

0.1 Lecture 1-2

Thursday 12th March, 2020. Compiled: Monday 1st June, 2020. Alice.

Fundamentals of Nanoscience (SdM)

Introduction to Nanophysics (Physics)

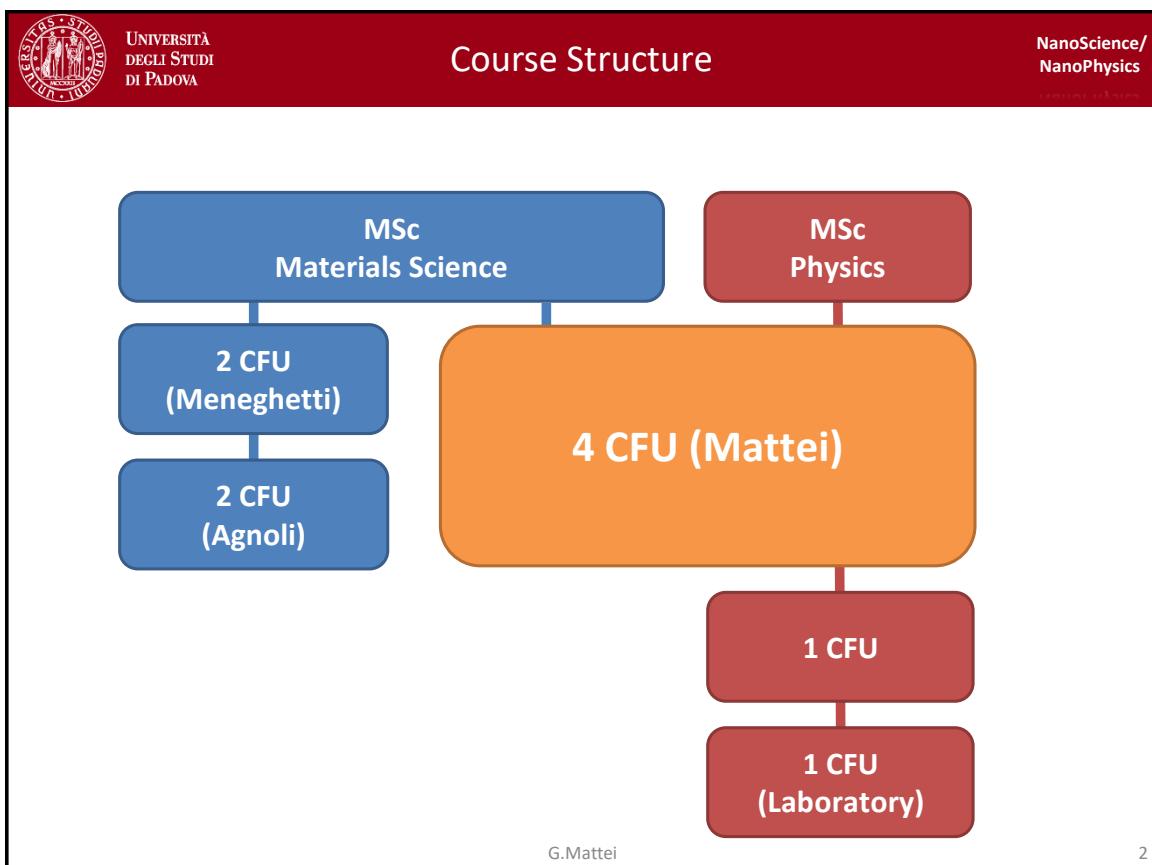
Giovanni Mattei

NanoStructures Group (NSG)
*Dept. of Physics and Astronomy
 University of Padova
 via Marzolo 8, Padova*

giovanni.mattei@unipd.it

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 UNIVERSA UNIVERSIS PATAVINA LIBERTAS

NSG





Schedule: WED 9:30 – 11:30
THU 8:30 – 10:30

Student Reception: *on request*

e-mail: giovanni.mattei@unipd.it

URL: <http://materia.dfa.unipd.it/mattei>

Room 82 – (ground floor) Dept. of Physics and Astronomy
(via Marzolo 8)



Learning Objectives

- Understanding the basic concepts describing the **chemical and physical properties** of nanostructured materials and their applications in **nanotechnology**
- Description of some **techniques** for the **synthesis** and **characterization** of confined nanostructures (nanoclusters) with nanotech application in **photronics, plasmonics** and **magnetism**.



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Final Exam

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Materials Science		Physics	
Exam	Weight	Exam	Weight
Written (2 hrs)	100 % (weighted average over CFUs)	Written (2 hrs)	75%
		Lab	25%

Written Exam:

- Open Question
- +
- Open Question (Meneghetti)
- Multiple Choice Qs & Open Question (Agnoli)

Written Exam:

- Open Question
- Numerical Application

Lab:

- Written Report



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Course Content

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4 CFU (SdM + Physics)

- Classification, characteristics and general properties of nanostructured materials: quantum confinement and electronic properties. **Size Equations**.
- Thermodynamic properties of nanostructured materials: **thermodynamic size effect**, nucleation (**Gibbs-Thomson equation**) and growth of nanostructures (**Diffusion-Limited Aggregation and Ostwald Ripening regimes**).
- Nanostructures embedded in solid matrices: ion implantation for the synthesis and processing of metallic nanostructures. **Verification of the nucleation and growth models**.
- **Optical properties** of nanostructured materials: (i) **plasmonic** properties of metallic nanostructures (Mie theory and its extensions); (ii) **quantum confinement** and photoluminescence in semiconductor quantum dots
- **Magnetic properties** of nanostructured materials: super-paramagnetism.

1 CFU (Physics)

- Fundamental description of the **dynamics** of electrons and photons
- **Confinement of electrons and photons** in nanostructured or periodic materials:
 - Photon confinement in **photonic crystals**
 - Electron confinement in **metal nanoparticles**
 - Electron confinement in **semiconductor nanoparticles**
- Metamaterials and **negative-refractive index** materials

1 CFU (Lab., Physics)

- Lab (Synthesis Nano-Au, simulation OD, XRD, SEM on the synthesized Au NPs).

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Notes

Register on the Course Moodle :

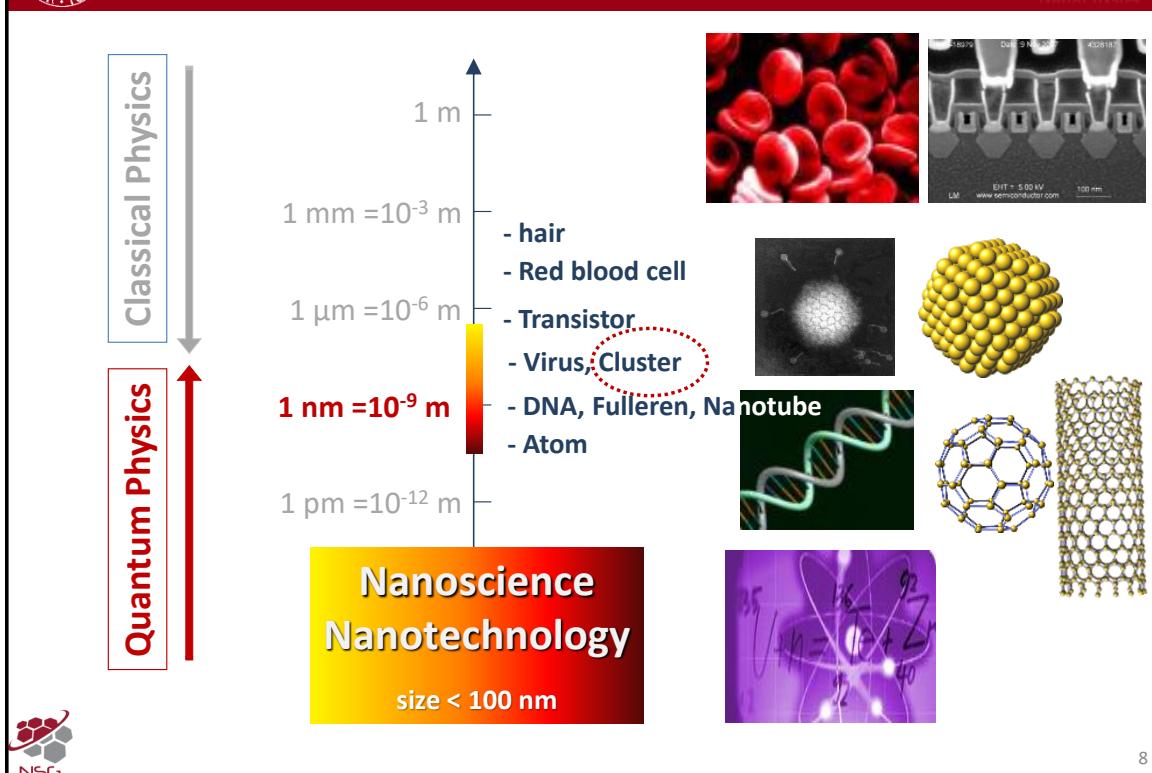
- SdM -> <https://elearning.unipd.it/chimica/>
- Physics -> <https://elearning.unipd.it/dfa/>

