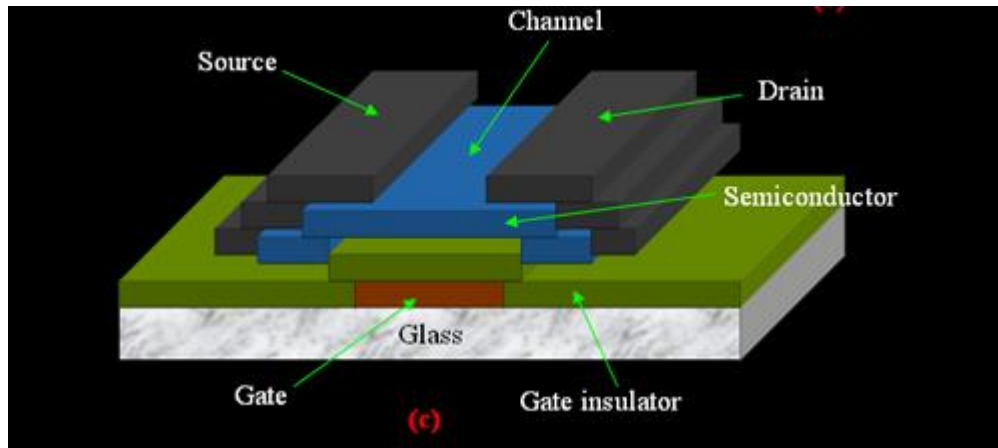
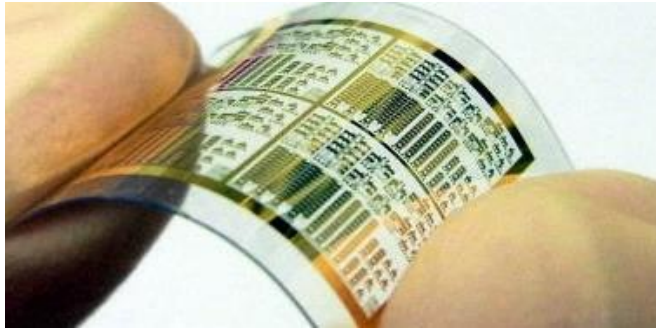
Nanostructured gas sensors



Beyond the “ductile vs strong” paradox in bulk nanostructured materials



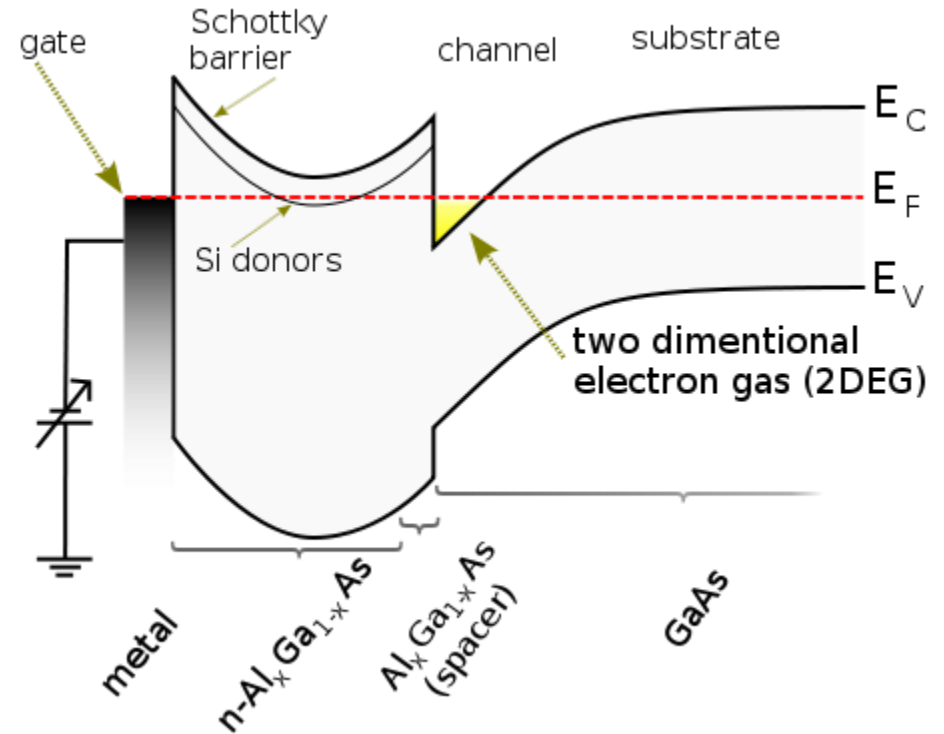
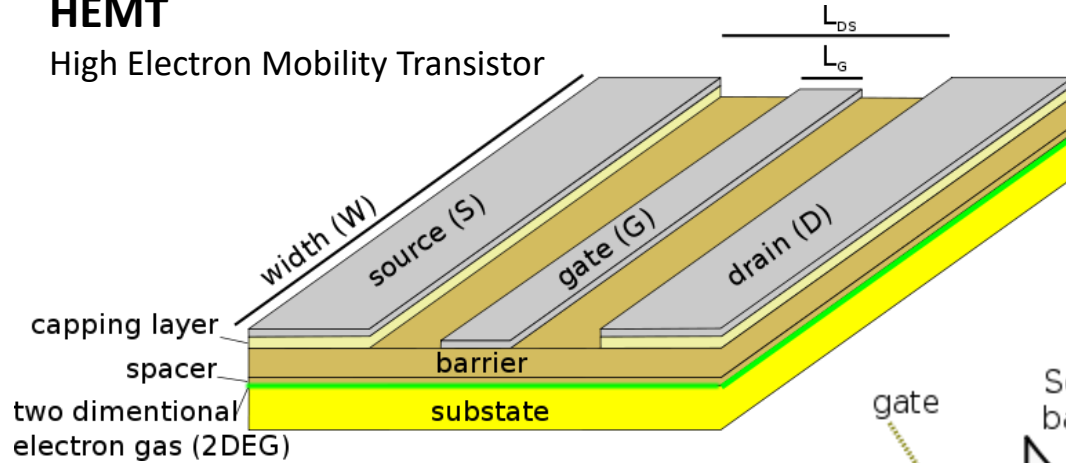
Thin Films (2 dimensions)



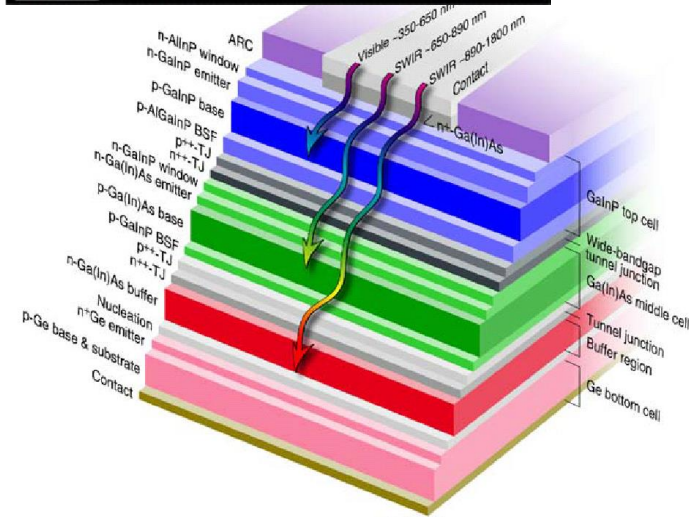
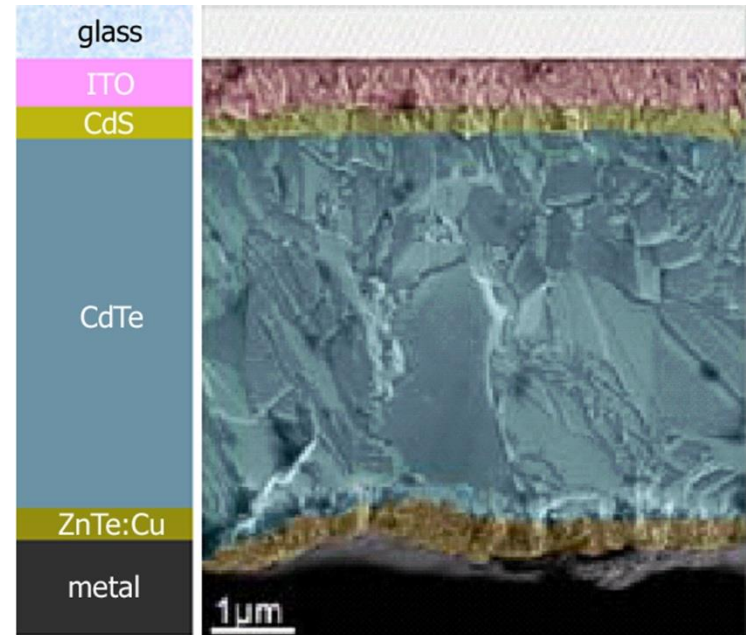
2D heterostructures and superlattices: bandgap engineering and 2D electron gas

