Electromagnetic waves interaction with various metallic nanomaterials

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Light Scattering

The scattering of light was first studied in a careful manner by Tyndall in 1859

A major step to explain the phenomenon was taken in 1871 by Rayleigh.

The electric polarisation induced in an atom or a molecule by the electromagnetic field is proportional to ω^2 and the field radiated by such induced oscillating dipoles then becomes proportional to ω^4.

Rayleigh thus found that the molecular scattering by blue light is many times more than that by red light and so explained the blue colour of the sky as the result of scattering from the air molecules.
When the wavelength of light becomes comparable to the size of the scattering particles, like dust particles, the mutual interference from the scattering by the different portions of the dust particle become important and this is called Mie scattering.

- For spherical simple metal nanoparticles $\boxed{\omega = \omega_p / \sqrt{3}}$
- Generalized Kohn's theorem

L. Brey, N.F. Johnson, and B.I. Halperin, Phys. Rev. B40,10647 (1989)
P. Bakshi, D.A. Broido and K. Kempa, Phys. Rev. B42,7416 (1990)

Gustav Mie, 1908

Fabrication of nanomaterial's: application in electronics

Solar Cell

Photonic

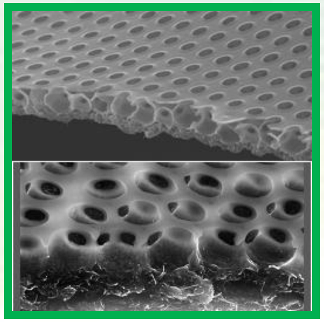
Memory devices

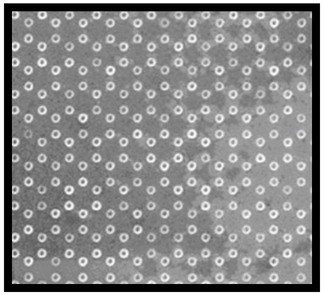
Detection devices

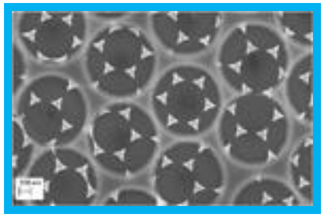
<u>Nano Materials:</u>

anthena, dots, tubes, 2-D and 3-D rods, rings, photonic crystals, Hybrides

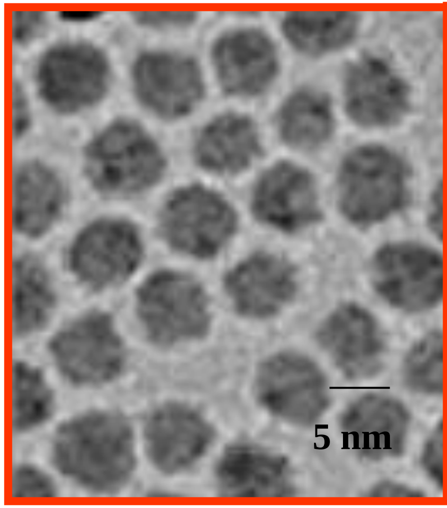
semiconductor: CdTe,CdS, ZnO
metallic: Au, Ag, Pt
magnetic: Co, FexOy, Ni
Graphene, carbon SWCNT, MWCNT
Polymer

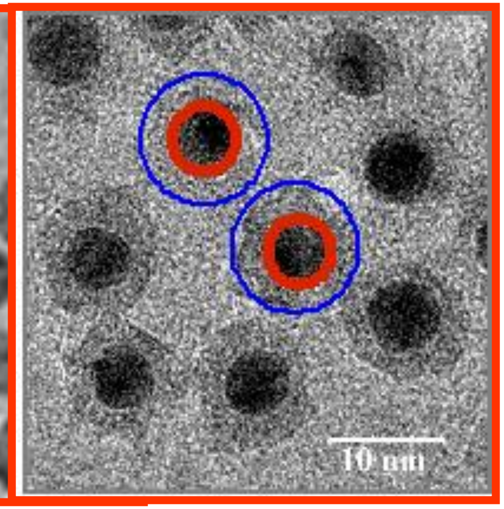


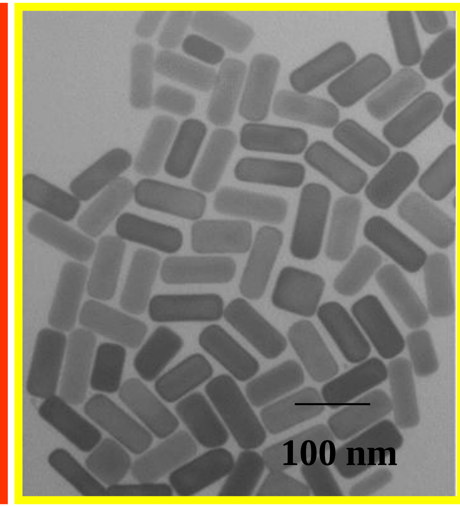


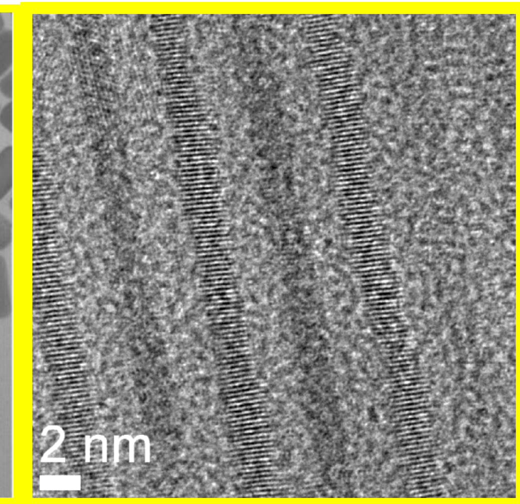


Selected Nanostructures produced by wet chemistry method



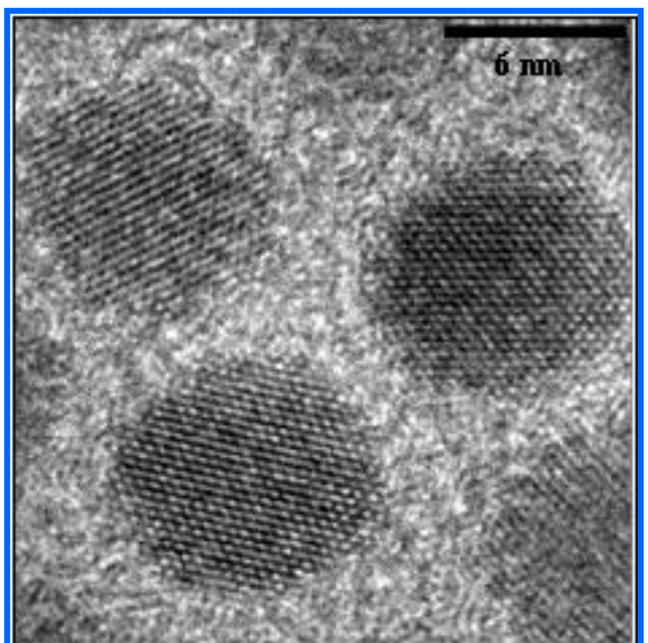


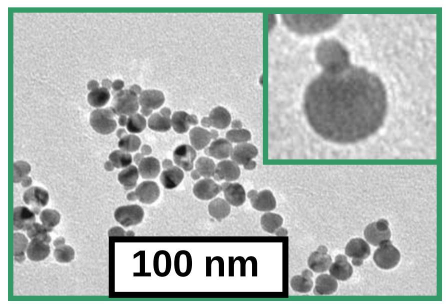


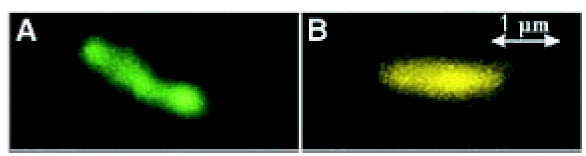


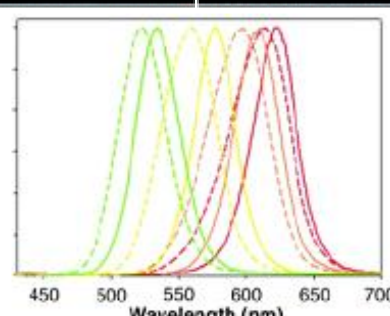
Particle / Q-dots /Bimetallic/ core –shell

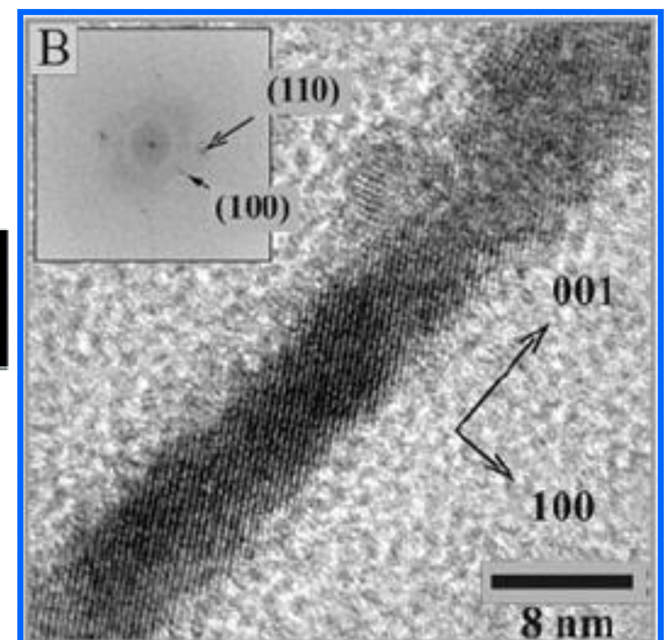
Metallic and semiconductors Wires

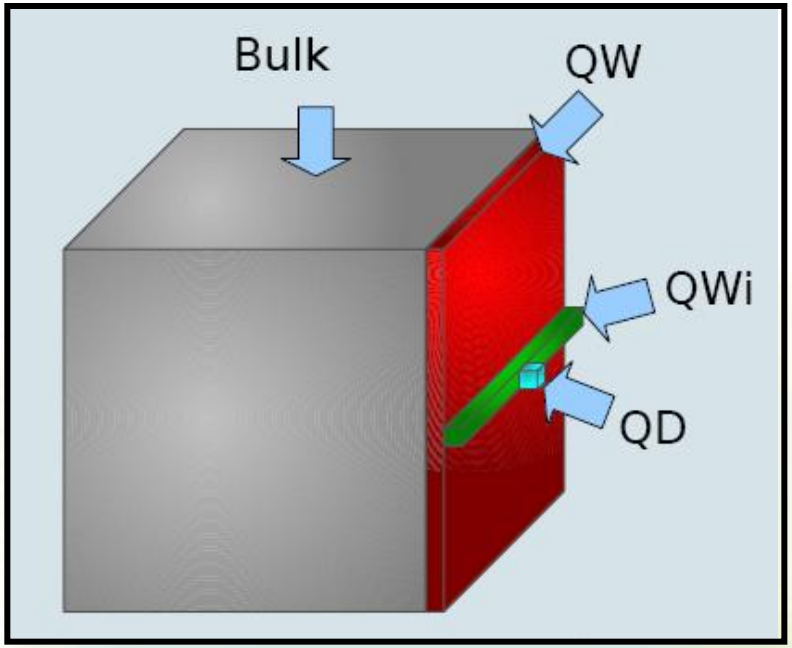


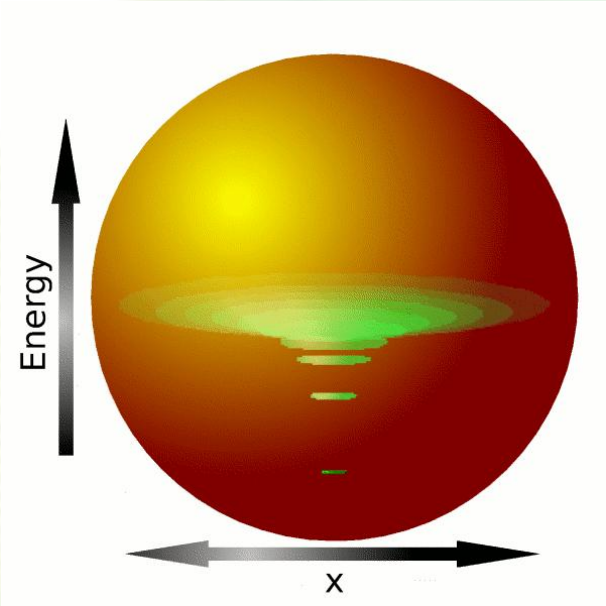


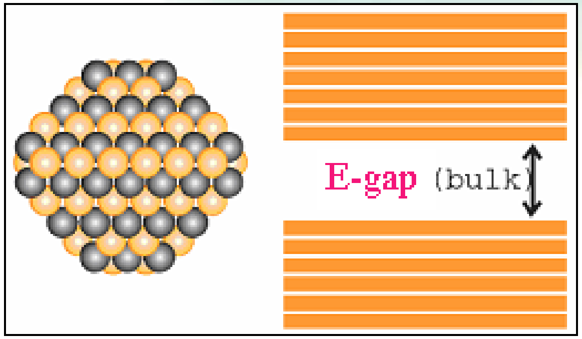


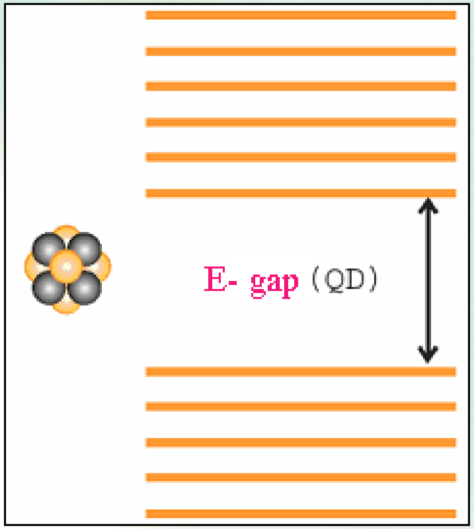


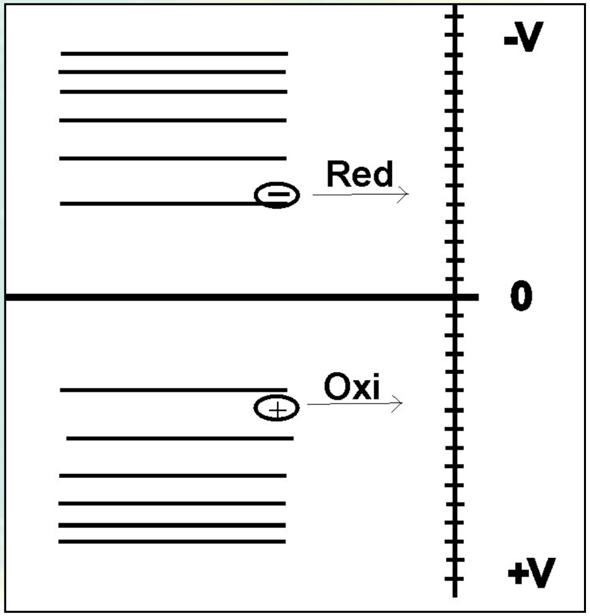



Bulk
QW
QWi
QD

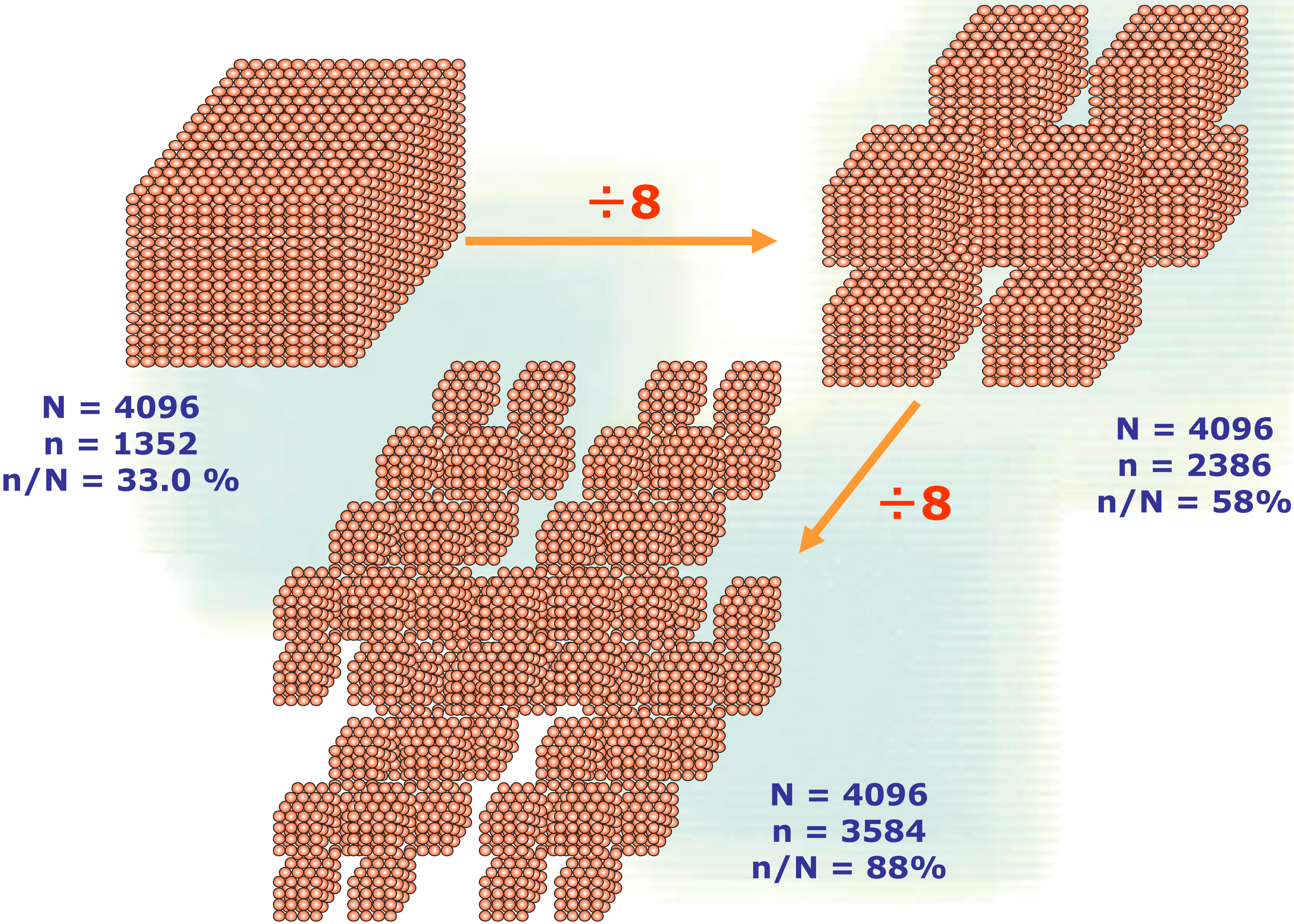

Energy
x


E-gap (bulk)

