Introduction to Nano-Science and Technology (Emphasis on Nanostructured Materials)

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Background Figure from Helmut Goesmann, Claus Feldmann, *Angew. Chem., Int. Ed.* **2010**, *49*, 1362-1395.

What is Nanotechnology?

Fabrication and Manipulation of Nanostructures

"a future in which the ability to understand and control matter at the nanoscale leads to a revolution in technology and industry that benefits society."

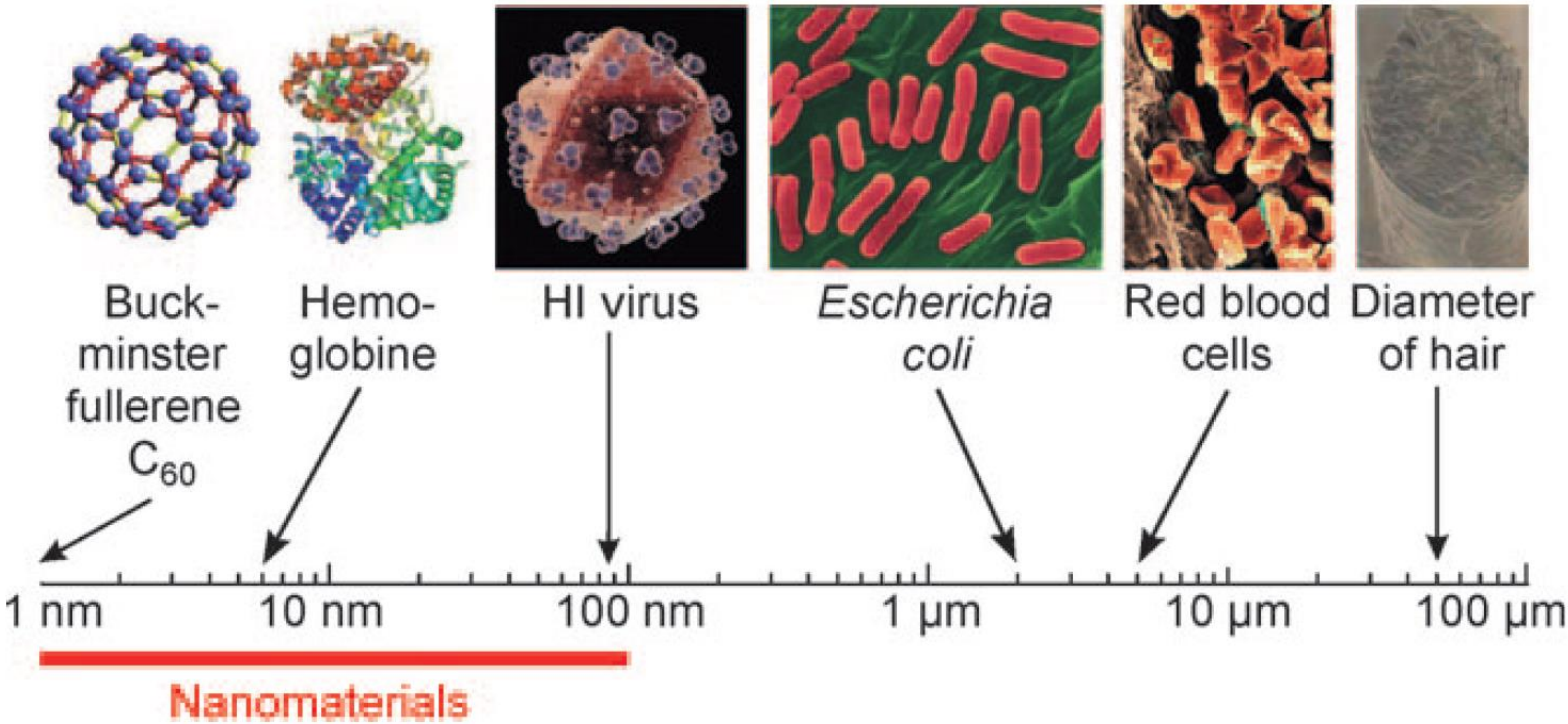
Size of water: 0.28 nm; Au: 0.27

National Nanotechnology Initiative (NNI) in U. S. A.:

"nanotechnology is the understanding and control of matter at dimensions between approximately 1 and 100 nm, where unique phenomena enable novel applications."

nanometer, nm

- **1/5000 of Hair string diameter**
- **3~4 Au atoms in a raw**
- **Typical proteins: 1 ~ 20 nm**



Helmut Goesmann, Claus Feldmann, *Angew. Chem., Int. Ed.* **2010**, *49*, 1362-1395.

History: Richard Feynman, 1959

- "There's Plenty of Room at the Bottom"
- "The problems in chemistry and biology can be greatly helped if our ability to see what we are doing, and do thing on an atomic level, is ultimately developed – a development which I think cannot be avoided."
- Making, manipulating, visualizing and controlling things on small scale the way they want

What are Nanostructured Materials?

• Materials with dimension of nanometer size (1 ~ 50 nm)

• Novel physical and chemical properties compared to bulk

- Properties in between Molecules and Bulk materials

• Nanophase, Nanoscale, Nanocrystal, Nanocluster

Why are Nanostructured Materials so important?

1. Novel electronic, optical, magnetic, chemical, catalytic, and mechanical properties: different from bulk materials

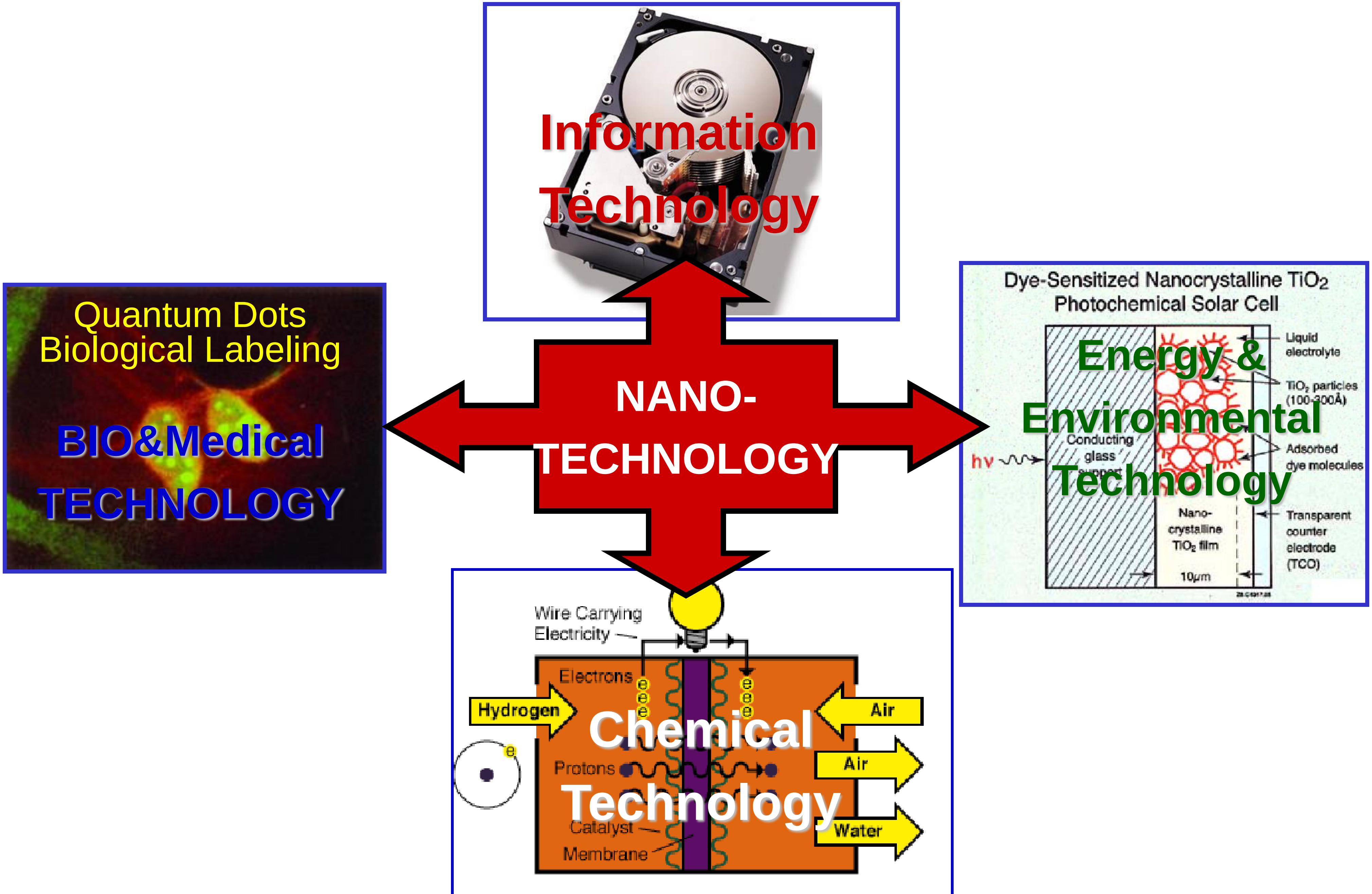
- High surface to volume ratio: high defect sites, surface property dominant, catalysis, battery electrodes
- Quantum size effect: semiconductors (quantum dots)

2. Properties in between Molecules and Bulk materials: where is the borderline?

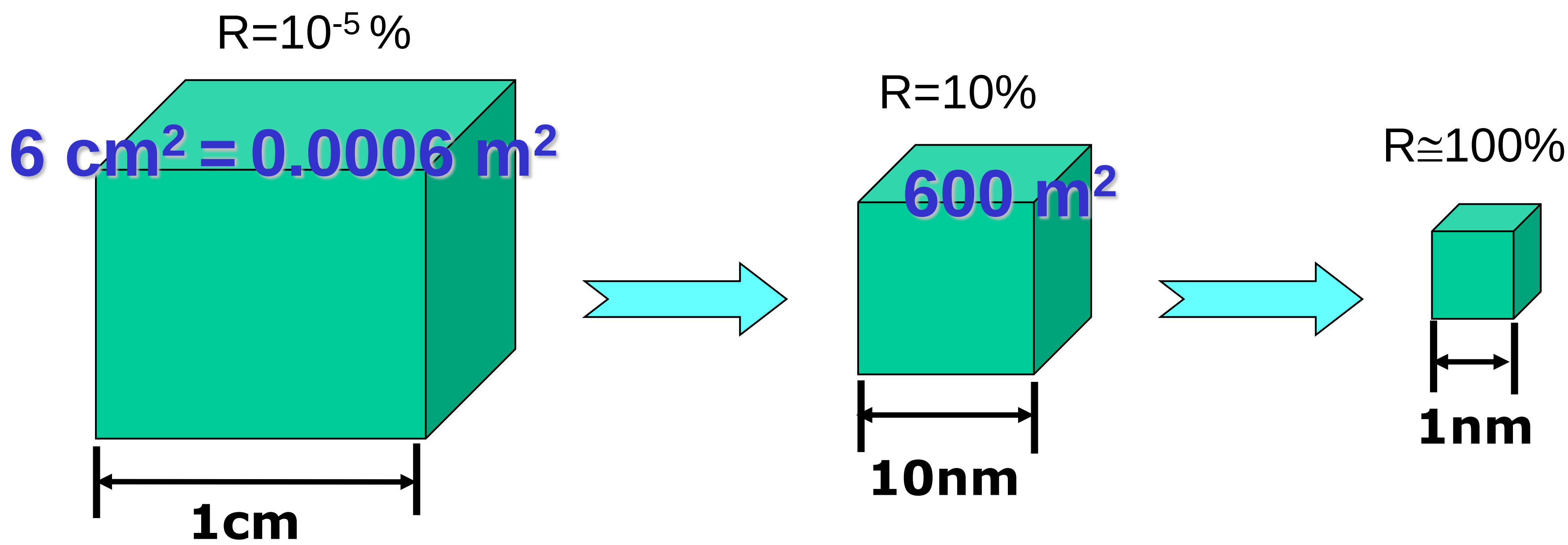
3. Applications to Various Technologies including IT, BT, Medicine, Energy and Environment

→ Nanoscience and Nanotechnology is interdisciplinary and multidisciplinary Research.

Nanotechnology is Basic Technnology for IT, BT, and ET



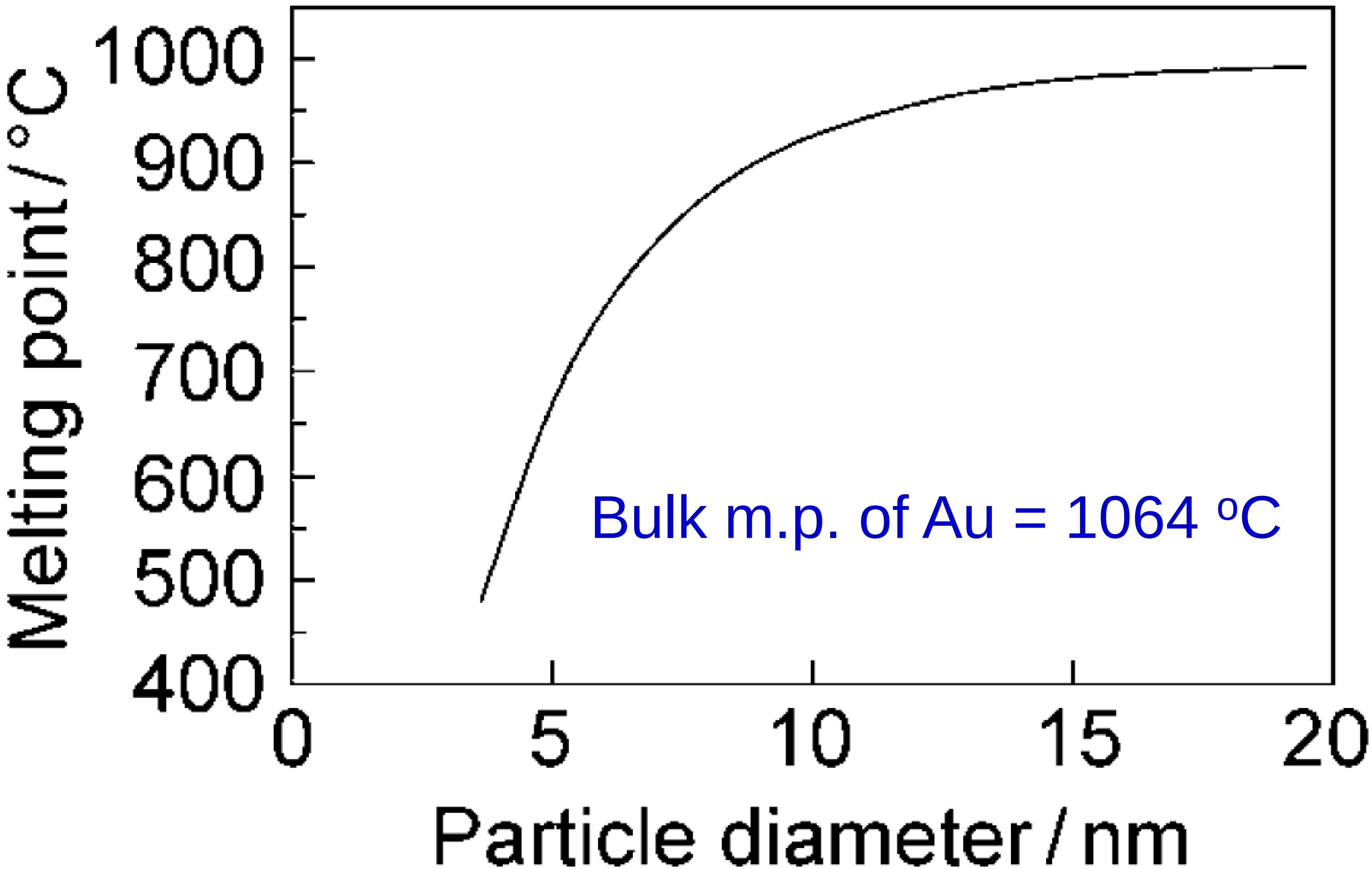
High surface to volume ratio



A dramatic Increase in the ratio of surface atoms to interior atoms in nanostructures and nanomaterials.

Great changes in the physical and chemical properties: Important for Catalysis, Solar cells, and Fuel cells.

Melting point of Au Nanoparticles vs. Diameter



Helmut Goesmann, Claus Feldmann, *Angew. Chem., Int. Ed.* **2010**, *49*, 1362-1395.

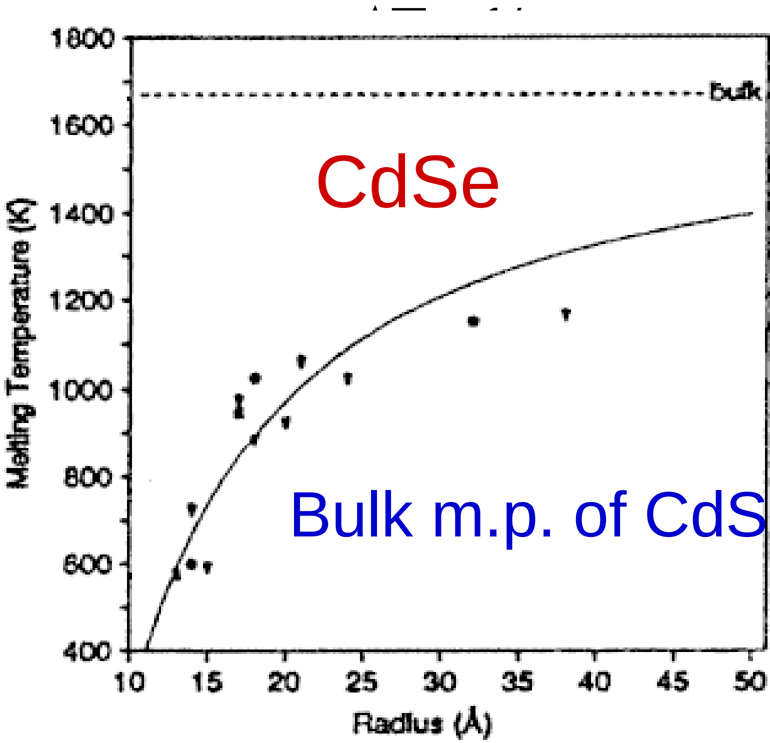
Melting temp. & optical property as a function of size

Melting points of nanocrystals decrease significantly

Absorption spectra of CdSe nanocrystals cover full visible range by varying particle size