HEMT

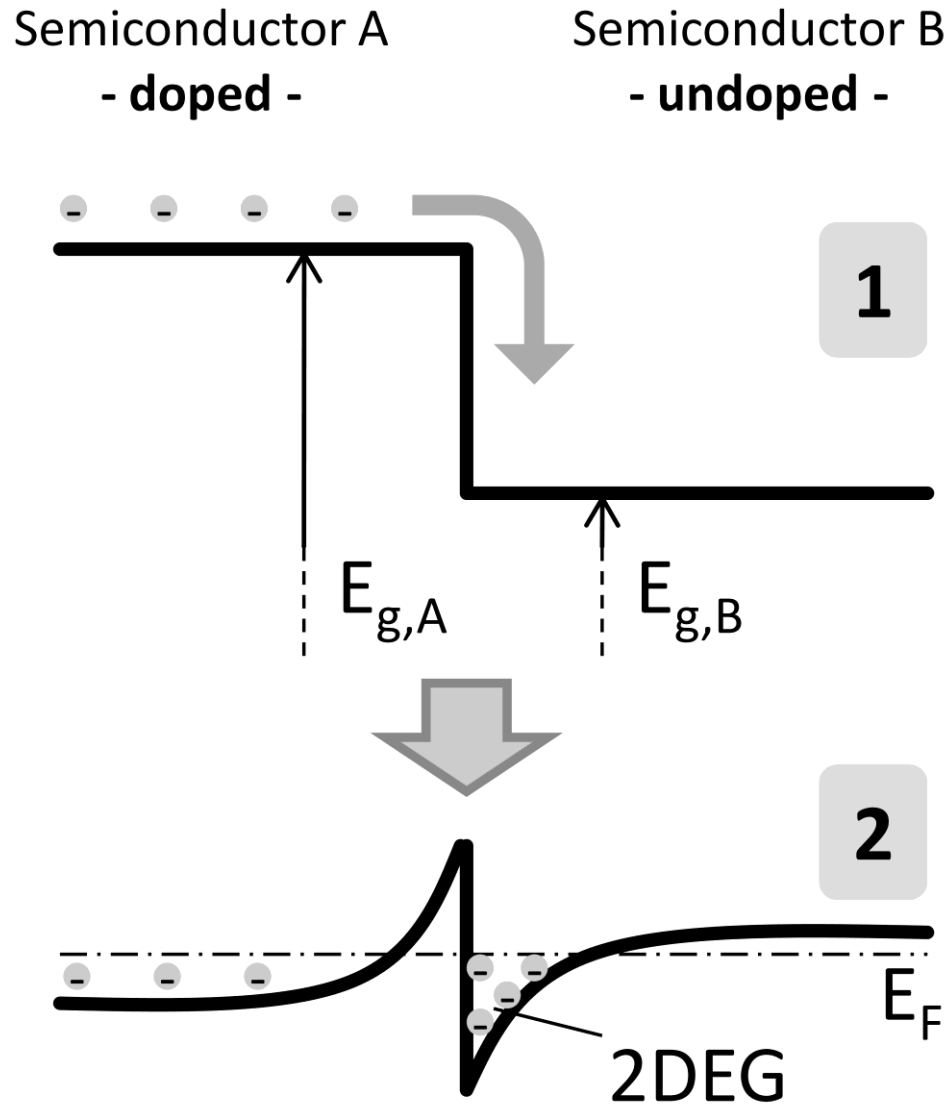
High Electron Mobility Transistor



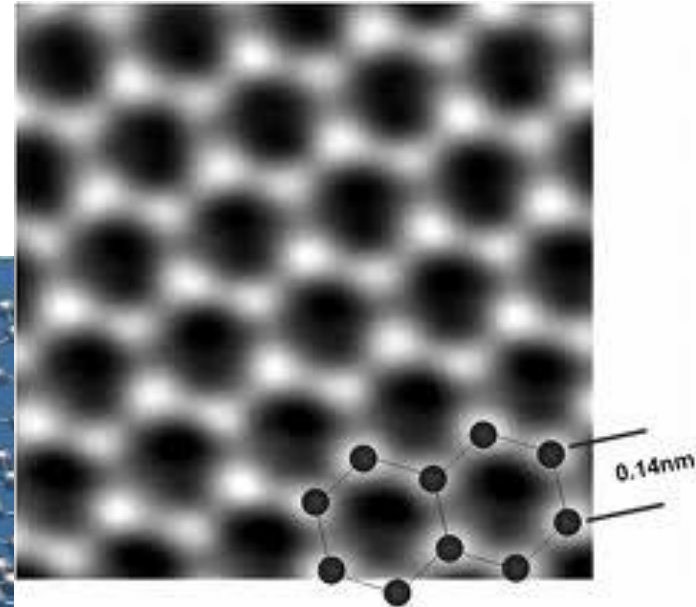
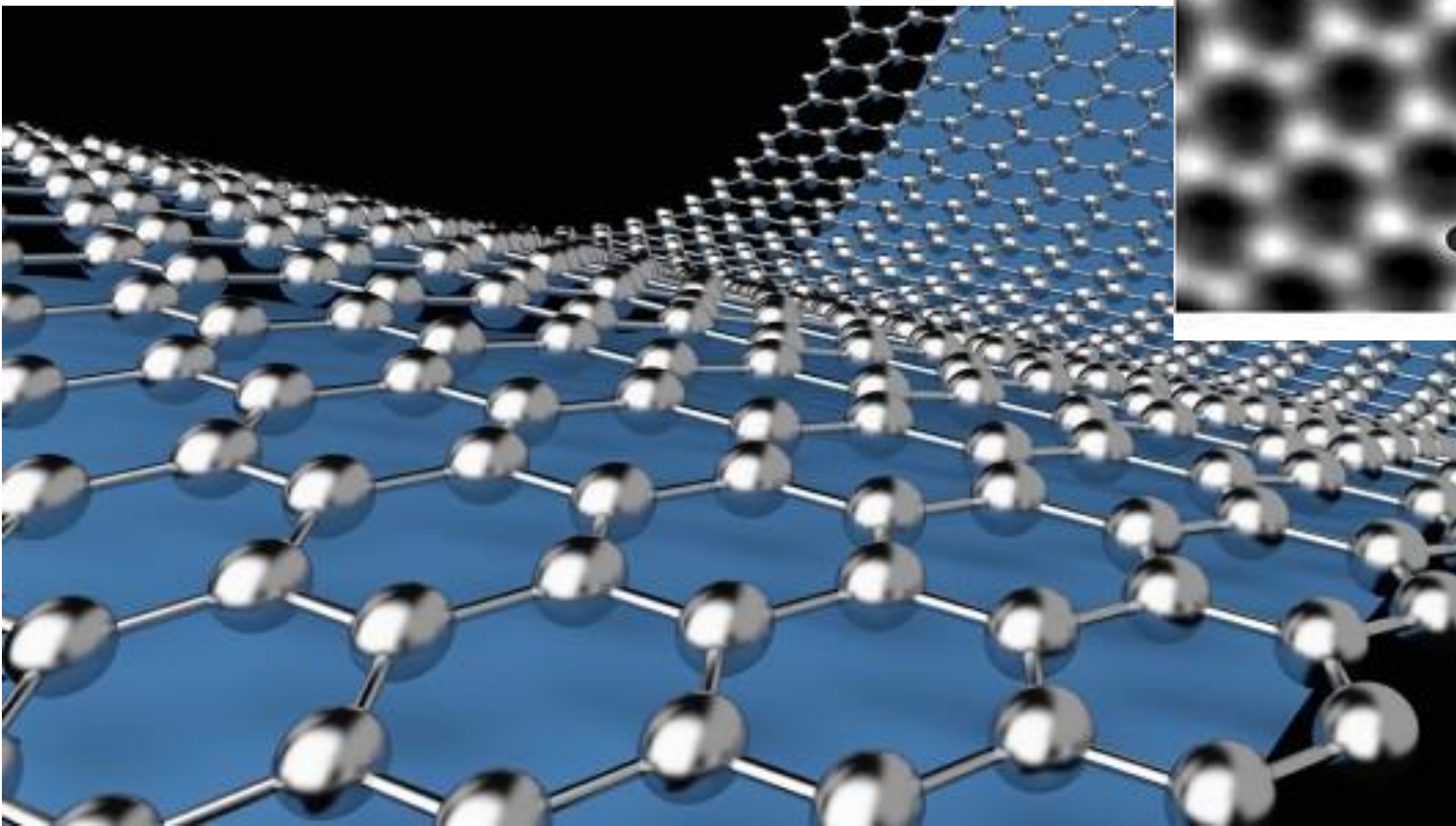
Thin Film solar cells