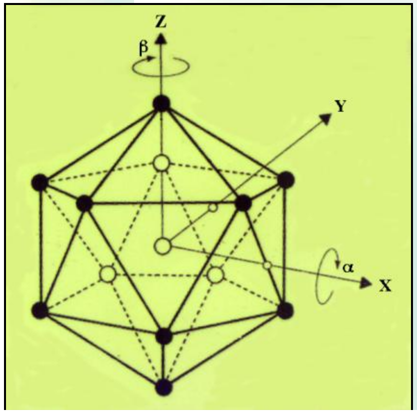

E- gap (QD)

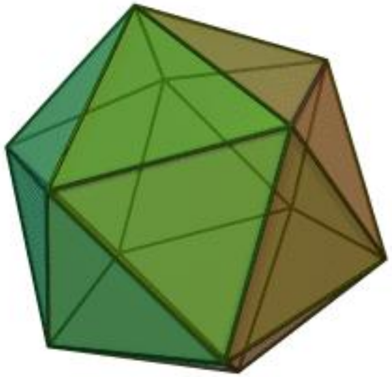

-V
Red
0
Oxi
+V

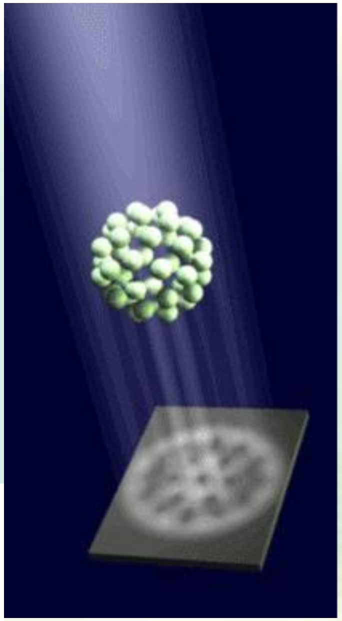
Surface: volume ratio

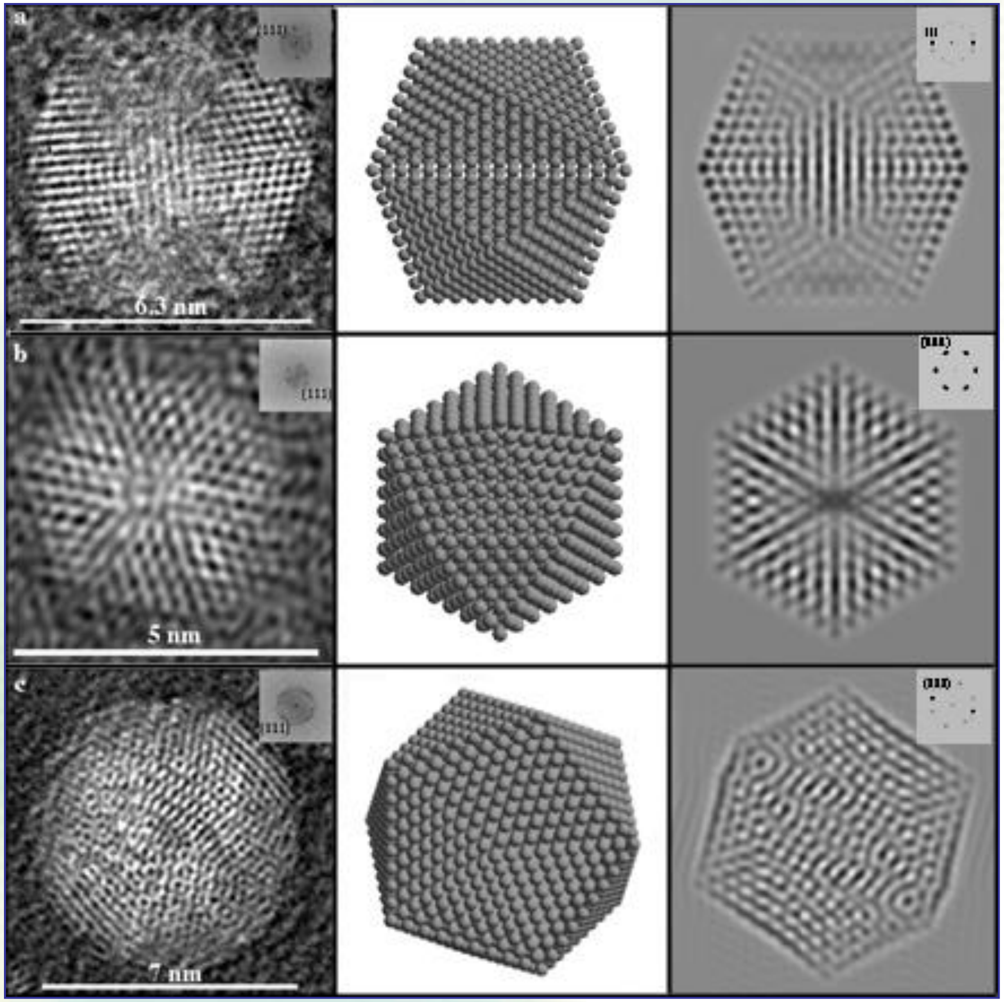


Experimental results and theory





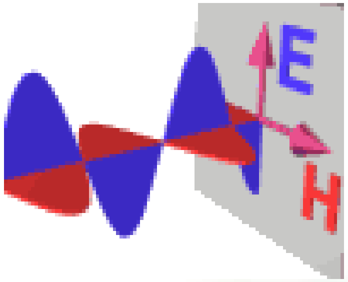


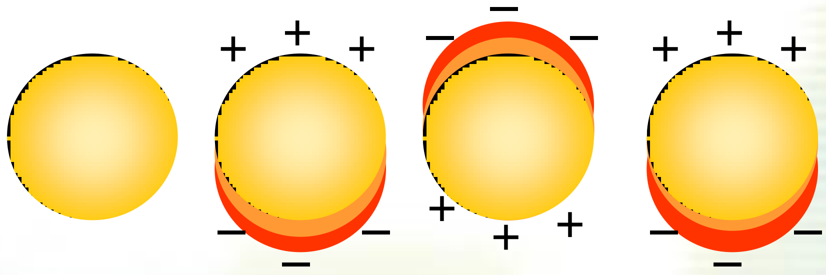


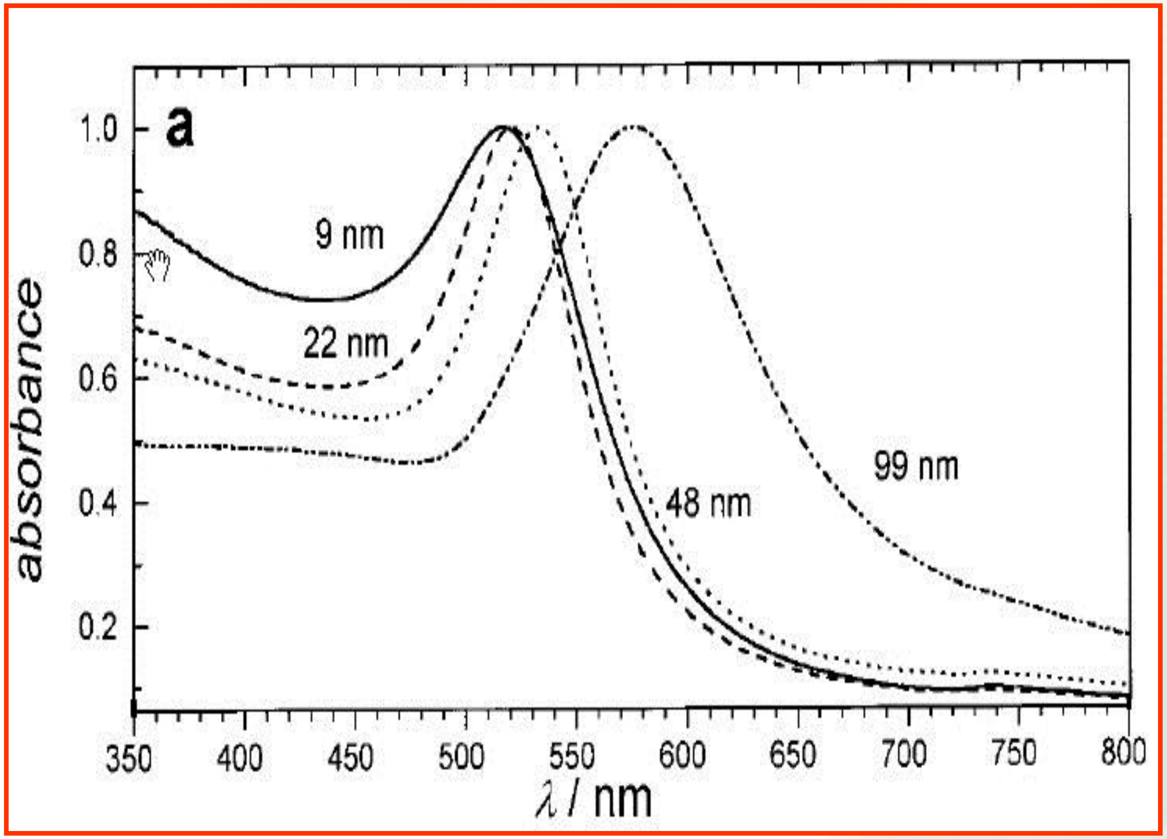
Giersig, M., et al., J. Phys. Chem., B 103, 9533-9539, 1999

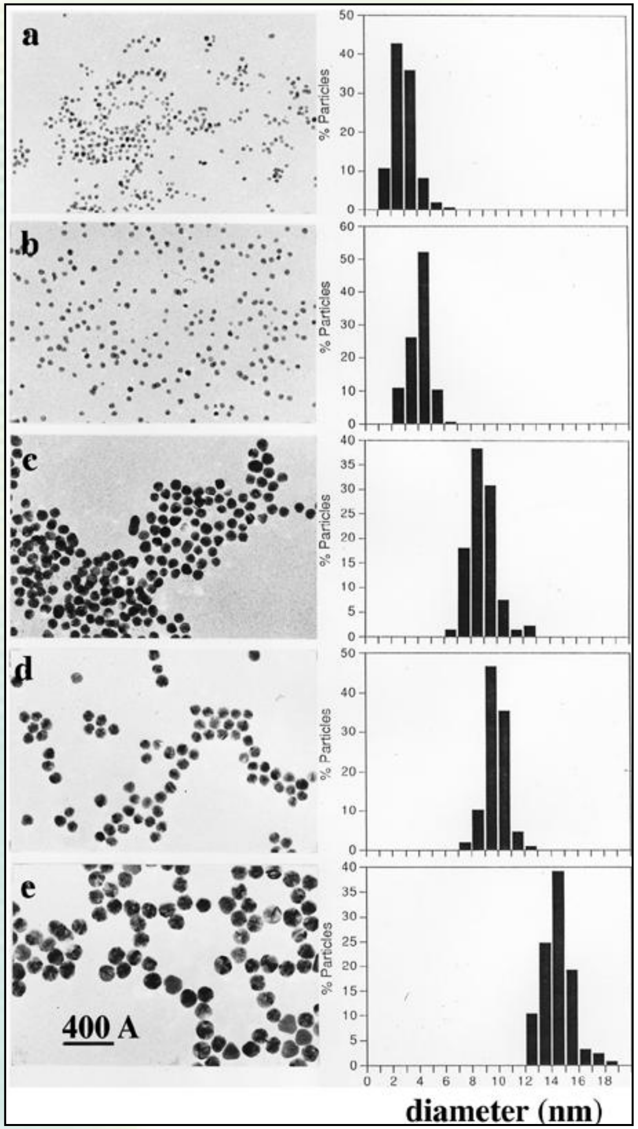
Metal: (Ag,Cu, Pt..) Au-particles

$$\omega_p = \sqrt{\frac{4\pi n e^2}{m}}$$



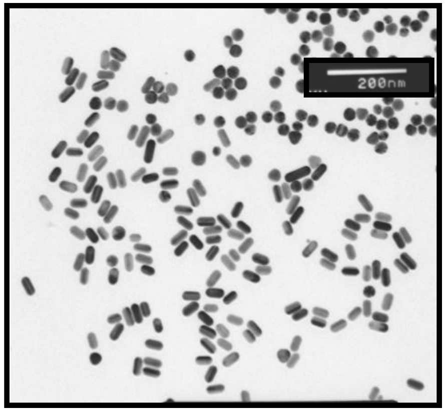




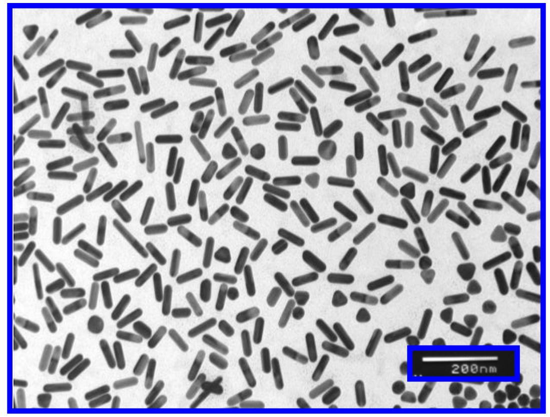


Fischer CH., and Giersig M., JOURNAL OF CHROMATOGRAPHY A 688 1-2 97-105 **1994**

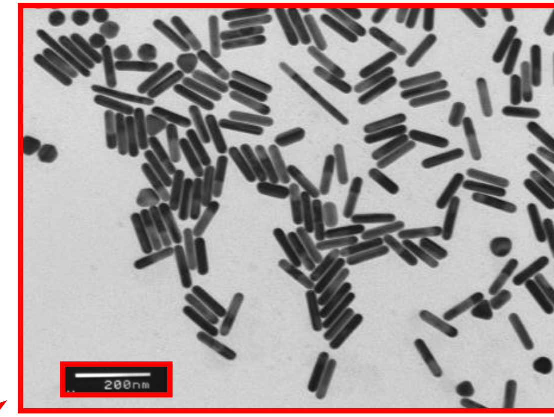
Different Aspect Ratios - Different Colours



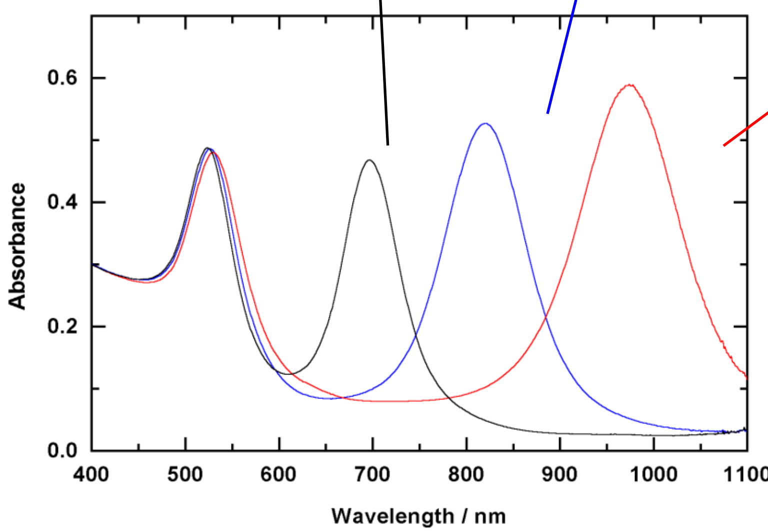
A.R.: **2.25**
Width: **20.7 nm**
Length**: 46 nm**

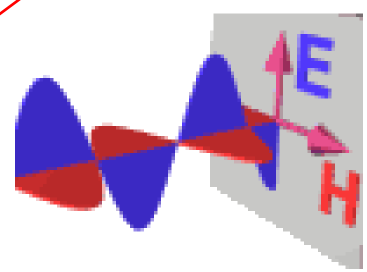


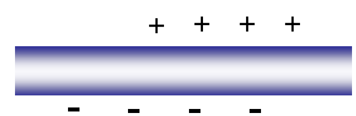
A.R.: **3.35**
Width: **22.4 nm**
Length**: 75 nm**

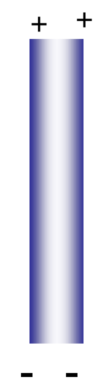


A.R.: **4.75**
Width: **22.8 nm**
Length**: 108 nm**





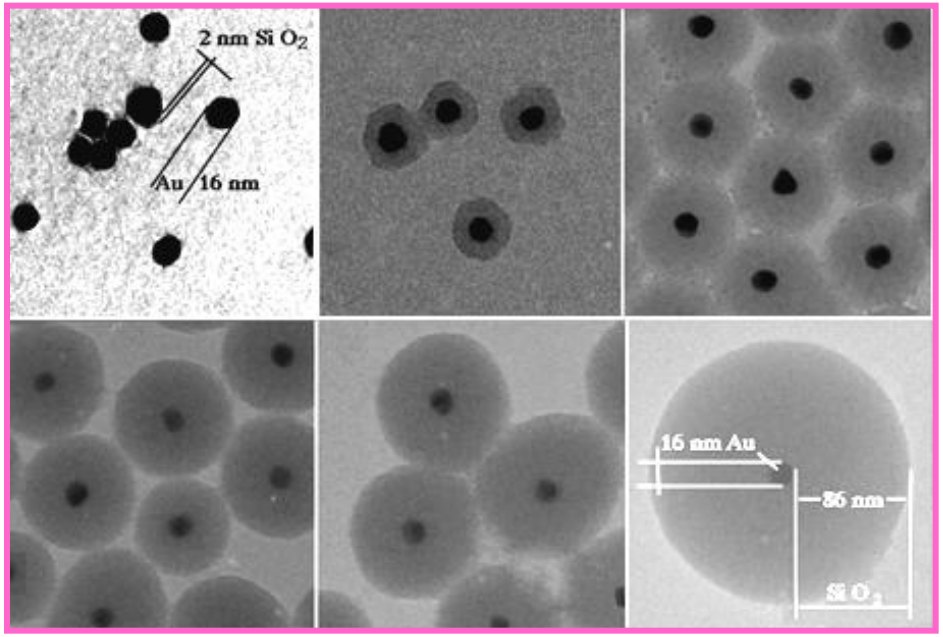




$$\boxed{\omega_p = \sqrt{\frac{4\pi n e^2}{m}}}$$

Pérez-Juste et al. Adv. Funct. Mat. 14, 571-579 **2004**
Pérez-Juste et al. Chem Soc Rev 37, 1783-91 **2008**
Pérez-Juste et al. Coord Chem Rev 249, 1870 **2005**