Further Readings

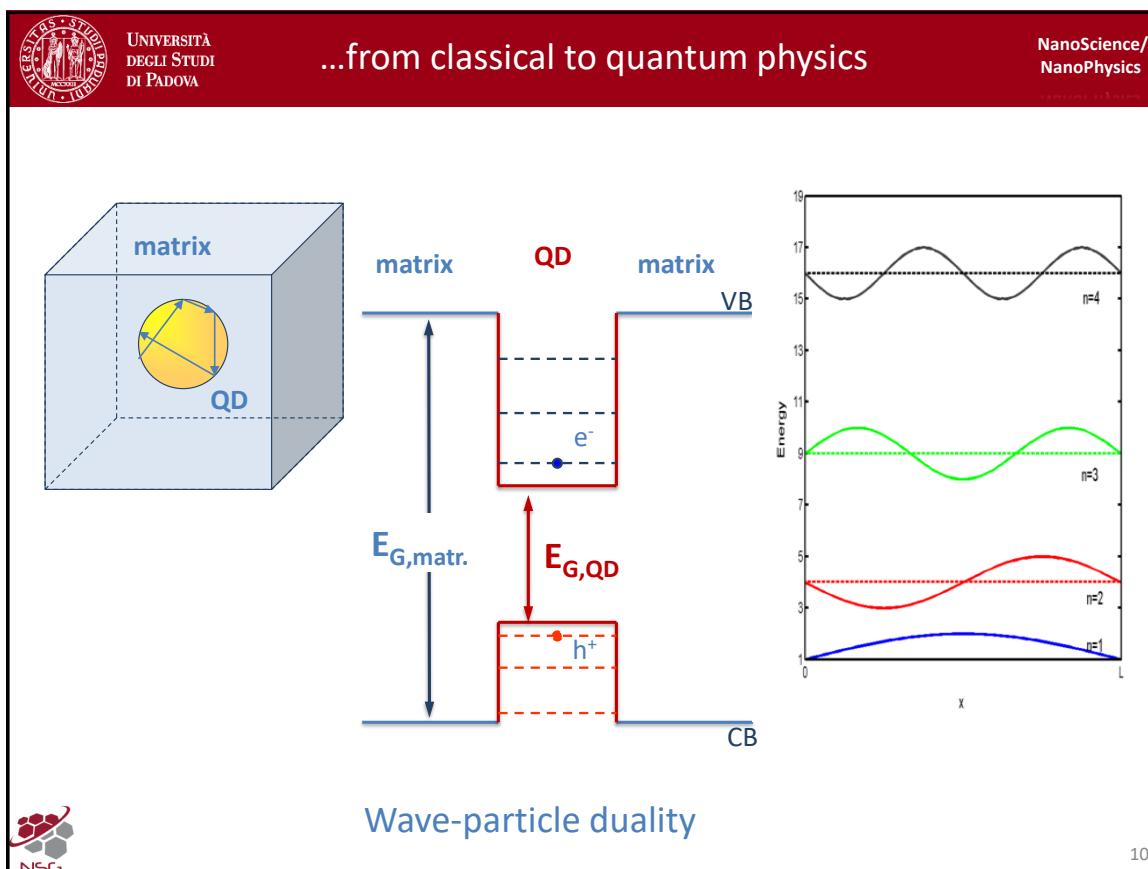
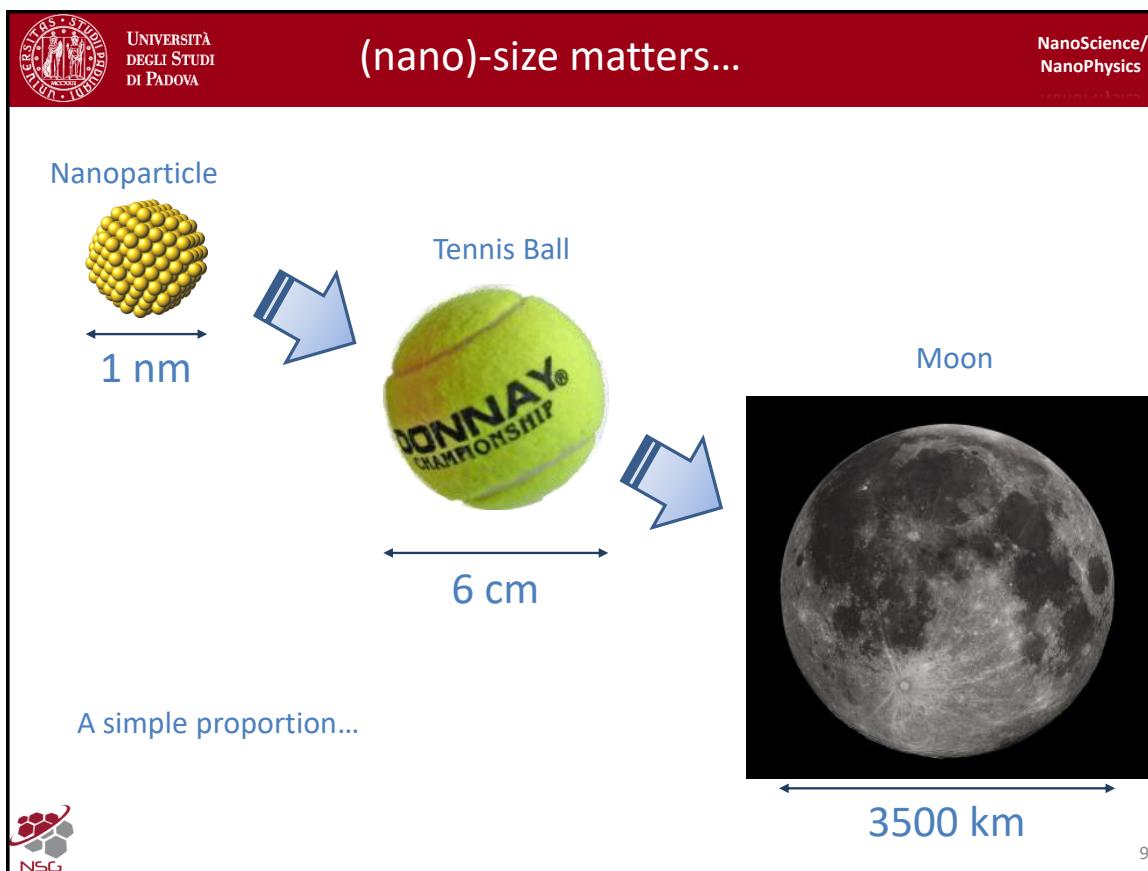
- S. Maier, *Plasmonics, fundamentals and applications*, Springer (2007)
- C. Bohren and D. Huffmann, *Absorption and scattering of light by small particles*, Wiley-Interscience (2004)
- P. Prasad, *Nanophotonics*, Wiley-Interscience (2004)
- C. Poole, F. Owens, *Introduction to Nanotechnology*, Wiley-Interscience (2003)
- G. Schmid, *Nanoparticles*, Wiley-Interscience (2004)

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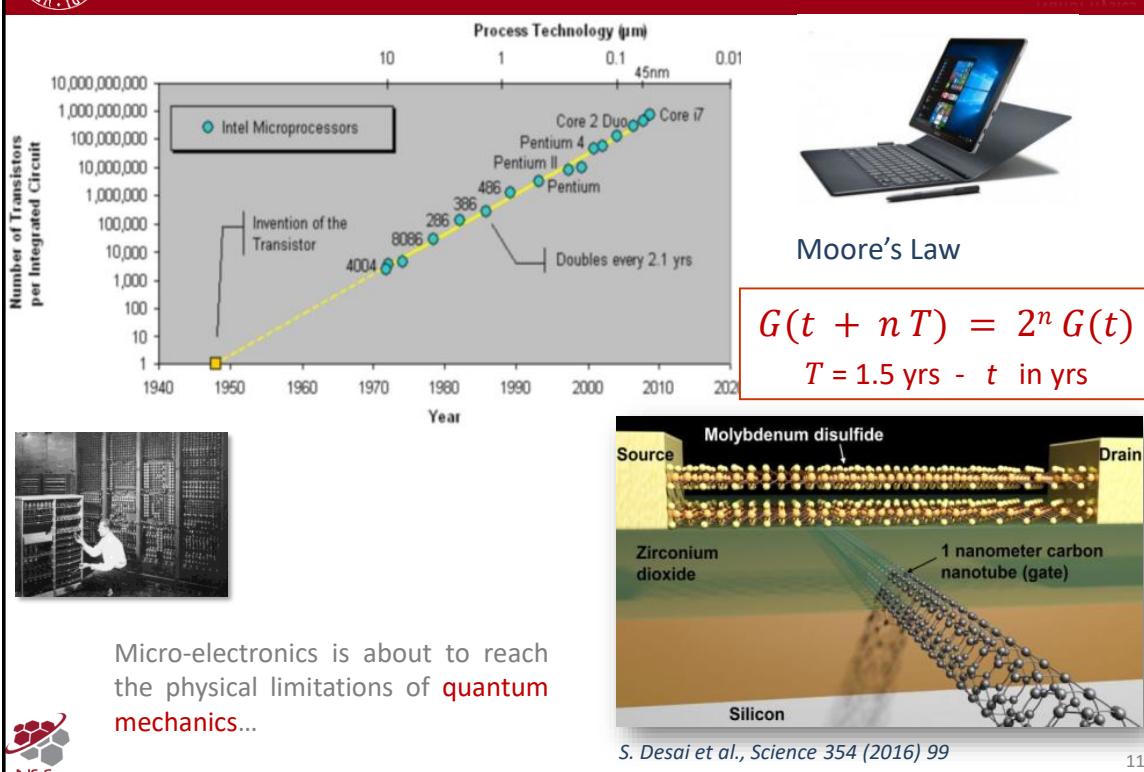
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Nano-electronics



What if Moore's Law were valid for...