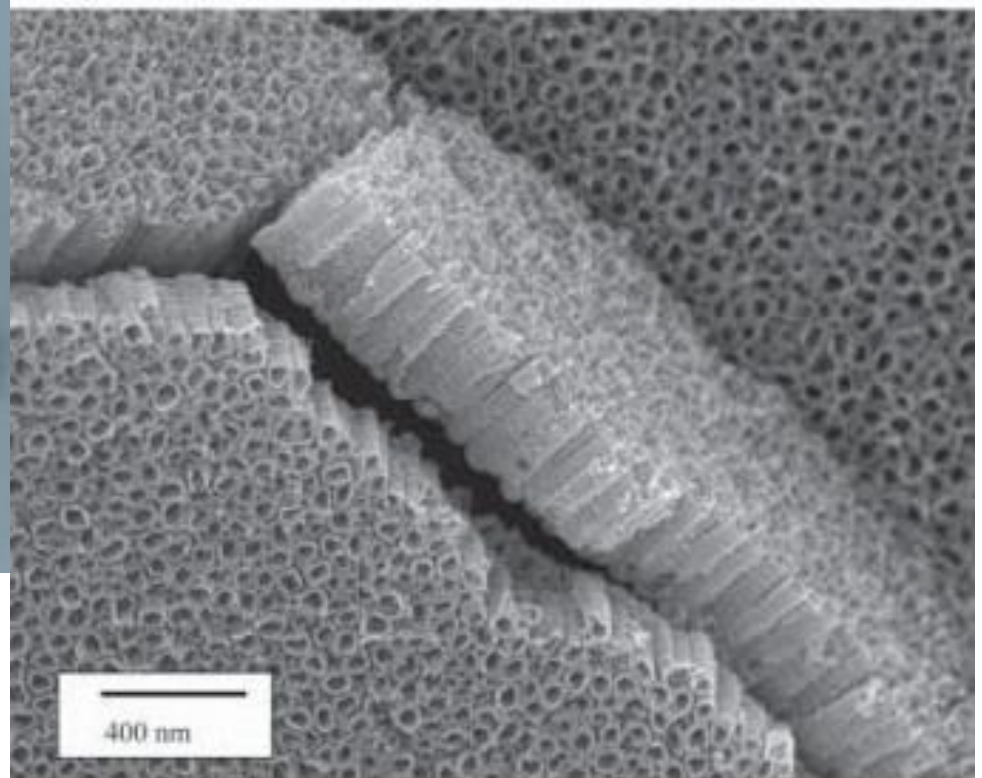
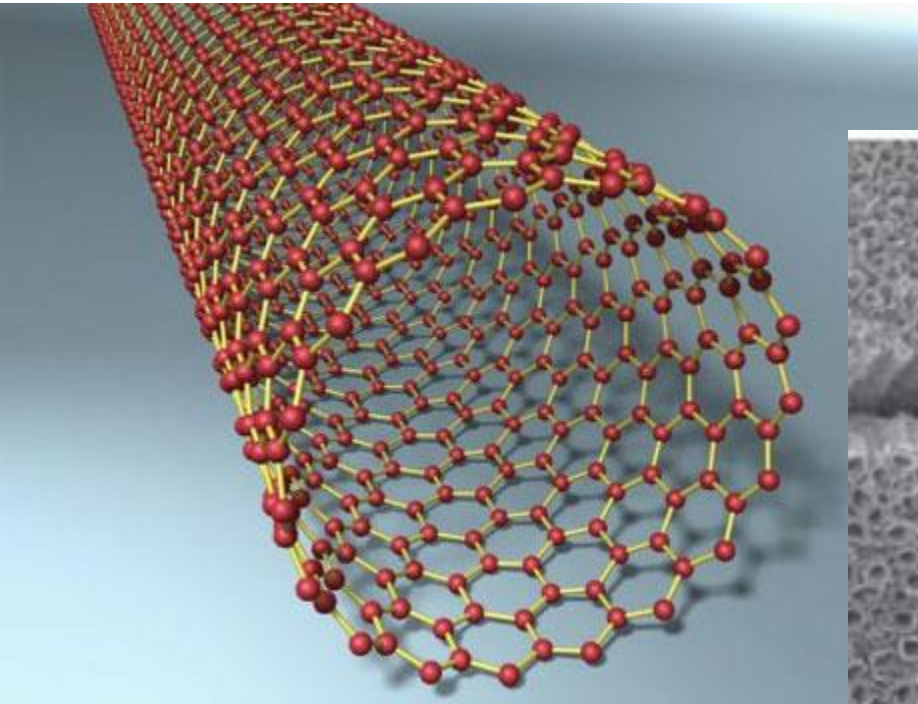
2D heterostructures and superlattices: bandgap engineering and 2D electron gas



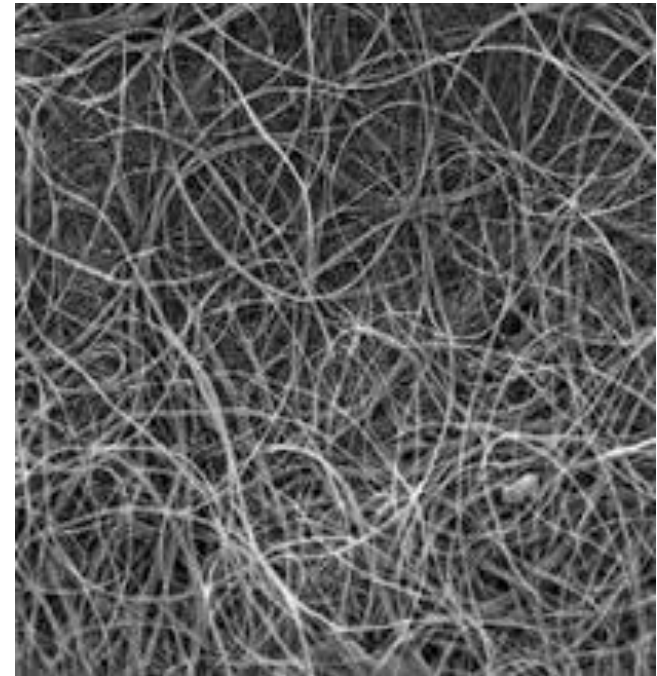
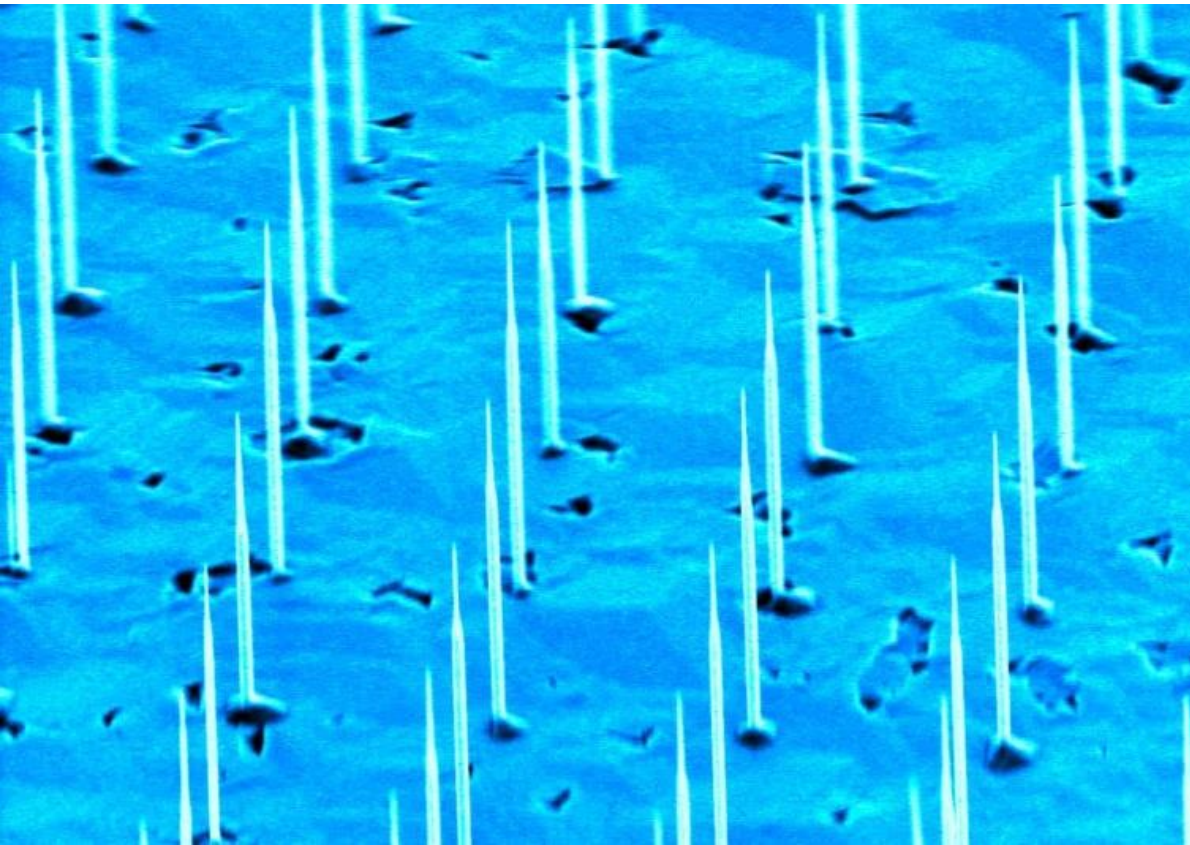
Graphene (2 dimensions)