Successive growing process of SiO_2 on Au particles and their optical properites



Liz-Marzan L., Giersig M., Mulvaney P.,

LANGMUIR 12 4329-4335 **1996**

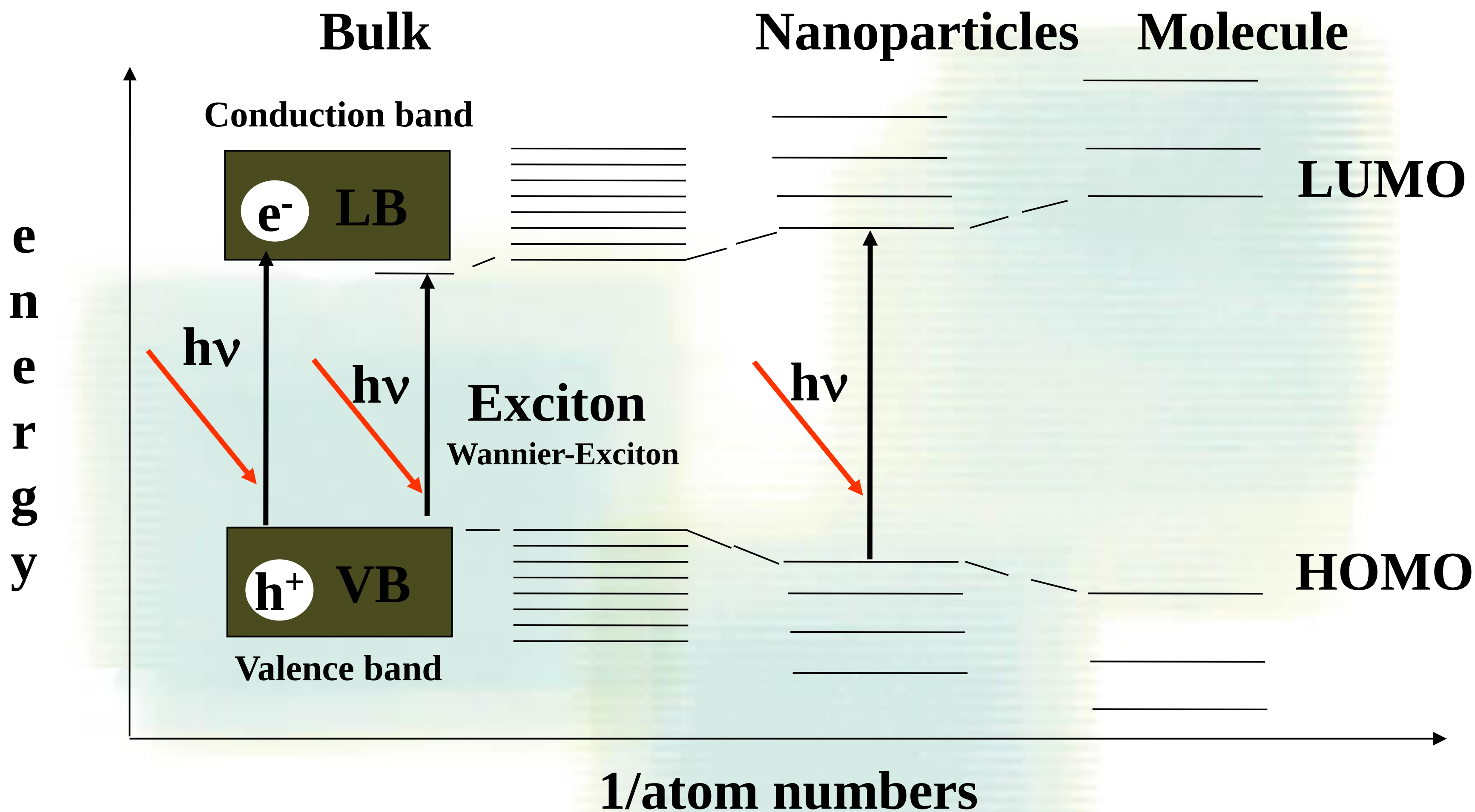
Giersig M., Ung T., Liz-Marzan L., and Mulvaney P.,

Advanced Materials 9, 570-575, **1997**

1 - is a sputter coated gold l0nm
2 -15 nm diameter Au-core particles + sodium citrate (0.5 nm)
3 -15 nm diameter Au-core particles +sodium mercaptopropionate (1.0 nm)
4-15 nm diameter Au-core +
5- 5 nm diameter Au-core +
6- 5 nm diameter Au-core +
7- 5 nm diameter Au-core +
8- 5 nm diameter Au-core +

Mulvaney P., Liz-Marzan L. M., Giersig M., and Ung T.,
J. Mater. Chem. 10, 1259±1270 **2000**

The electronic nature of the colloidal semiconductors

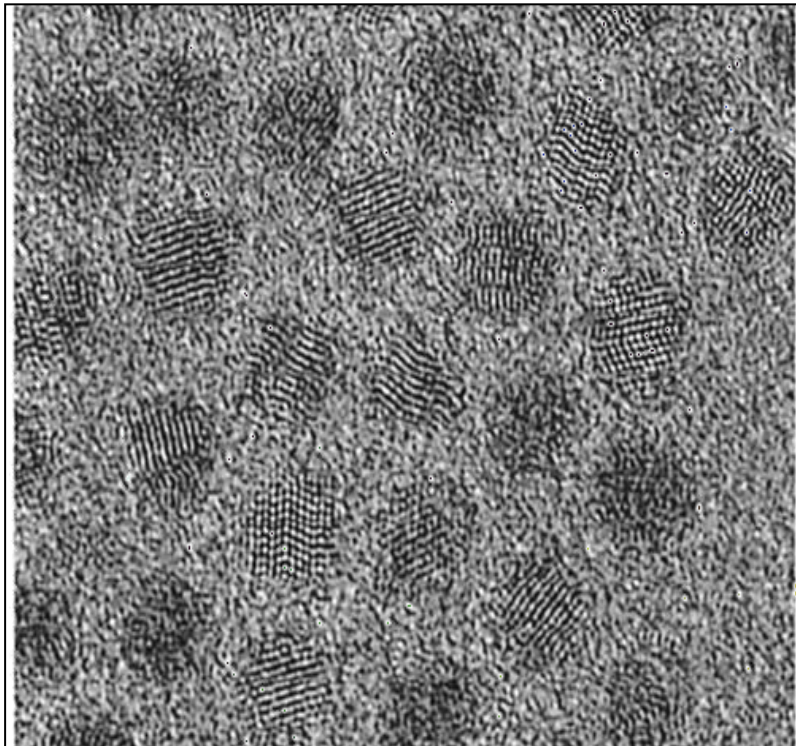


CdS binding energy =0.026
radius = 2.5 nm

CdS 5 nm
band gap = 2.5 eV
CdS 1 nm
band gap = 4.5 eV

band gap = > 5 eV

The nature of the colloidal semiconductors of different size

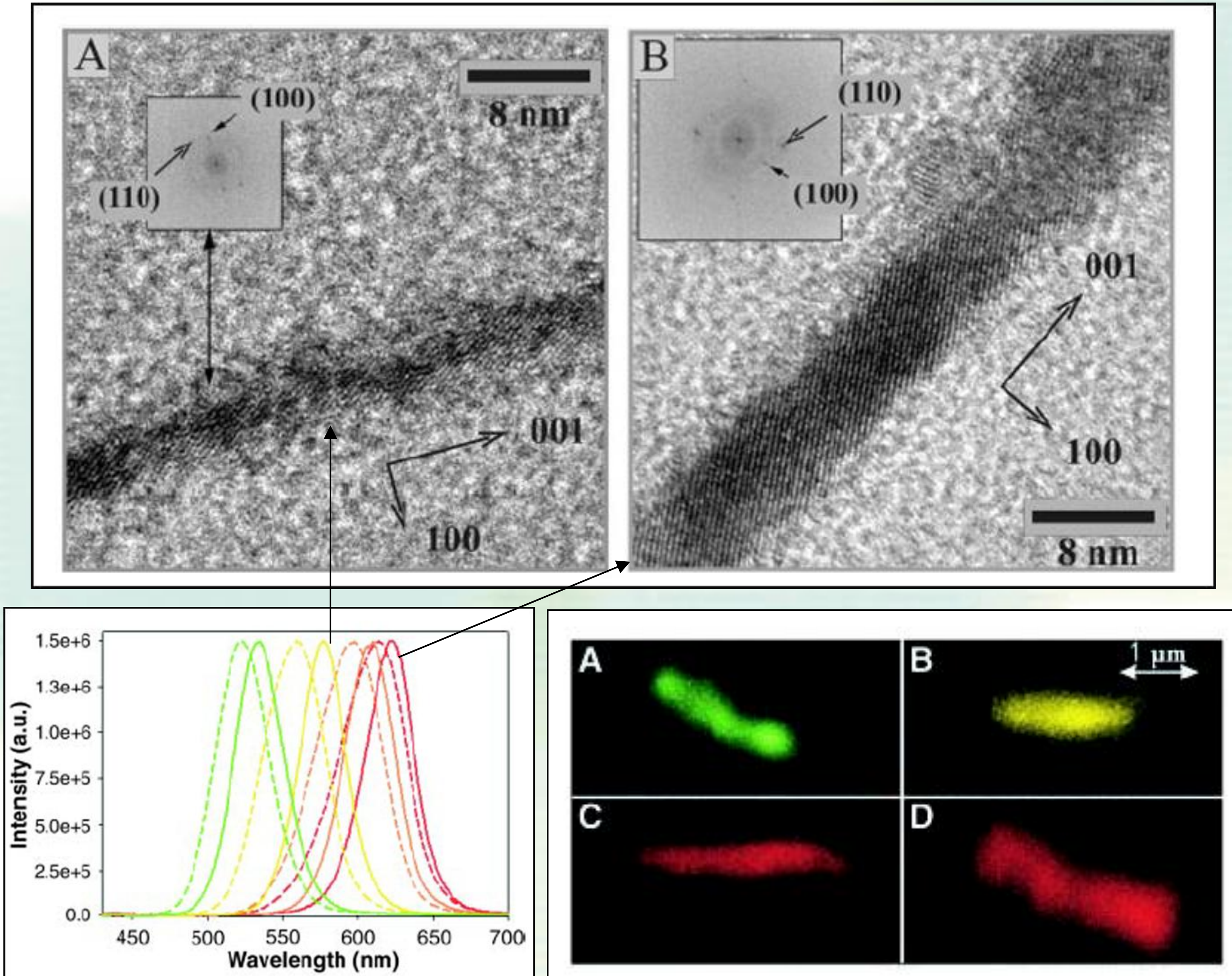


HRTEM CdSe/ZnS

Water stable, biocompatible CdSe/ZnS nanoparticles of different size (1,8--3,1 nm)

van Embden, J., Jasieniak, J., Gomez, E., et al.
Review of the synthetic chemistry involved in the production of core/shell semiconductor nanocrystals
AUSTRALIAN JOURNAL OF CHEMISTRY 60 7 457-471 2007

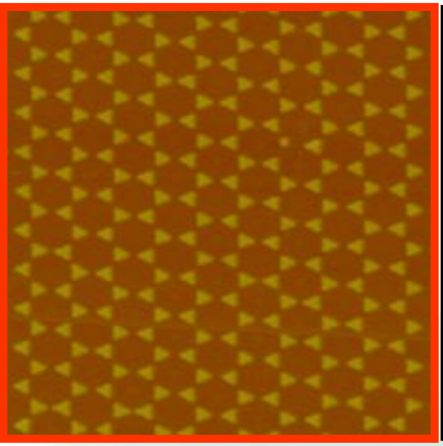
CdTe nanowires



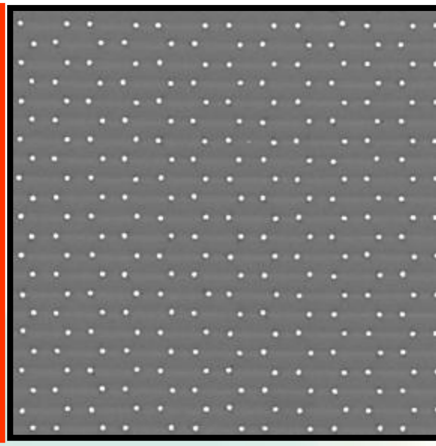
Tang, Z., Kotov, N., Giersig, M., Science 297, 237-240 **2002**

Selected Nanostructures produced by physical method

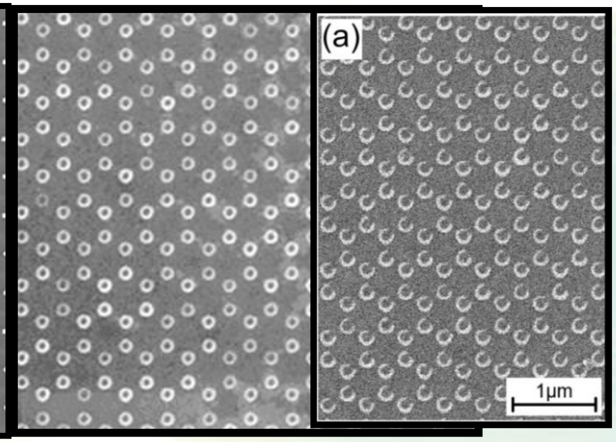
Triangles



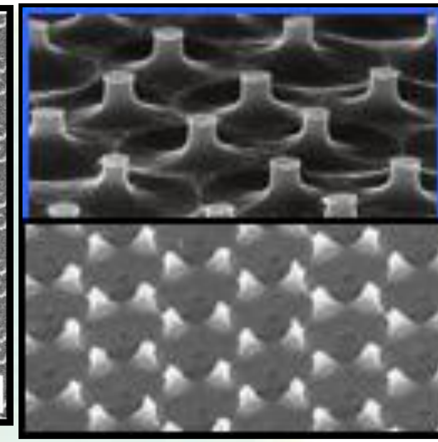
spherical shape



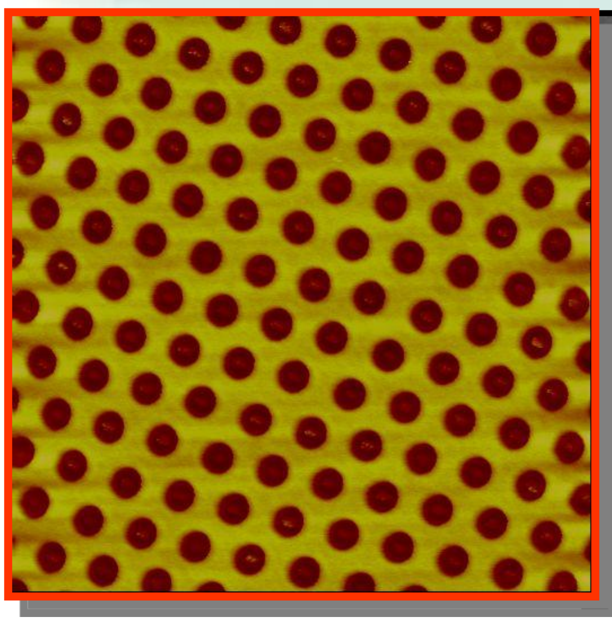
Nanorings



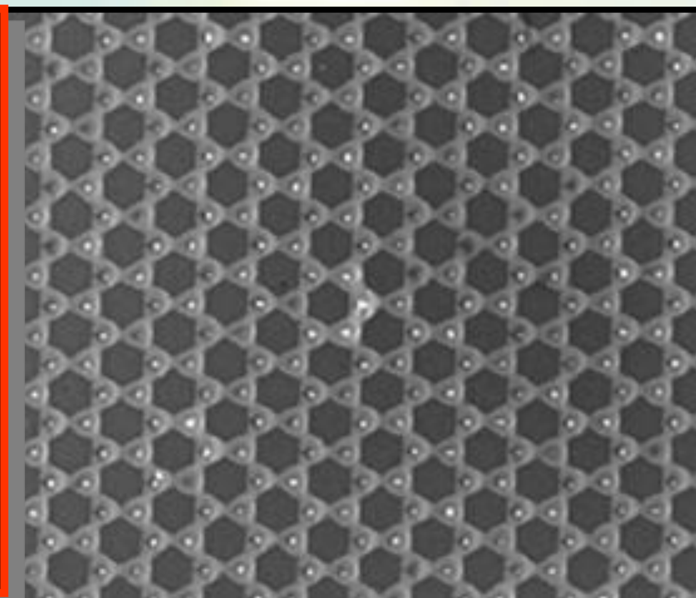
Pillars/Pyramids



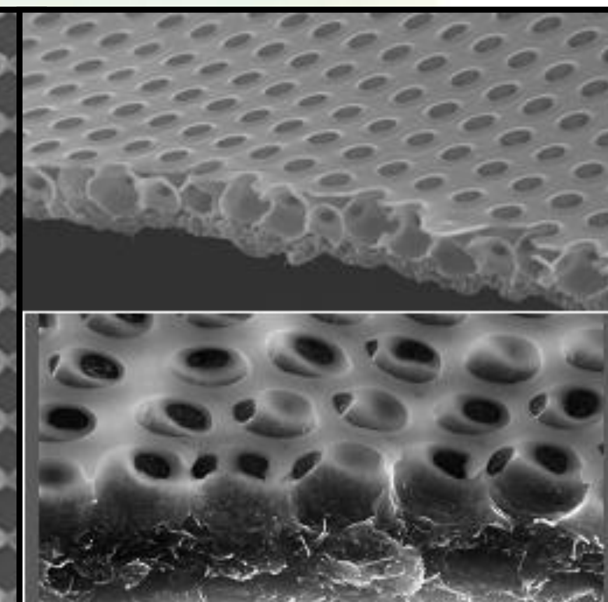
Nanoholes



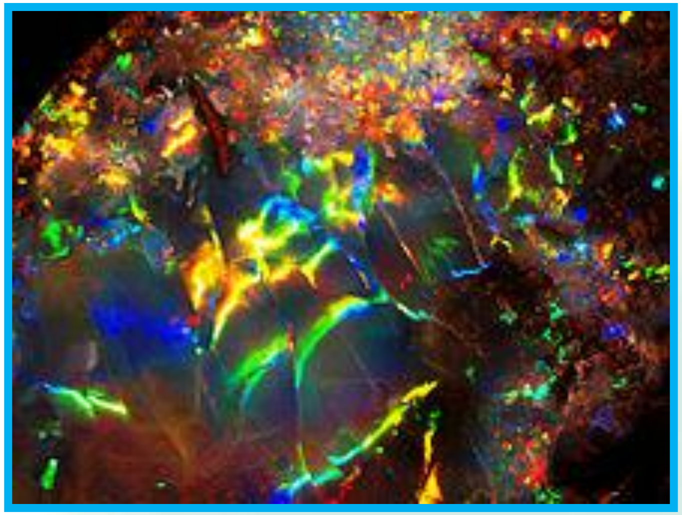
Bimetallic

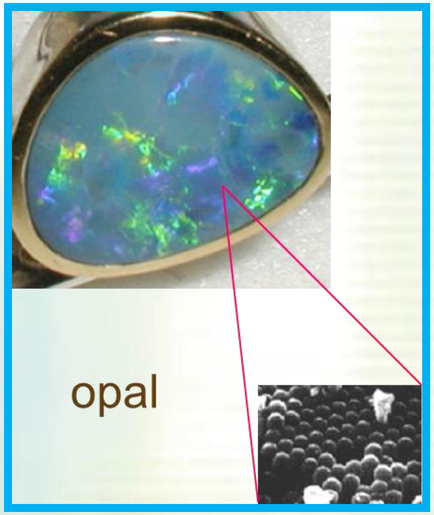


3-D Structures

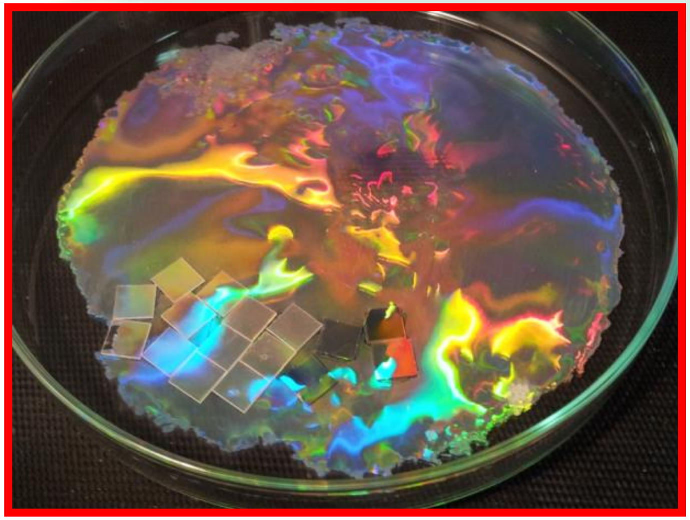


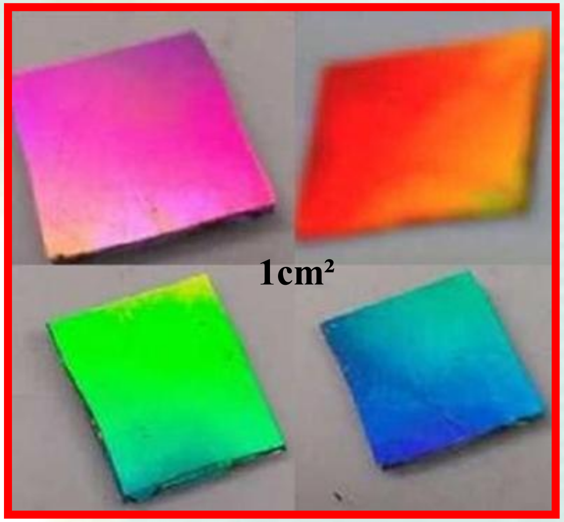
Examples of natural and artificial made Opals