Melting Temp as a function of Size

Optical Property as a function of Size

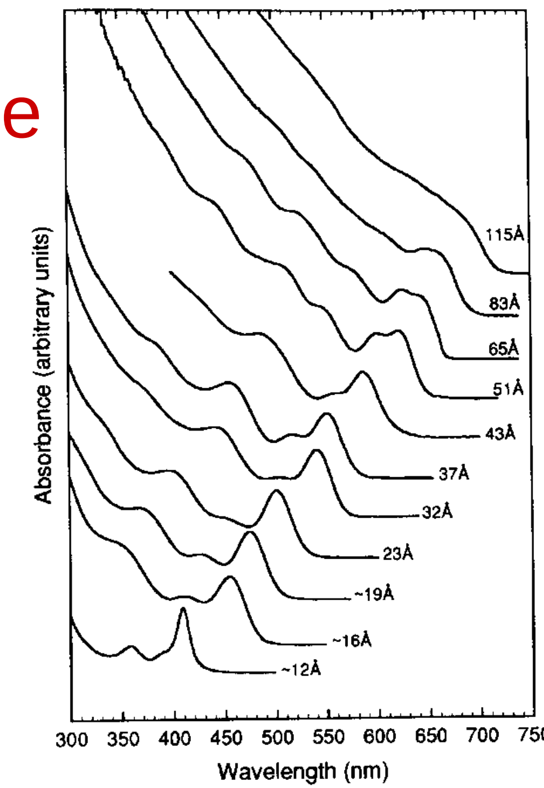


CdSe

Bulk m.p. of CdSe = 1268 ^{o}C

A. P. Alivisatos *et al., J. Phys. Chem.* **1996**, 100, 13226.

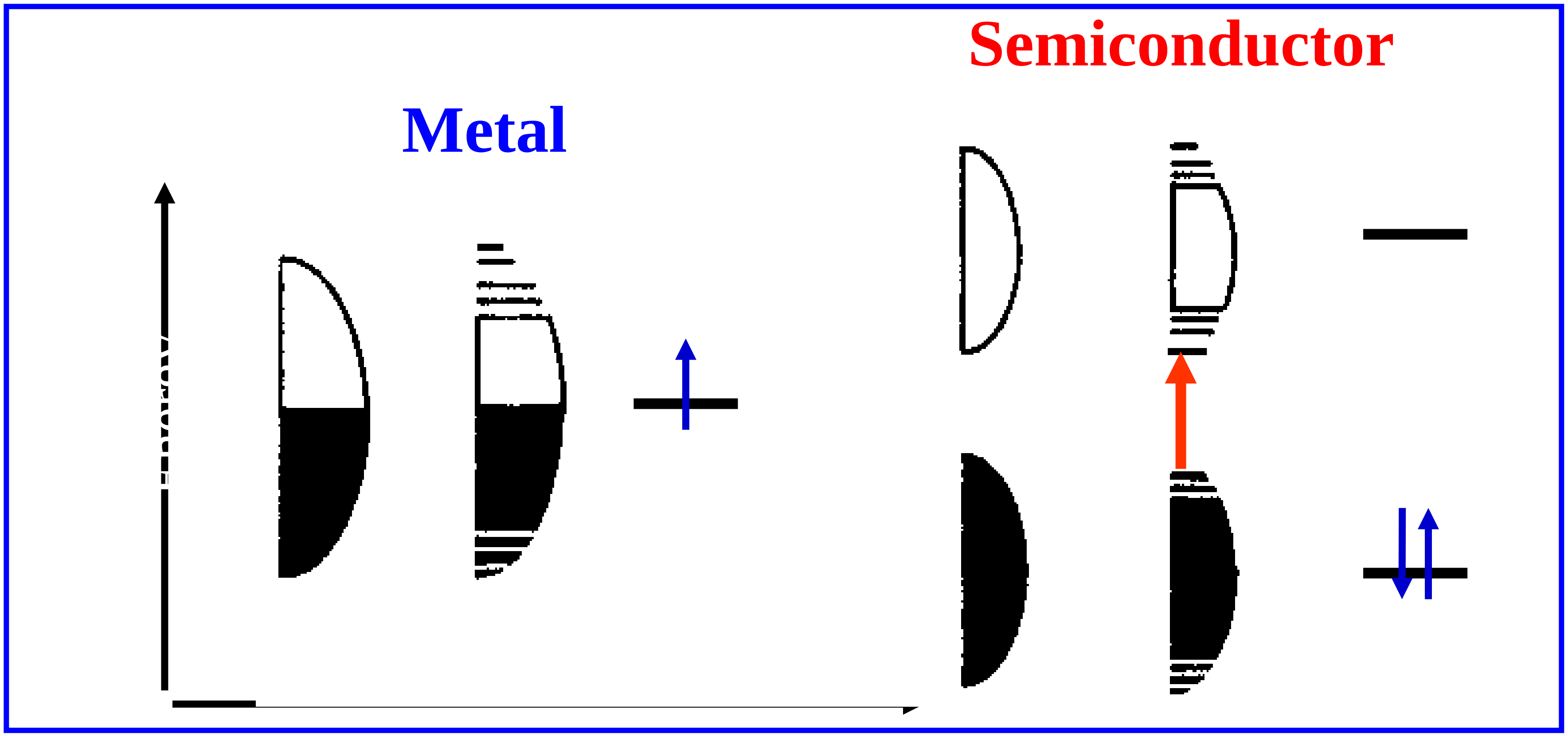
CdSe



Bawendi, M. G. *J. Am. Chem. Soc*. **1993**, 115, 8706.

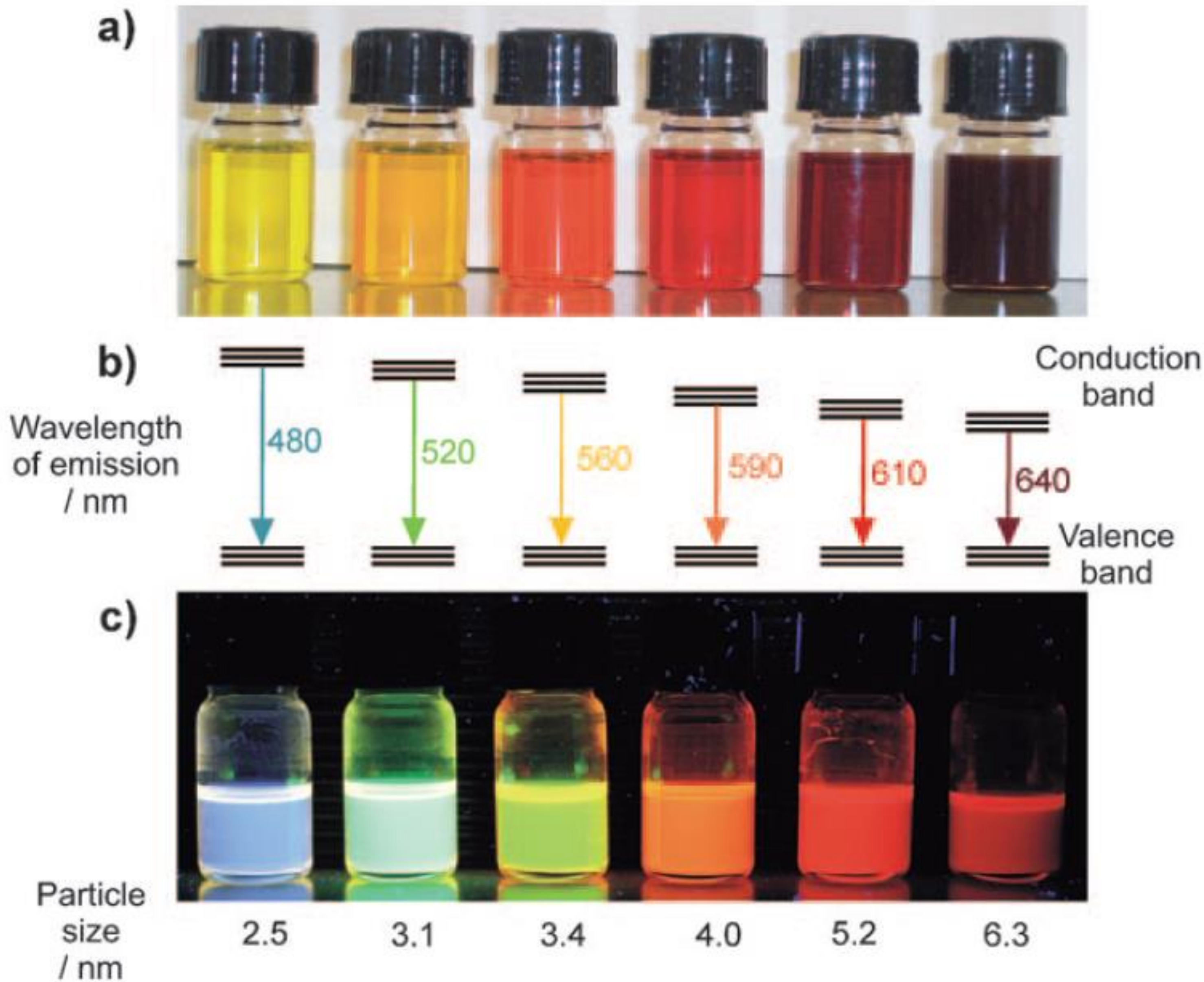
Band Gap Tuning in Semiconductor Nanocrystals

- Bandgap of Semiconductor nanocrystals (also known as quantum dots) can be tuned by varying the diameter of nanocrystals. For example, the bandgap of CdSe nanocrystals can be tuned from 4.5 eV to bulk value of 1.73 eV.



Alivisatos, A. P. *Science* **1996**, 271, 933

CdSe semiconductor Quantum Dots

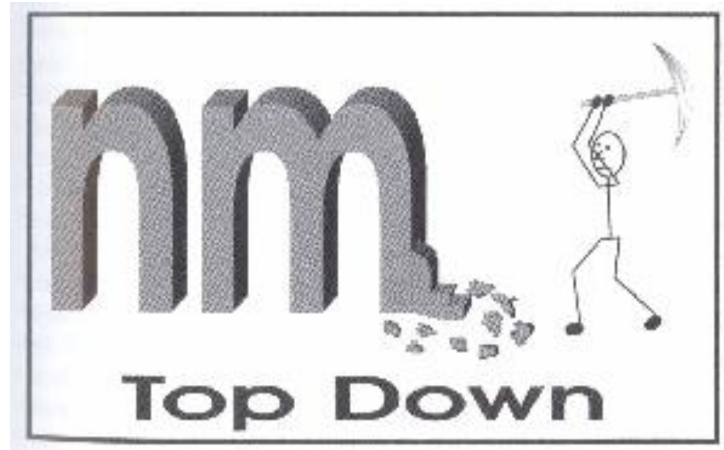


Helmut Goesmann, Claus Feldmann, *Angew. Chem., Int. Ed.* **2010**, *49*, 1362-1395.

Synthesis of Nanostructured Materials

Physical Methods (Top-Down)

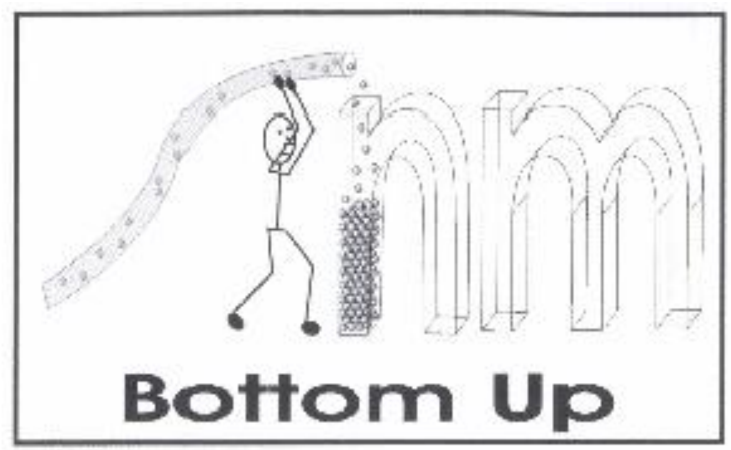
- Gas Condensation
- Spray Pyrolysis
- Ball milling



Chemical Methods (Bottom-up)

- **Colloidal chemical synthesis**

- Reduction of Metal Salts
- Thermal decomposition
- Nonhydrolytic sol-gel Process



G.A. Ozin, *Adv. Mater.* **1992**, 4, 612-649.

Two approaches to synthesize nanomaterials

- Top-down approach: Physical methods
  - production of a large quantity
  - synthesis of uniform-sized nanocrystals and their size-control is very difficult
- Bottom-up approach: solution-phase colloidal chemistry

  - Synthesis of uniform nanocrystals with a controlled particle size

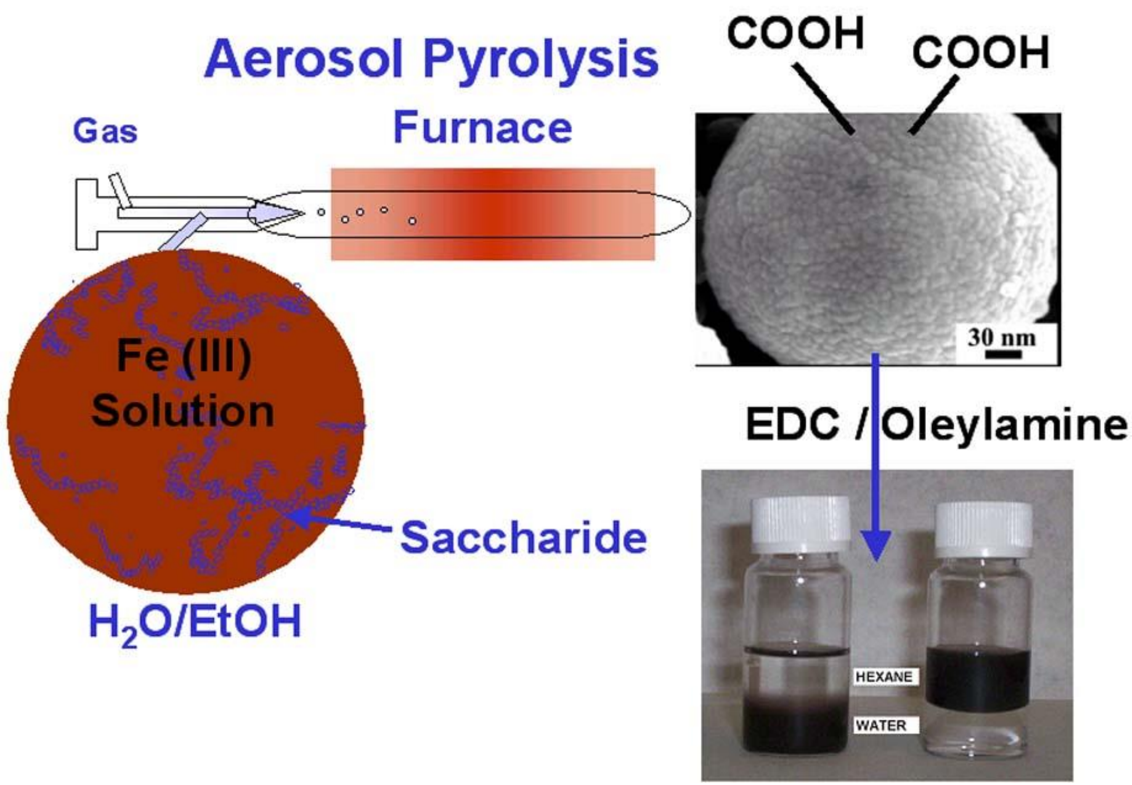
  - sub-gram quantities are generally produced

  - various shaped nanocrystals

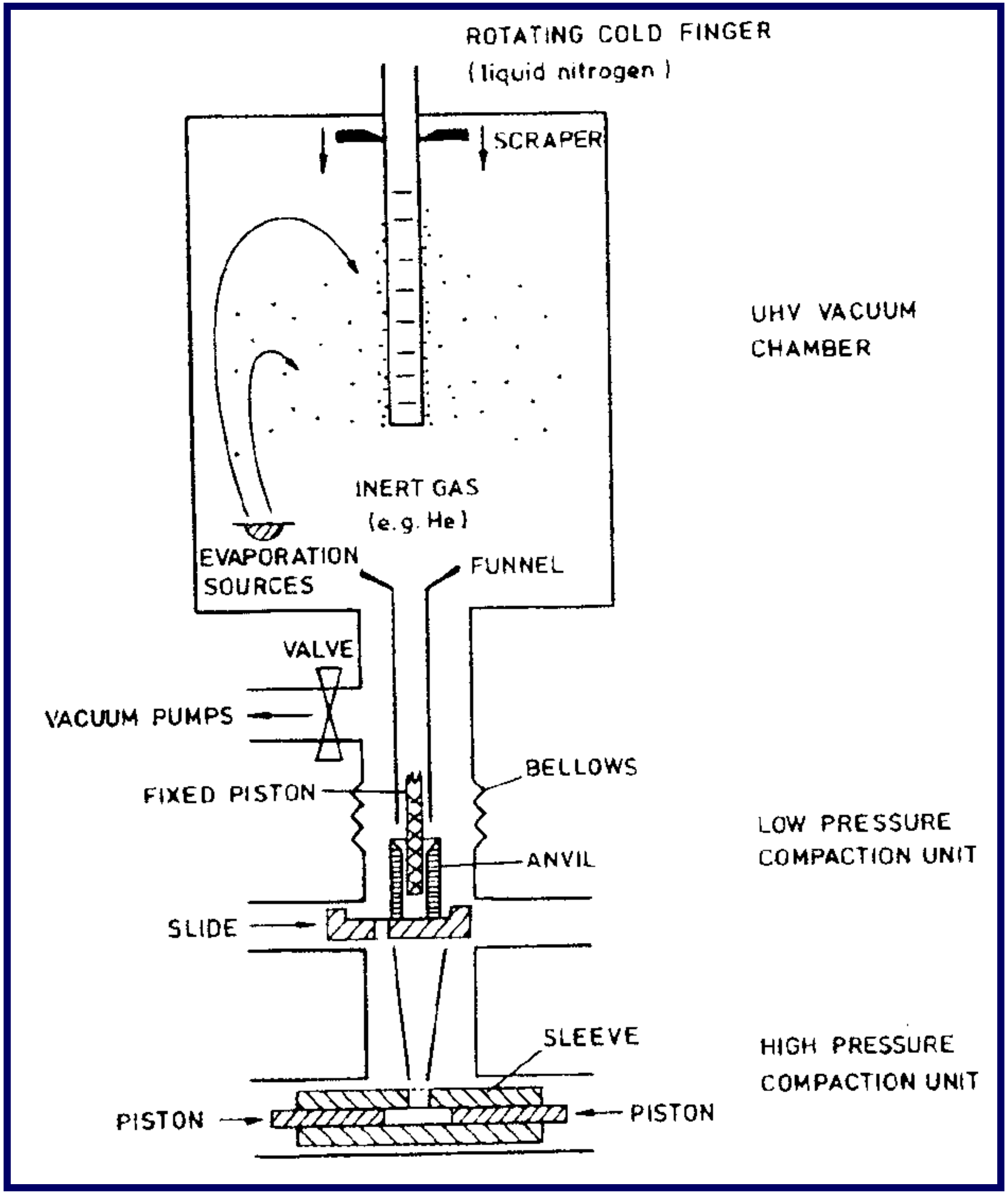
  - thermal decomposition, reduction, and nonhydrolytic sol-gel process

Top-Down Approach: Physical Methods

- Evaporation and condensation
- Various aerosol processing techniques: combustion flame, laser ablation, spray pyrolysis, chemical vapor condensation



Vapor Condensation Method



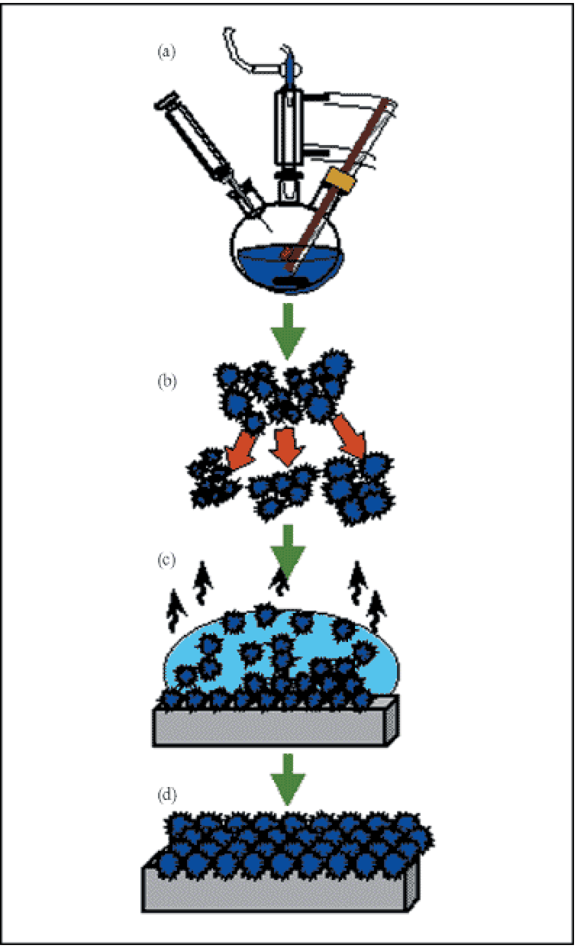
Gleiter, H.
Adv. Mater. **1992**, 4, 474

Flame Spray Pyrolysis (ETH)

HMDSO/EtOH spray flame producing 300 g/h of silica.