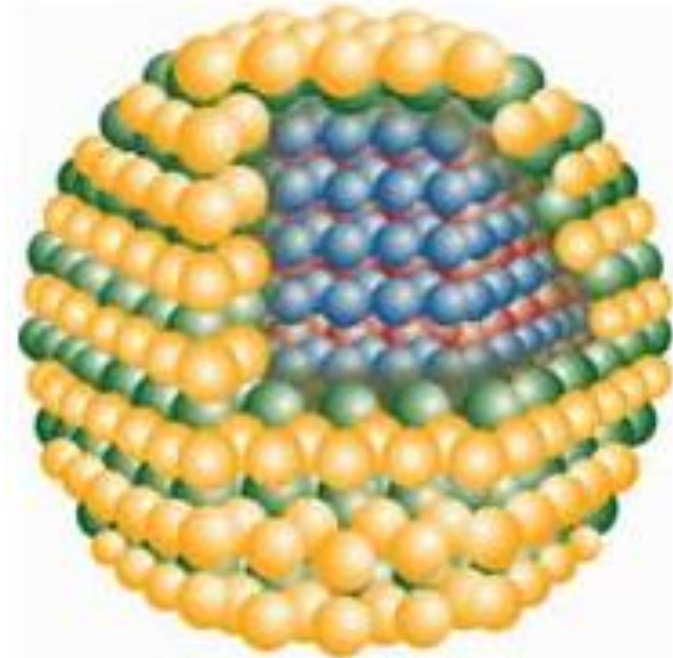
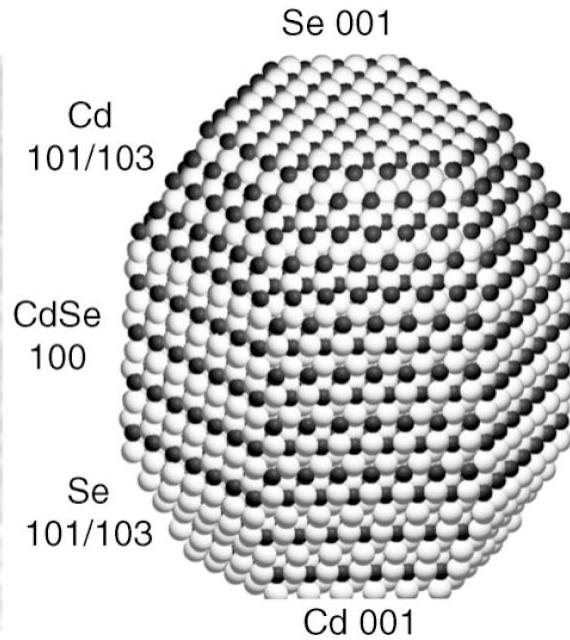
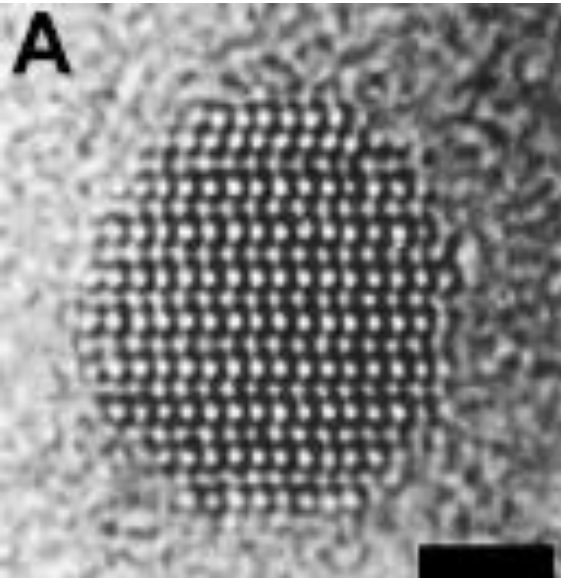
Carbon nanotubes (1 dimension)



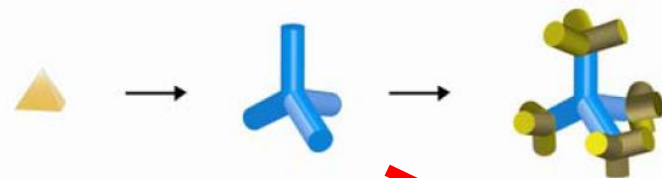
Nanowires (1 dimension)



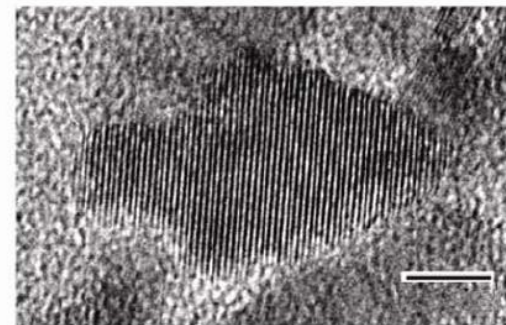
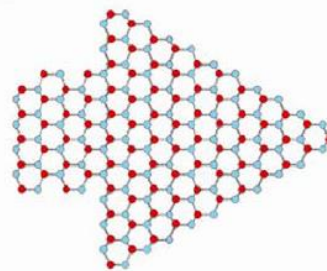
Nanoparticles (0 dimensions)



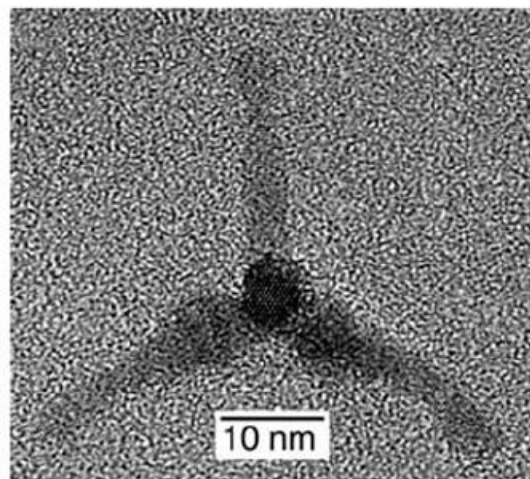
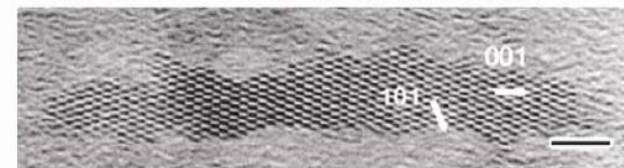
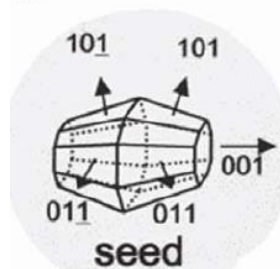
Having fun with shapes...



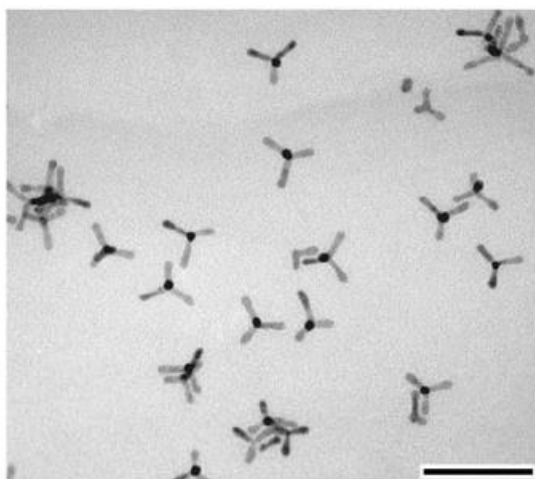
a



b

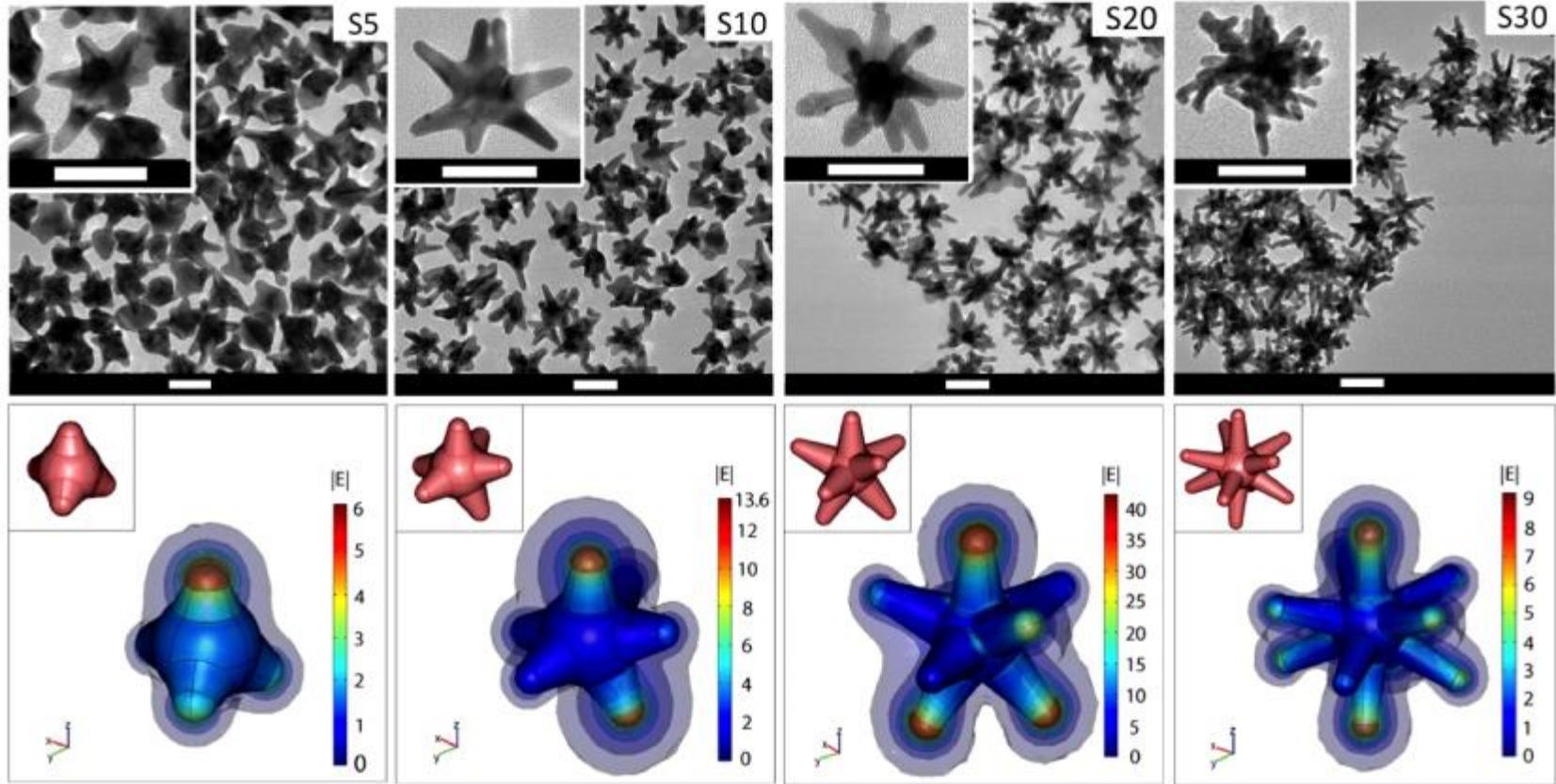


b



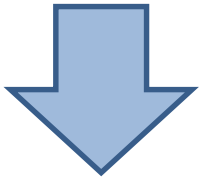
Paul Alivisatos, UC Berkeley

Having fun with shapes: Nanostars



Using nanocrystals in solids: NCs/polymer composite material

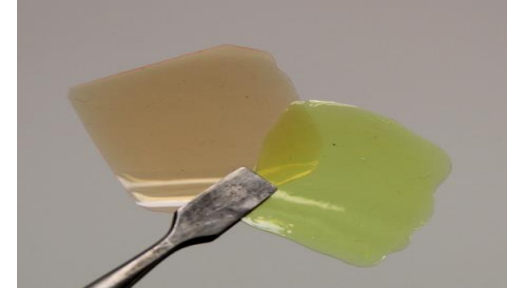
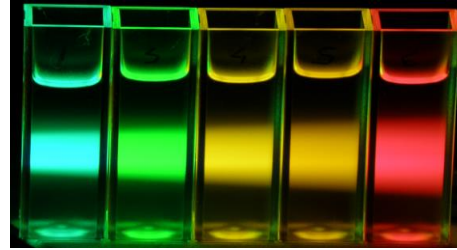
LIQUID