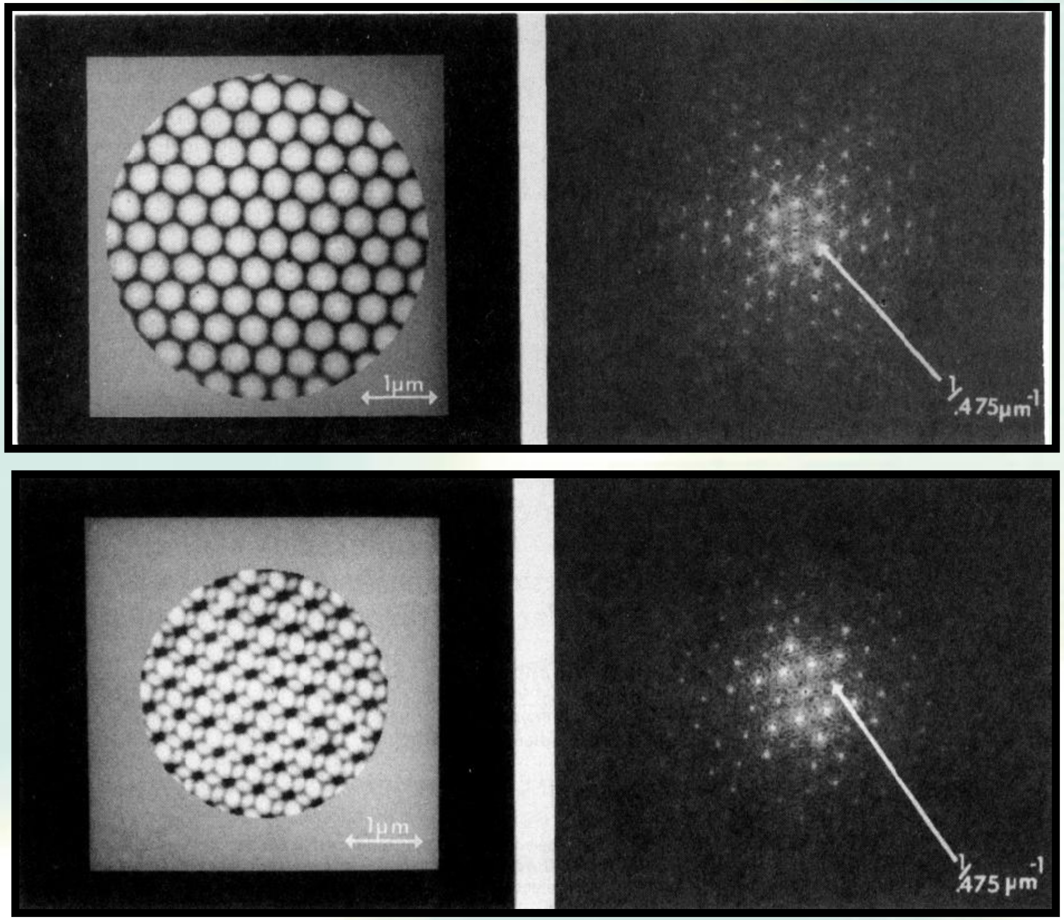
An opal bracelet.
The stone size is 18 by 15 mm.
Opal is composed of silica spheres
some 150 to 300 nm in diameter in
a hexagonal or cubic close-packed lattice





Photographs of 2-D a hexagonal
close-packed lattice based on
490 nm in diameter Latex particles

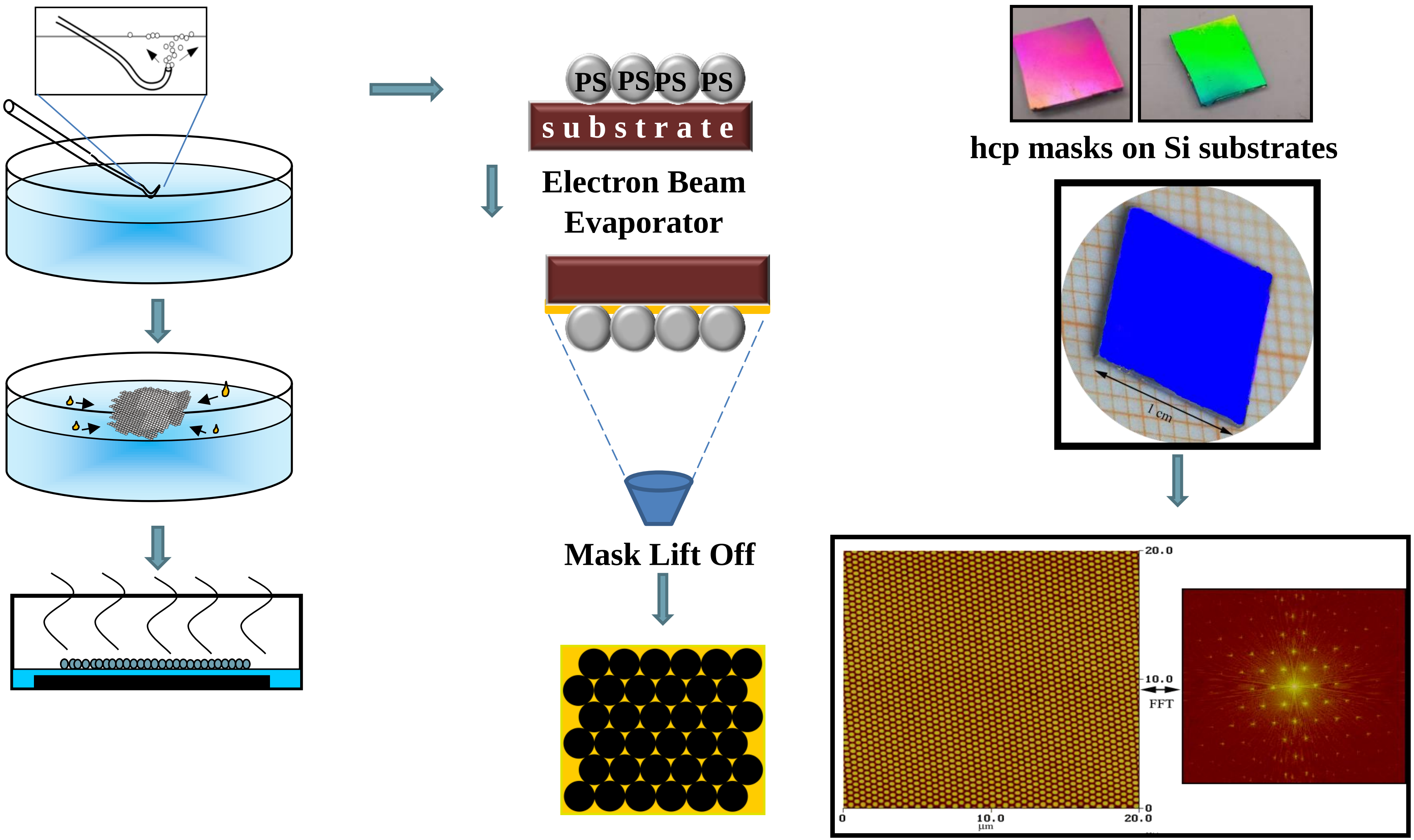
2D ordered latex monolayer prepared by electrophoresis



In the left row TEM images of the 2-D and 3-D structures based on Latex particles with the mean particle size of 440 nm and their Fourier transform respectively, showing numerous higher order reflexes (right).

Giersig M. and Mulvaney P.
Preparation of Ordered Colloid Monolayers by Electrophoretic Deposition; Langmuir 9, 3408-3413**, 1993**

General introduction to NSL



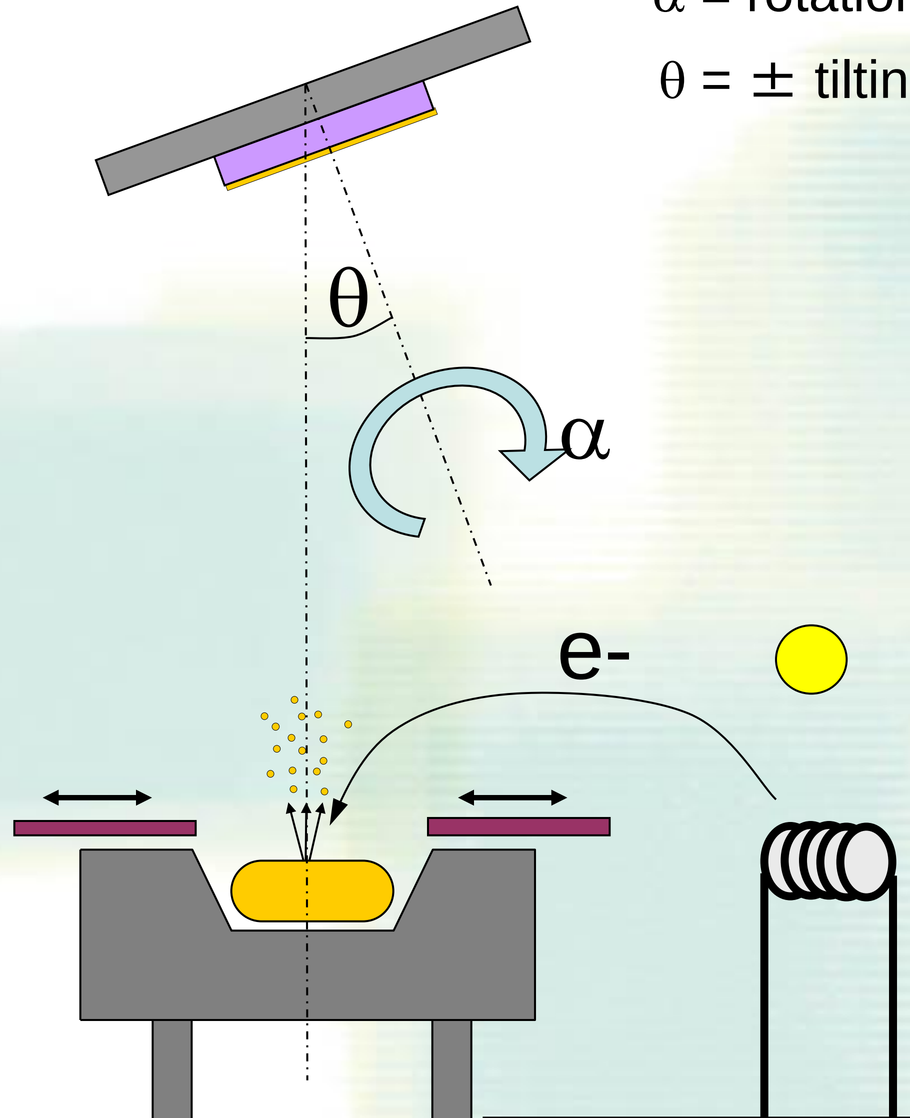
Rybczynski J., Ebels U., Giersig M.,

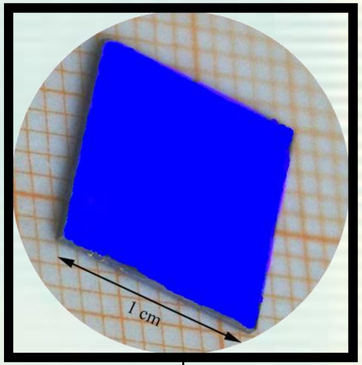
Large-scale, 2D arrays of magnetic nanoparticles; COLLOIDS AND SURFACES A 219 1-3 1-6 **2003**

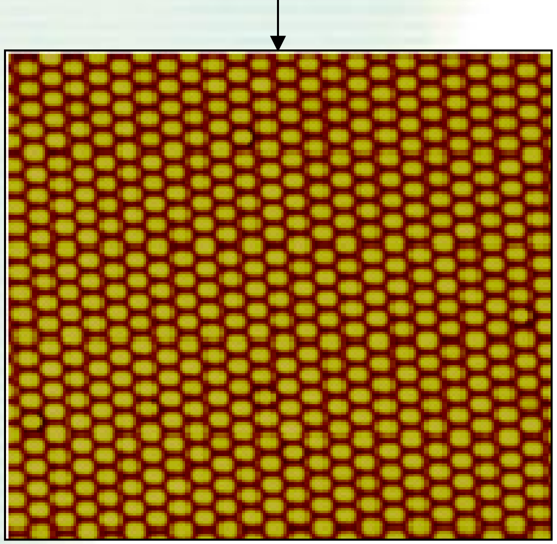
Geometry of an electron beam evaporation system

α = rotation

θ = $\pm$ tilting angle



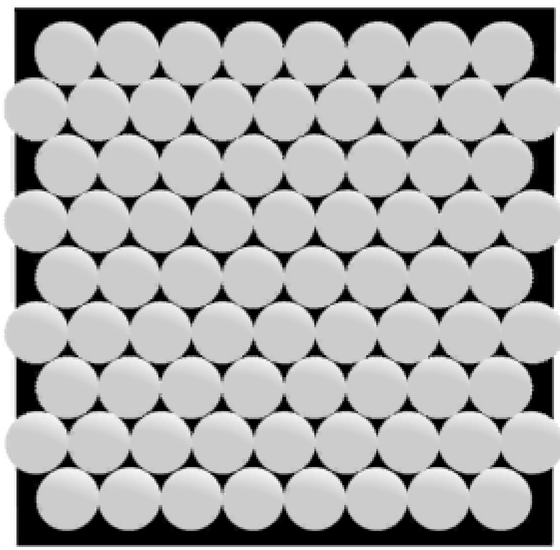


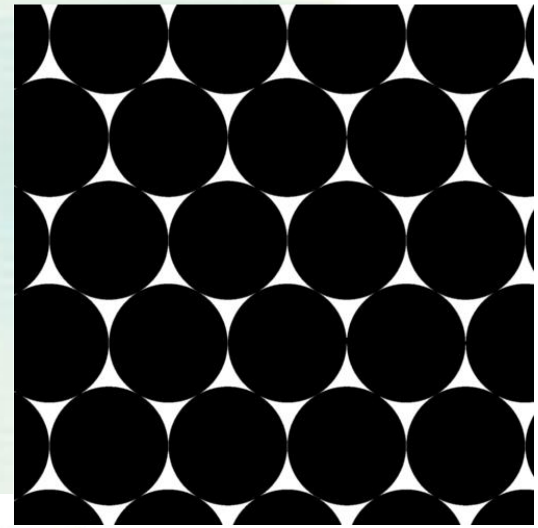


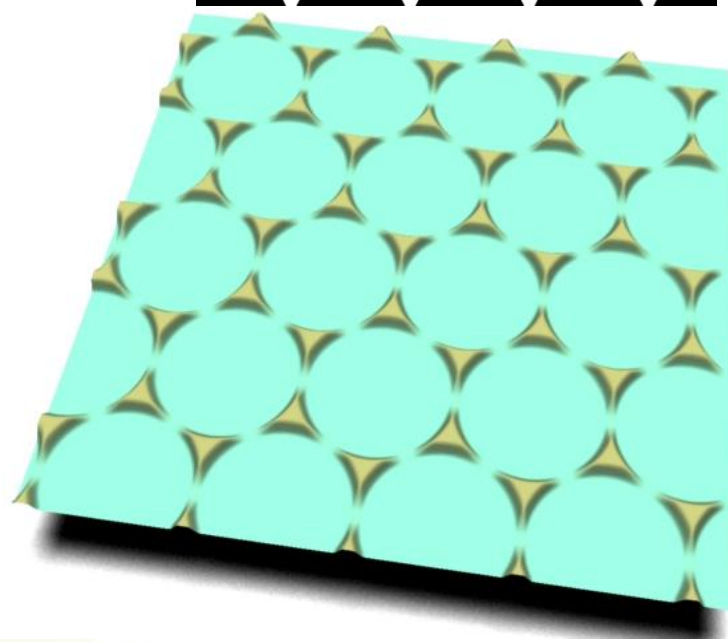
Shadow nanosphere lithography: Simulation and experiment
Kosiorek A., et al. NANO LETTERS 4 1359-1363 **2004**