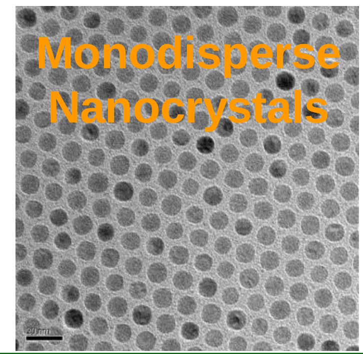
Kammler, H. K., Mädler, L., and Pratsinis, S. E., "Flame synthesis of nanoparticles, " *Chem. Eng. Technol.*, **24** (6), 583-596 (2001).

Bottom-up process: Chemical Methods



Metal Chloride + Na-Oleate → Metal-Oleate Complex + NaCl

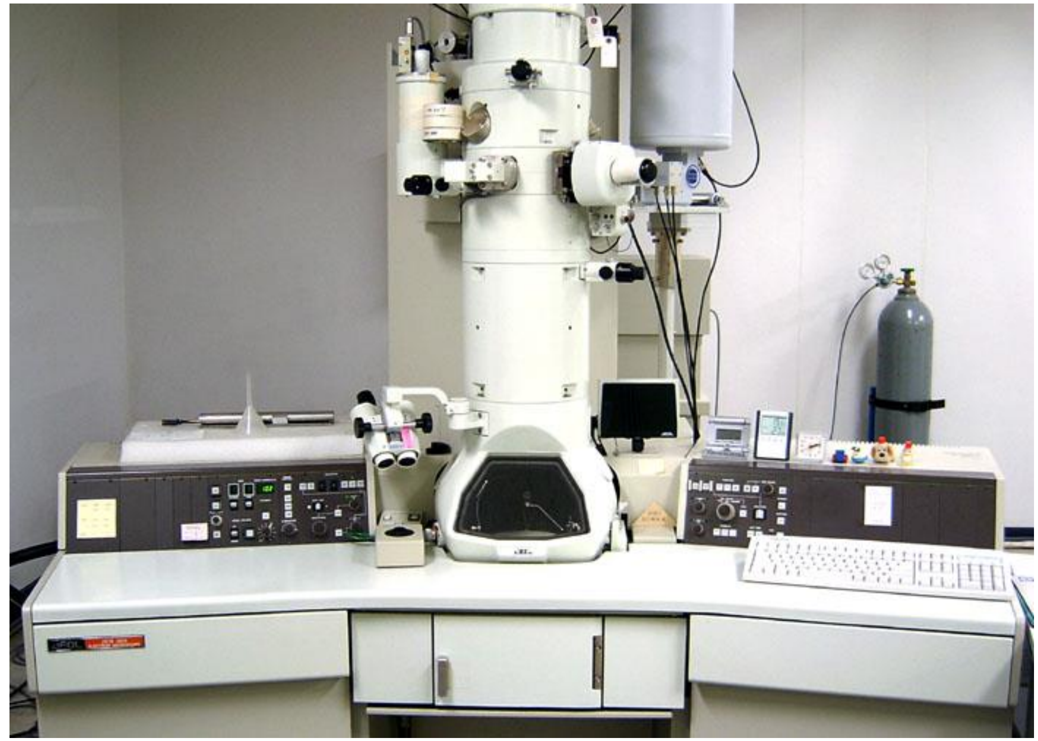
Metal-Oleate Complex → (Thermal decomposition in high boiling solvent)



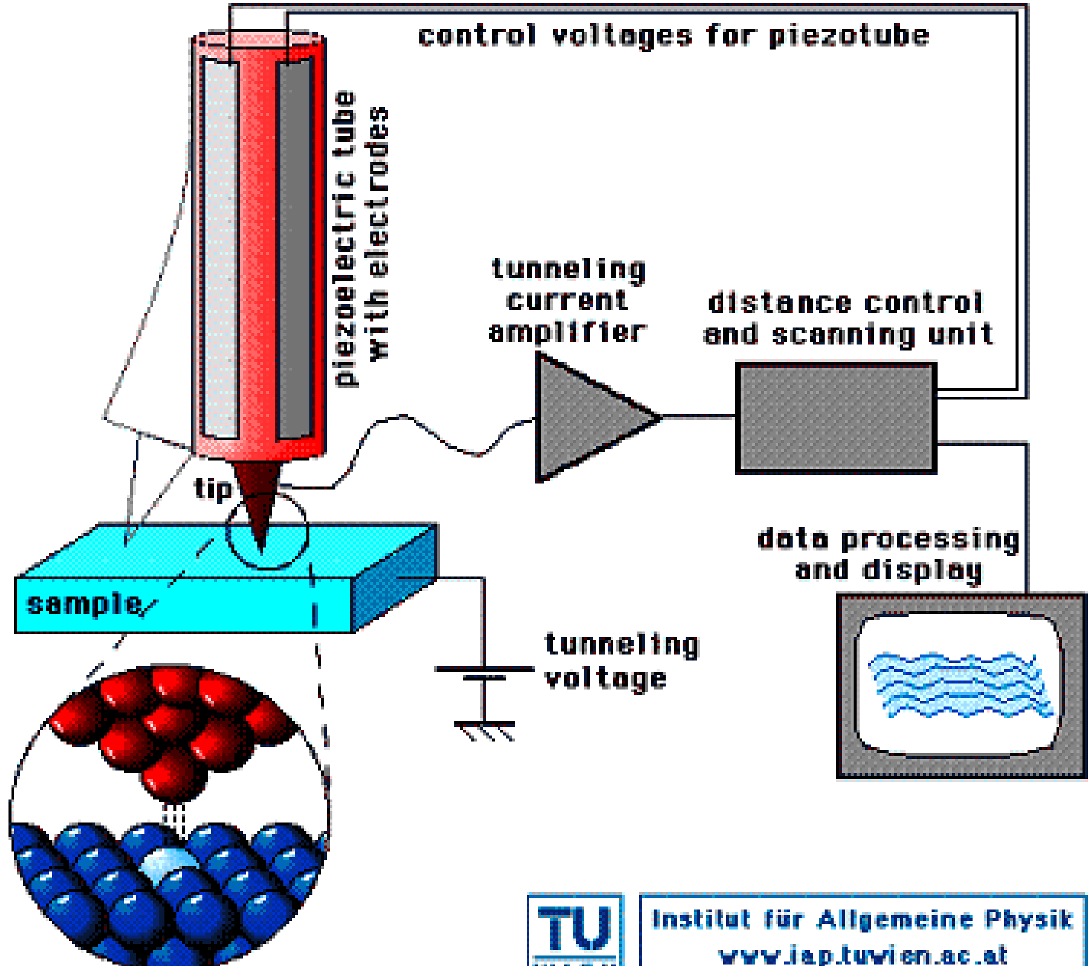
J. Park *et al.*, *Nature Mater*. **2004**, 3, 891.

Nano-Scale Measurement And Manipulation

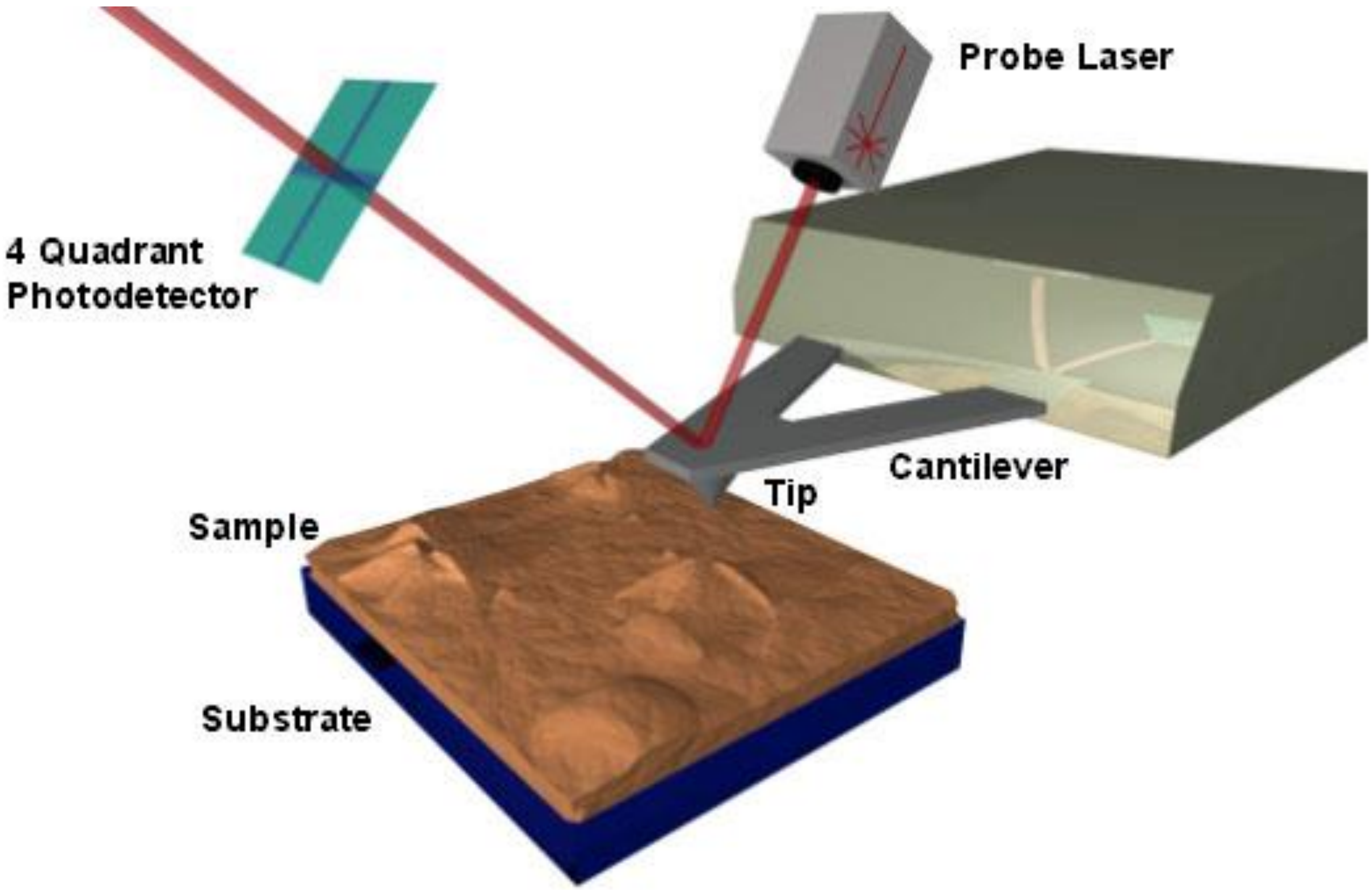
Transmission Electron Microscope (TEM)



Scanning Probe Microscope



Scanning Tunneling Microscope
Atomic Force Microscope

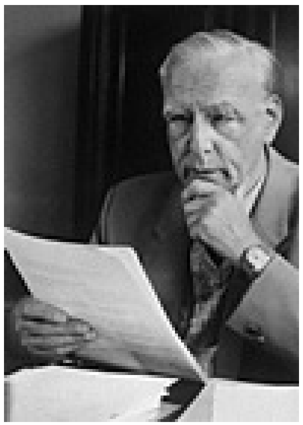


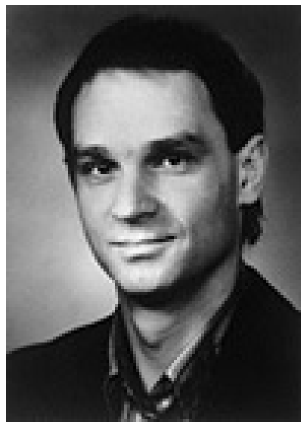
TEM vs. AFM

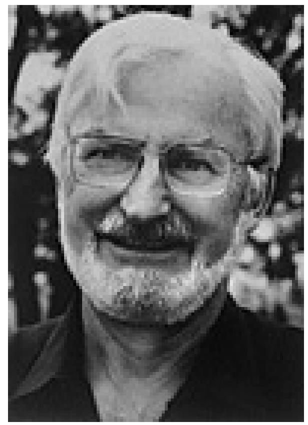
The Nobel Prize in Physics 1986

"for his fundamental work in electron optics, and for the design of the first electron microscope"

"for their design of the scanning tunneling microscope"







Ernst Ruska

1/2 of the prize

Federal Republic of Germany

Fritz-Haber-Institut der Max-Planck-Gesellschaft
Berlin, Federal Republic of Germany

b. 1906
d. 1988

Gerd Binnig

1/4 of the prize

Federal Republic of Germany

IBM Zurich Research Laboratory
Rüschlikon, Switzerland

b. 1947

Heinrich Rohrer

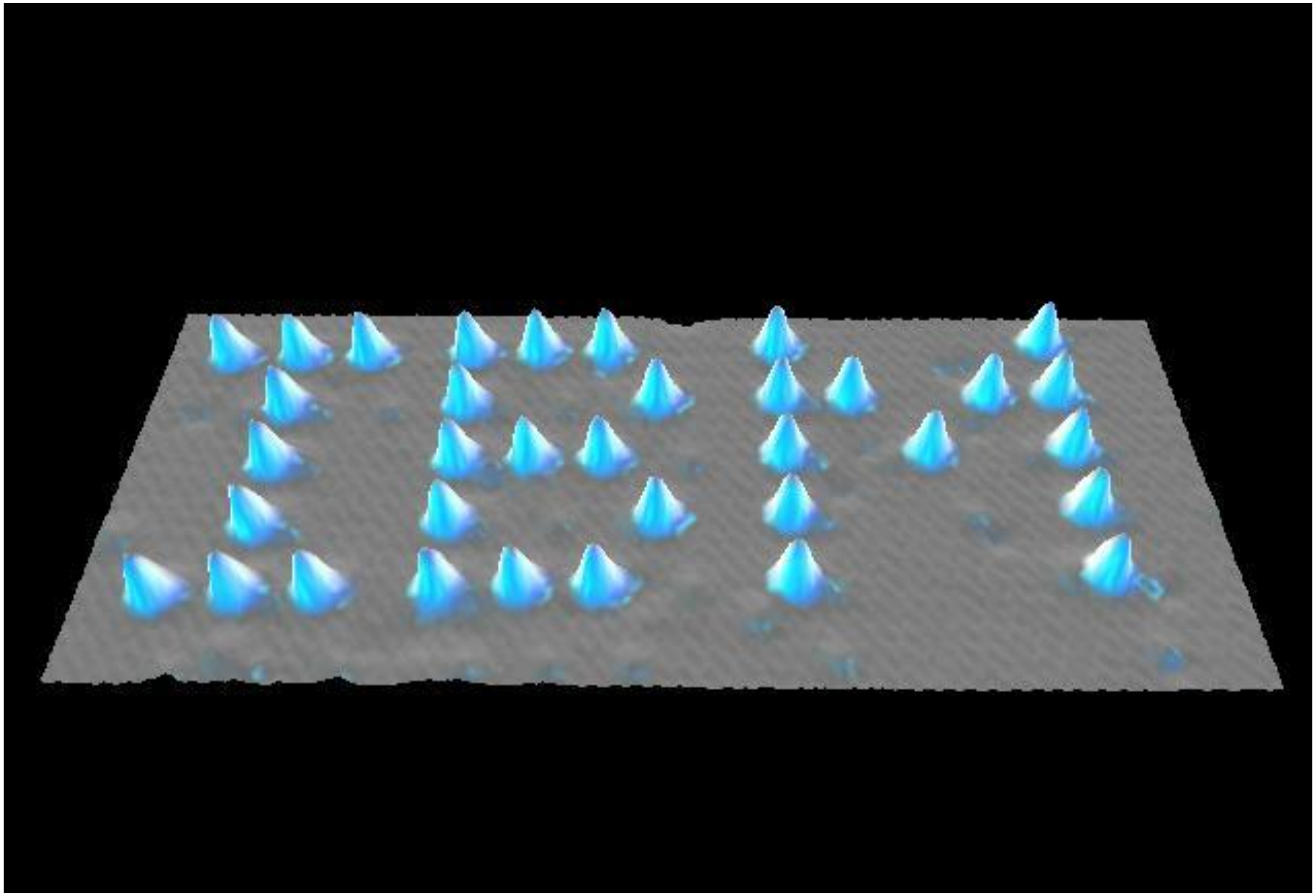
1/4 of the prize

Switzerland

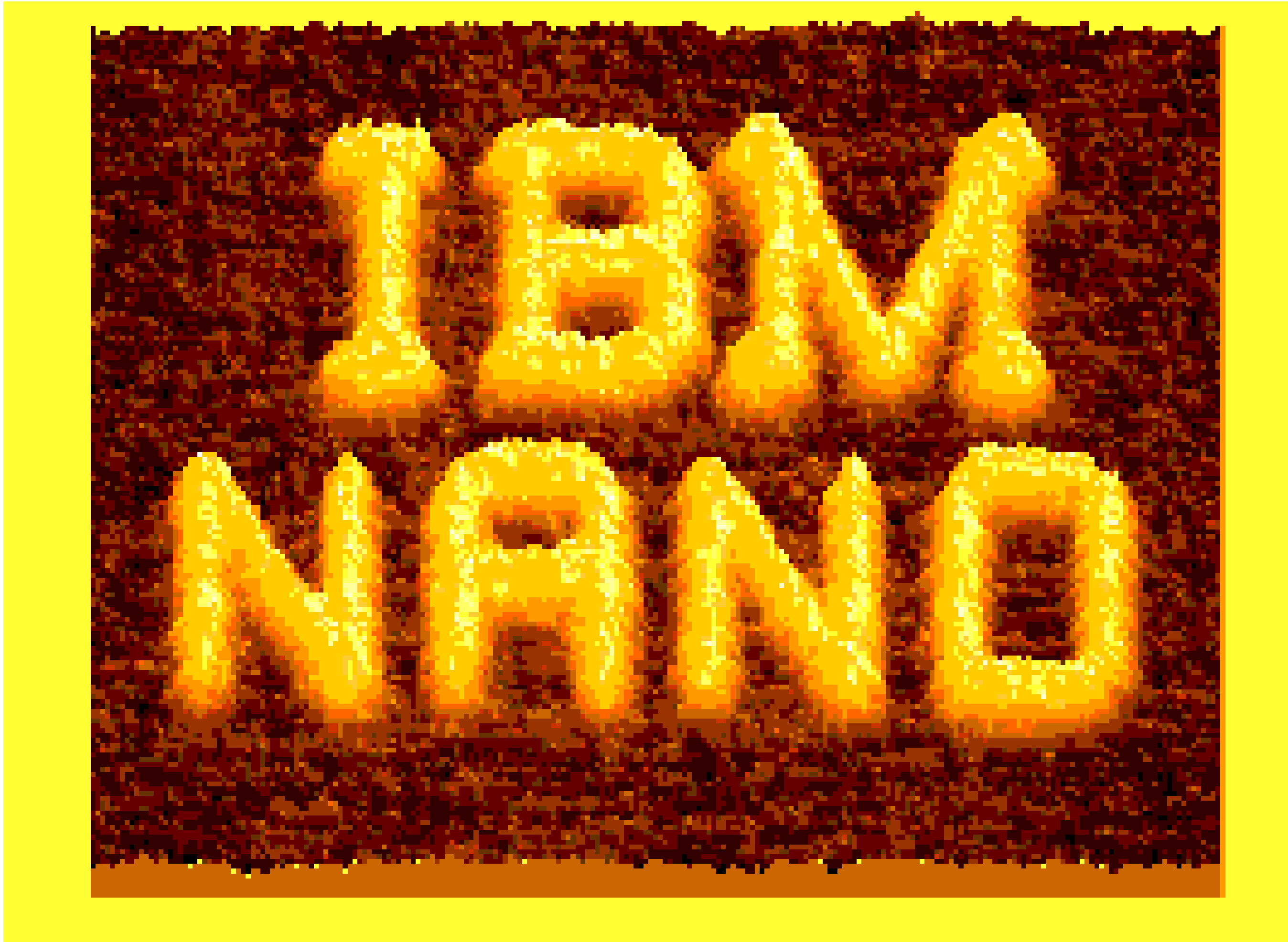
IBM Zurich Research Laboratory
Rüschlikon, Switzerland