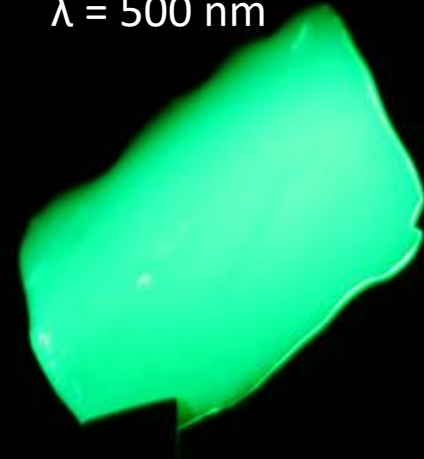
SOLID

BLEND in PMMA

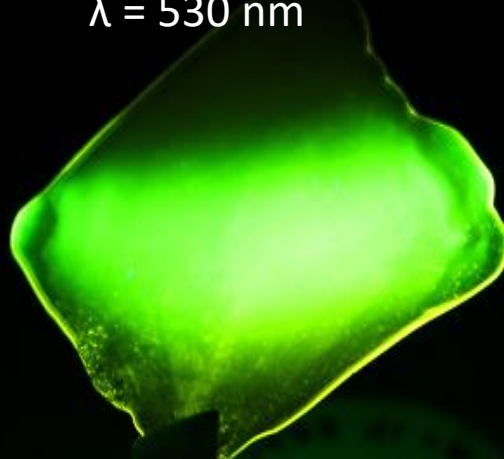
$\text{CdSe}_x\text{S}_{1-x}$ - CdS colloidal NCs