Simulation

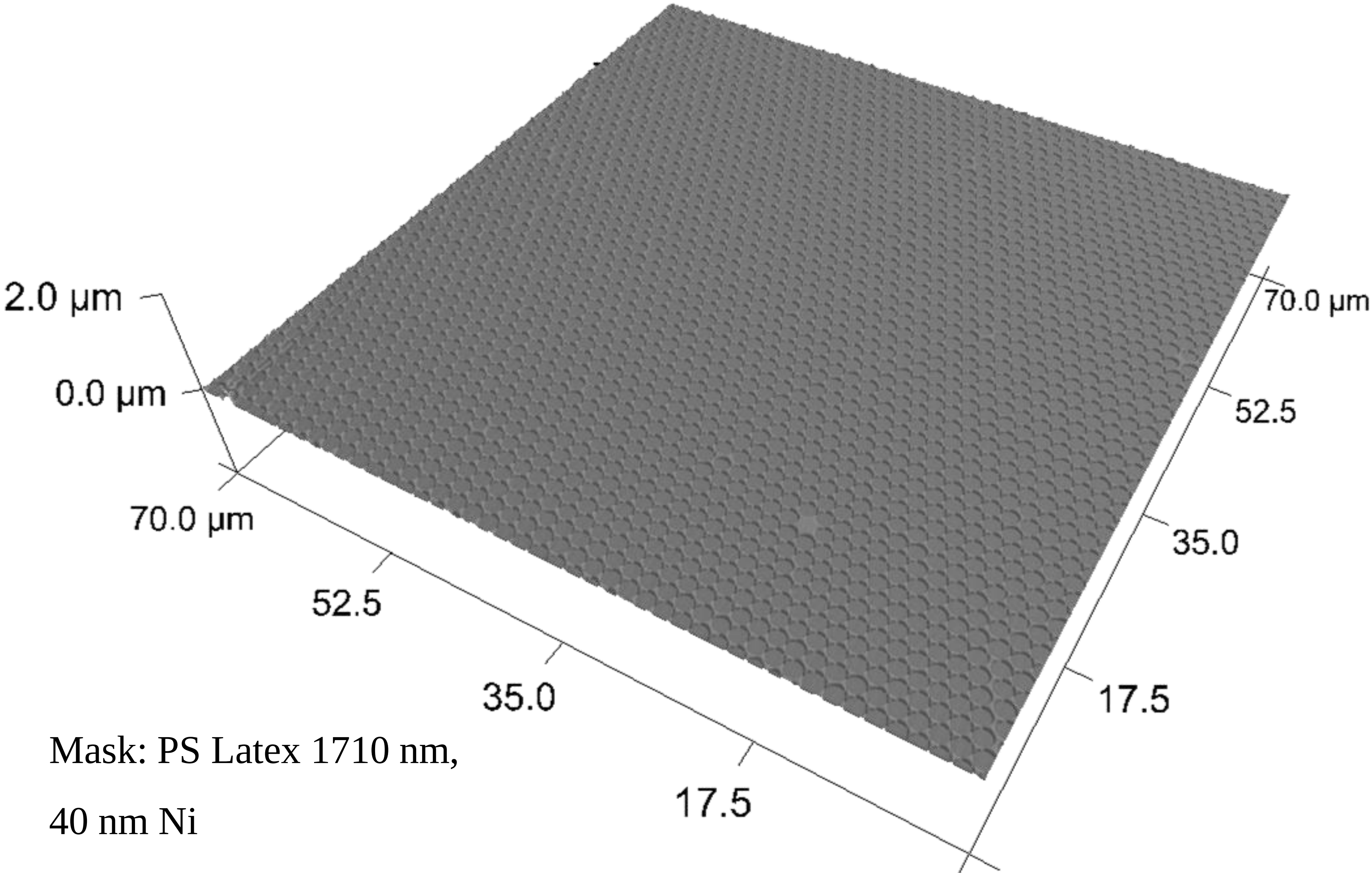
evaporation angle 90°







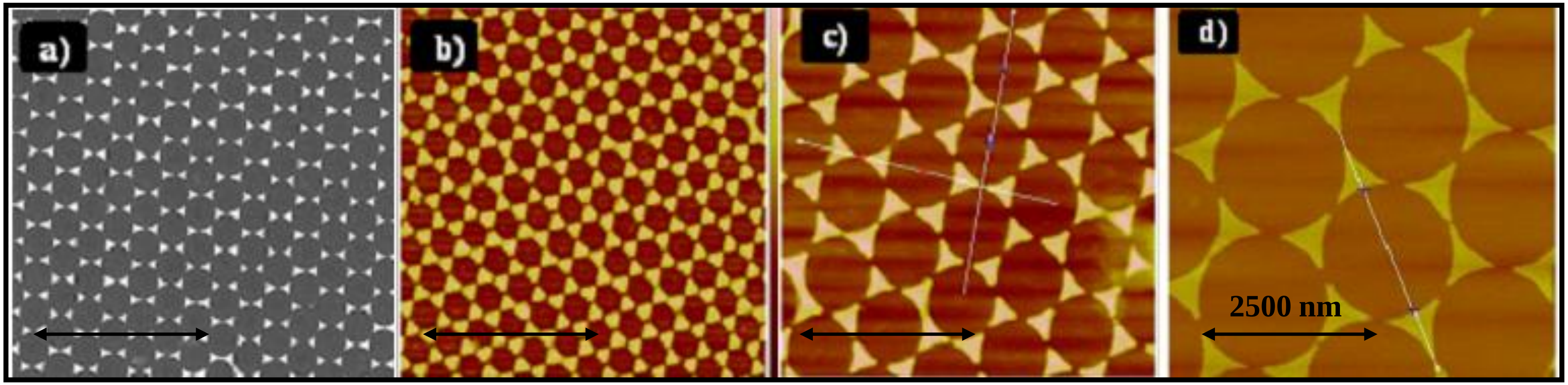
Large 2-D nanotriangles structures



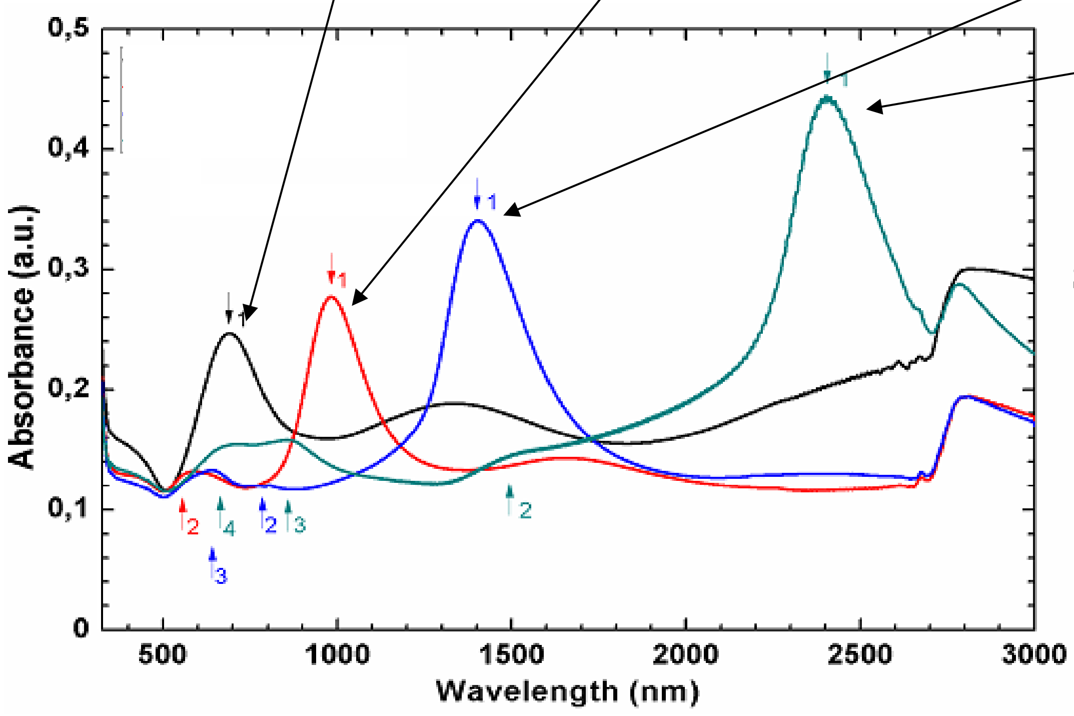
Mask: PS Latex 1710 nm,

40 nm Ni

Plasmonic properties of array of triangular shaped gold nanoislands



PS-diameter a = 380 540 980 1710 nm



The experimental spectra for 20 nm thick Au triangles on a sapphire substrates

Important!!

The spectra exhibit first (most pronounced) Second and third and fourth absorbance peaks

It is expected, that these resonances are from a highly dispersive, plasmon polaritonic mode since similar resonances have been observed in metallic particles

Theoretical approach

The experimental spectra shown for structures obtained with sphere diameters a = 380, 540, 980, 1710 nm,

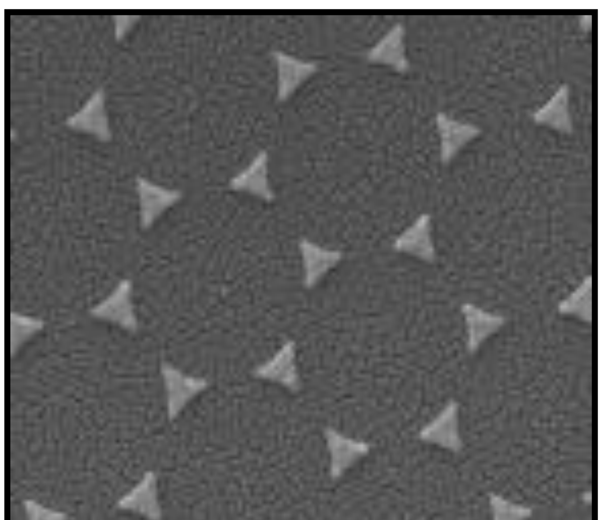
Each spectrum is dominated by a pronounced resonance peak, position of which strongly depends on a.

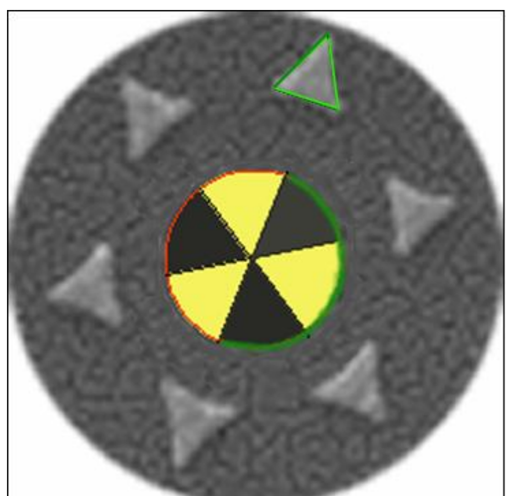
We assume, that these resonances can be viewed as circumferentially quantized surface plasmon waves and ignore the particle-particle interactions.

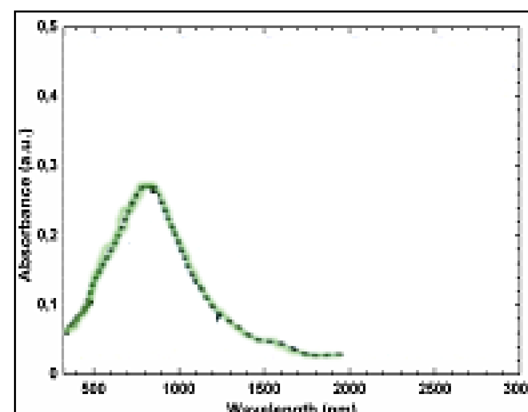
Since each side of the quasi-triangul  **particle equals approximately 1/6 of the sphere circumference π a**

The circumference of the particle ~ π a/ 2 and thus the circumference quantization condition requires that this circumference is equal an integral multiple (l) of the wavelengths of the resonating surface/edge plasmon wave (λ p)

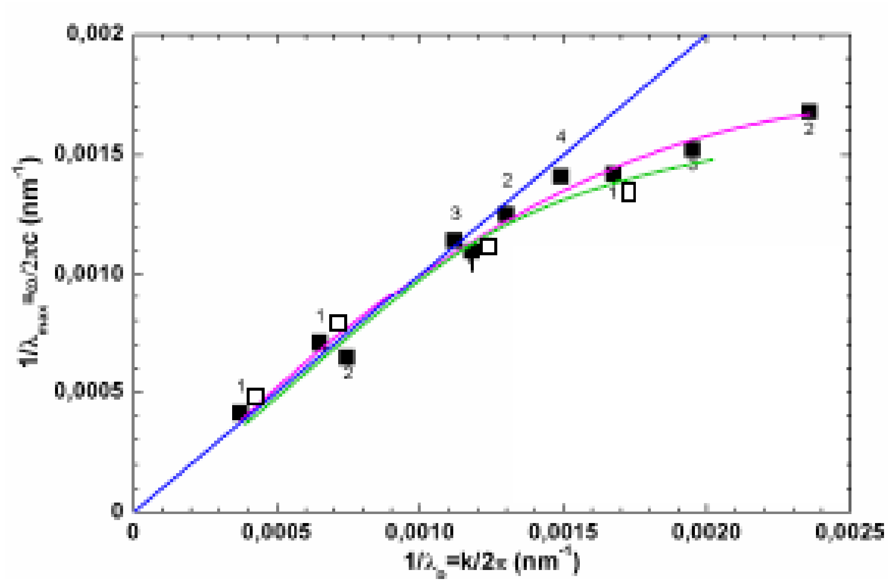
$$\boxed{l\,\lambda_p \sim \pi\, a/\,2}$$



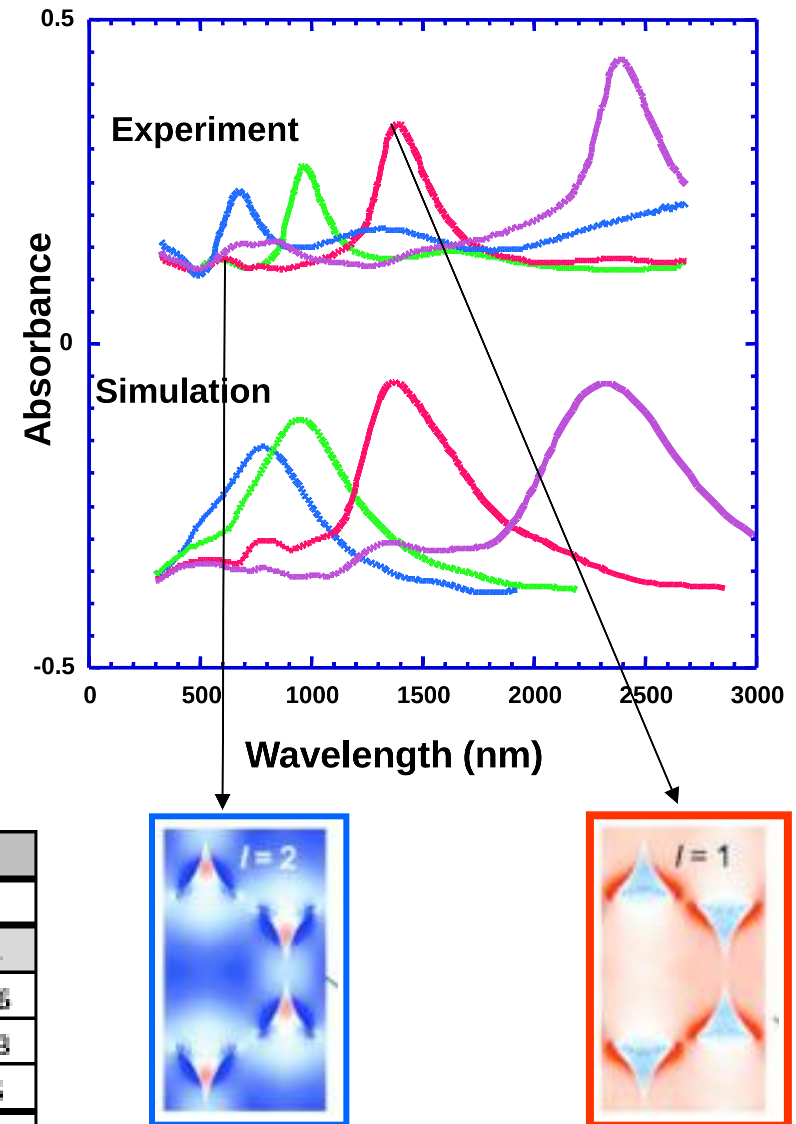




Surface plasmon resonances in metallic nanoparticles:



Simulated dispersion of the resonating surface/edge plasmon (white squares)

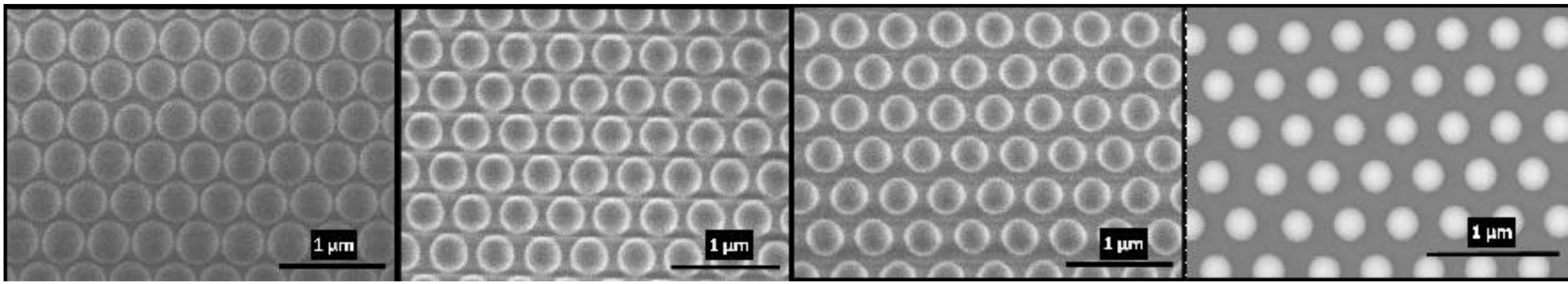


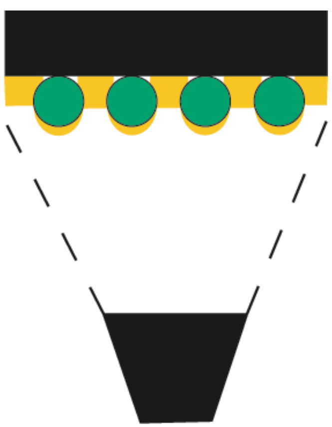
	D_0[nm]							
	380		540		980		1710	
l	λ_{max}	λ_{SP}	λ_{max}	λ_{SP}	λ_{max}	λ_{SP}	λ_{max}	λ_{SP}
1	704	597	996	848	1417	1539	2417	2686
2	-	298	596	424	799	769	1551	1343
3	-	198	-	282	658	513	875	895
4	-	149	-	212	-	385	709	671

Marcoux C., et al. Appl. Phys.Lett. 96, 133104 **2010**

2-D nanocylinders :
Light Transmission and manipulation of dielectric constant

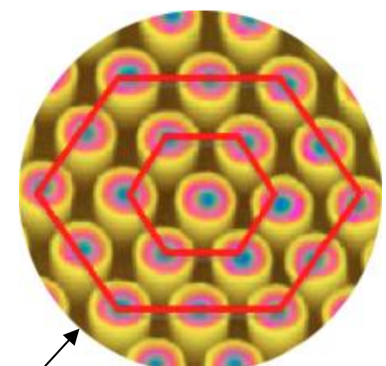
Mask modification - reactive ion etching (RIE) for reduction of PS-diameter