b. 1933

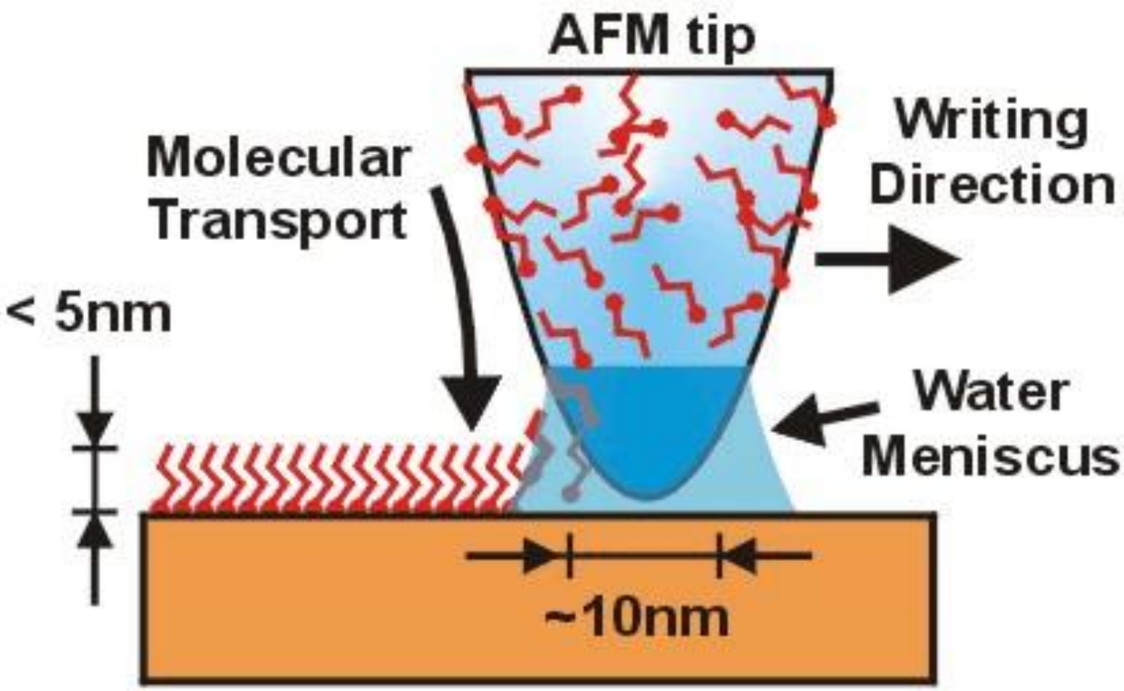
***Title** : The Beginning **Media** : Xenon on Nickel (110)*

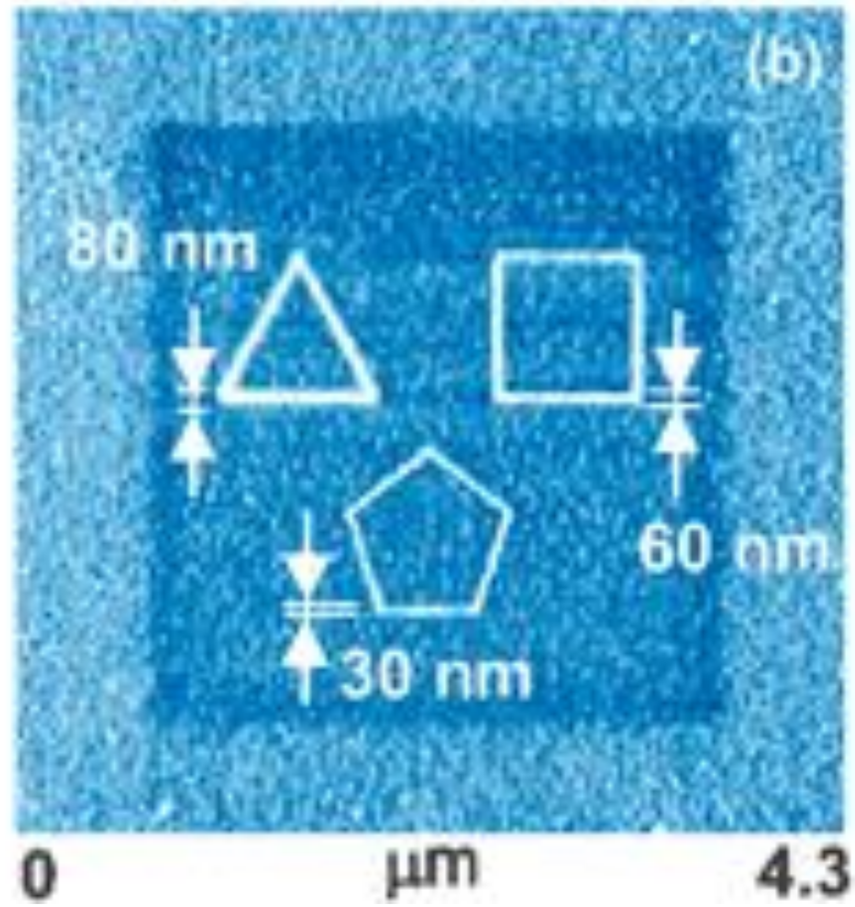


Artists have almost always needed the support of patrons (scientists too!). Here, the artist, shortly after discovering how to move atoms with the STM, found a way to give something back to the corporation which gave him a job when he needed one and provided him with the tools he needed in order to be successful.

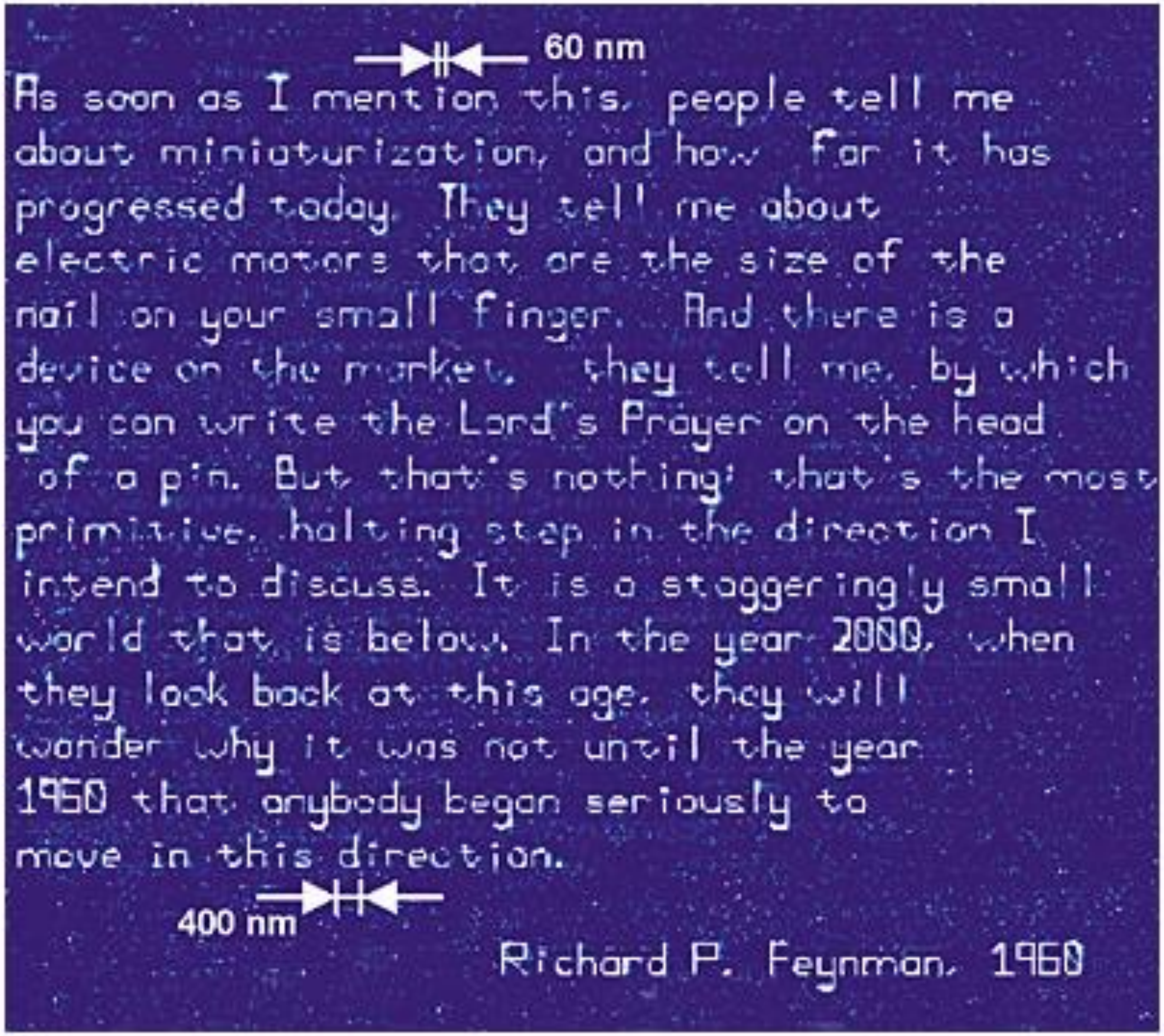


STM and AFM are tools for Nanotechnology



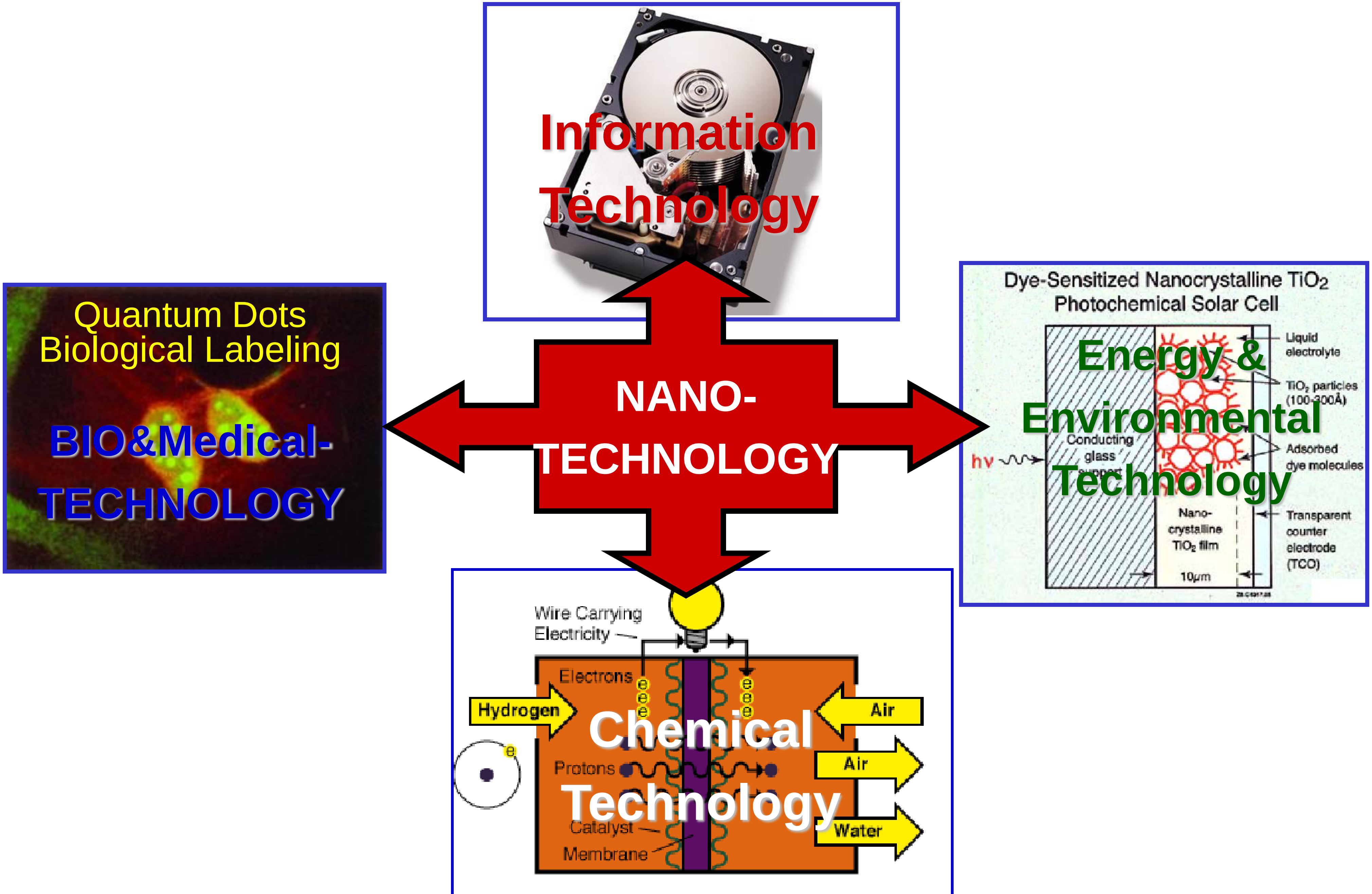


S. H. Hong and Chad Mirkin



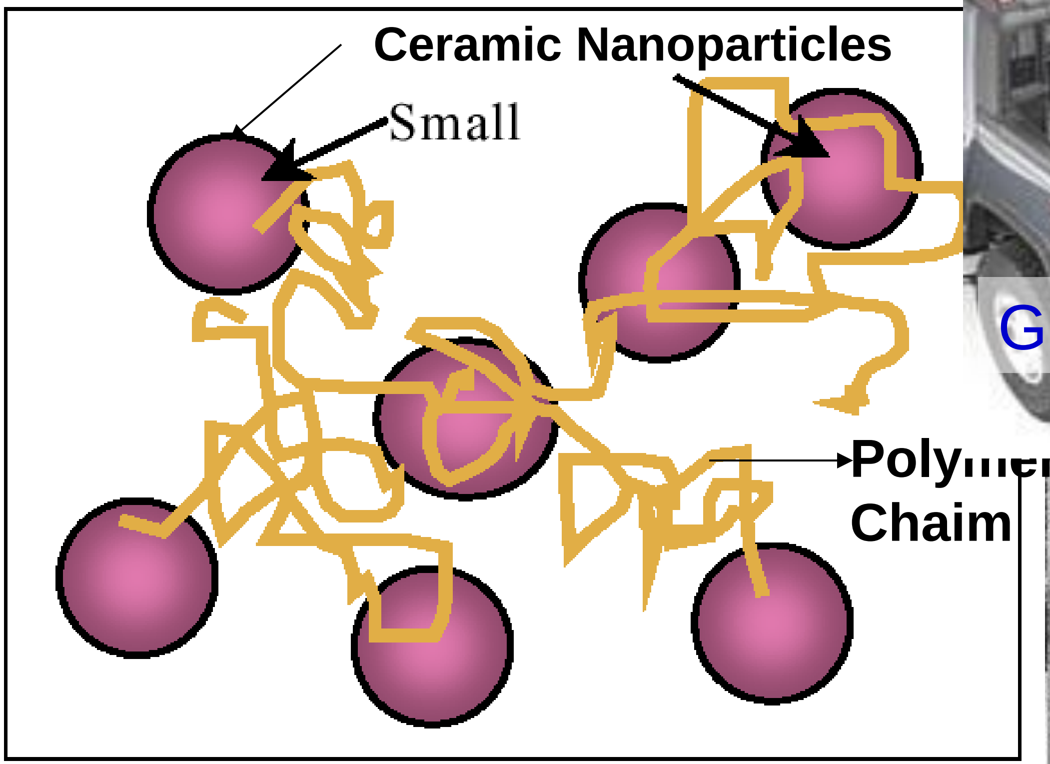
Taking on Feynman's miniaturization challenge, researchers at Northwestern University use an AFM tip to write a paragraph of nanometer-sized letters with a single layer of mercaptohexadecanoic acid on a gold surface. Contrast is enhanced by surrounding each letter with a layer of a second "ink"--octadecanethiol.