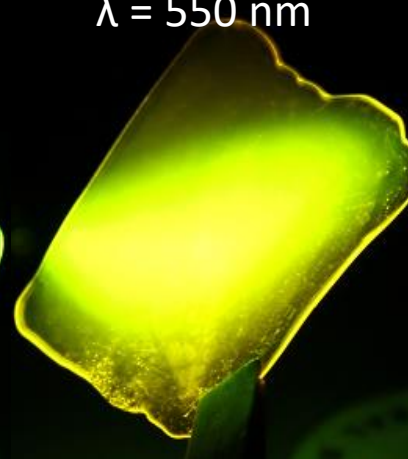
$\lambda = 500 \text{ nm}$



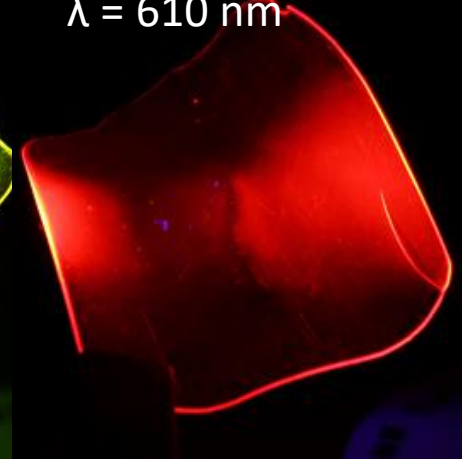
$\lambda = 530 \text{ nm}$



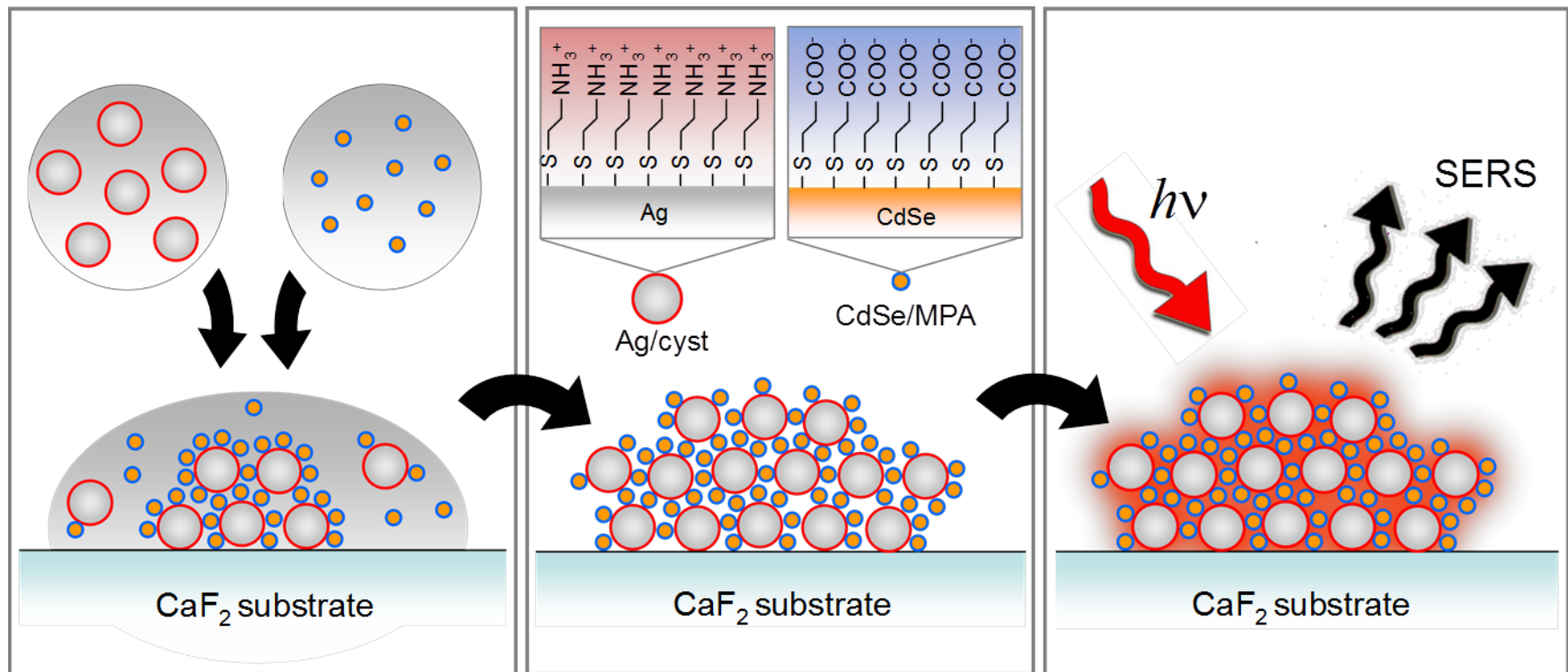
$\lambda = 550 \text{ nm}$



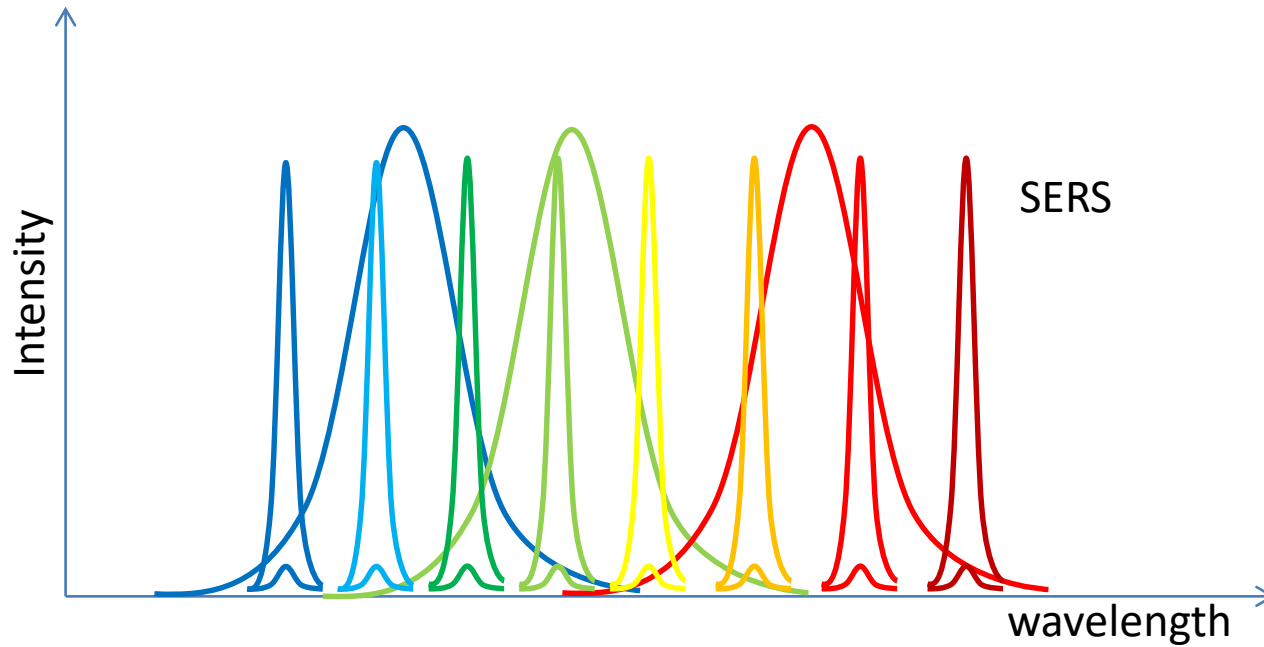
$\lambda = 610 \text{ nm}$



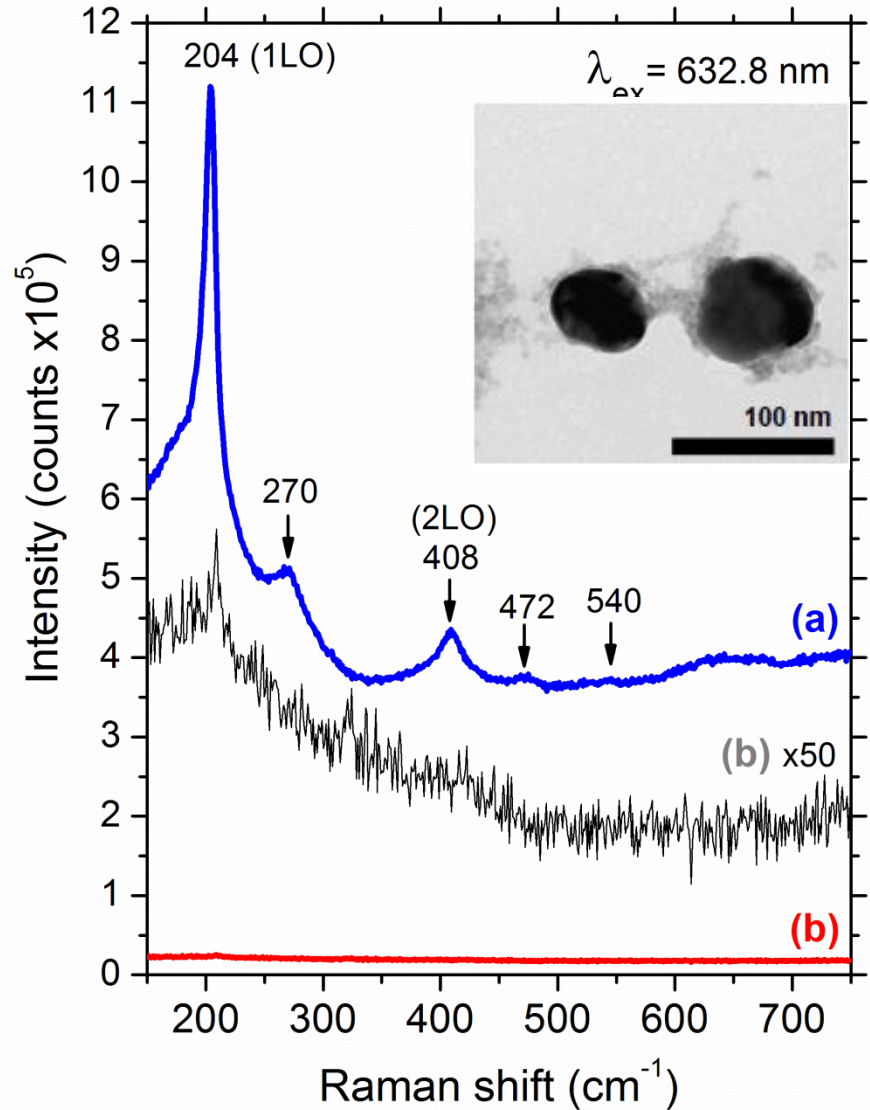
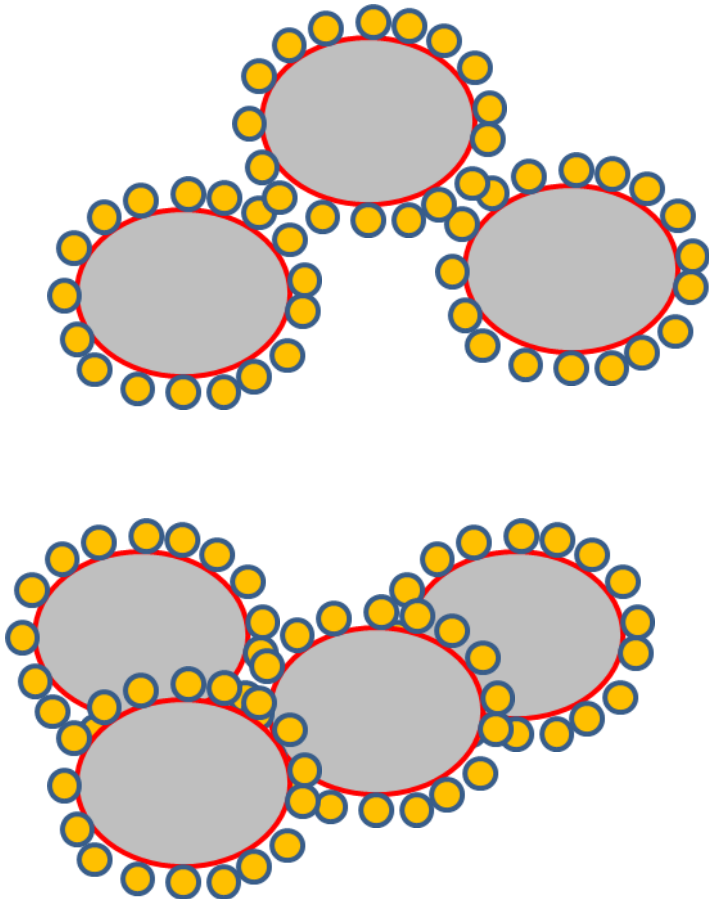
Nano-hybrid particles as SERS-based optical biomarkers



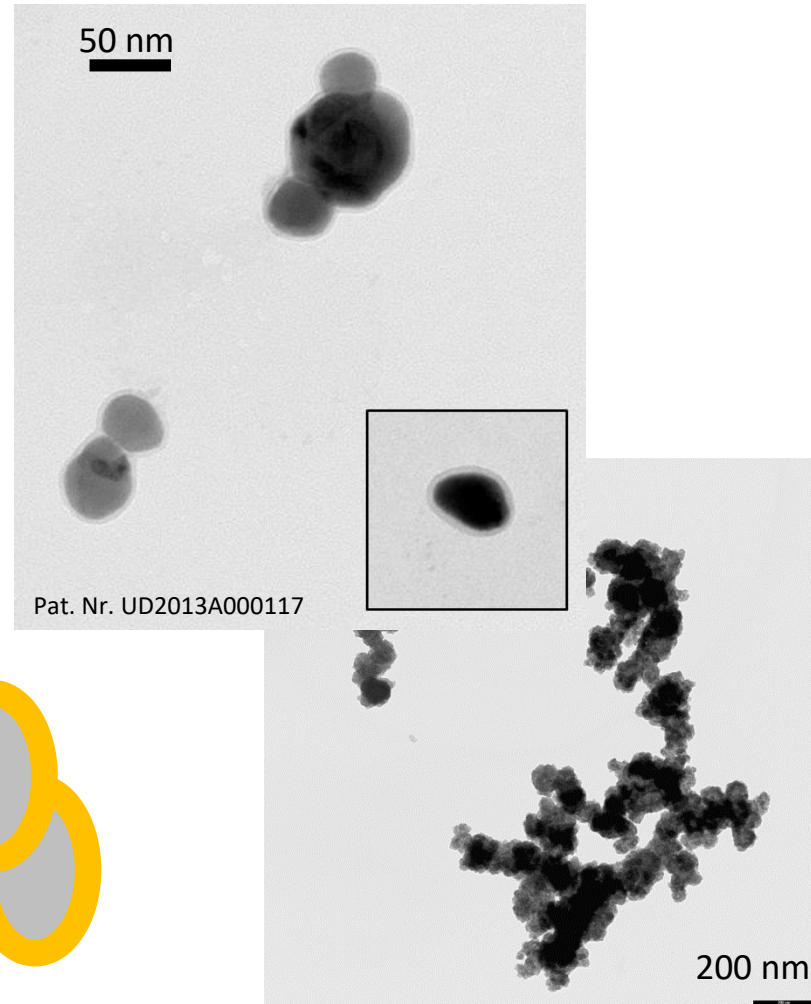
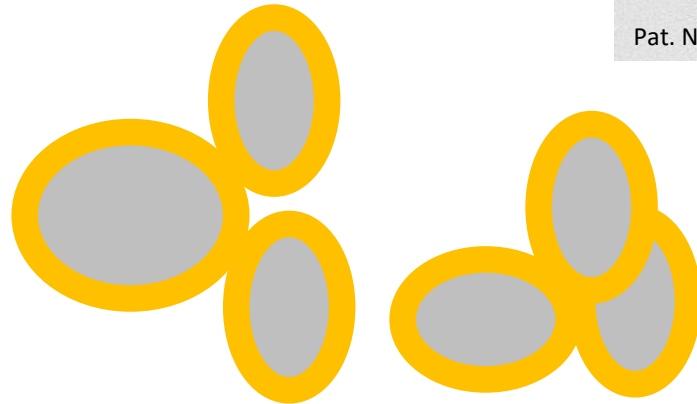
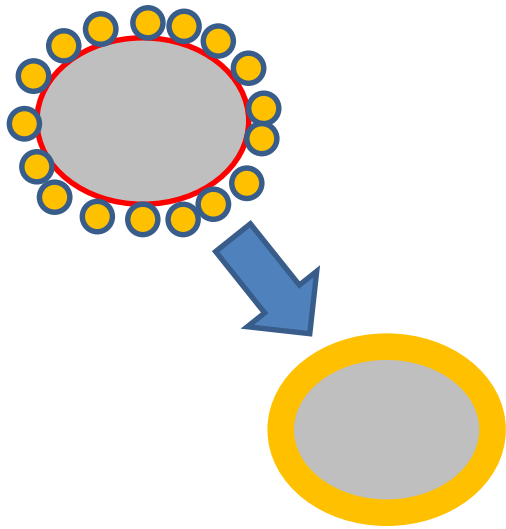
Raman vs Photoluminescence