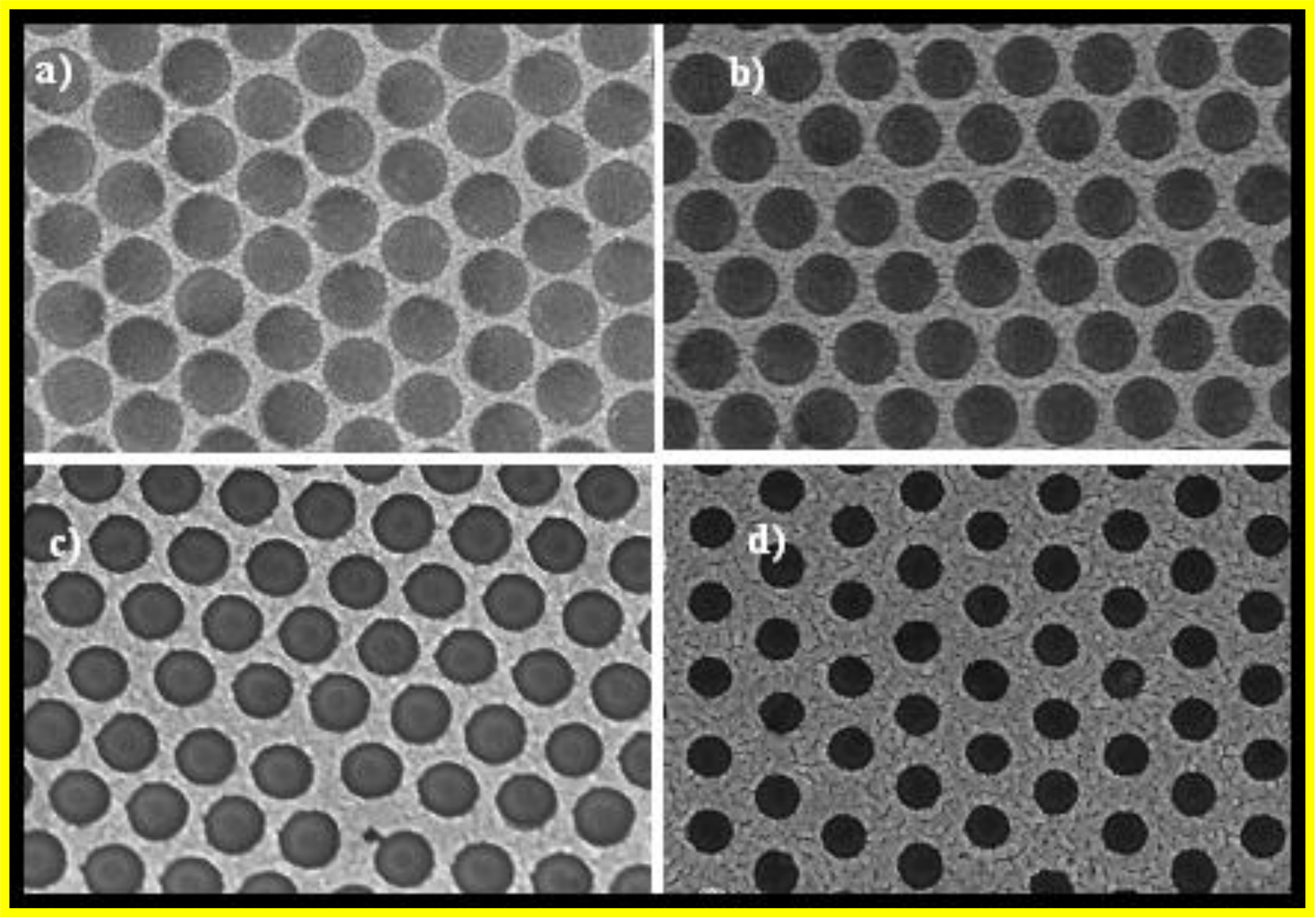
- Evaporation of desired
material with MBE

- 35nm Au
- 15nm Fe
- 35nm Au
- 2nm Ti
- Al_2O_3 - substrate



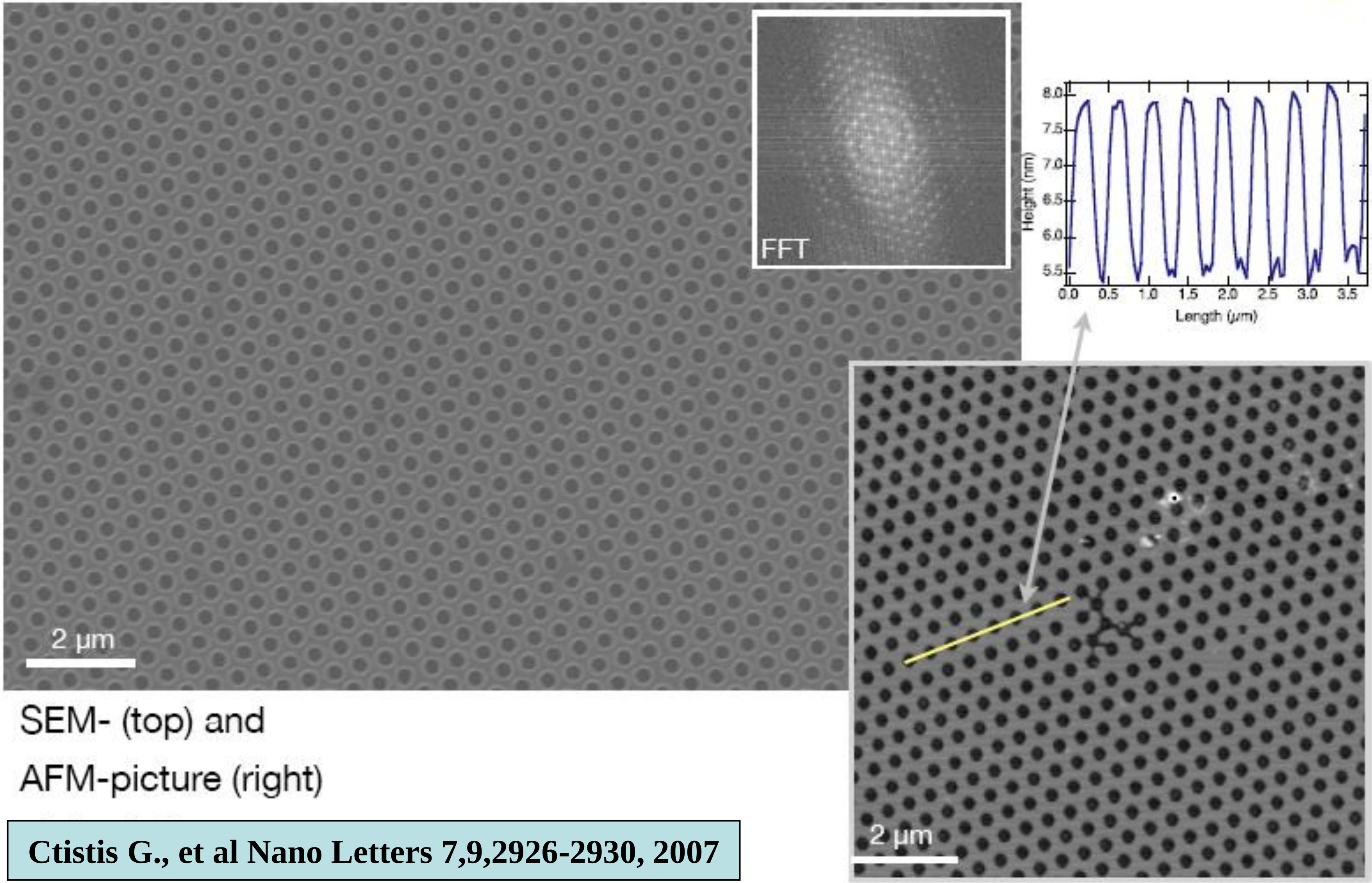
Removal of PS-spheres leads to film with hexagonal array of nanocylinders

Example of 2-D arrays of nanocylinders



SEM images of nanocylinder arrays. Diameter of single hole is a) 385nm, b) 340nm, c) 325nm and d) 265nm

Characterization of 2-D structures



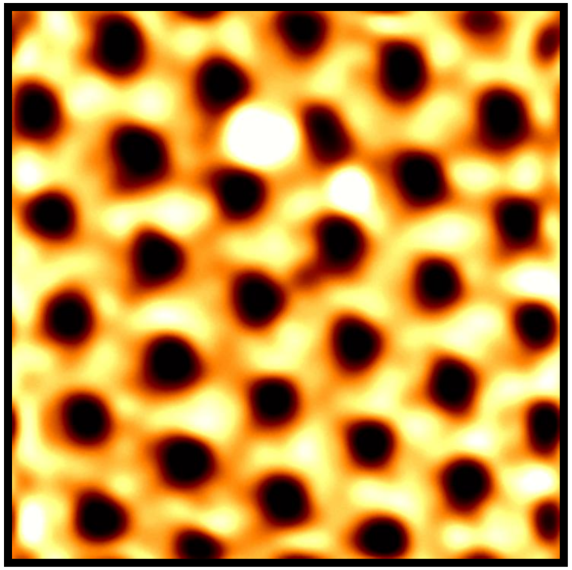
SEM- (top) and

AFM-picture (right)

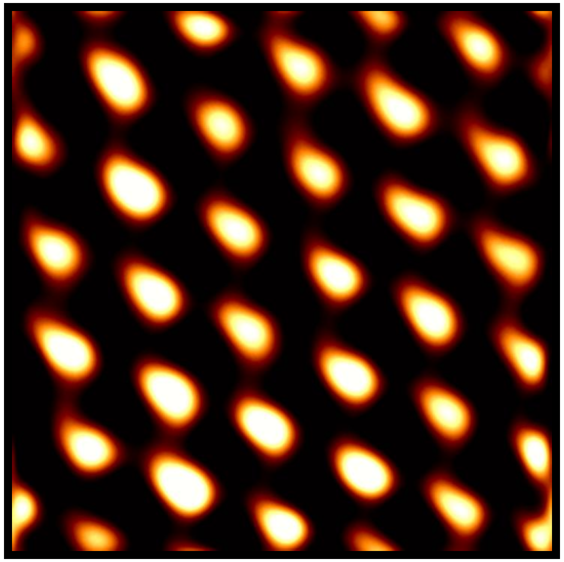
Ctistis G., et al Nano Letters 7,9,2926-2930, 2007

Nano-hole arrays / Plasmonic metal

SNOM pictures for a 50 nm thick gold film



topography



near-field optics

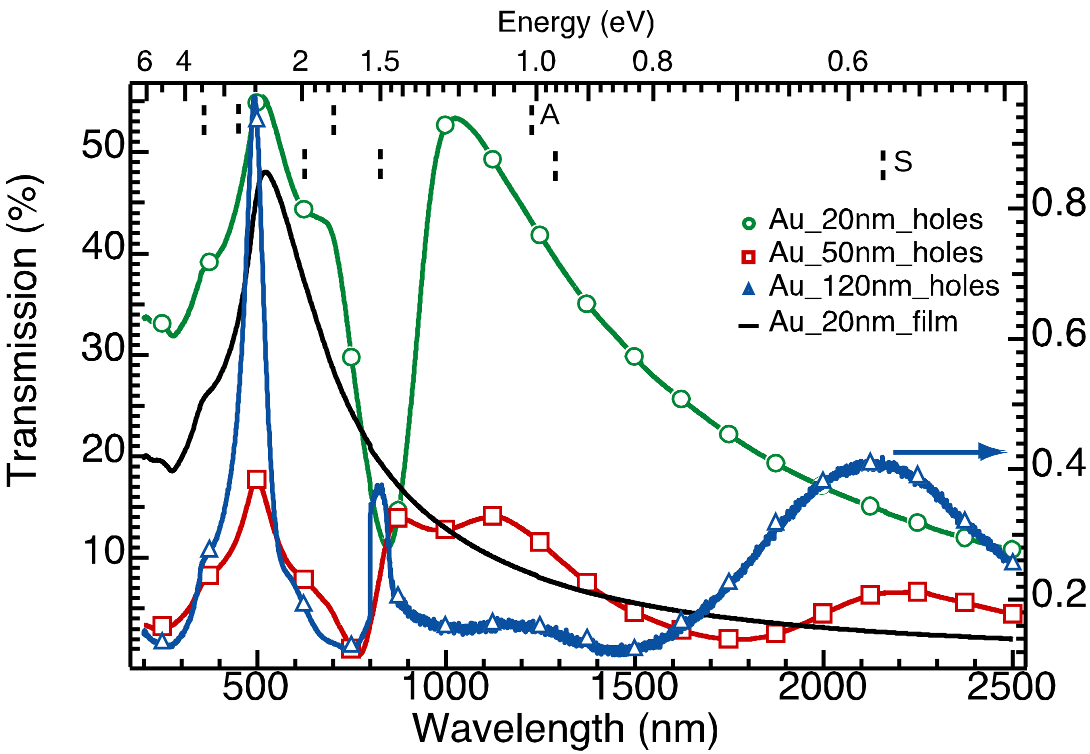
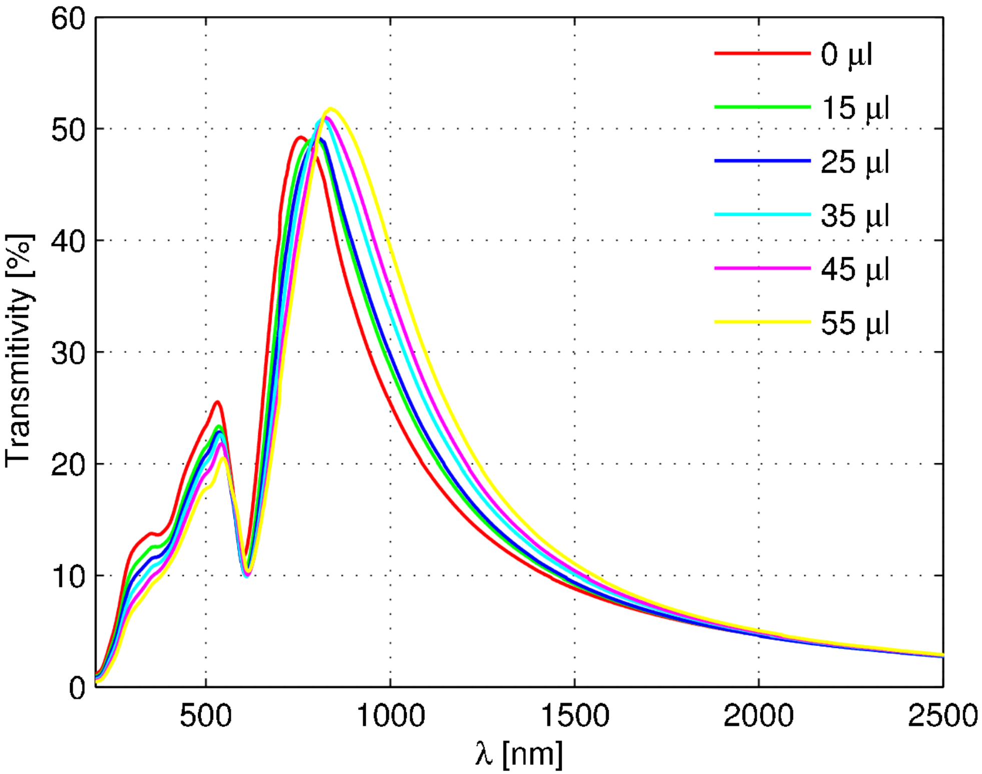


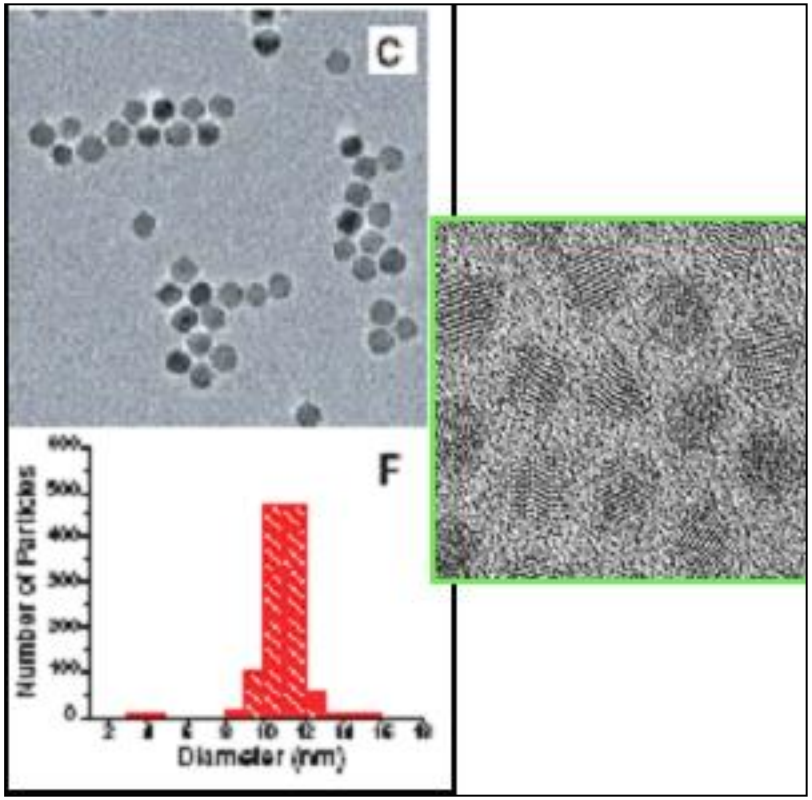
Image size: $(3.5\ \mu m)^2$

○ Main transmission path through the holes

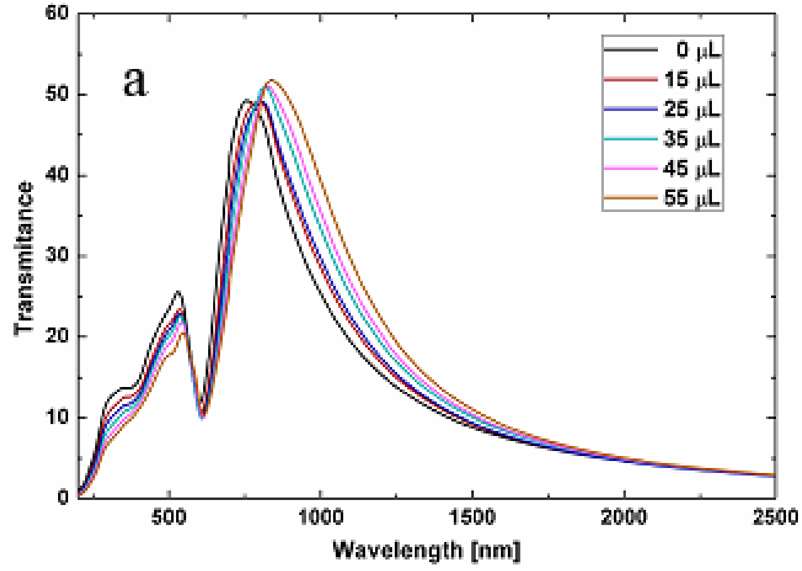
Au/Fe/Au – influence of Fe_3O_4 particles

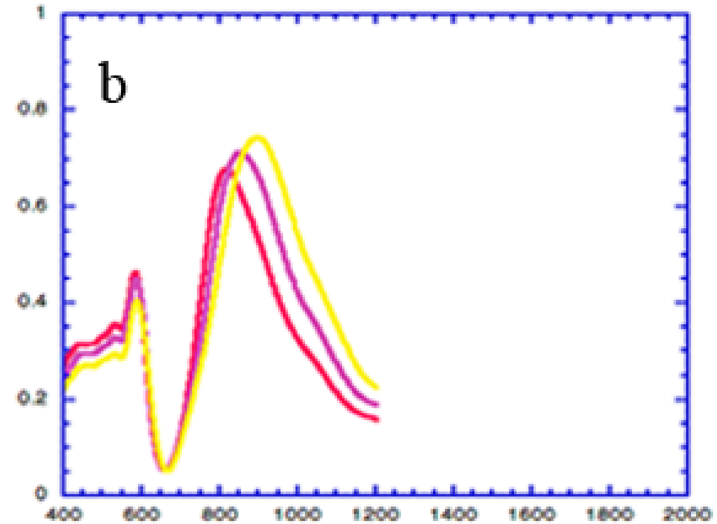
- subsequent addition of Fe3O4 nanoparticles on the sandwich structure introduced changes in the position and intensity of the transmission peaks