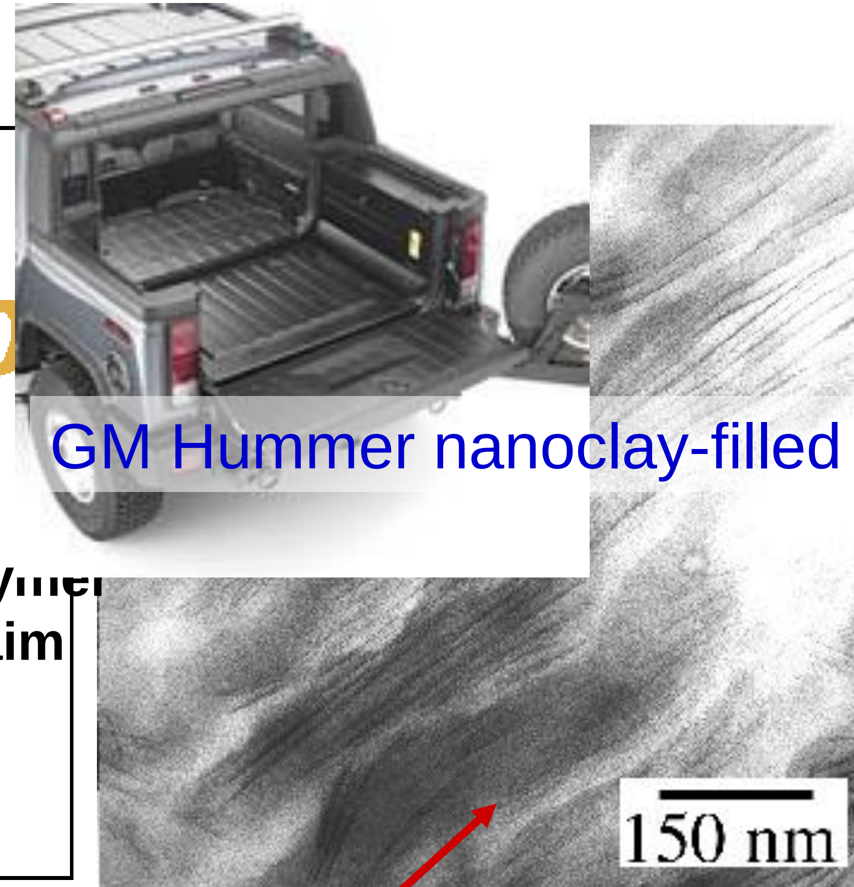
Nanotechnology is Basic Technnology for IT, BT, and ET



Nano-Mechanics

Nano-Concrete: Nanocomposites of Polymer and Ceramics





Polymer intercalated into Montmorillonite clay

3 times lighter but 3 times tougher than steel:
Applications to Auto-parts (bumper and fuel tank)

Nanochemistry

Most-representative (conventional) Nanotechnology

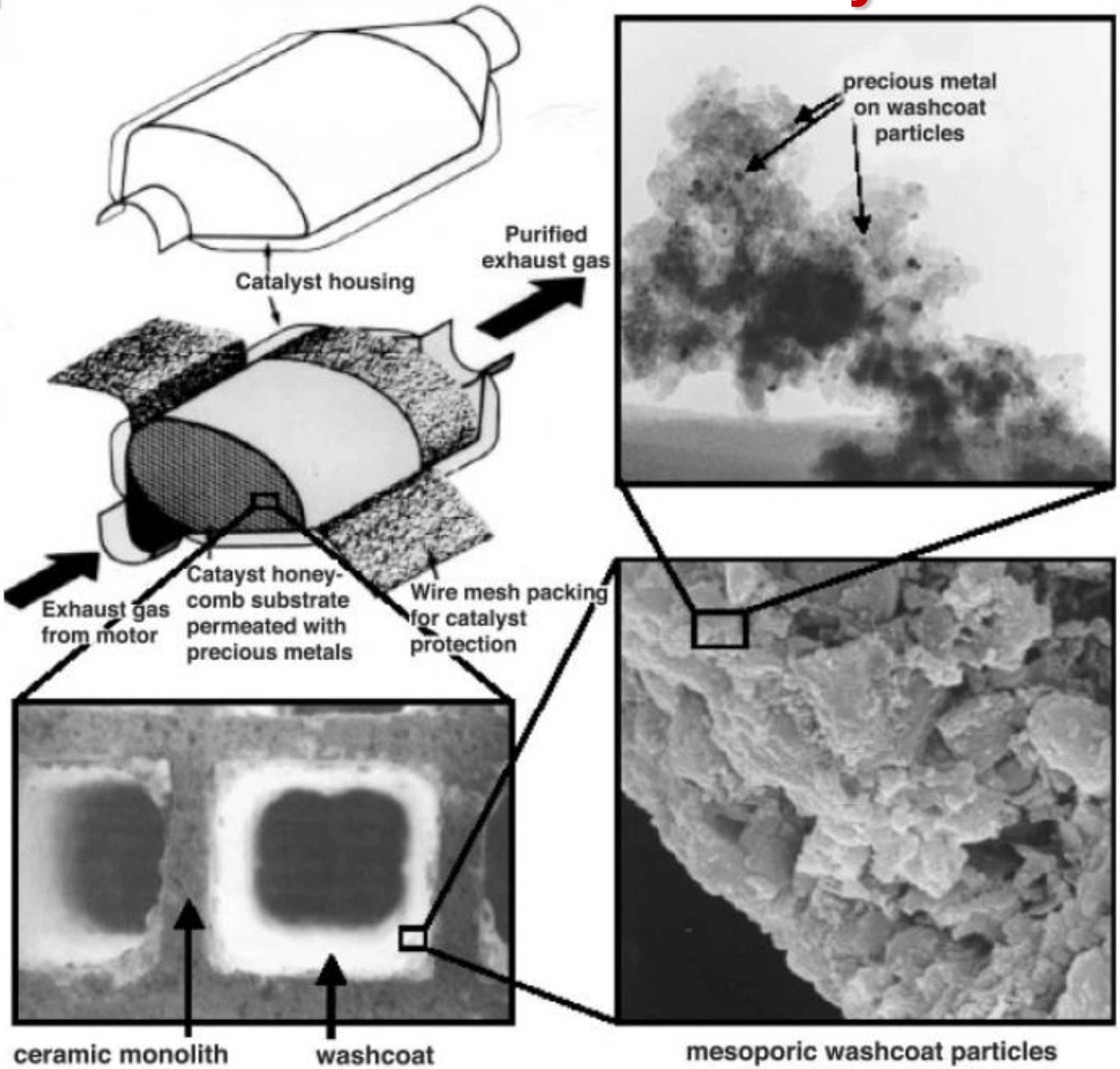
Heterogeneous Catalysts:

- **Expensive noble metals (Pt, Pd, Rh) dispersed**

in nanometer-scale onto supports (silica, allumina, carbon)

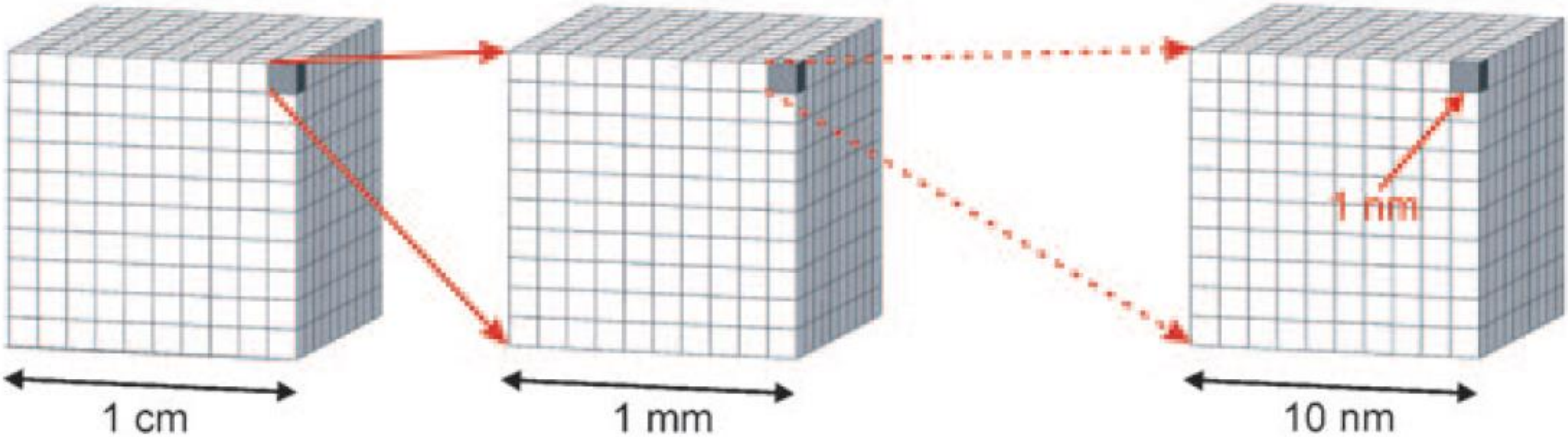
- **Applied to many chemical processes**

Nanoparticles in automotive catalytic converters



A. T. Bell, *Science* **2003**, 299, 1688.

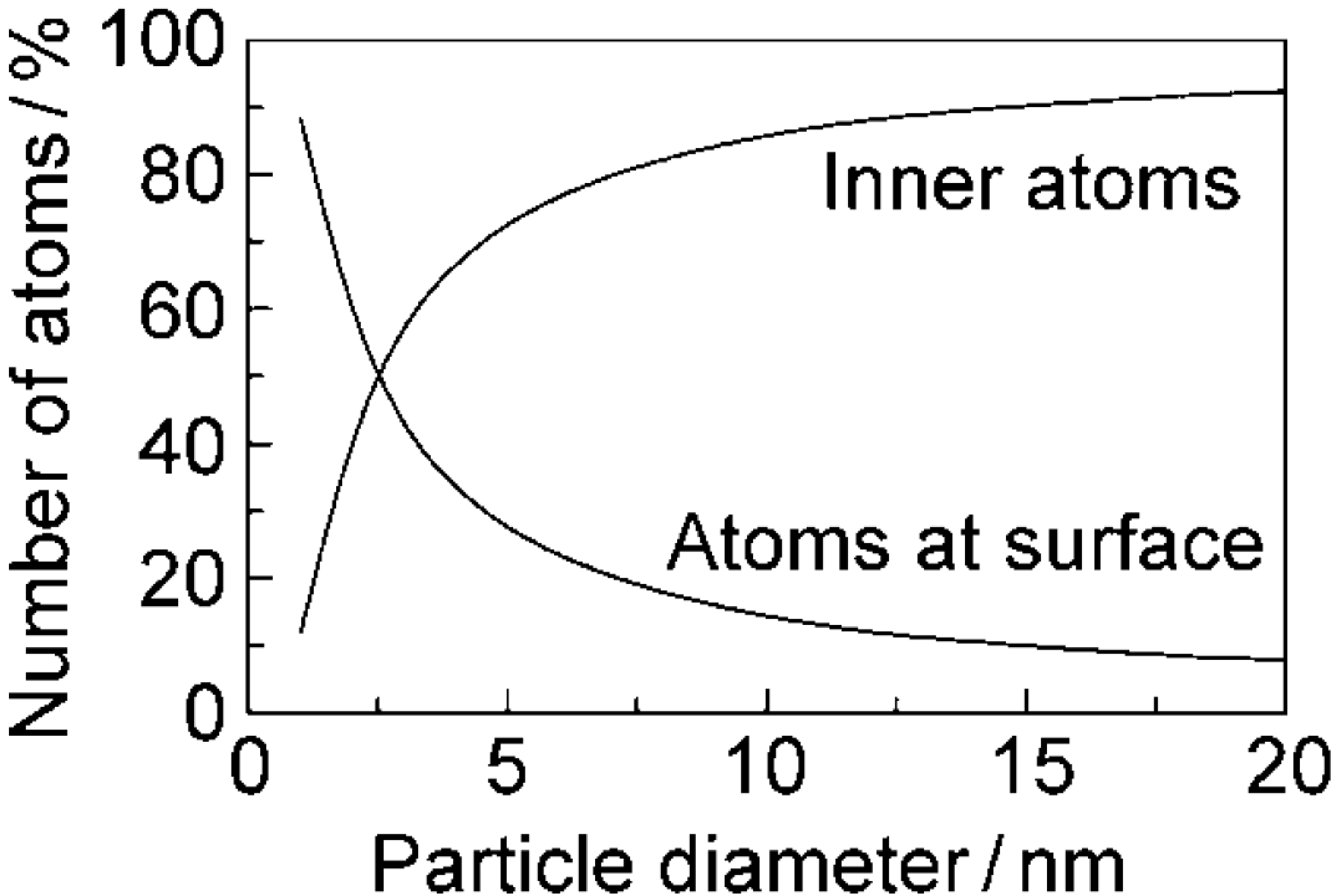
Particle size vs. Surface area



Edge length of cubes	Number of cubes	Volume of cubes	Surface area of cubes
1 cm	1	1 cm^3	0.0006 m^2
1 mm	10^3	1 cm^3	0.006 m^2
1 µm	10^{12}	1 cm^3	6 m^2
1 nm	10^{21}	1 cm^3	6000 m^2

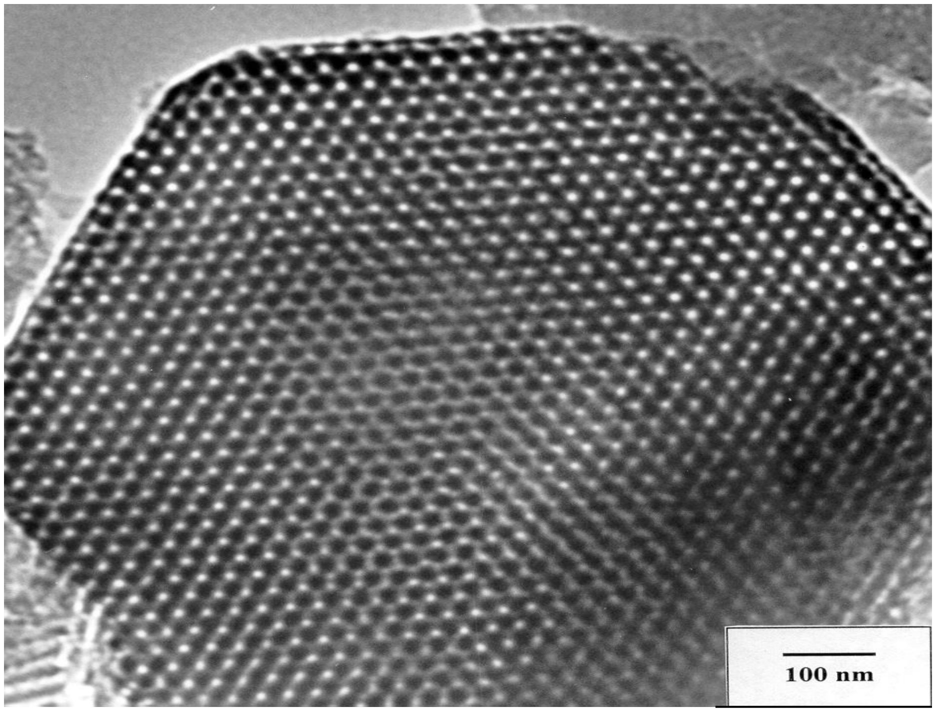
Helmut Goesmann, Claus Feldmann, *Angew. Chem., Int. Ed.* **2010**, *49*, 1362-1395.

Number of surface & inner atoms vs. Diameter



Helmut Goesmann, Claus Feldmann, *Angew. Chem., Int. Ed.* **2010**, *49*, 1362-1395.

Nanoporous Materials

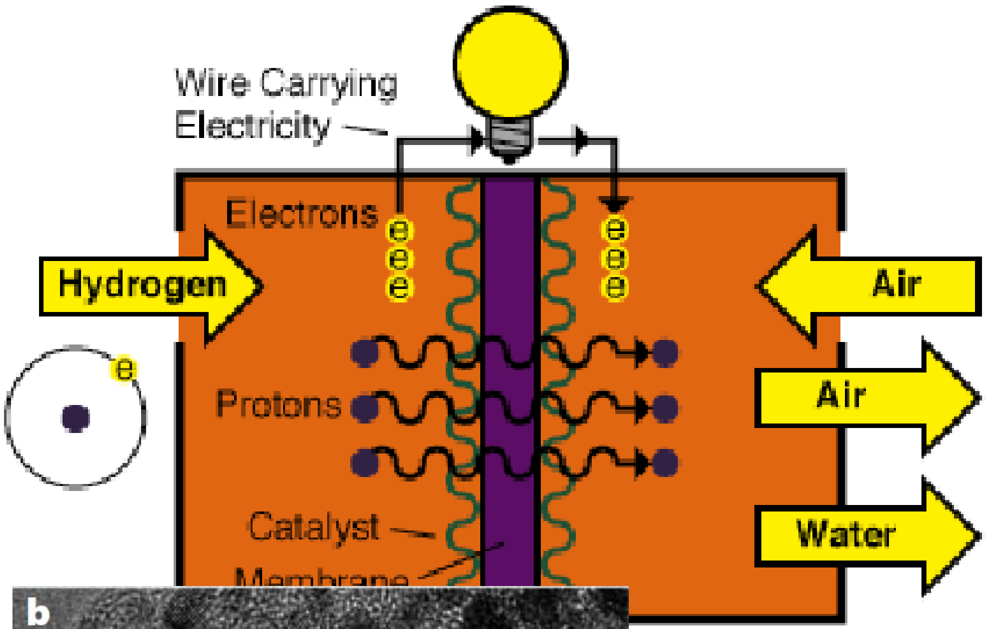


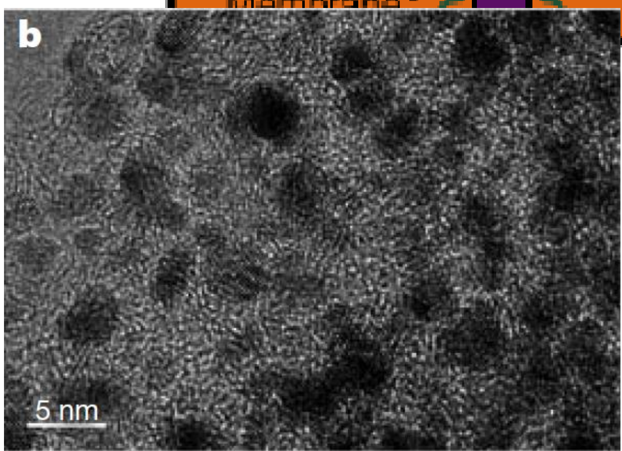
- Silica, alumina, titania
- Now Carbons
- Catalysts,
- Hosts for nanomaterials

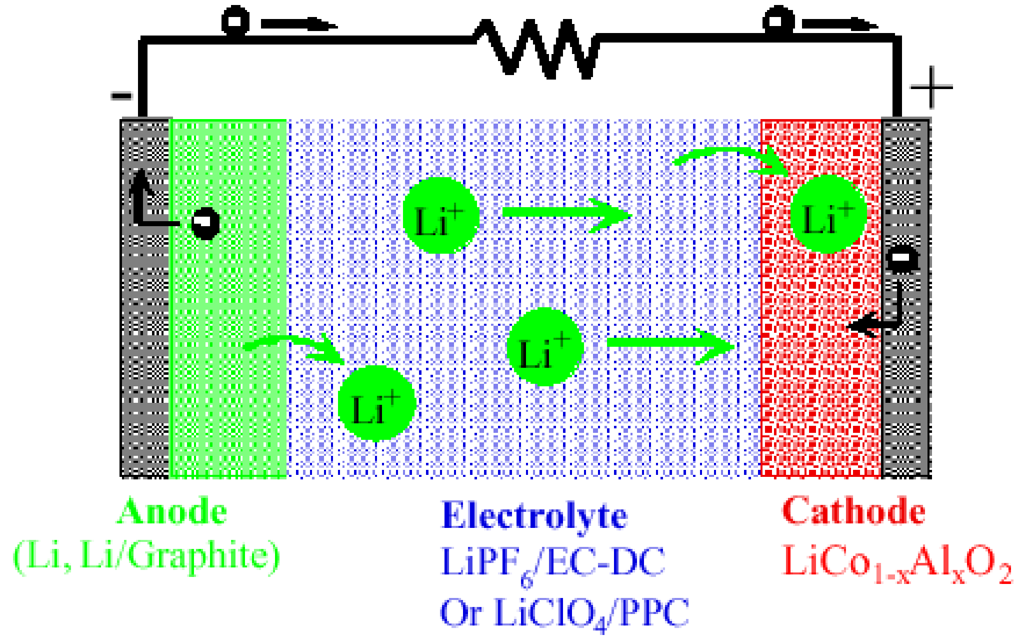
S. J. Bae et al., *Chem. Comm*. **2000**, 31.