(1) civil aviation

New York - Frankfurt:
1980
Time: 7 hrs
Price: 900 €



New York - Frankfurt:
today
Time: 0.02 s
Price: 0.1 cent

(2) motorbike company



Ducati 2019

Weight: 1 g
Speed: 60.000 km/s
Price: 5 cent

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Nano-Systems



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Nano-size

	Bulk Material	Nano Material
Size (L)	$\sim 1 \text{ m}$	$< 100 \text{ nm} = 10^{-7} \text{ m}$
Property (A)	$A \neq A(L)$	$A = A(L)$

- Characteristic lengths $\lambda_c \sim 1-100 \text{ nm}$
- Nano-physics: $L < \lambda_c$
- E.g.:
 - λ_e = electronic mean free path (10-100 nm)
 - λ_{exc} = excitonic Bohr radius (1-10 nm)
 - λ_M = magnetic domain (30-50 nm)

control L = control A(L)



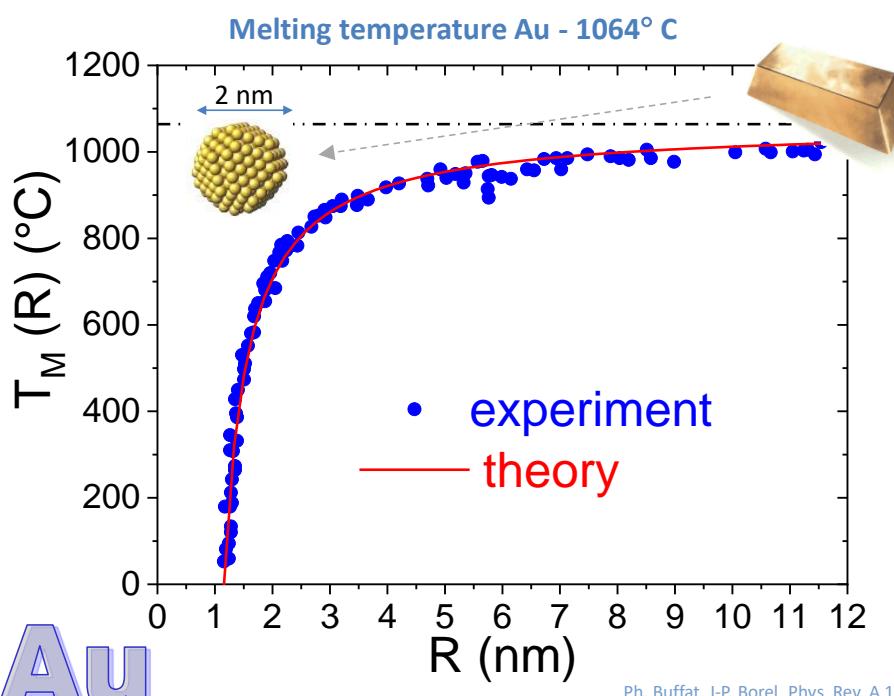
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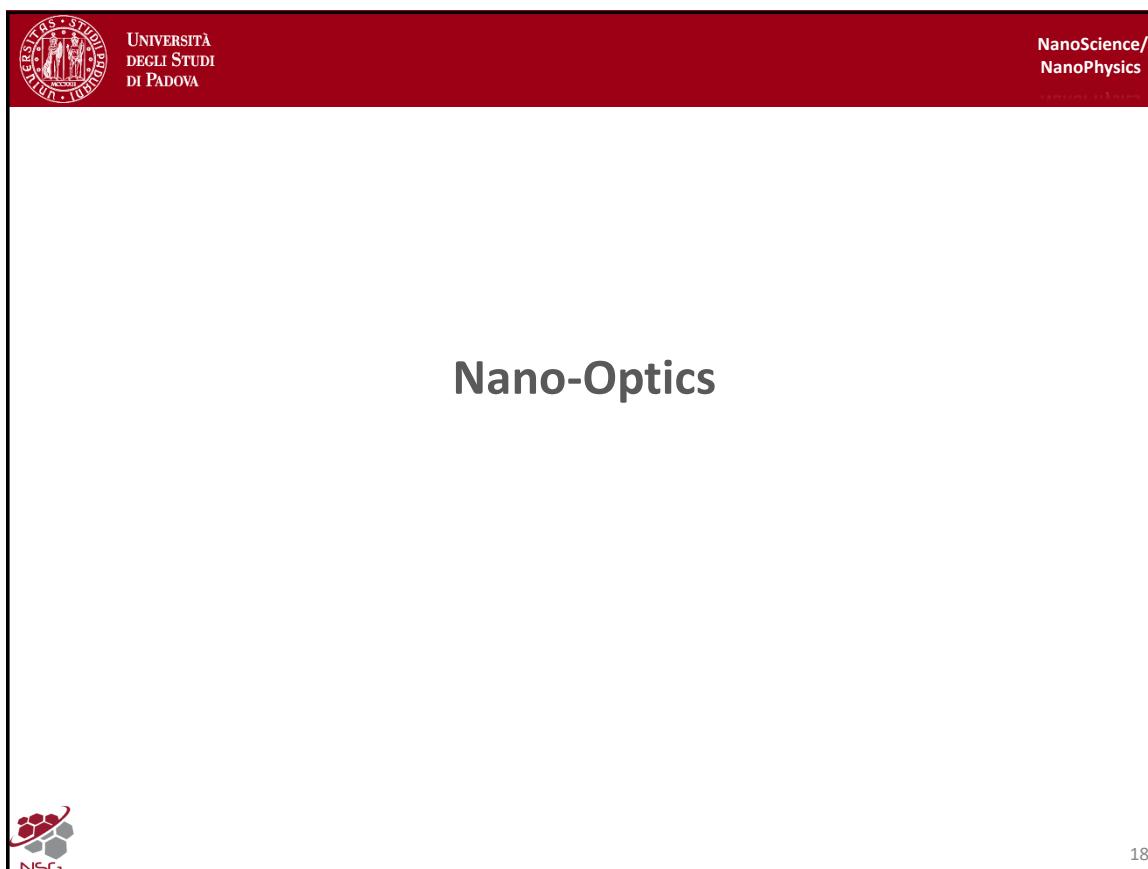
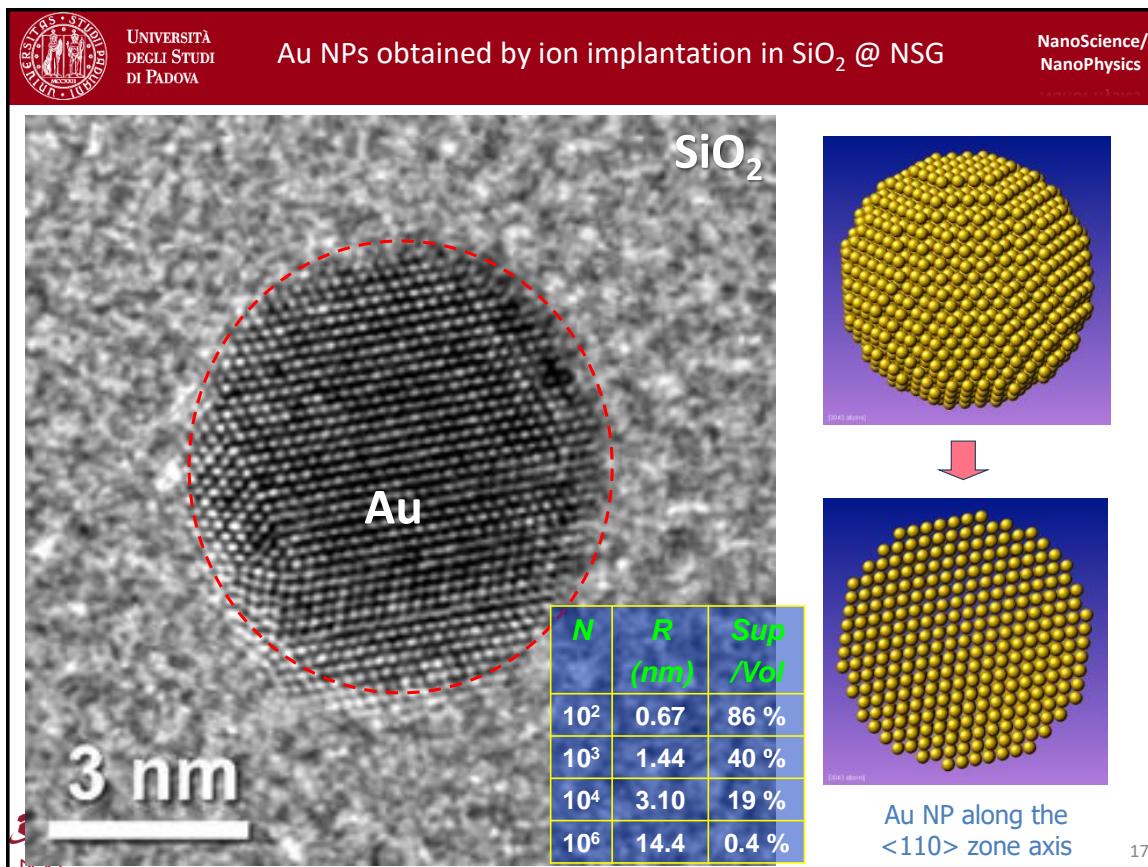