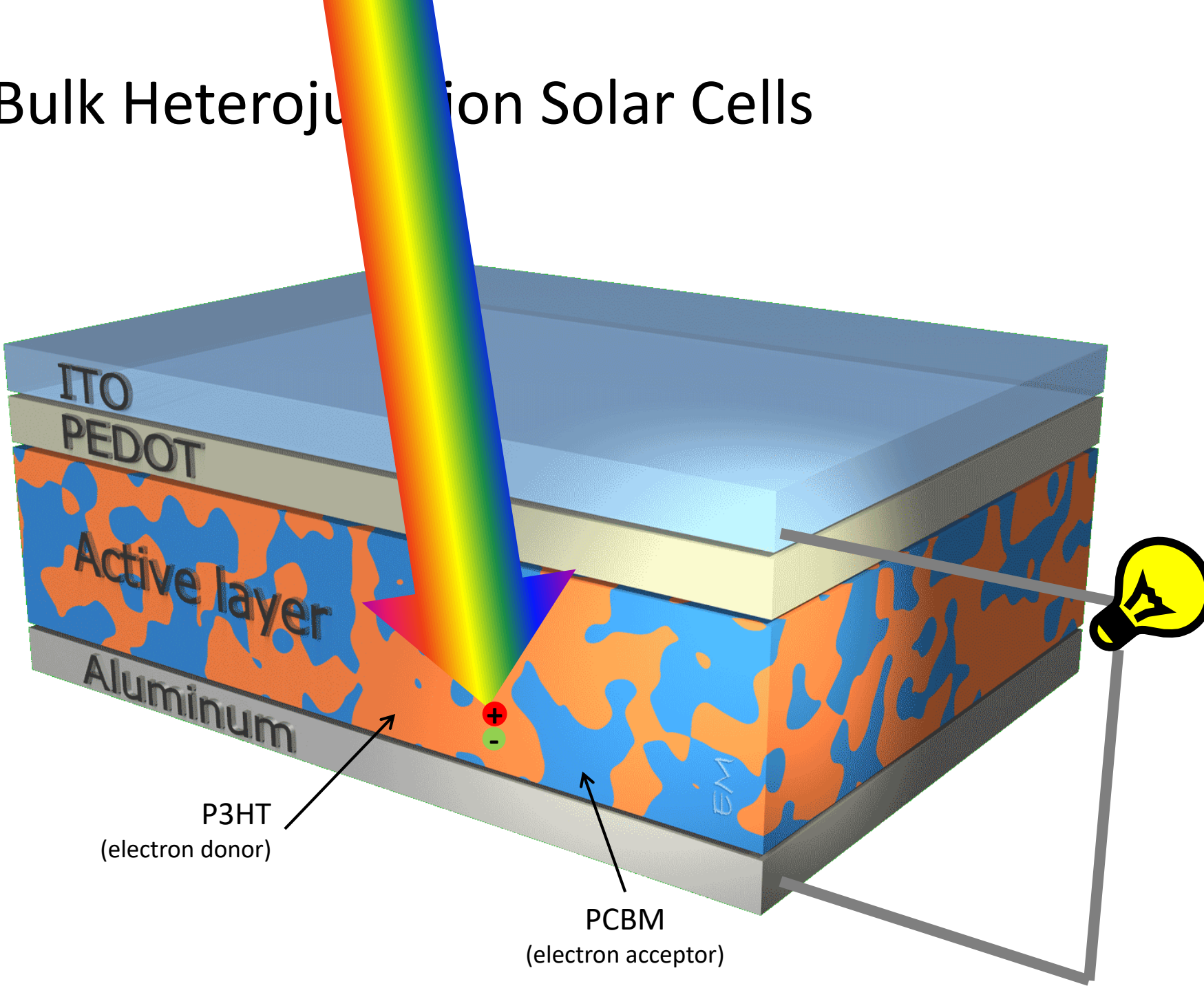
Quantum dot-capped metal nanoparticles



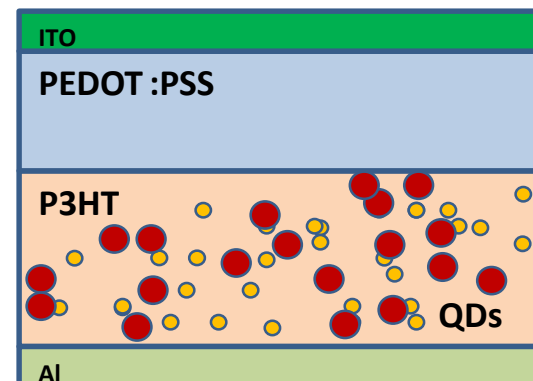
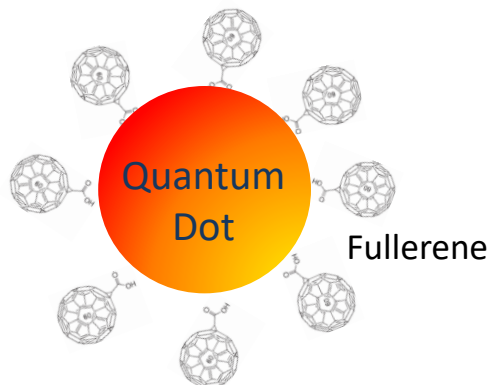
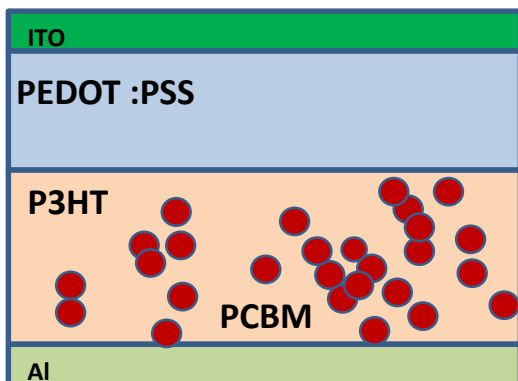
In-situ coated hybrid SERS-active nanoparticles



Bulk Heterojunction Solar Cells



State of the Art and Founding Idea

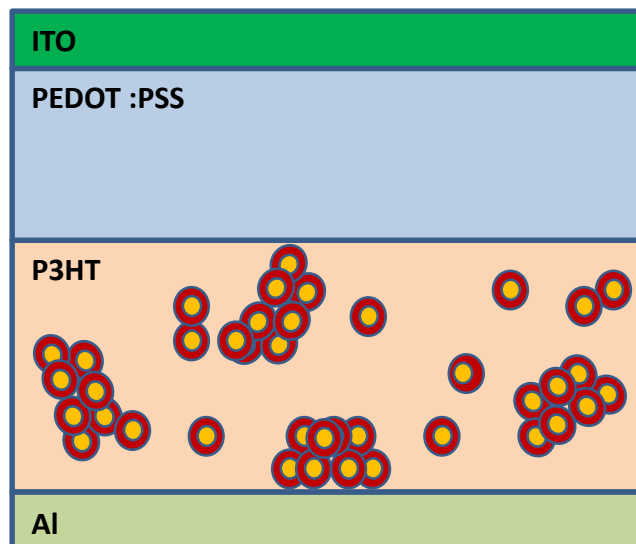


Fullerenes

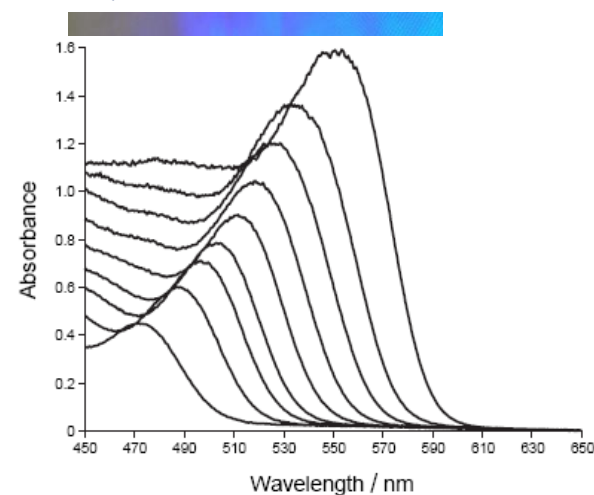
(e.g. PCBM)