Fuel Cells and Batteries
based on New Nanostructured materials

Fuel Cells



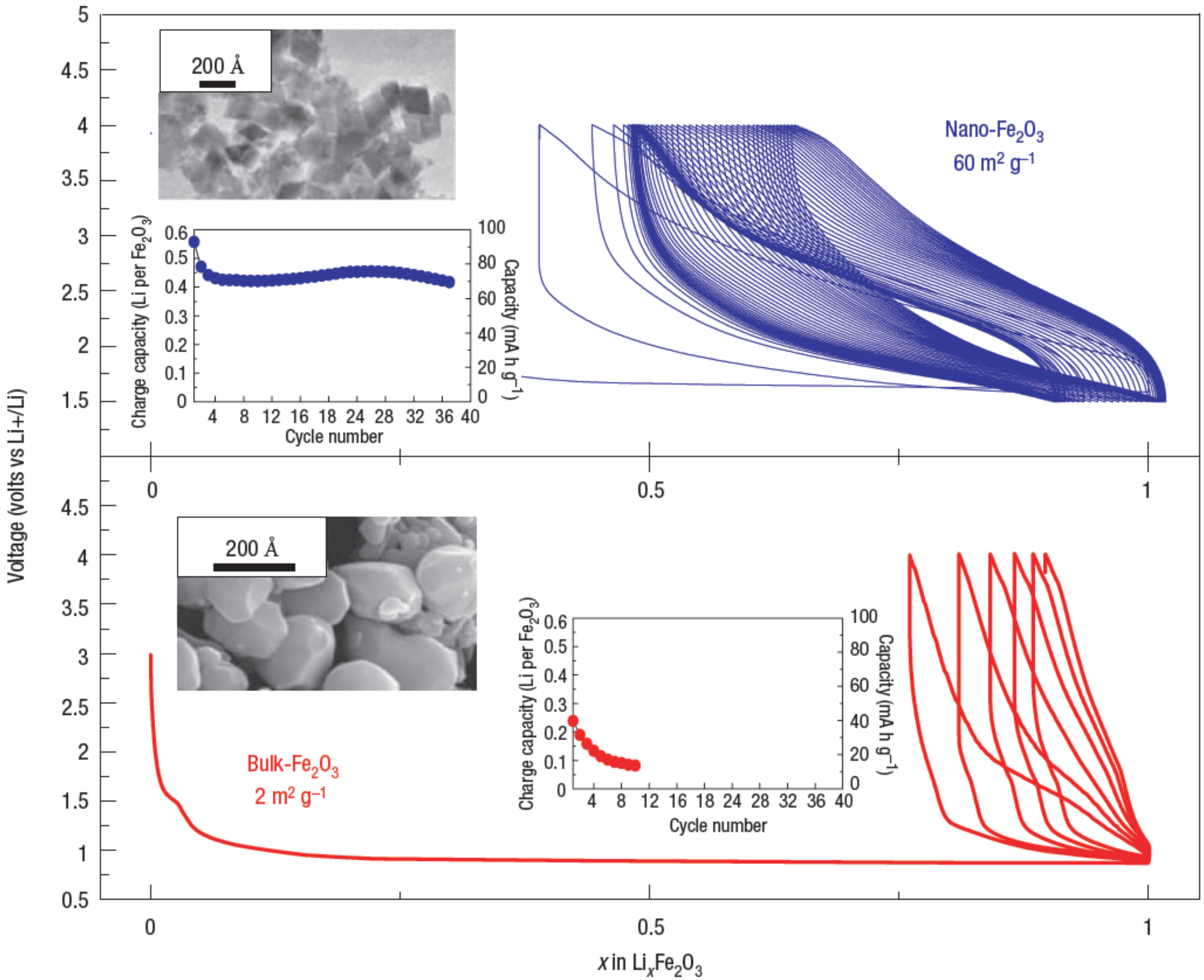




Lithium Secondary Batteries

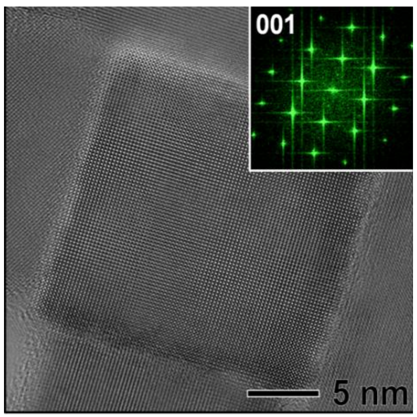
R. Ryoo et al., *Nature* **2001**, 412, 169.

Arico, A. S., Bruce, P., Scrosati, B., Tarascon, J. M. & Schalkwijk, W. V. Nanostructured materials for advanced energy conversion and storage devices. *Nature Mater.* **2005**, 4, 366-377.



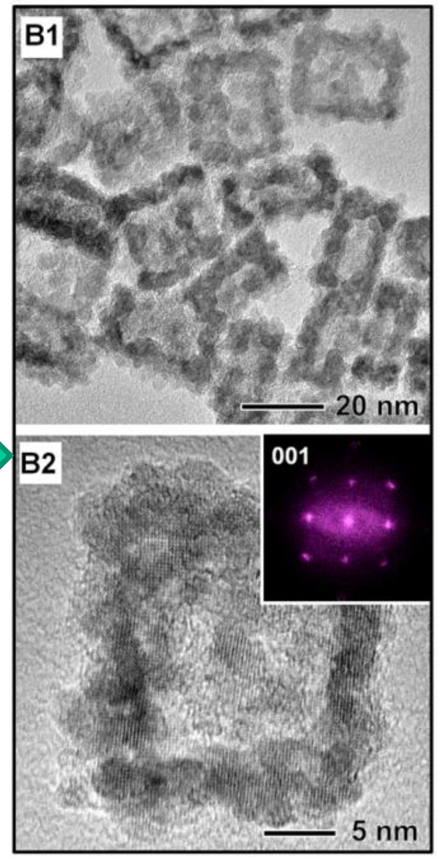
Galvanic Repacement Reactions in Metal Oxide Nanocrystals

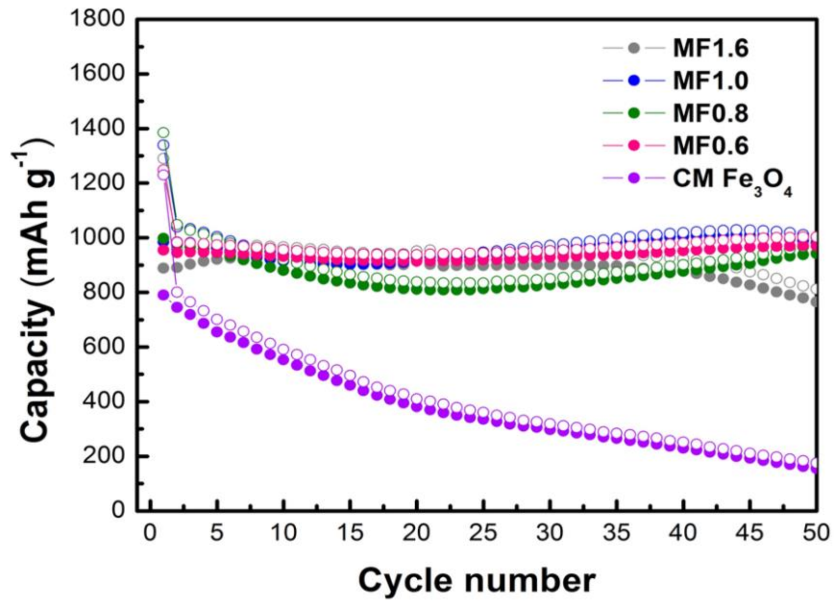
Manganese Oxide



Galvanic corrosion

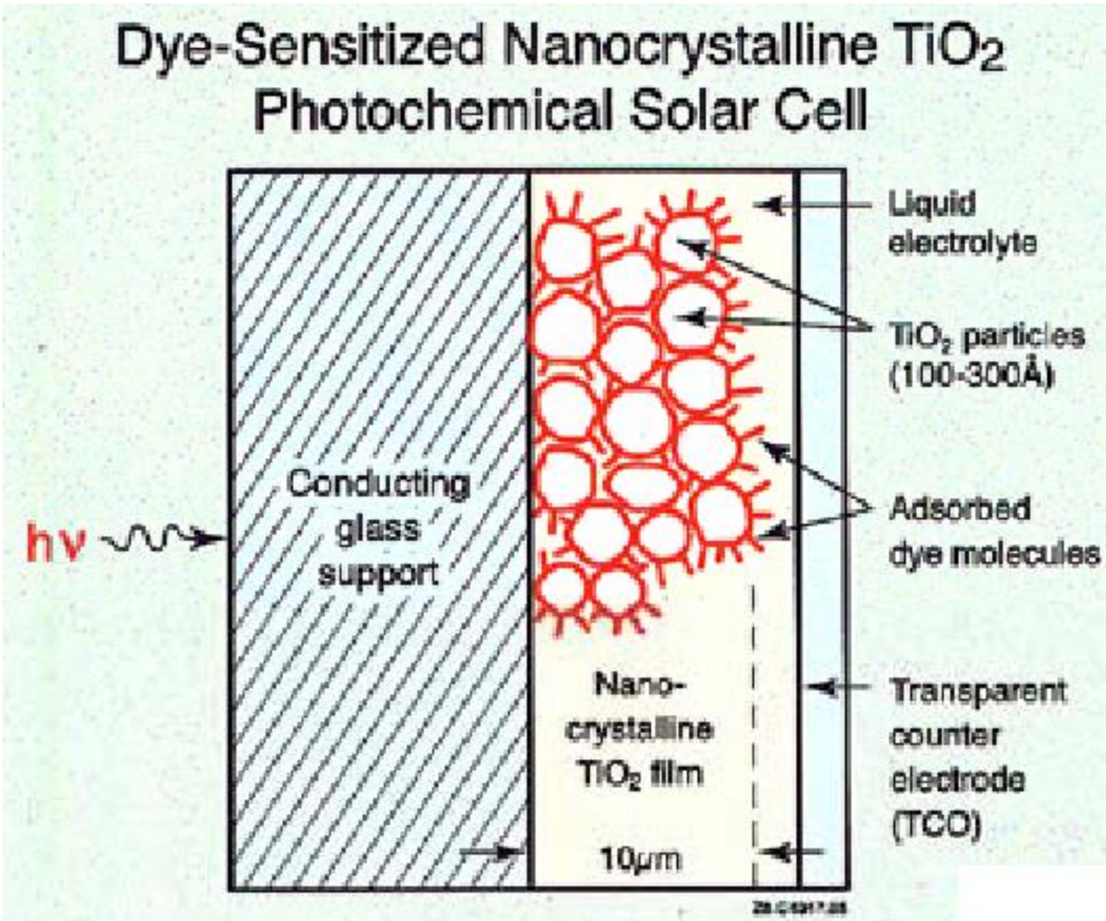
γ-Fe_2O_3 Nanocages





Myoung Hwan Oh, *et al*., *Science* **2013**, 340, 964.

Photochemical Solar Cells
Based on TiO2 nanoparticles

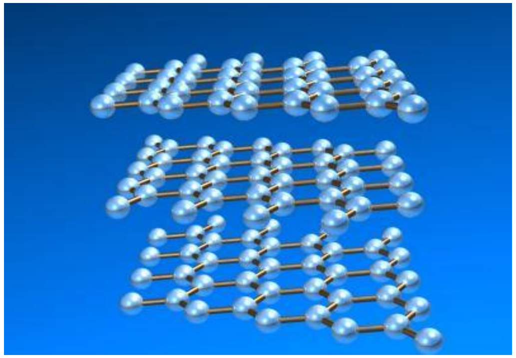


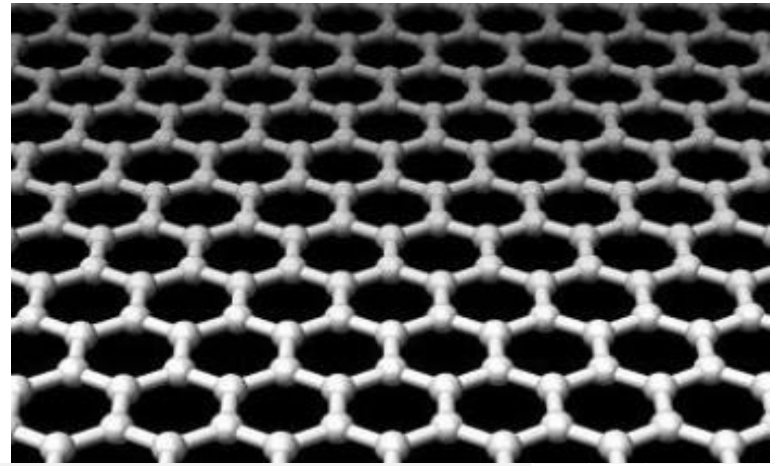
Self-cleaning glass using TiO_2 nanoparticle coating

www.selfcleaningglass.com

NanoTech for IT

Graphenes





The Nobel Prize in Physics 2010
Andre Geim, Konstantin Novoselov

The Nobel Prize in Physics 2010

Andre Geim

Konstantin Novoselov

Photo: Sergeom, Wikimedia Commons

Andre Geim

Konstantin Novoselov

!란을 사용하여 인용 보고서에서 개별 항목을 제거하거나
; 기간 사이에 출판된 항목으로 제한할 수 있습니다. 1900 - 2014 이동

	8341	10918	13516	14841	9230	67659
Electric field effect in atomically thin carbon films 저자: Novoselov, KS; Geim, AK; Morozov, SV; 등등. SCIENCE 권: 306 호: 5696 페이지: 666-669 출판연도: OCT 22 2004	1655	2364	3008	3333	2163	14665
The rise of graphene 저자: Geim, A. K.; Novoselov, K. S. NATURE MATERIALS 권: 6 호: 3 페이지: 183-191 출판연도: MAR 2007	1222	1686	2176	2445	1521	10464
Two-dimensional gas of massless Dirac fermions in graphene 저자: Novoselov, KS; Geim, AK; Morozov, SV; 등등. NATURE 권: 438 호: 7065 페이지: 197-200 출판연도: NOV 10 2005	941	1117	1245	1206	696	7055
The electronic properties of graphene 저자: Castro Neto, A. H.; Guinea, F.; Peres, N. M. R.; 등등. REVIEWS OF MODERN PHYSICS 권: 81 호: 1 페이지: 109-162 출판연도: JAN-MAR 2009	848	1108	1353	1336	795	6030
Raman spectrum of graphene and graphene layers 저자: Ferrari, A. C.; Meyer, J. C.; Scardaci, V.; 등등. PHYSICAL REVIEW LETTERS 권: 97 호: 18 논문 번호: 187401 출판연도: NOV 3 2006	391	554	711	820	541	3446
Two-dimensional atomic crystals 저자: Novoselov, KS; Jiang, D; Schedin, F; 등등. PROCEEDINGS OF THE NATIONAL ACADEMY OF SCIENCES OF THE UNITED STATES OF AMERICA 권: 102 호: 30 페이지: 10451-10453 출판연도: JUL 26 2005	320	368	491	606	385	2699
Detection of individual gas molecules adsorbed on graphene 저자: Schedin, F.; Geim, A. K.; Morozov, S. V.; 등등. NATURE MATERIALS 권: 6 호: 9 페이지: 652-655 출판연도: SEP 2007	323	409	466	484	336	2315