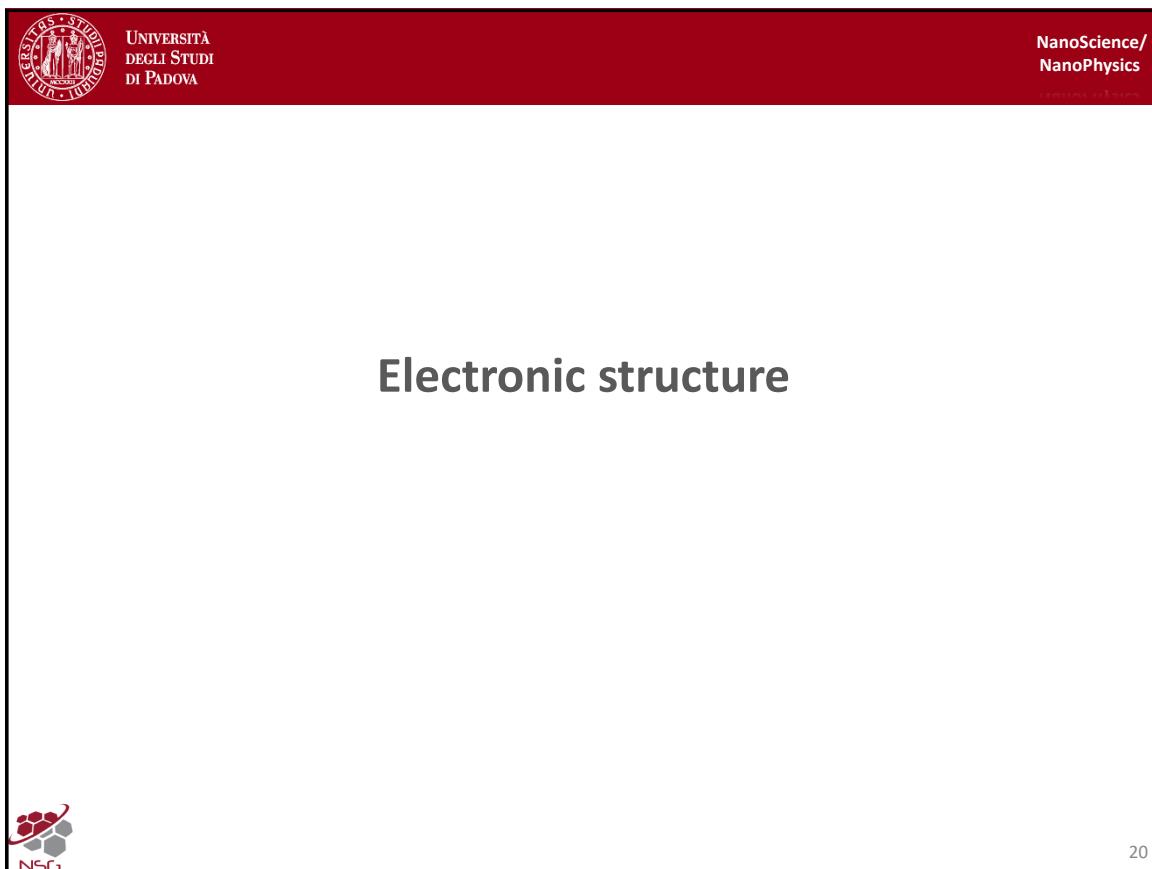
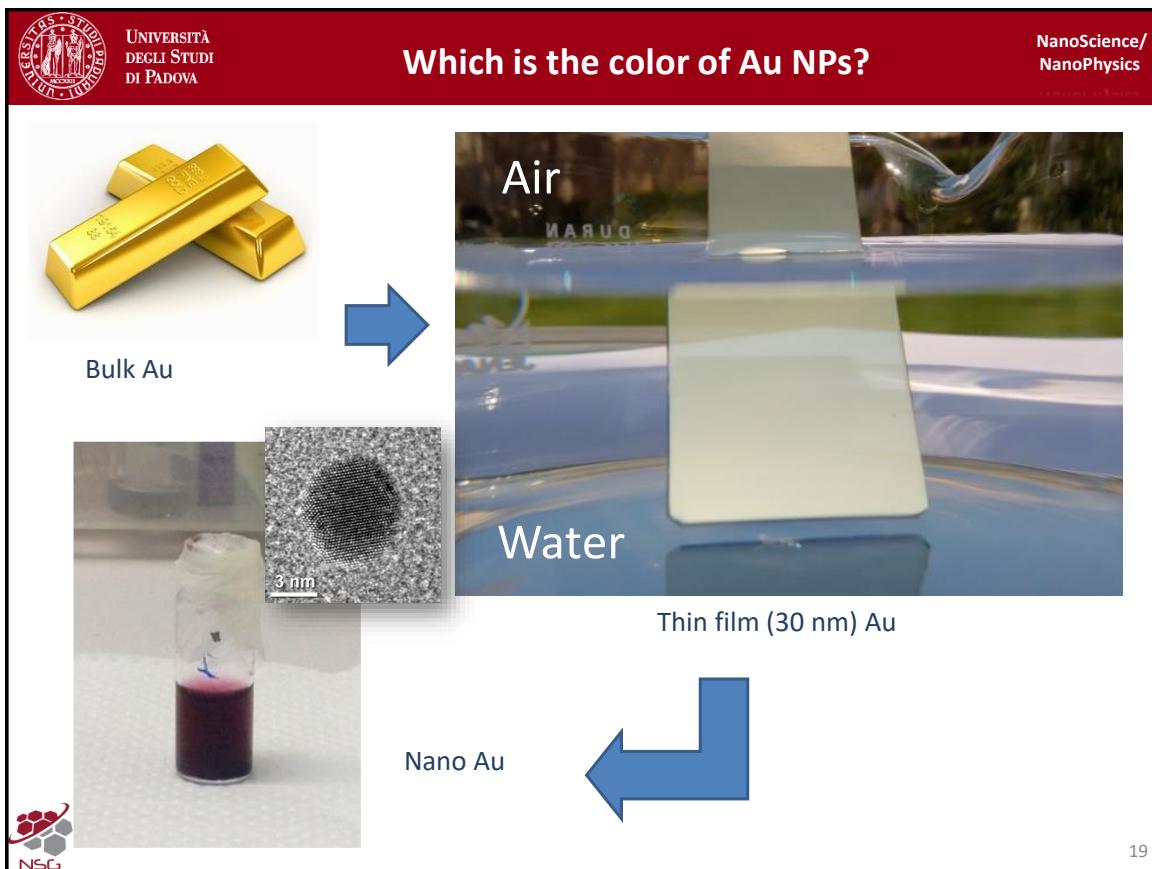
Nano-Thermodynamics