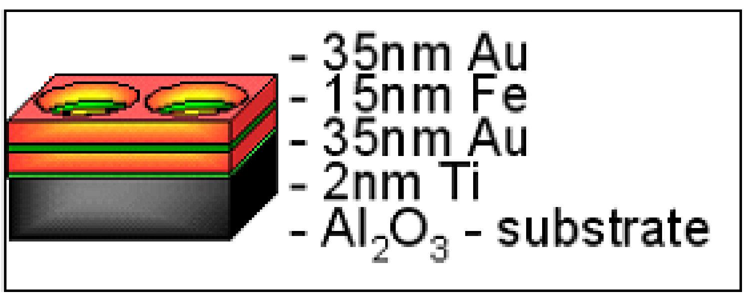


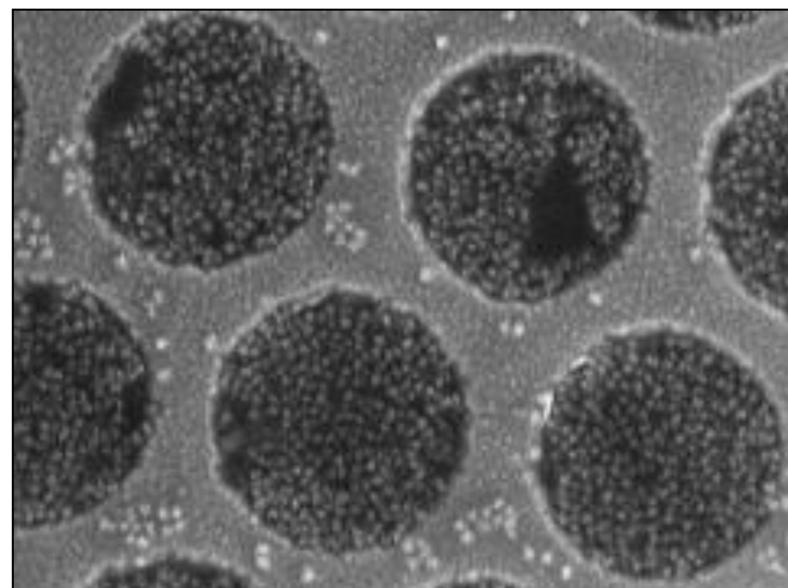


Fe_3O_4 deposition inside the nanocylinders



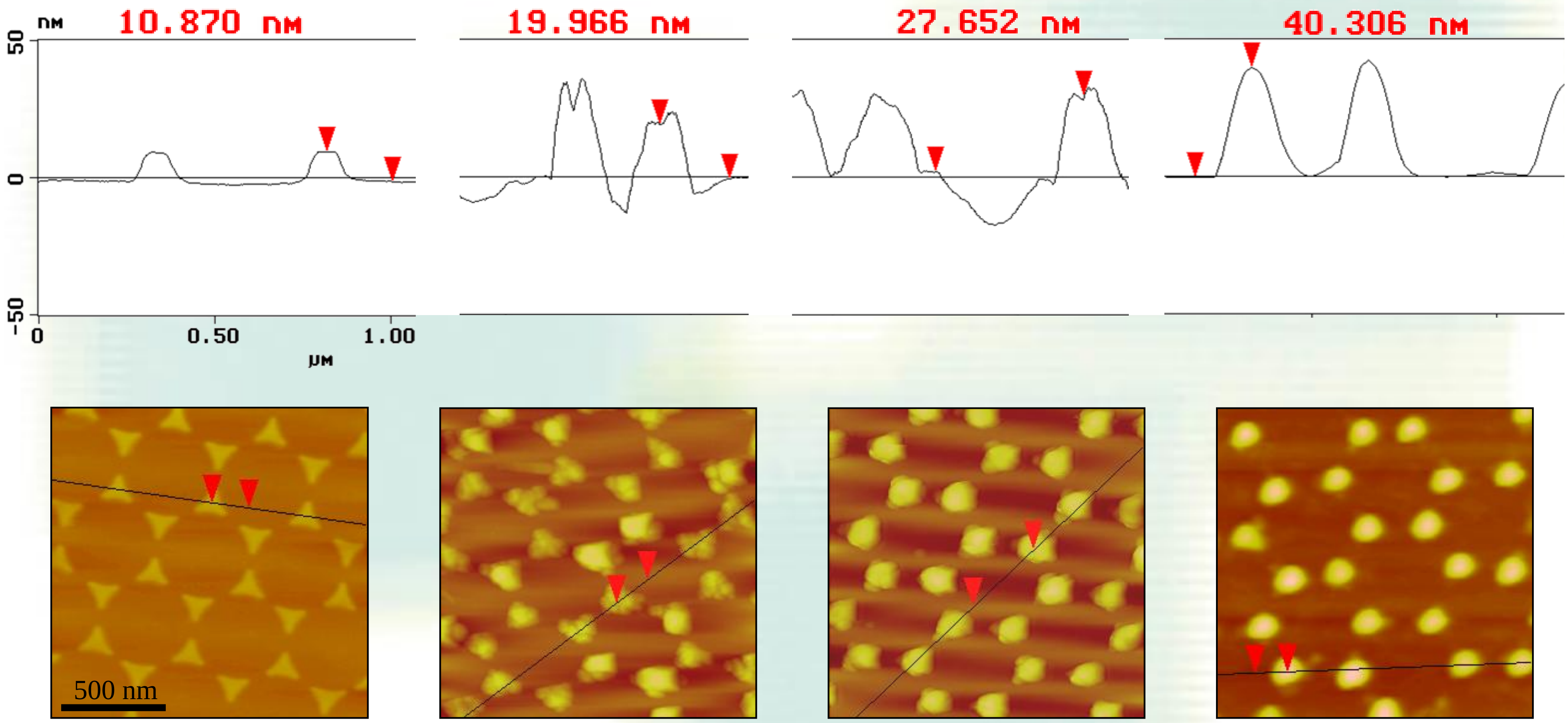






Transmission of light through magnetic nanocavities
Patoka P., et al. Small 7, 21, 3096-30100 **2011**

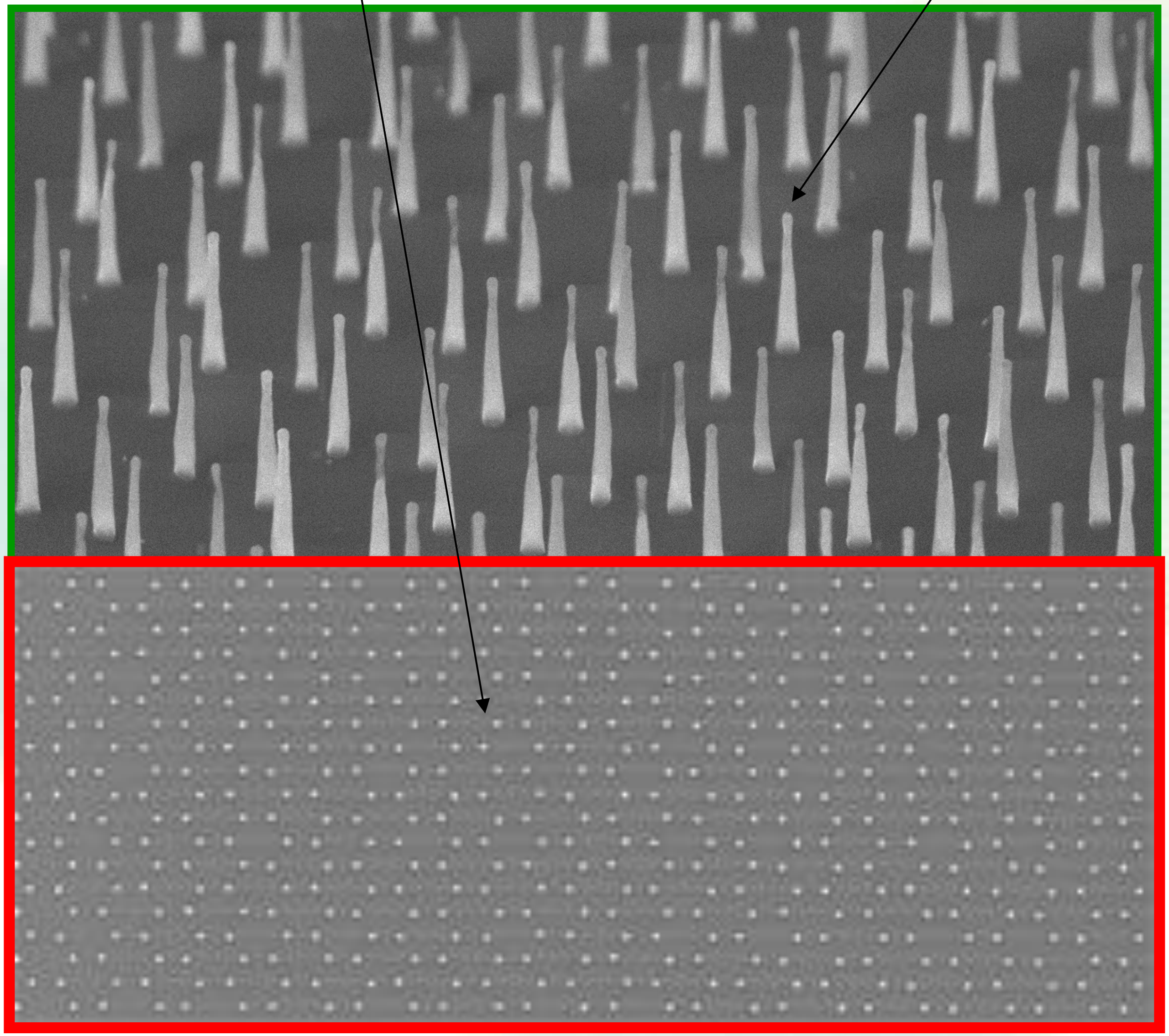
Modification of morphology



RT 750° C 850° C 950° C

10 nm Ni evaporated through 496 nm latex beads mask after annealing for 50 min.

Application of nanocatalyst for growth of Carbon Nanotubes

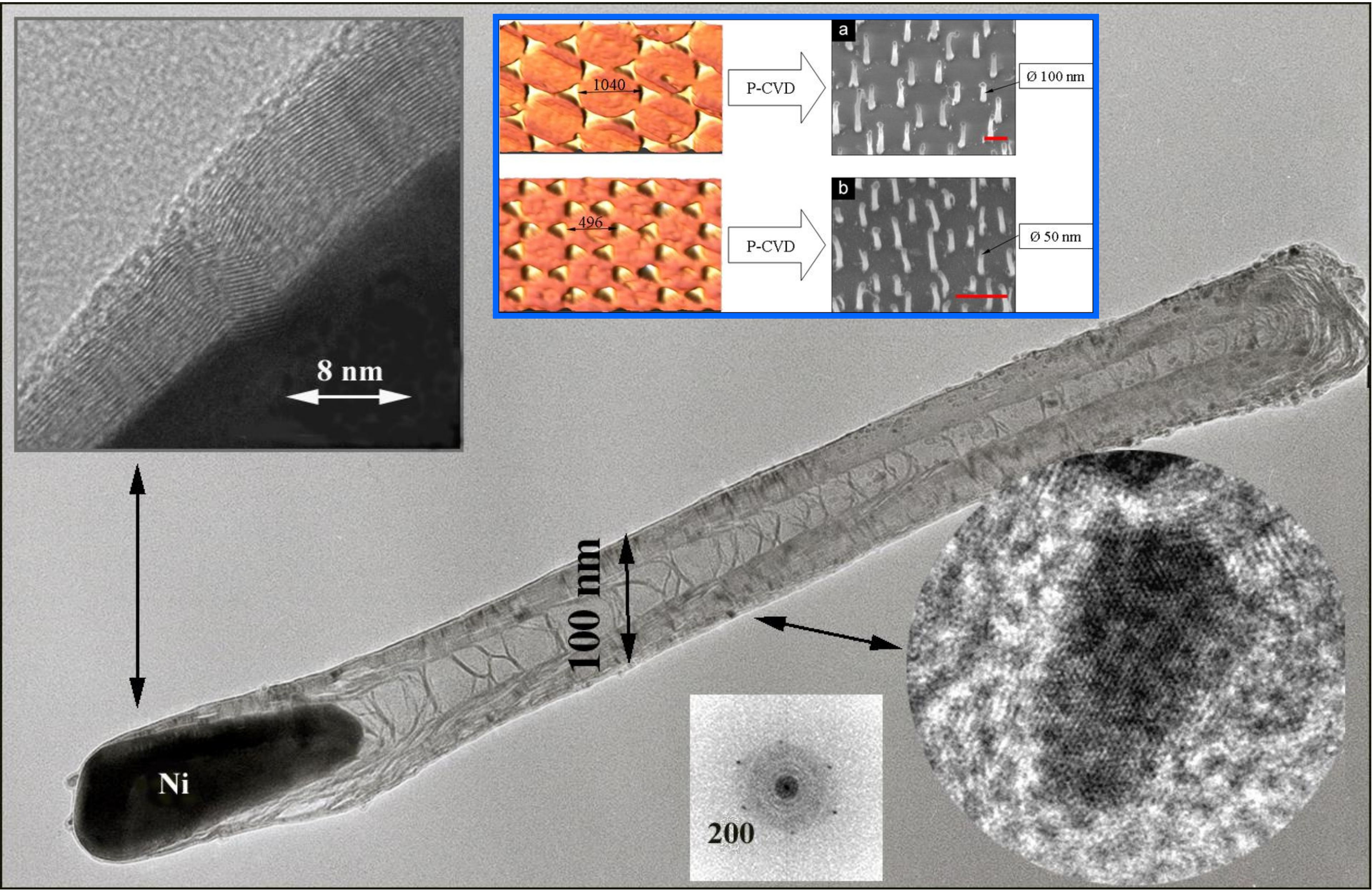


Multiwalled carbon nanotubes prepared in P-CVD from triangle-shaped 200 nm nickel particles

Kempa K., et all; NanoLetters 3, 13-18**, 2002**

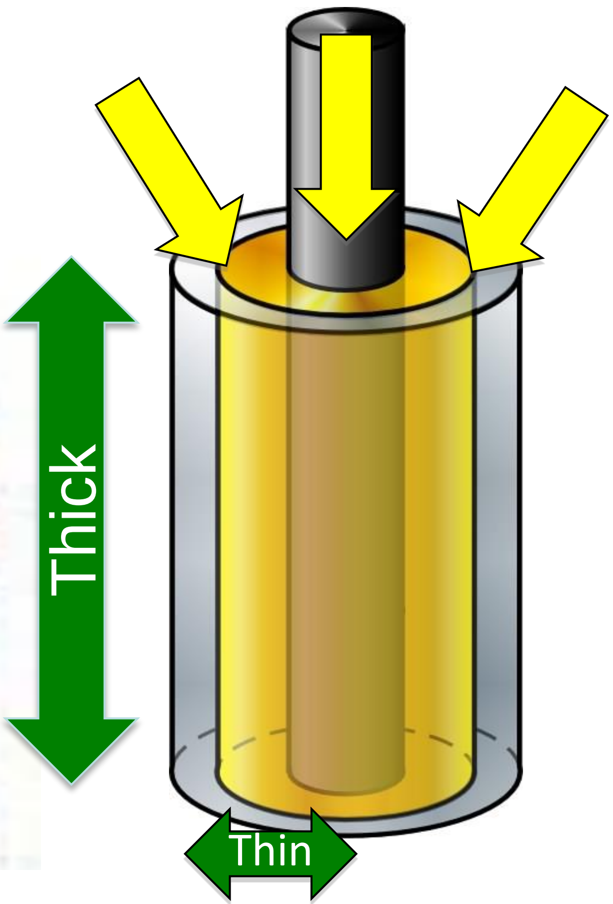
Rybczynski J., et al., Colloids and Surface; 219 1-6 **2003**