Characteristics of Graphenes

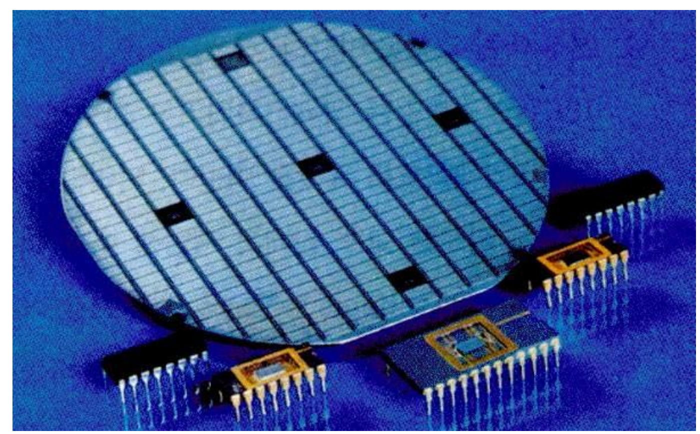
→ Thinnest & strongest material

X 200 strength of steel

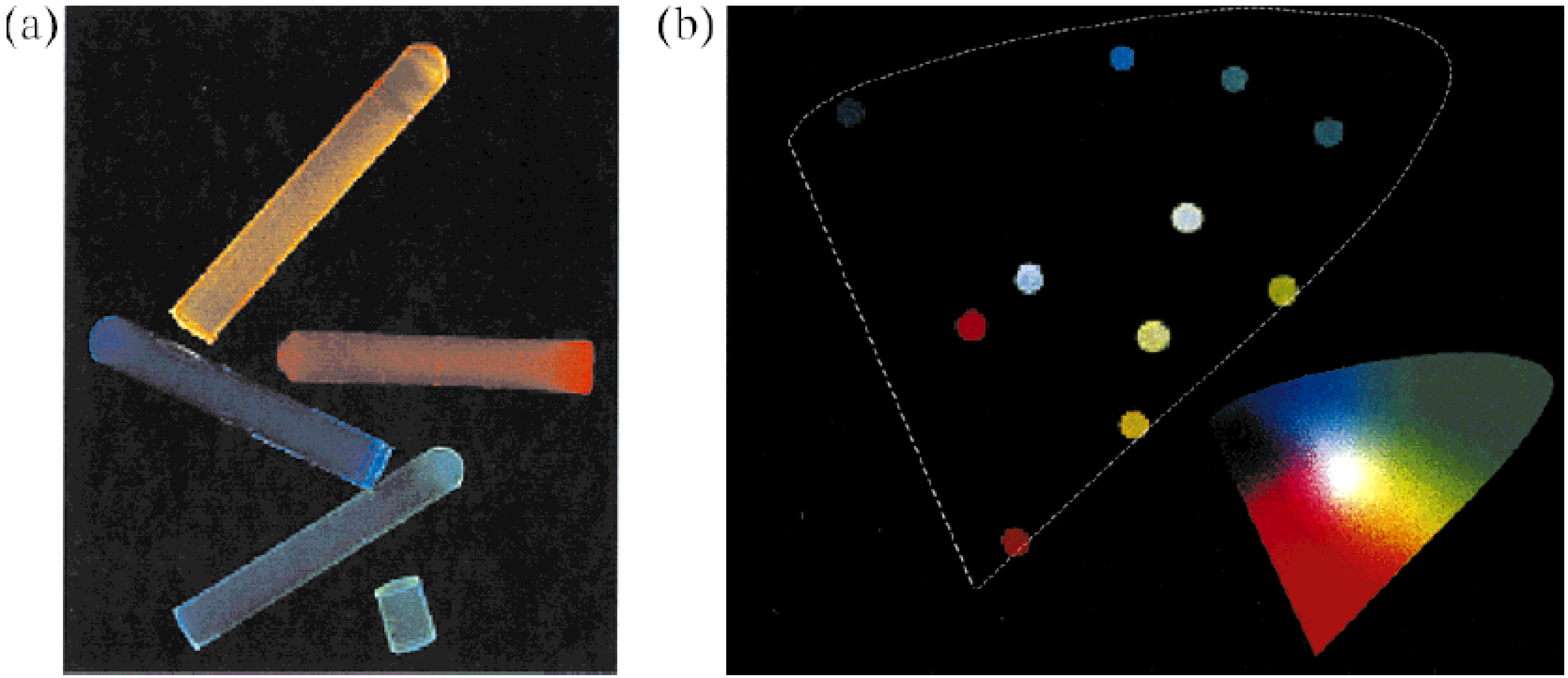
X 100 thermal conductivity

X 100 electrical conductivity

Various Applications of Graphenes

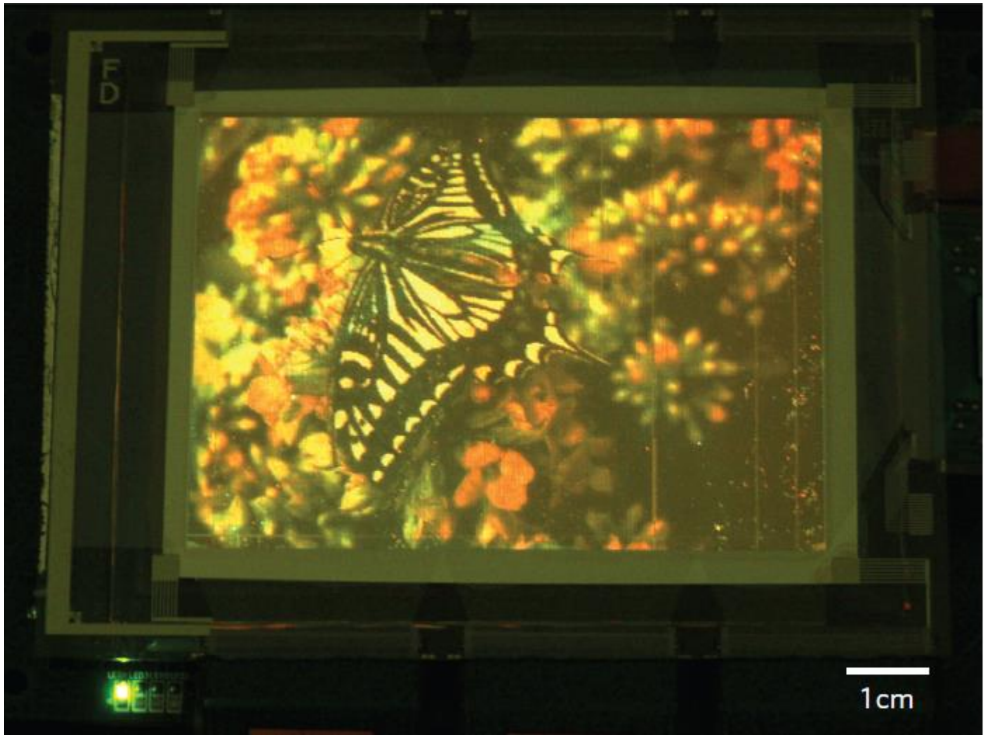


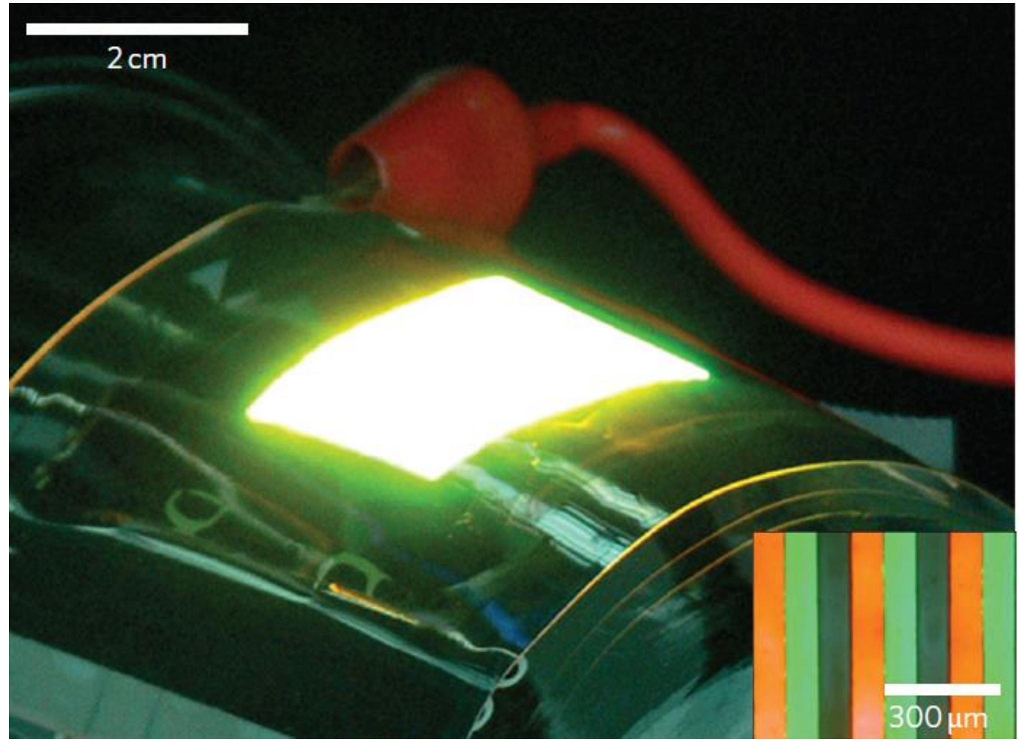
Full color emission from II-VI semiconductor quantum dot-polymer composites,



Bawendi, *Adv. Mater.* **2000**, 12, 1102.

Full-colour QD display and its flexible form





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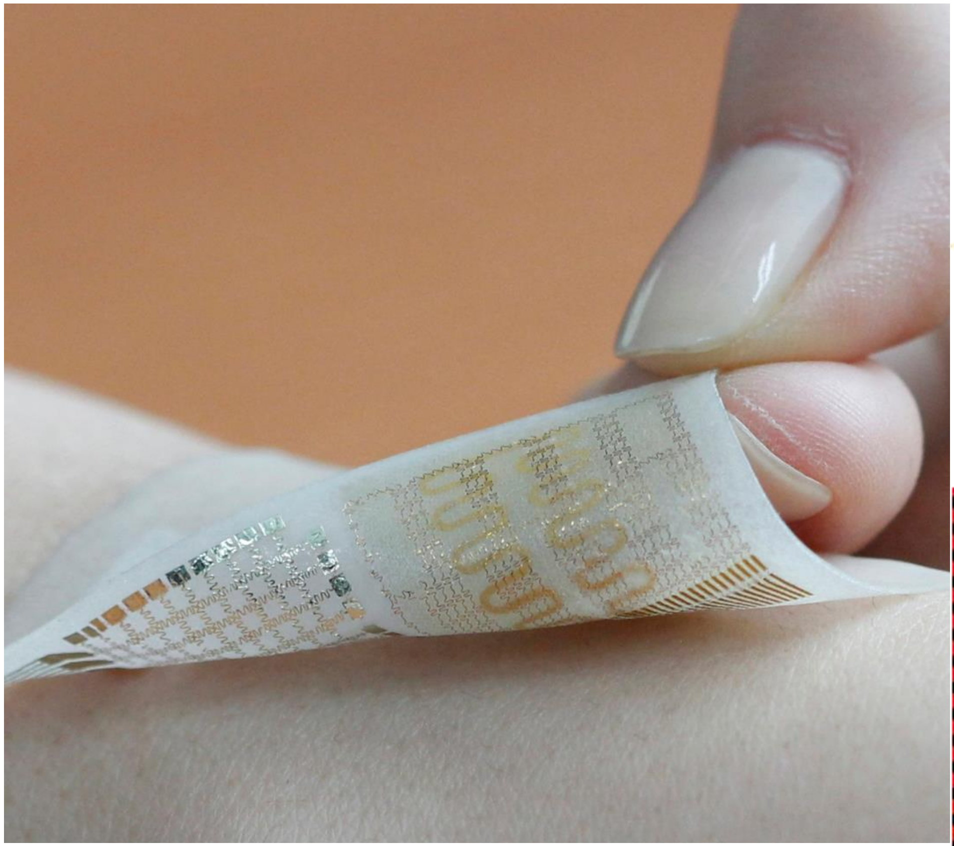
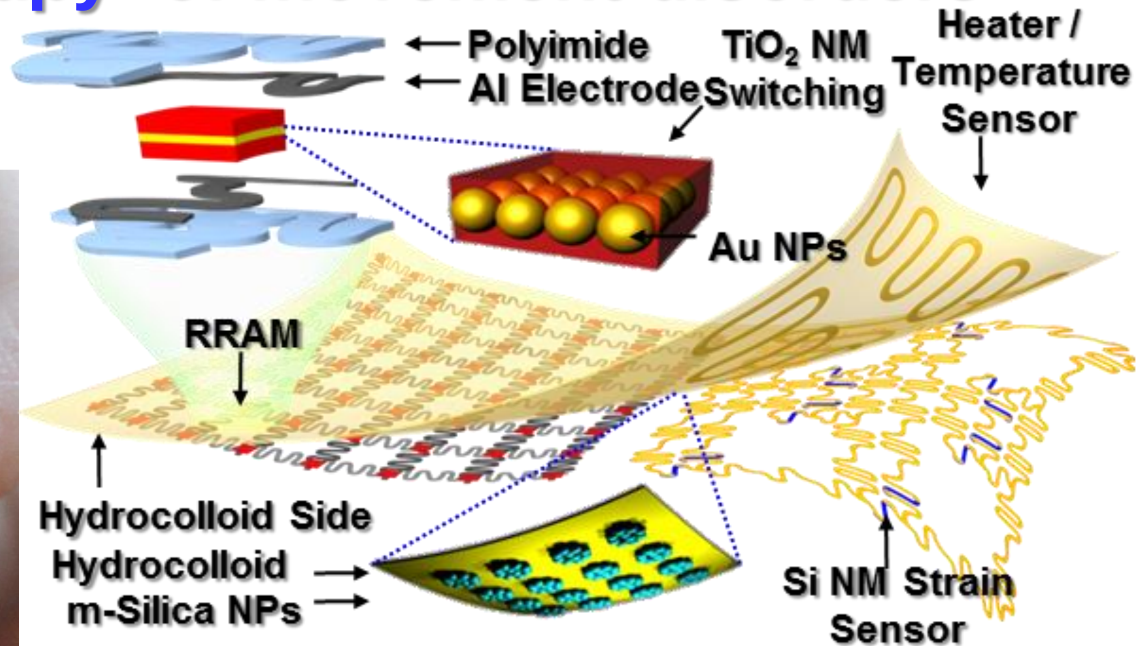
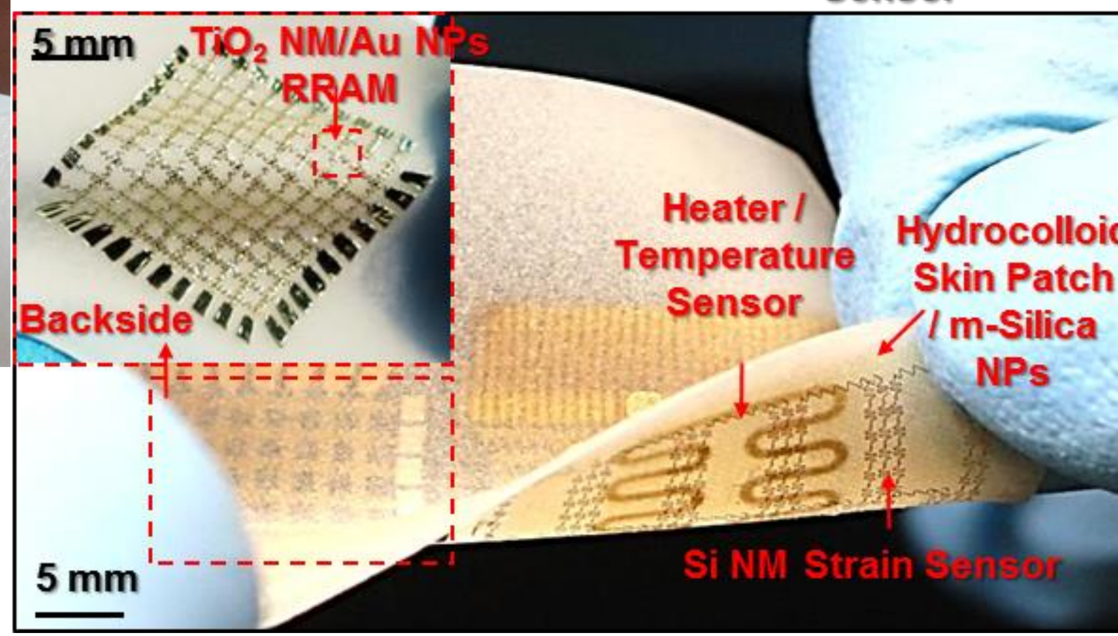
Nanoparticle-integrated multifunctional wearable devices for diagnosis and therapy of movement disorders



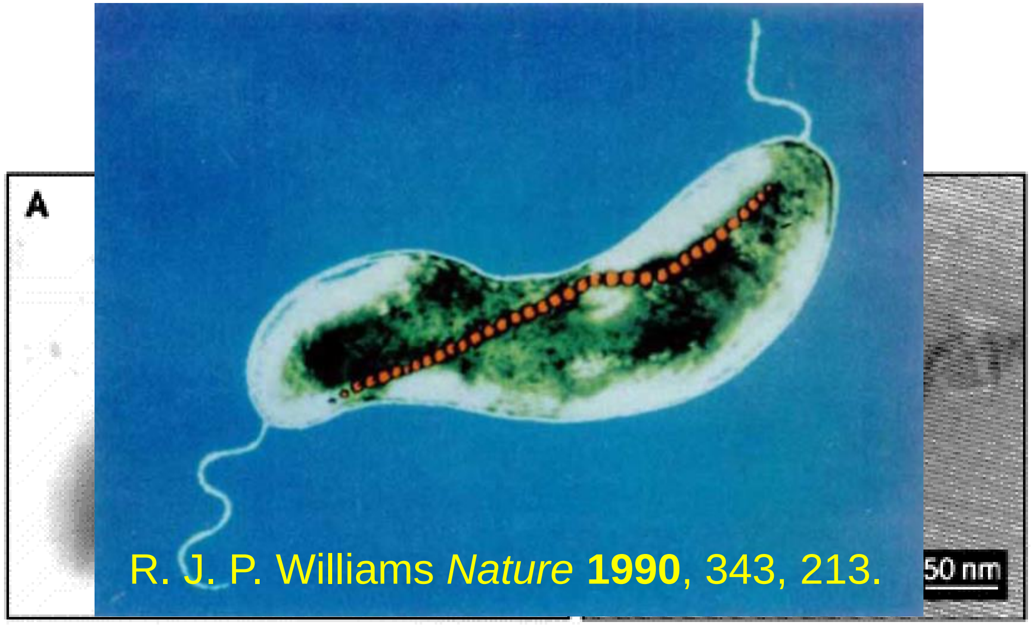




D. Son, J. Lee, ….., T. Hyeon, Dae-Hyeong Kim*
Nature Nanotechnol. **2014**, 9, 397.

Nanotech for Bio-Medicine

TEM image of magnetotactic bacteria



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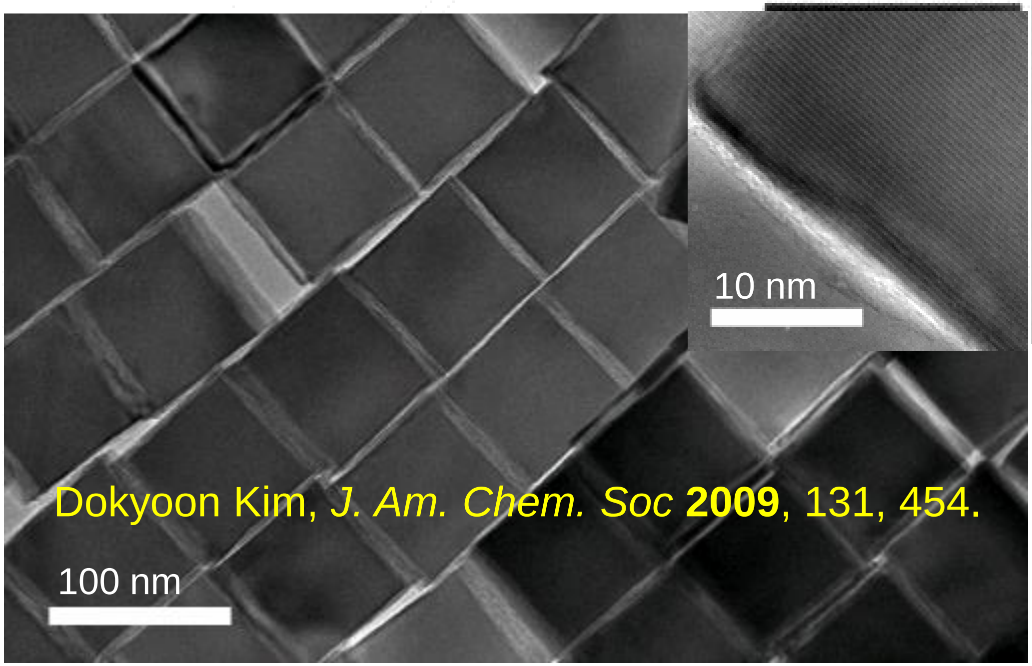

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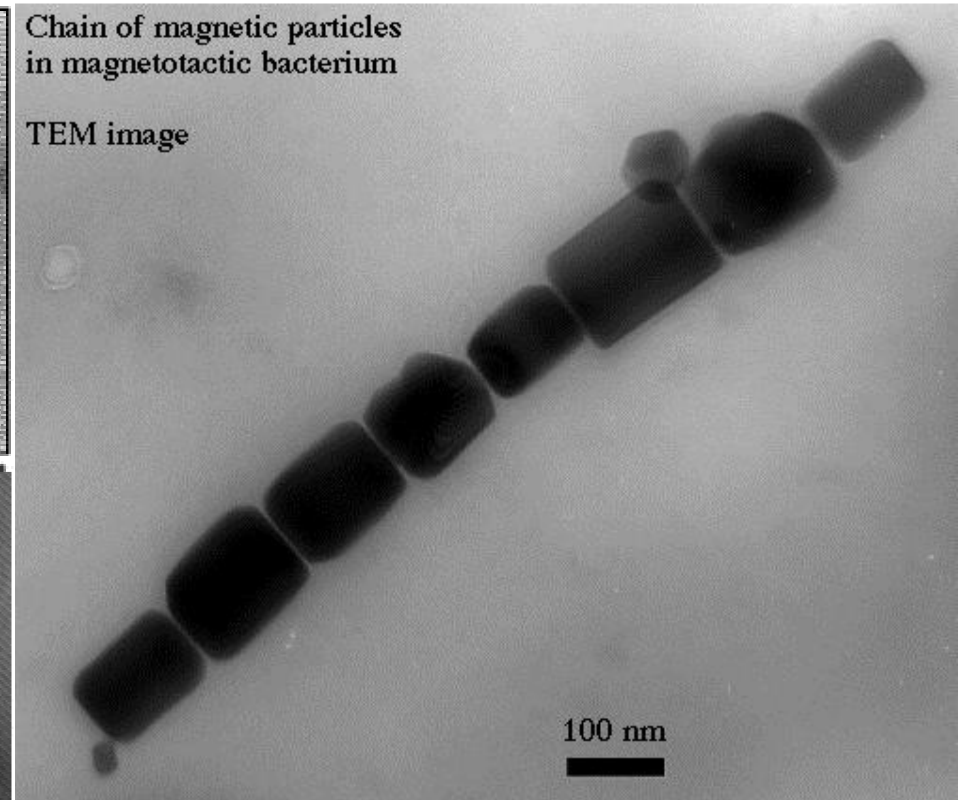