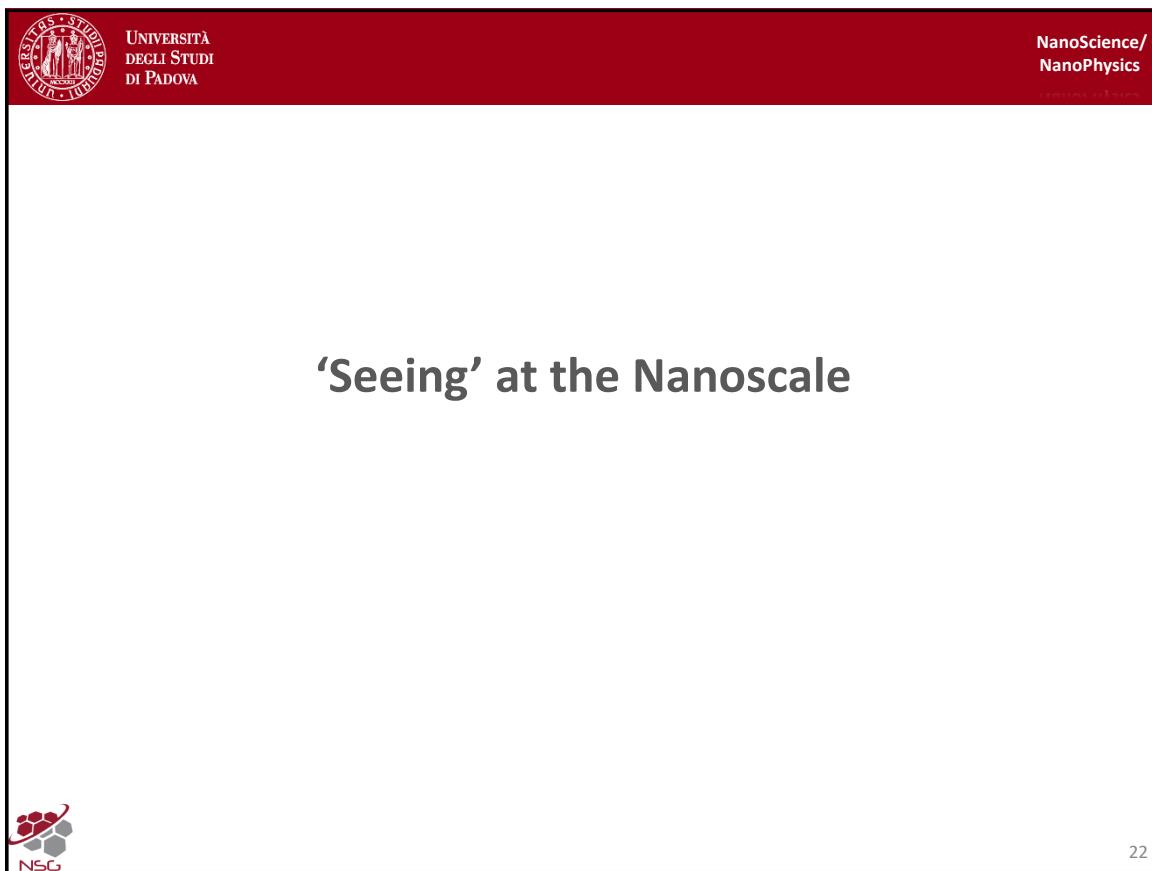
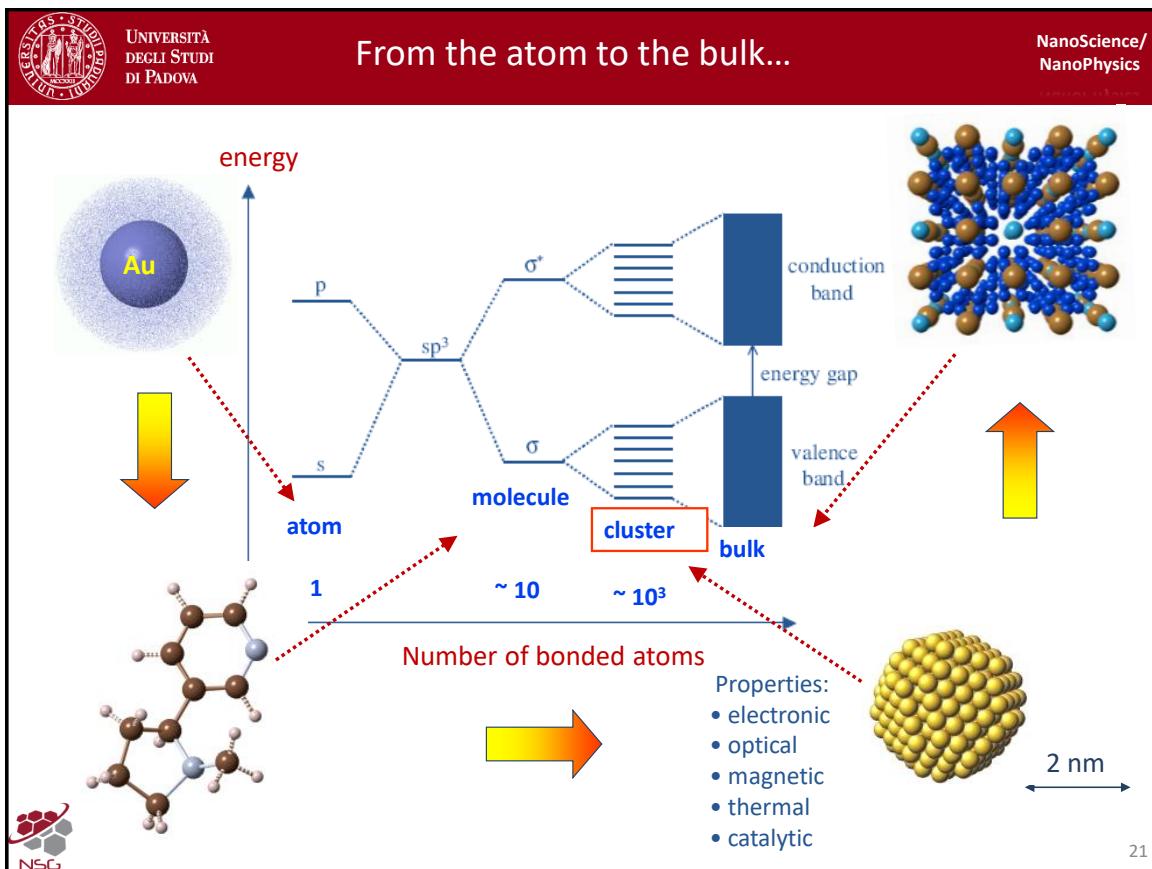


Example of $A = A(L)$









'seeing' at the nanoscale



A typical optical microscope

- photons

$\lambda = 400 \div 800 \text{ nm}$

$E = 1 \div 3 \text{ eV}$

- resolution

$\sim \lambda$ (500 nm)

- working pressure

ambient

'seeing' at the nanoscale



A typical electron microscope - TEM

- electrons

$\lambda = 1.2 \text{ pm}$ (*Quantum Mechanics*)