TRANSPORT

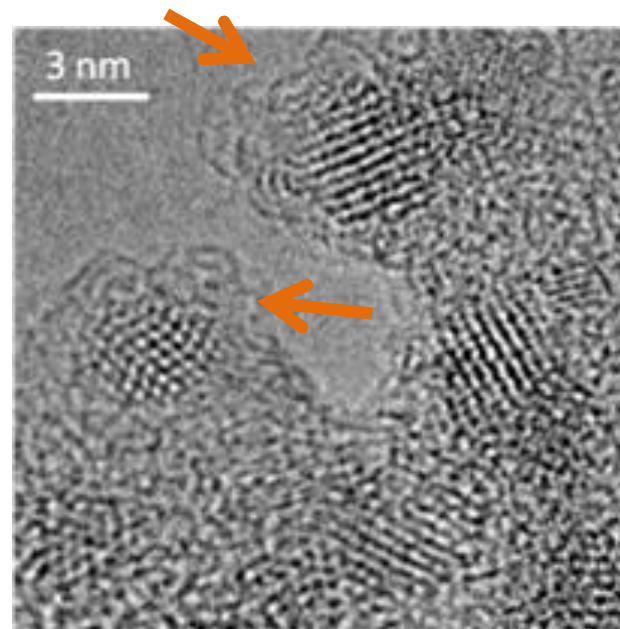
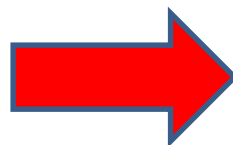
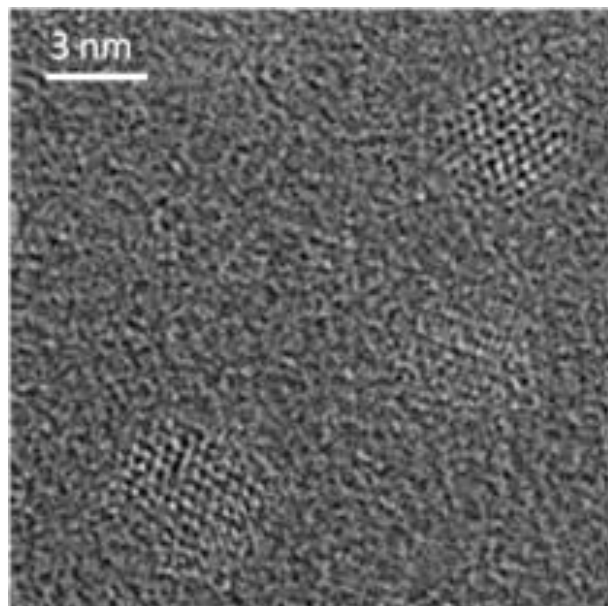
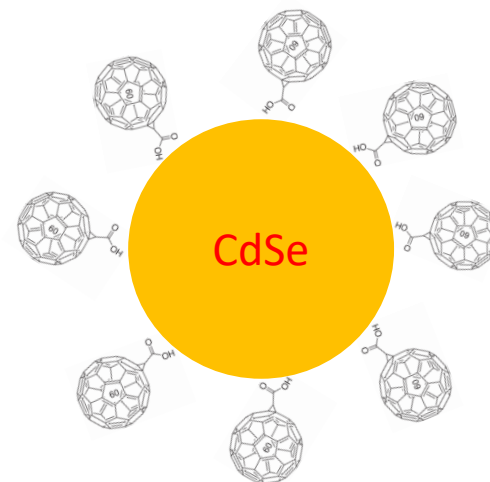
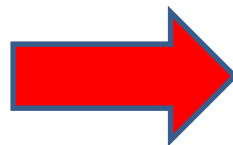
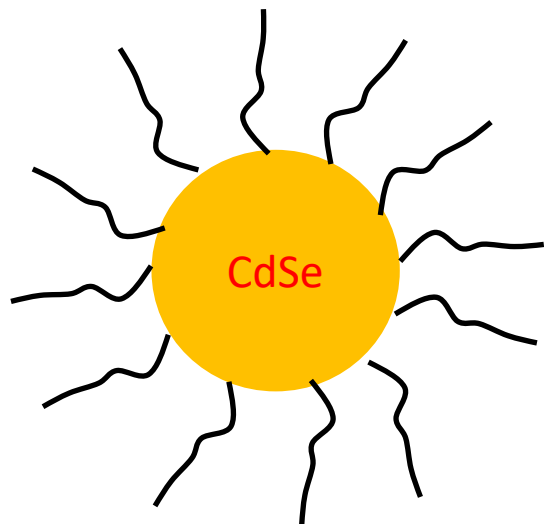


Quantum dots



ABSORBANCE

CdSe@C6: Synthesis via Capping Exchange

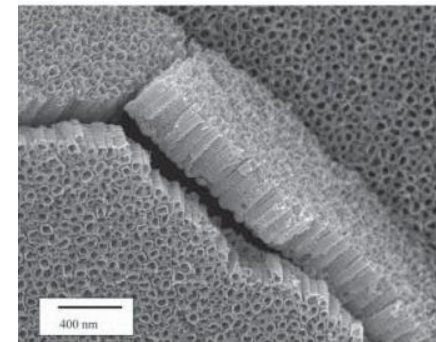
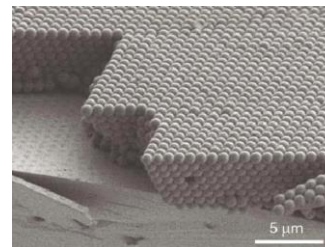
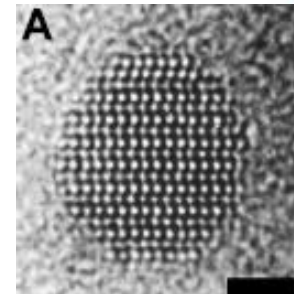
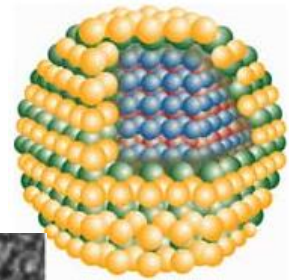


Argomenti del corso (1)

1. Introduzione e contesto:

Cosa sono e perché vogliamo usare materiali nanostrutturati?

- Definizioni
- Esempi di materiali nanostrutturati: quantum dot, nanowire, film sottili, materiali "bulk" nanostrutturati, nanostrutture al carbonio
- Esempi di come cambiano le proprietà alla nanoscala

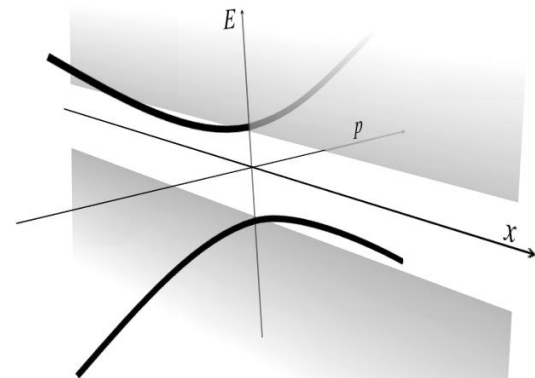


Argomenti del corso (2)

2. Design di materiali nanostrutturati

Fondamentali: stato solido, approfondimenti di fisica e chimica (anche sparsi durante il corso)

- Proprietà alla nanoscala
- Attività seminariale sulla modellazione
- Esempi in cui la nanostruttura determina le proprietà e di come queste possono essere "previste":
 - quantum wells; banda intermedia; nanocompositi; opali artificiali; modificazione dell'energia superficiale mediante nanocoatings; etc.



Argomenti del corso (3)

3. Fabbricazione

- Approcci “bottom-up”:
 - Building blocks (nanocristalli: wells and films, wires, dots; carbon based nanostructures: fullerenes, graphenes, etc.)
 - Proprietà dei building blocks
 - Metodi di fabbricazione (deposizione di film, aerosol, sospensioni colloidali, epitassia controllata, etc.)
 - Assemblaggio (self assembly bioassistito, self assembly via polimeri, eterostrutture, Marangoni, ...)
- Approcci “top-down”
 - Litografia, ball milling, ion implantation, thin film layers + thermal treatment, etc.

5 μm



Argomenti del corso (4)

4. Caratterizzazione

Microscopie (TEM, SEM), spettroscopie, XRD (WAXS e SAXS), Scanning Probe Microscopy (AFM, etc.), nanoindentazione, ...

5. Esempi di applicazioni

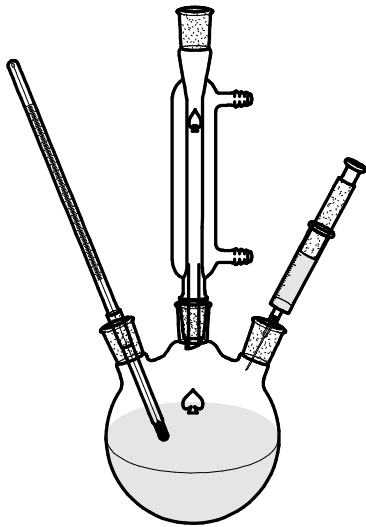
- Materiali fotovoltaici
- Cristalli fotonici (Norris' inverse opal)
- Nanocompositi
- Ibridi
- Sensori
- ...



Argomenti del corso (5)

6. Attività di laboratorio

- Sintesi colloidale di nanocristalli
- Litografia



Take-home message

- Know what the course is about and the “instructions for use”
- Know how you will be evaluated

Homework #1

Identify «hot topics» in the nanoworld. Classify them according to: societal challenges, key enabling technologies, applications

Societal Challenges:

- **Health and Wellbeing**
- **Secure, green, efficient energy**
- **Food and Waste**

Key Enabling Technologies

- Micro- and nanoelectronics
- Advanced Materials and Advanced Manufacturing
- Photonics
- Biotechnology (industrial)