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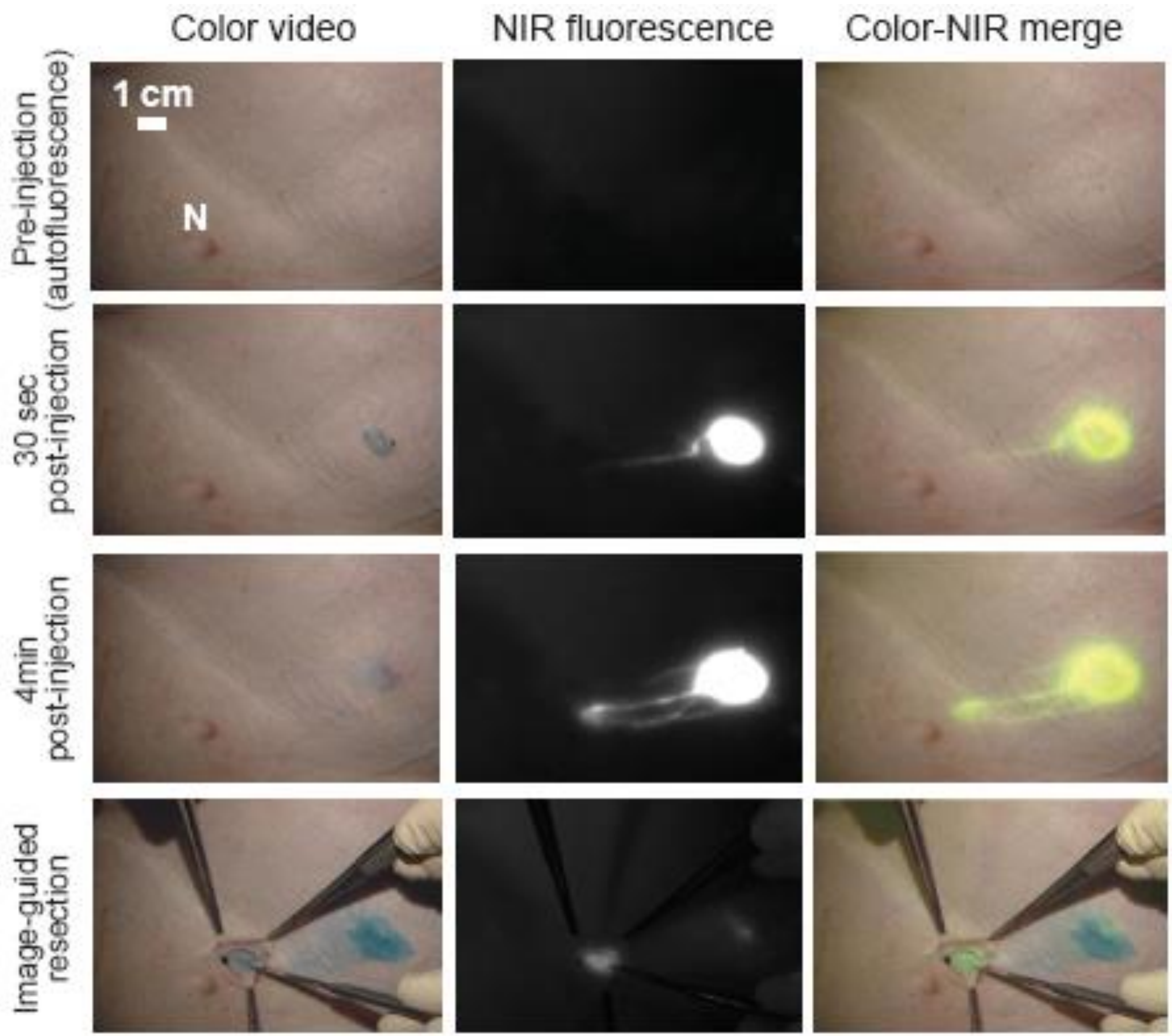
NIR-imaging guided Surgery using NIR QDs (CdTe/CdSe QDs



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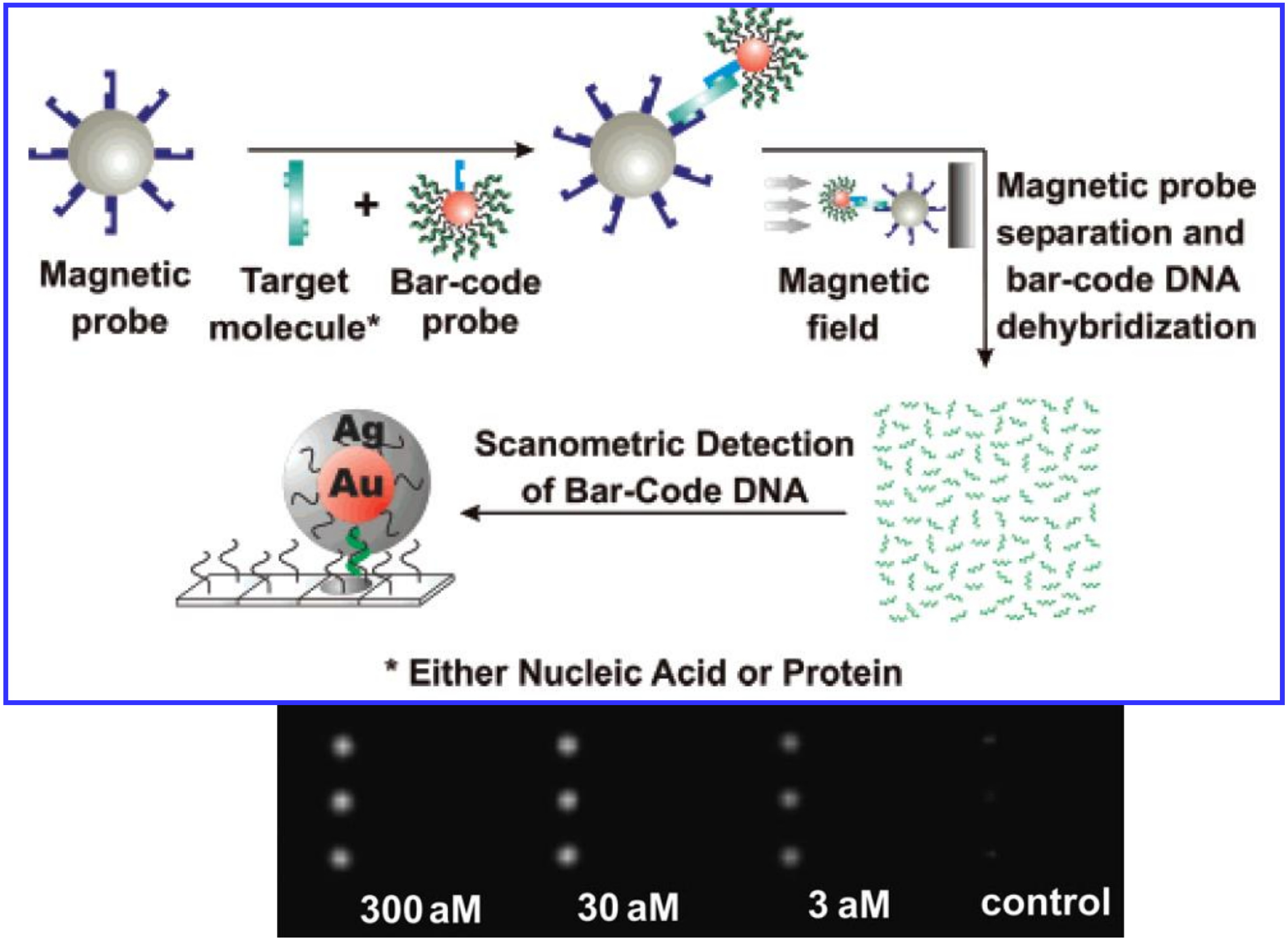
Detection of Cancer cells at very early stage.



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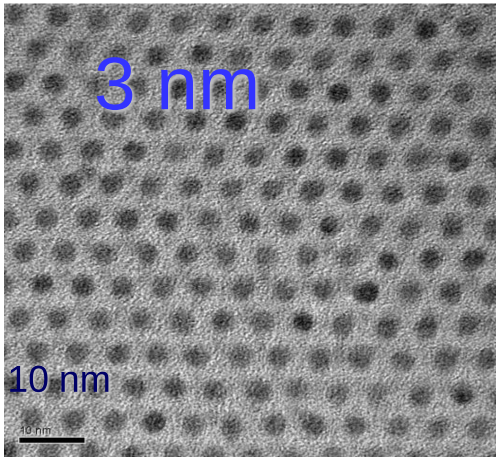
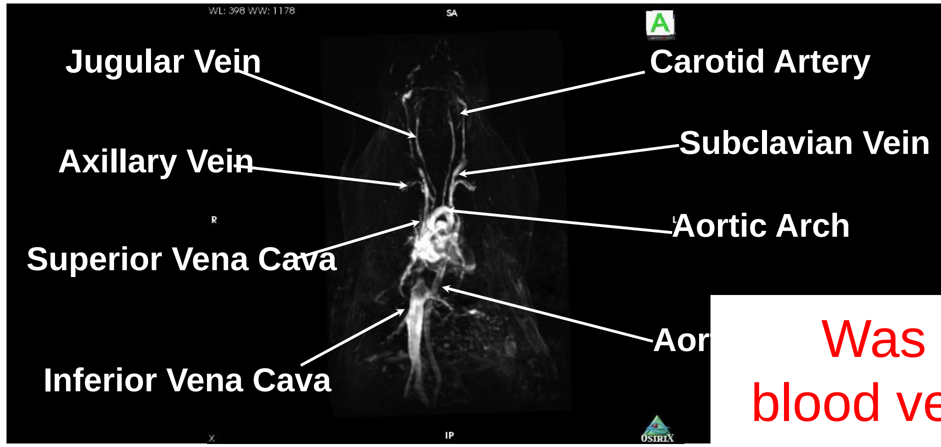
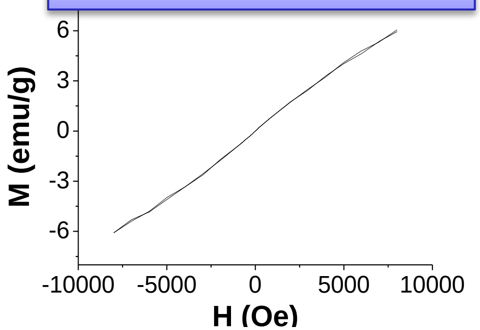
New non-toxic T1 MRI contrast agent using paramagnetic 3 nm Iron Oxide Nanoparticles

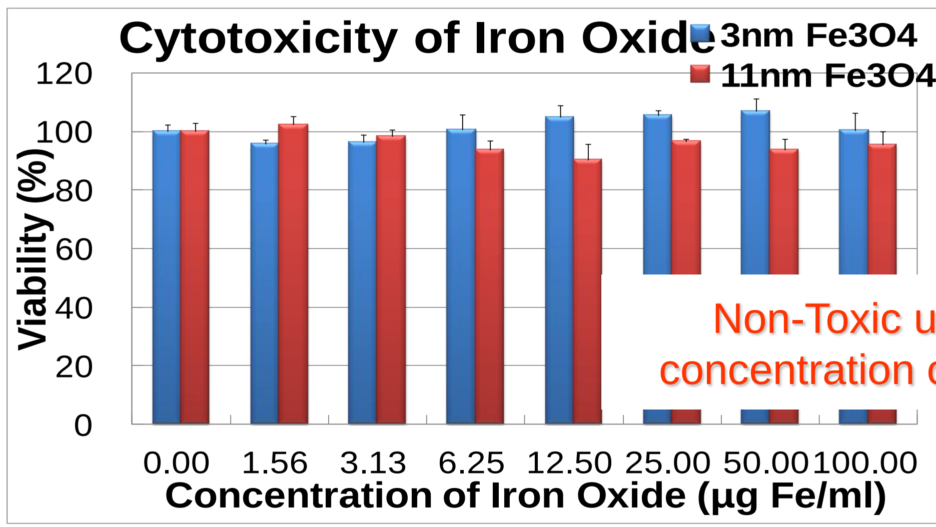




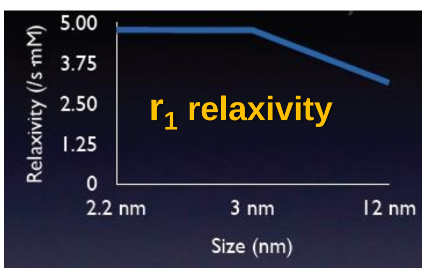
Was able to image blood vessel of < 200 μm

Nearly Paramagnetic





Non-Toxic up to very high concentration of 100 μg Fe/ml !



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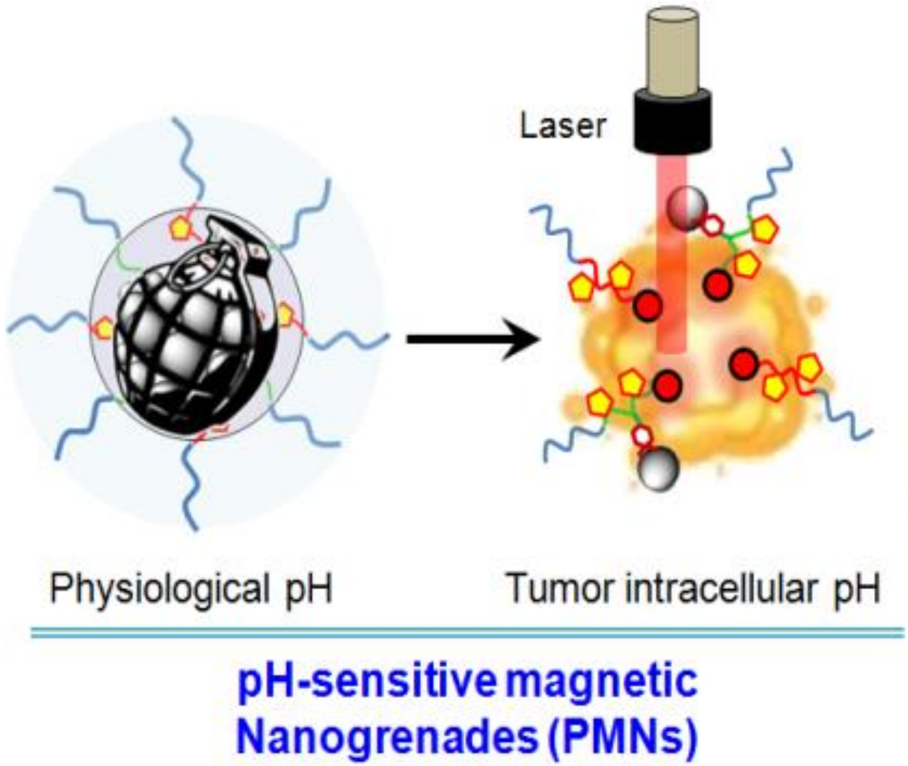
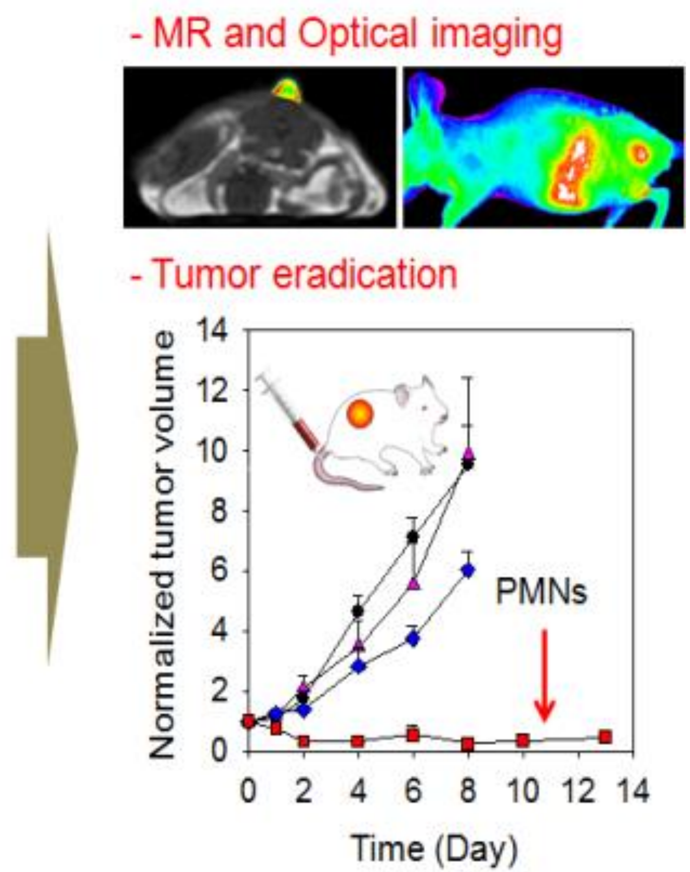
TUMOR PH-SENSITIVE MAGNETIC NANO-GRENADES (Multifunctional tumor pH-sensitive self-assembled nanoparticles for bimodal imaging and treatment of resistant heterogeneous tumors)

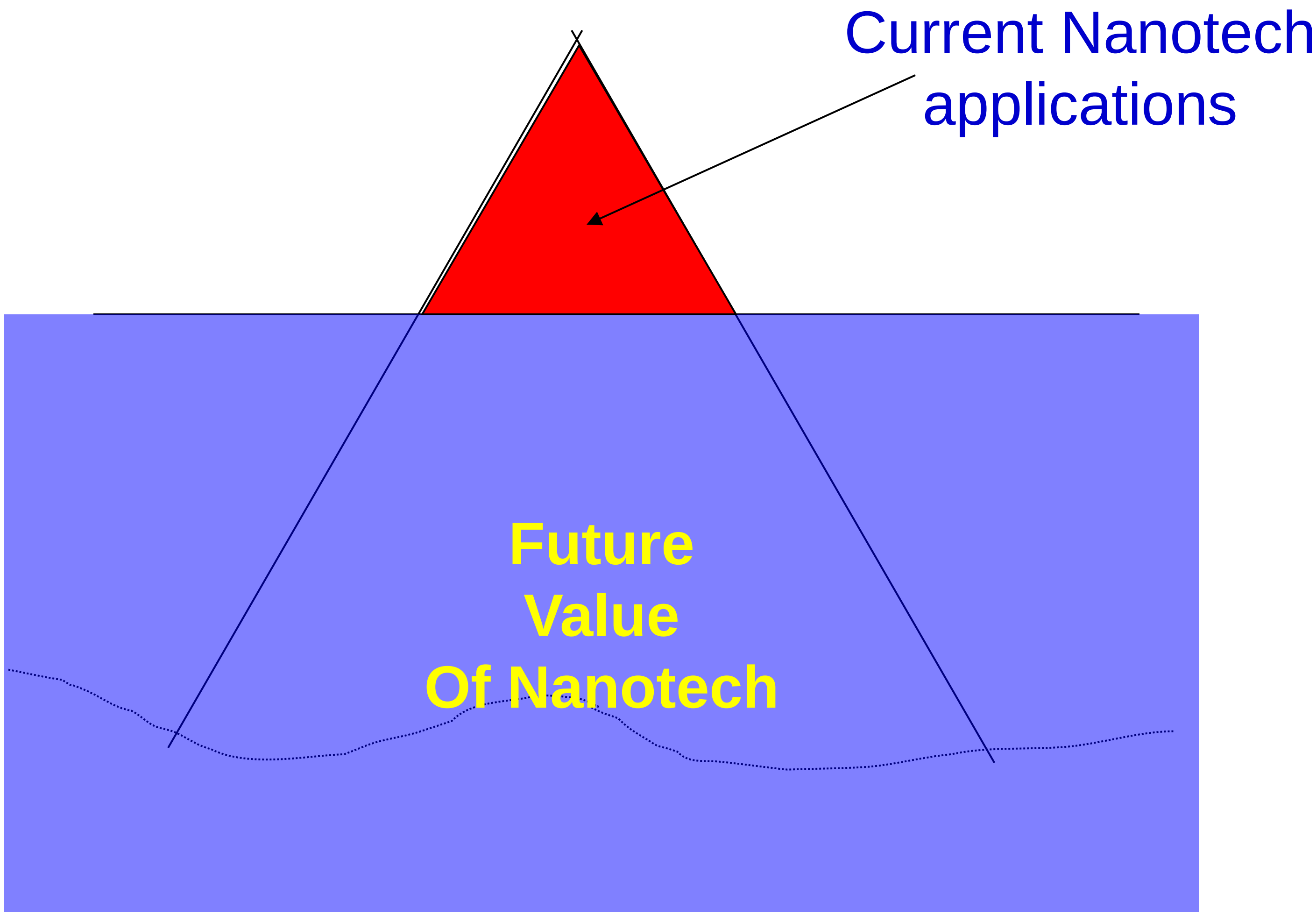




Daishun Ling *et al.*, *J. Am. Chem. Soc.* **2014**, *136*, 5647.

"My budget supports a major new National Nanotechnology Initiative, worth $500 million. … the ability to manipulate matter at the atomic and molecular level. Imagine the possibilities: materials with ten times the strength of steel and only a small fraction of the weight -- shrinking all the information housed at the Library of Congress into a device the size of a sugar cube -- detecting cancerous tumors when they are only a few cells in size. Some of our research goals may take 20 or more years to achieve, but that is precisely why there is an important role for the federal government."

--President William J. Clinton
January 21, 2000
California Institute of Technology



Current Nanotech applications
Future Value Of Nanotech