$E = 200 \div 300 \text{ keV}$

- resolution

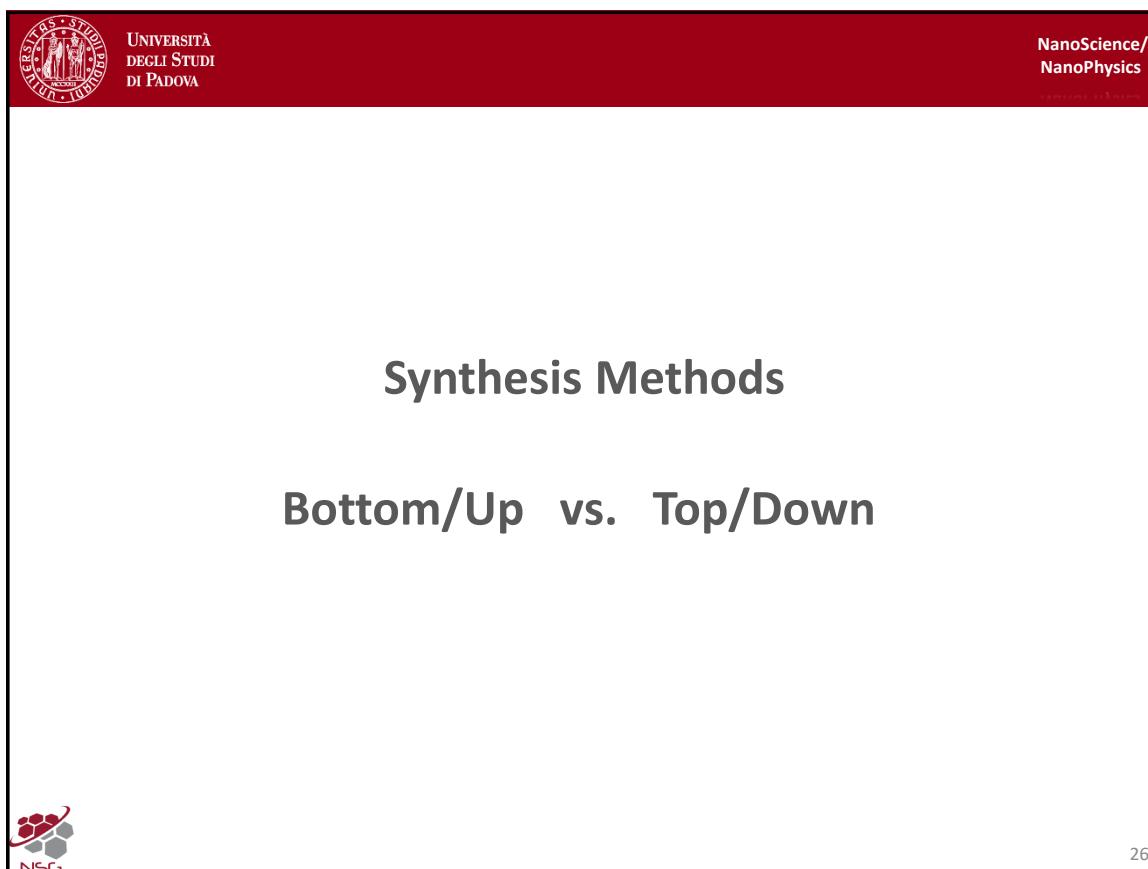
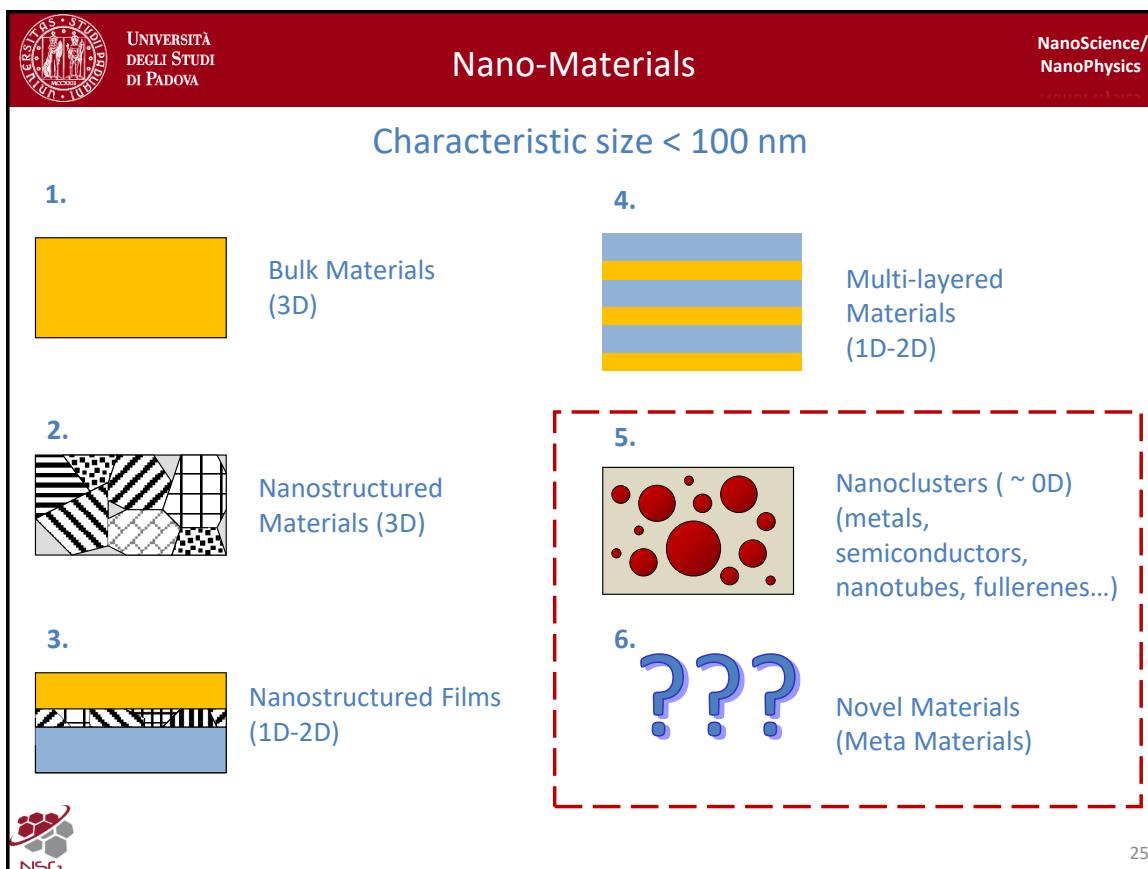
0.1 nm

- working pressure

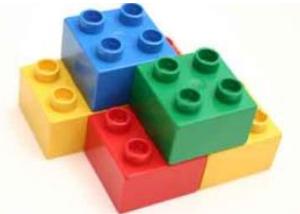
10^{-4} Pa ($\sim 10^{-9} \text{ atm}$)

- price

1.5-2.0 M€



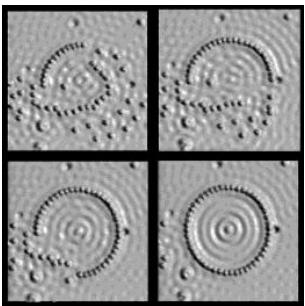
From small to large or from **simple to complex**



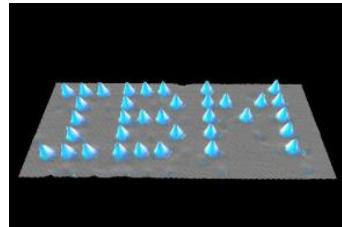
LEGO

'building block' assembly with quantum supramolecular rules

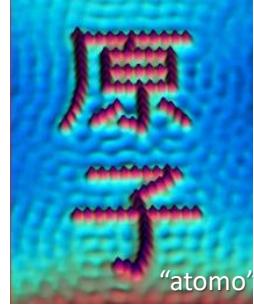
Using atoms or simple units as LEGO blocks one can build artificial nano-objects
(nano-positioning and self-assembling)



Quantum corral: 48 atoms of Fe on Cu
M.F. Crommie, C.P. Lutz, D.M. Eigler.
Science 262, 218-220 (1993)



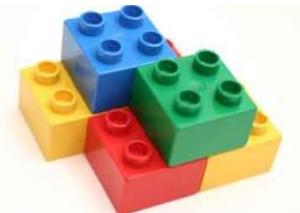
Xe on Ni (111)
D.M. Eigler, E.K. Schweizer,
Nature 344, 524-526 (1990)



Fe on Cu (111)
C.P. Lutz, D.M. Eigler, *IBM*

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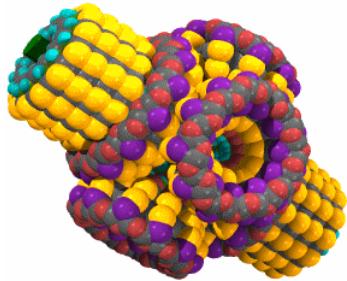
From small to large or from **simple to complex**



LEGO

'building block' assembly with quantum supramolecular rules

Using atoms or simple units as LEGO blocks one can build artificial nano-objects
(nano-positioning and self-assembling)

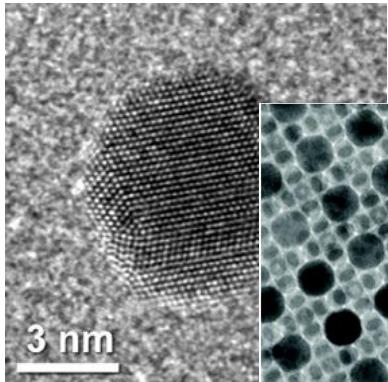


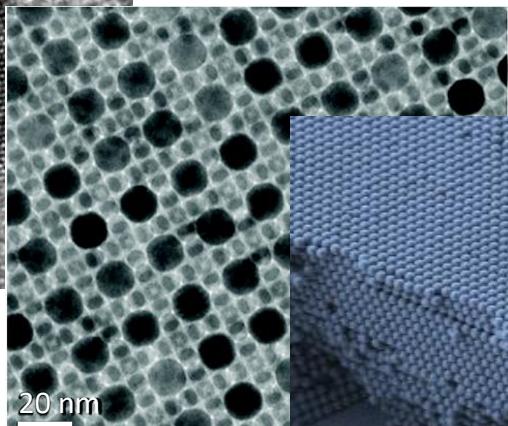
Nano-machine (*E. Drexler, Nanorex Inc.*)

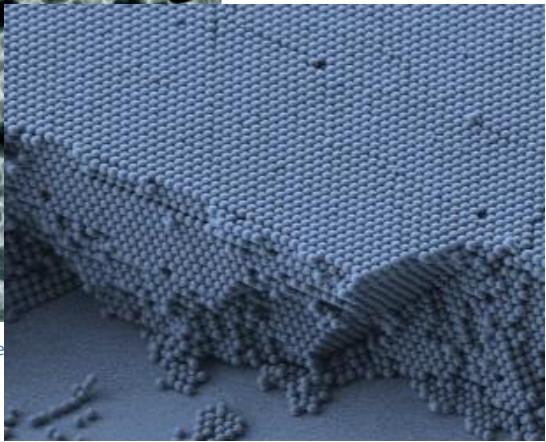
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Bottom/Up


3 nm
Au NC in SiO₂ (UniPD)


20 nm
Fe₃O₄ NC: Chen, J. et al. Nano Lett.


Photonic crystal: 3D self-assembly of SiO₂ NPs (1 μm).