Photonic crystal based on Multiwall Carbon Nanotubes



Solar Cell

Nanocoax solar cell decouples photo- from -voltaic



<u>Nanocoax Solar Cell:</u>

1. Antenna collection

2. Optically thick

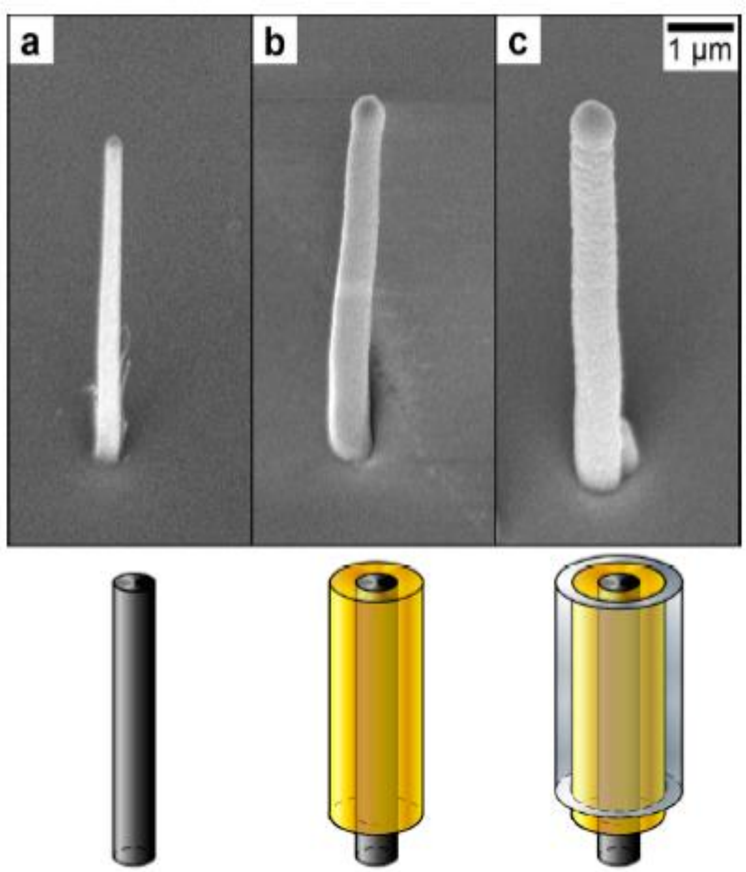
3. Electronically thin

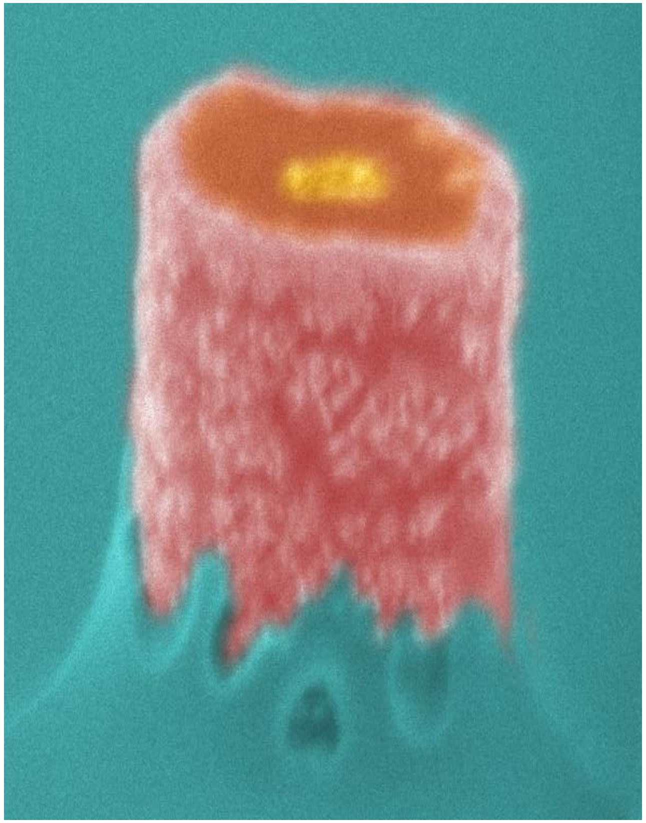
↓

ultimate light trapping scheme, allowing ultrathin absorbers

Solar Cell

Nanocoax subwavelength waveguide for visible light

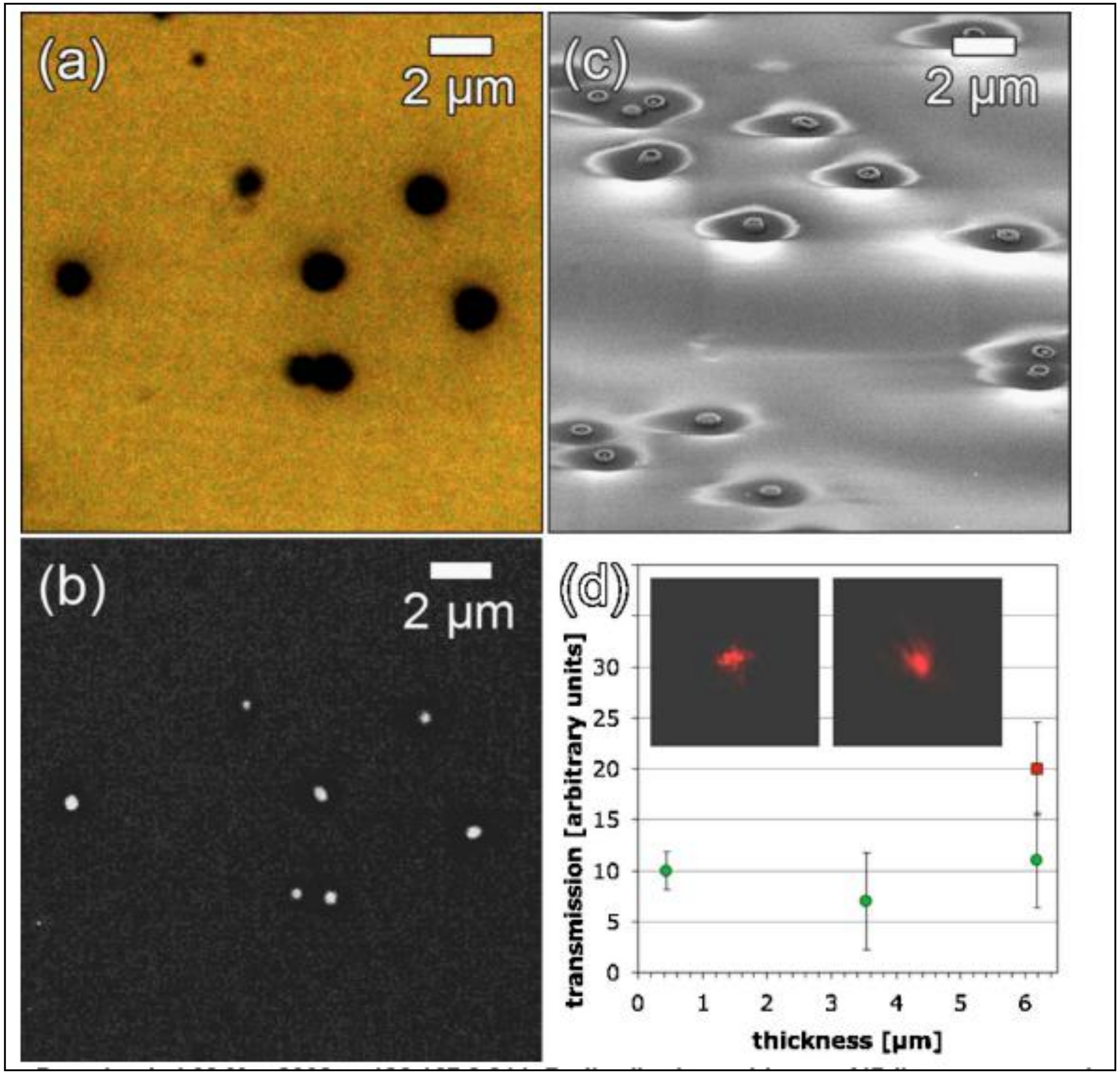




Rybczynski J, *et al.*, Appl. Phys. Lett. 90, 021104 **2007**

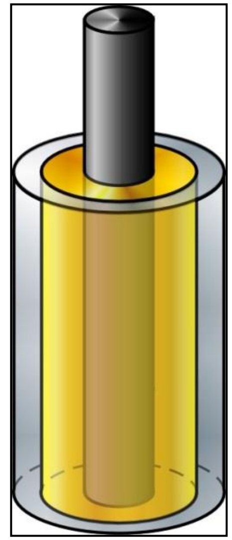
Solar Cell

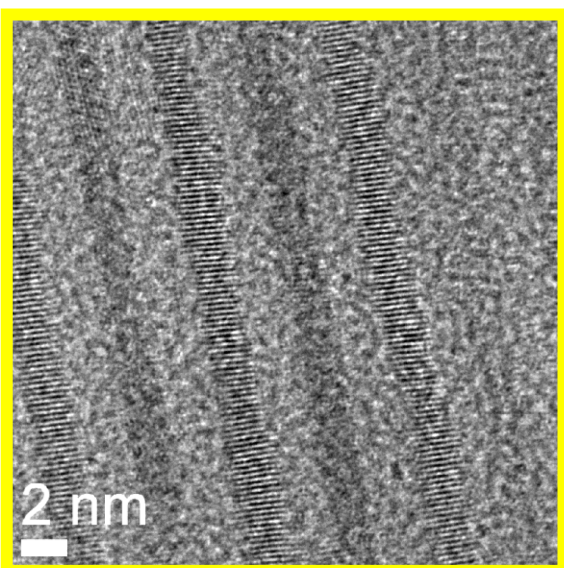
Nanocoax : subwavelength waveguide for visible light

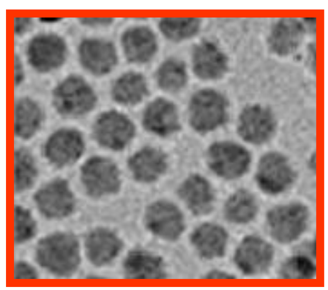


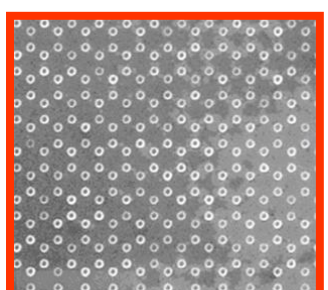
Rybczynski J, *et al.*, Appl. Phys. Lett., 90 021104 **2007**

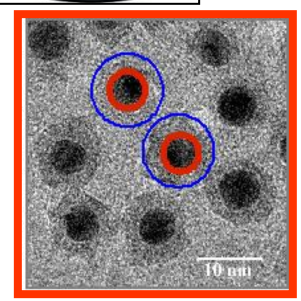
The third-generation of solar cells :Nanocoax Solar Cell
(high efficiency solar power requiring ultrathin absorbers)

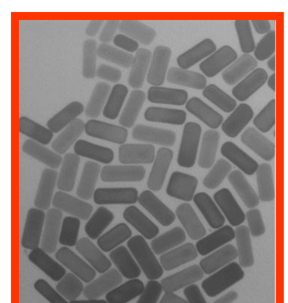


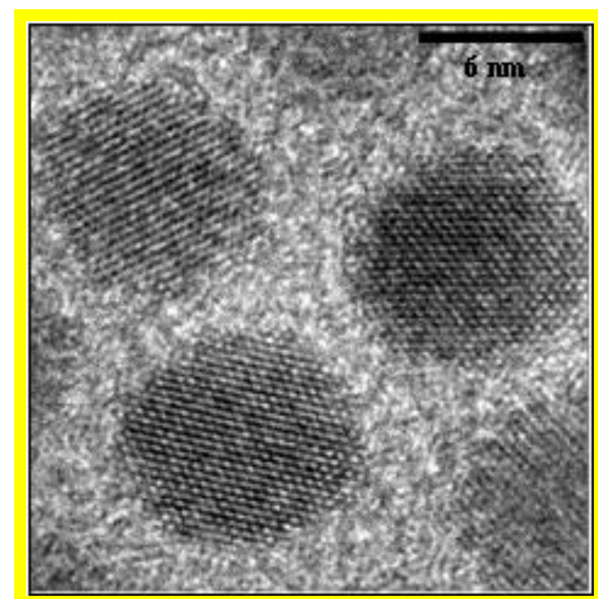




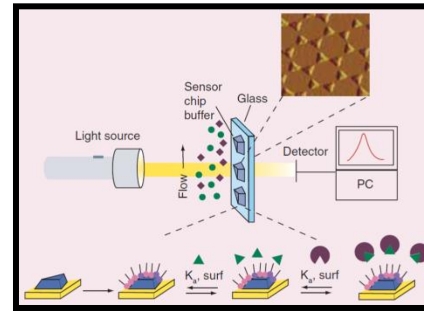








Outlook



Measurement of biosensing properties by Localized Surface Plasmon Resonance (LSPR) and Surface-Enhanced Raman Spectroscopy (SERS)

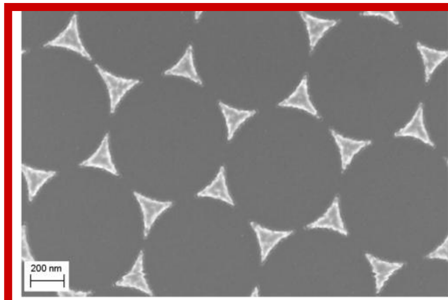


Fig.4 SEM image of array of golden nanoparticles deposited on silicon substrate in EBPVD process. Prepared with PS nanospheres of 756nm Ø

Mask deposition with NSL, etching

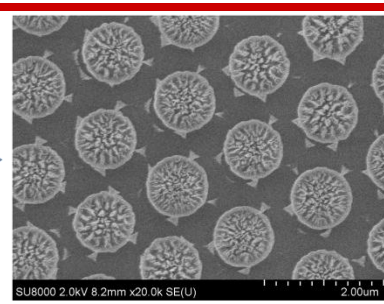


Fig.5 SEM image of a mask of PS nanospheres deposited on an array of golden nanospheres and etched afterwards. Prepared with PS nanospheres of 1300nm Ø

Evaporation of SiO_2film, removal of PS nanospheres

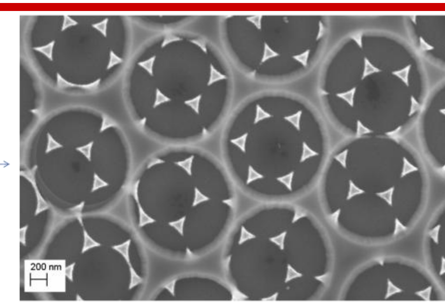
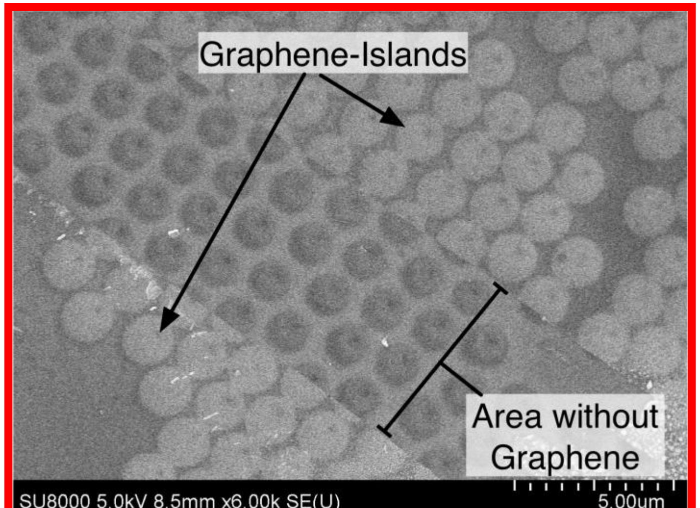
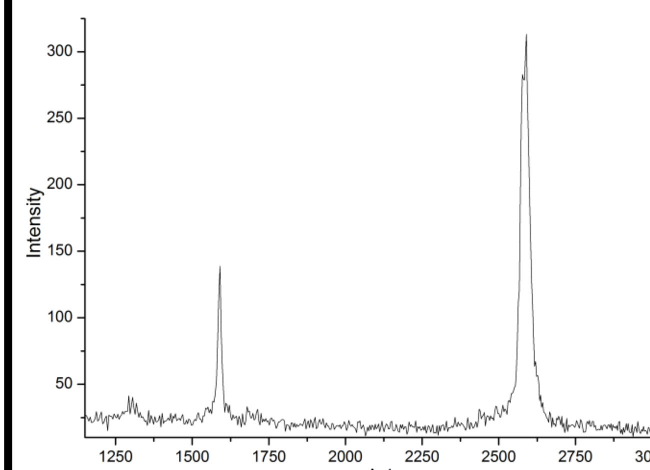
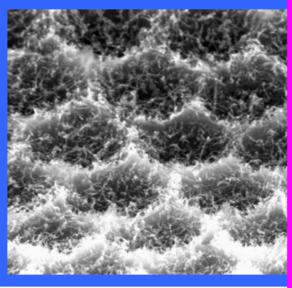


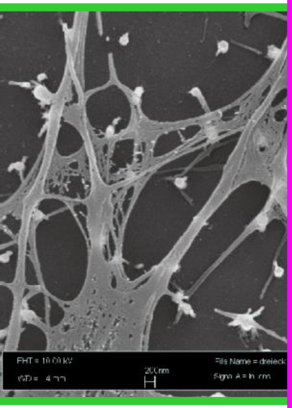
Fig.6 SEM image of silicon dioxide film with an array of holes, on top of triangular gold nanoparticle array deposited on silicon substrate. The structure was obtained in EBPVD process.

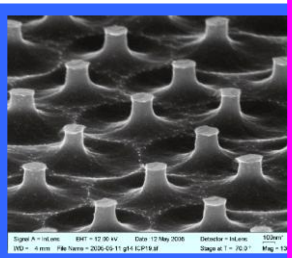
Low temperature CVD growth of Graphene

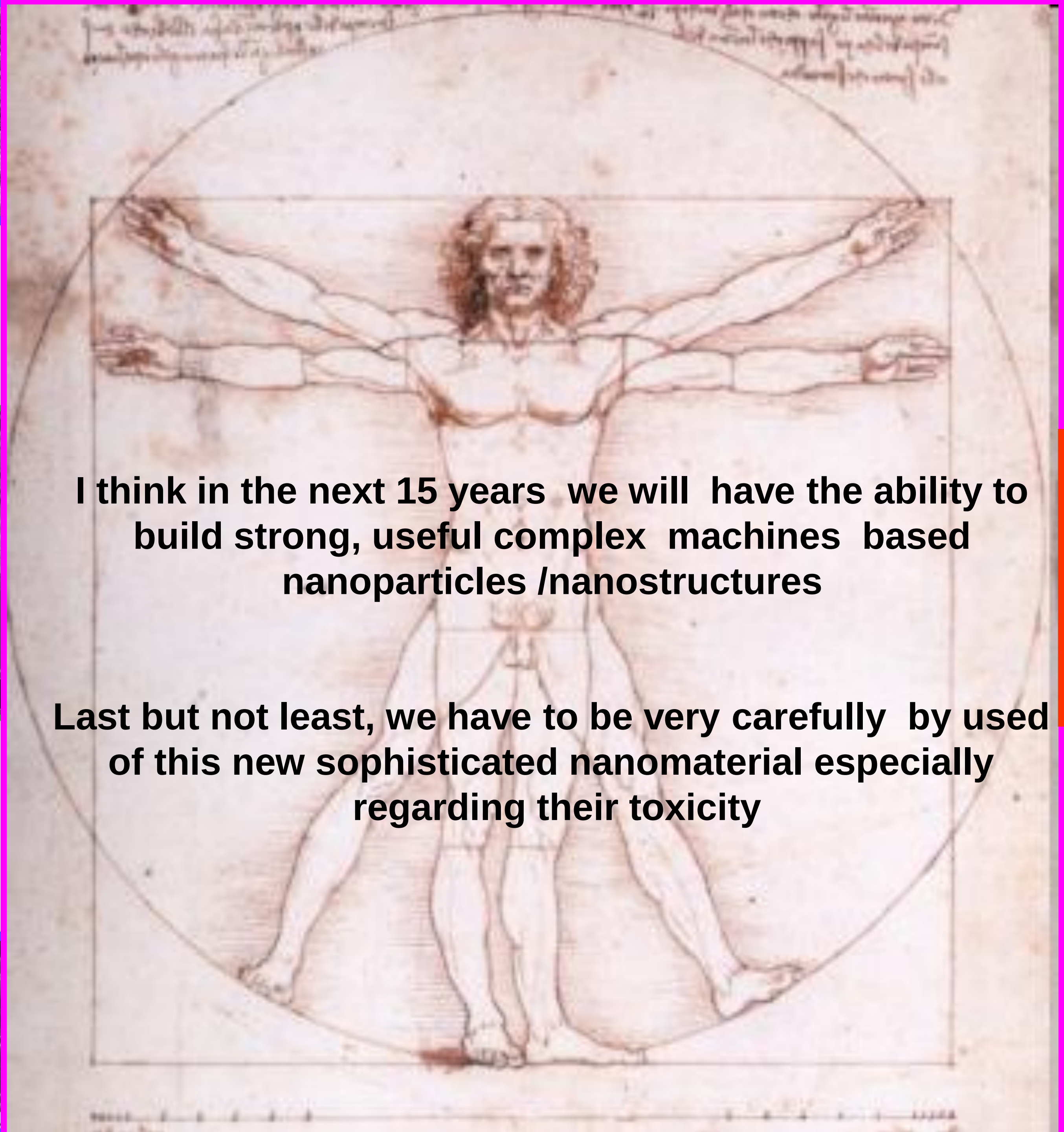






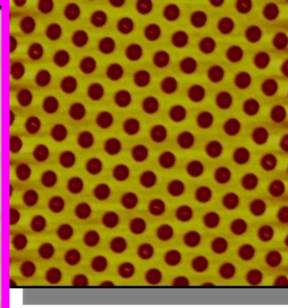


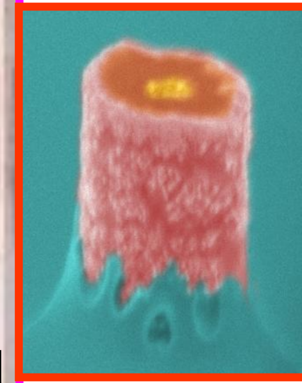


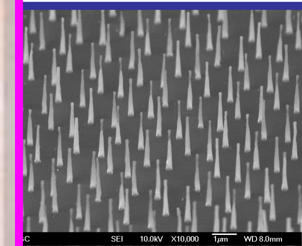


I think in the next 15 years we will have the ability to build strong, useful complex machines based nanoparticles /nanostructures

Last but not least, we have to be very carefully by used of this new sophisticated nanomaterial especially regarding their toxicity







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