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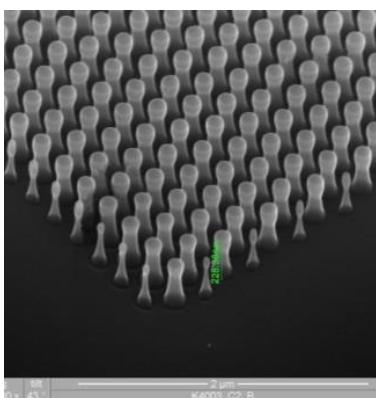
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Top/Down

 From large to small

Lithography
A bulk material is processed ('sculpted') and re-shaped down to the nanosize: **nanofabrication** and **nanolithography**


Anti-reflective
coating made by
a pillar array
(EBL) for optical
and photonic
applications


Close-up view of a moth's eye



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Top/Down

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Photonic Crystal

Nano-guitar

...Nano-toilet

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Top/Down

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bio-mimetic systems: **Lotus Effect** (super-hydrophobicity)

smooth surface

Lotus-Effect* surface

10 μm

152.3
contact
angle

LEFT : 0K
Set the Left Point of the Droplet. [END]

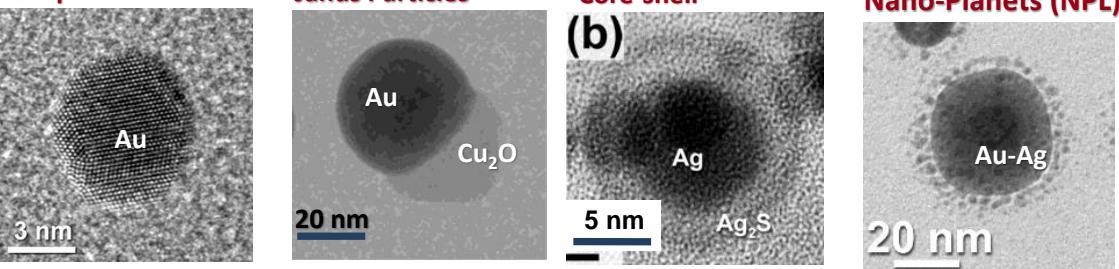
REM recording of a
holographically pro-
duced self-cleaning
surface.
© Fraunhofer ISE

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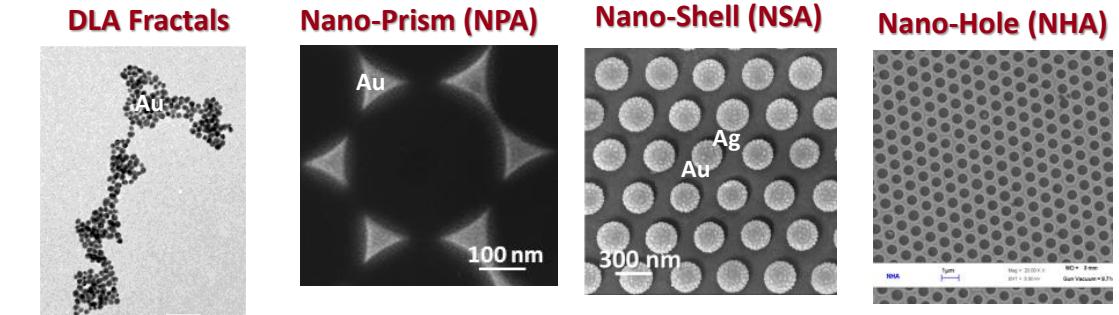
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Some nano-structures produced @ NSG

Simple NP **Janus Particles** **Core-shell** **Nano-Planets (NPL)**



DLA Fractals **Nano-Prism (NPA)** **Nano-Shell (NSA)** **Nano-Hole (NHA)**



Monoelemental
Au, Ag, Cu, Pt, Co, Ni, Fe

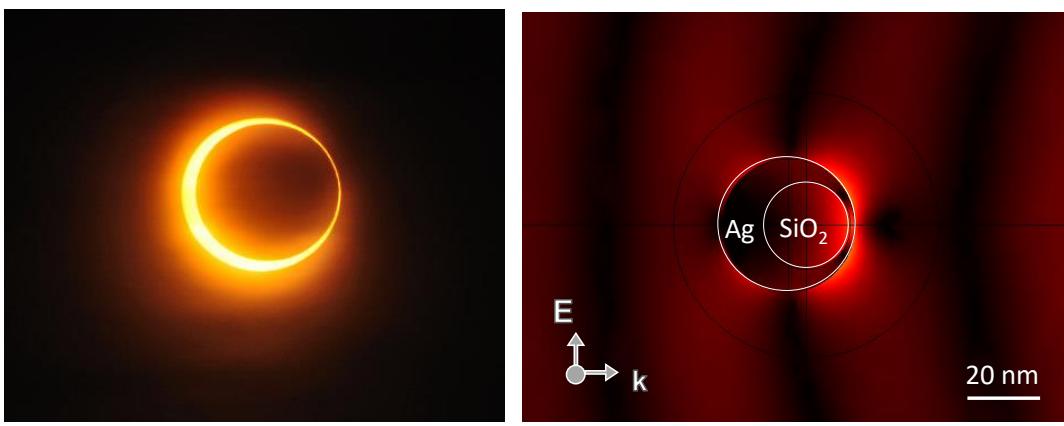
Bimetallic
Au-Cu, Au-Ag, Au-Fe, Pd-Cu, Co-Ni, Co-Fe, Co-Cu, Fe-Pd

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Nano-eclipse



Solar Eclipse 2015

Asymmetric – NanoShell
 SiO_2 @ Ag





Metallic Nanostructures



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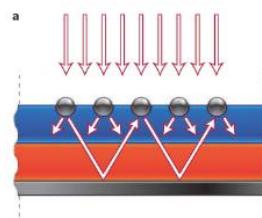


Metallic Nanostructures

Optical Properties (Plasmonics):

1. Plasmonic sensors
2. Plasmonic waveguides
3. Nano-Antennas
4. Iperthermia (cancer therapy)

Light confinement $< \lambda$



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Materials for plasmonics

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$Re[\epsilon(\omega, R)] < 0$

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18						
hydrogen H 1.00794(7)	boron B 6.941(2)	carbon C 12.0115(2)	nitrogen N 14.0121(2)	oxygen O 16.0000(2)	fluorine F 18.0000(2)	neon He 4.002602(2)																	
lithium Li 6.941(2)	beryllium Be 9.01215(2)	sodium Na 22.98970(2)	magnesium Mg 24.3050(6)	potassium K 39.09845(4)	calcium Ca 44.9559(10)	scandium Sc 47.8571(1)	titanium Ti 50.9415(1)	vandium V 51.9991(6)	chromium Cr 54.933049(9)	manganese Mn 55.945(2)	iron Fe 56.933200(9)	cobalt Co 58.9634(4)	nickel Ni 59.9546(3)	copper Cu 63.546(3)	zinc Zn 65.38(2)	gallium Ga 69.723(1)	germanium Ge 72.64(1)	arsenic As 74.9216(2)	antimony Se 78.96(3)	phosphorus P 80.0555(3)	sulfur S 32.056(5)	chlorine Cl 35.453(2)	argon Ar 36.948(1)
rubidium Rb 85.467(3)	strontium Sr 87.62(1)	yttrium Y 88.90585(2)	zirconium Zr 91.234(2)	niobium Nb 92.9033(2)	molybdenum Mo 95.95(2)	technetium Tc 98.1	rhodium Ru 101.07(2)	rhodium Rh 102.9285(2)	rhodium Pd 106.42(1)	rhodium Ag 107.8652(2)	silver Ag 108.91(1)	platinum Pt 124.85(2)	platinum Au 125.41(8)	gold Hg 144.818(3)	mercury Tl 148.710(7)	thallium Pb 151.760(1)	lead Bi 152.50447(3)	tin Sn 152.60(3)	antimony Sb 153.57(3)	iodine Te 157.60(3)	xenon I 159.50447(3)	radon Xe 161.29(6)	
casadium Cs 132.95545(2)	barium Ba 137.337(7)	lithium Lu 174.6655(3)	hafnium Hf 175.45(2)	tantalum Ta 193.5575(1)	tungsten W 193.5575(1)	mercury Re 195.32(1)	mercury Os 199.32(3)	mercury Ir 203.217(3)	mercury Pt 205.07(3)	mercury Ds 206.66555(2)	mercury Rg 206.66555(2)	mercury Uut 206.66555(2)	mercury Uuu 206.66555(2)	mercury Uup 206.66555(2)	mercury Uuh 206.66555(2)	mercury Uuo 206.66555(2)	mercury Uuo 206.66555(2)	mercury Uuo 206.66555(2)	mercury Uuo 206.66555(2)	mercury Uuo 206.66555(2)			
Lanthanoids	lanthanum La 138.9055(2)	cerium Ce 140.116(1)	praseodymium Pr 140.9075(2)	neodymium Nd 144.24(3)	promethium Pm 145(1)	samarium Sm 150.36(3)	euroopium Eu 151.964(1)	europium Gd 157.25(3)	europium Tb 158.92534(2)	europium Dy 162.500(1)	europium Ho 164.33032(2)	europium Er 167.259(3)	europium Tm 168.9242(1)	europium Yb 173.054(5)									
Actinoids	actinium Ac 127(1)	radium Th 232.0381(1)	protoactinium Pa 231.03889(2)	uraniium U 238.0289(1)	neptunium Np 237(1)	plutonium Pu 244(1)	americium Am 243(1)	curium Cm 247(1)	berkelium Bk 251(1)	californium Cf 251(1)	einsteinium Es 252(1)	fermium Fm 257(1)	mendelevium Md 258(1)	nobelium No 259(1)									

Key:
element name
atomic number
symbol
2003 atomic weight (mean relative mass)

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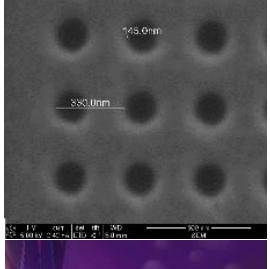
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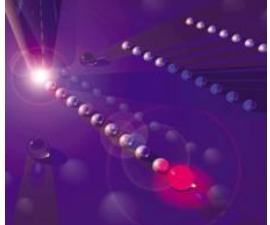
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“Cool” Plasmonic Properties

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- Extraordinary transmission of light (EOT):**
from array of nanoholes with sub- λ size in metal thin film.
- Plasmonic waveguides:**
from array of NP or at the dielectric-metal interface
- MetaMaterials:** negative refractive index materials (invisibility cloak)







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Plasmonic waveguides

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Optical waveguide

Plasmonic waveguide

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Plasmonics

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Ag nanoparticles (R = 50 nm) in SiO₂

La Sainte-Chapelle (Paris, France, 1248)

dipole

quadrupole

octupole

λ = 520 nm

λ = 406 nm

λ = 380 nm

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METALLIC NANOSTRUCTURES

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Optical Properties (Plasmonics):

1. Plasmonic sensors
2. Plasmonic waveguides
3. Nano-Antennas
4. Iperthermia (cancer therapy)

Magnetic Properties:

1. Super-paramagnetism
2. Magneto-optical properties
3. Medical diagnosis (Fe-oxides, NMR)

Light confinement $< \lambda$

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MATERIALS FOR MAGNETISM

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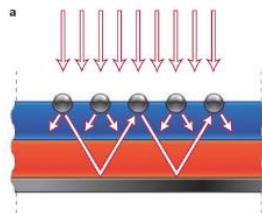
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18					
hydrogen H 1.00794(7)	beryllium Be 6.941(2)	boron B 10.01192(3)	carbon C 12.01078(1)	nitrogen N 14.00757(1)	oxygen O 15.99949(3)	fluorine F 18.99842(2)	neon Ne 20.1777(6)															
lithium Li 6.941(2)	magnesium Mg 24.3059(6)	aluminum Al 26.98158(2)	silicon Si 28.0555(3)	phosphorus P 30.97376(2)	sulfur S 32.065(5)	chlorine Cl 34.965(5)	argon Ar 36.451(2)															
sodium Na 22.98770(2)	potassium K 39.0593(1)	scandium Sc 40.0794(1)	titanium Ti 47.8571(1)	vandium V 50.9815(1)	chromium Cr 51.99816(6)	manganese Mn 54.939049(9)	iron Fe 55.845(2)	cobalt Co 58.933200(9)	nickel Ni 58.6934(4)	copper Cu 63.546(3)	zinc Zn 65.38(2)	zinc Zn 69.723(1)	gallium Ga 72.64(1)	germanium Ge 74.9216(2)	stibium As 78.96(5)	antimony Sb 79.95(4)	tin In 83.04(1)	lead Pb 126.90447(3)	tin In 121.760(1)	tin Tl 127.60(3)	tin Tl 128.948(1)	
rubidium Rb 85.467(3)	cesium Cs 132.9545(2)	strontium Ca 87.62(1)	barium Ba 88.9058(2)	lanthanum Lu 137.327(7)	cerium Lu 174.966(8)	europium Lu (178.49(2))	thulium Lu (180.547(1))	ytterbium Lu (183.84(1))	erbium Lu (186.207(1))	thulium Lu (190.23(3))	ytterbium Lu (192.217(3))	erbium Lu (195.078(2))	ytterbium Lu (196.9655(2))	thulium Lu (200.59(2))	ytterbium Lu (207.2(1))	erbium Lu (208.9433(2))	ytterbium Lu (210)	ytterbium Lu (222)	ytterbium Lu (218)	ytterbium Lu (226)	ytterbium Lu (231)	ytterbium Lu (232)
caesium Cs 132.9545(2)	francium Fr (223)	barium Ba (226)	lanthanum Lu (227)	europium Lu (228)	thulium Lu (229)	ytterbium Lu (229)	erbium Lu (230)	ytterbium Lu (231)	erbium Lu (232)	ytterbium Lu (233)	erbium Lu (234)	ytterbium Lu (235)	erbium Lu (236)	ytterbium Lu (237)	erbium Lu (238)	ytterbium Lu (239)	erbium Lu (240)	ytterbium Lu (241)	erbium Lu (242)			
lanthanoids	lanthanum La 138.9055(2)	cerium Ce 140.116(1)	praseodymium Pr 140.90765(2)	neodymium Nd 144.24(3)	promethium Pm 145(1)	samarium Sm 150.36(3)	europeum Eu 151.964(1)	gadolinium Gd 157.29(3)	terbium Tb 158.92534(2)	dysprosium Dy 162.500(1)	holmium Ho 164.93032(2)	erbium Er 167.259(3)	thulium Tm 168.9342(1)	ytterbium Yb 173.054(5)								
actinoids	actinium Ac (227)	thorium Th (232)	protactinium Pa (233)	uranium U (237)	neptunium Np (237)	plutonium Pu (244)	americium Am (243)	curium Cm (247)	bcurium Bk (247)	dyprosium Cf (251)	holmium Es (252)	erbium Fm (257)	thulium Md (258)	ytterbium No (259)								

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Optical Properties (Plasmonics):

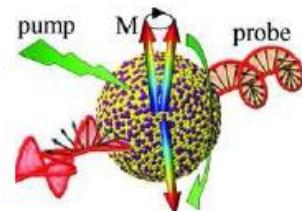
1. Plasmonic sensors
2. Plasmonic waveguides
3. Nano-Antennas
4. Iperthermia (cancer therapy)

Light confinement $< \lambda$



Magnetic Properties:

1. Super-paramagnetism
2. Magneto-optical properties
3. Medical diagnosis (Fe-oxides, NMR)



Catalytic Properties:

1. Catalysis e photo-catalysis (metal oxides, TiO₂)
2. Water splitting and hydrogen storage

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18										
hydrogen H 1.00794(7)	beryllium Be 9.012182(3)	lithium Li 6.941(2)	beryllium Be 9.012182(3)	sodium Na 22.9897(2)	magnesium Mg 24.3059(6)	potassium K 39.0794(1)	calcium Ca 40.0794(1)	scandium Sc 44.9591(0)	titanium Ti 47.857(1)	vandium V 50.9515(1)	chromium Cr 51.9951(6)	manganese Mn 54.939349(3)	iron Fe 55.845(2)	cobalt Co 58.933200(9)	nickel Ni 58.6934(4)	copper Cu 63.5463(3)	zinc Zn 65.38(2)	boron B 10.0117(1)	carbon C 12.0107(8)	nitrogen N 14.0251(7)	oxygen O 15.9954(3)	fluorine F 18.998421(5)	helium He 4.002602(3)				
lithium Li 6.941(2)	beryllium Be 9.012182(3)	sodium Na 22.9897(2)	magnesium Mg 24.3059(6)	potassium K 39.0794(1)	calcium Ca 40.0794(1)	scandium Sc 44.9591(0)	titanium Ti 47.857(1)	vandium V 50.9515(1)	chromium Cr 51.9951(6)	manganese Mn 54.939349(3)	iron Fe 55.845(2)	cobalt Co 58.933200(9)	nickel Ni 58.6934(4)	copper Cu 63.5463(3)	zinc Zn 65.38(2)	boron B 10.0117(1)	carbon C 12.0107(8)	nitrogen N 14.0251(7)	oxygen O 15.9954(3)	fluorine F 18.998421(5)	helium He 4.002602(3)						
rubidium Rb 85.467(3)	strontium Sr 87.62(1)	yttrium Y 88.058(2)	zirconium Zr 91.22(2)	niobium Nb 92.9033(2)	moodybium Mo 95.95(2)	tantalum Tc (98)	ruthenium Ru 101.07(2)	rhodium Rh 102.9555(2)	palladium Pd 106.42(1)	silver Ag 107.8562(2)	mercury Hg 110.99(1)	gold Ag 113.49(1)	mercury Hg 116.918(3)	tin Tin 118.710(7)	germanium Ge 120.0107(8)	silicon Si 121.9216(2)	phosphorus P 123.9737(12)	sulfur S 126.955(5)	chlorine Cl 127.9304(1)	argon Ar 131.777(6)							
caesium Cs 132.9545(2)	barium Ba 137.327(7)	lutetium Lu 174.966(8)	hafnium Hf (78.49(2))	zirconium Zr (180.547(1))	niobium Nb (183.84(1))	tantalum Tc (186.207(1))	rutheium Ru (186.938(1))	rhodium Rh (187.954(1))	palladium Pd (187.955(1))	silver Ag (188.956(1))	gold Ag (189.957(1))	mercury Hg (190.958(1))	mercury Hg (191.959(1))	tin Tin (191.961(1))	germanium Ge (192.962(1))	silicon Si (193.963(1))	phosphorus P (194.964(1))	sulfur S (195.965(1))	chlorine Cl (196.966(1))	argon Ar (197.967(1))							
francium Fr (223)	radium Ra (226)	barium Ba (227)	lanthanum Lr (228)	europium Rf (229)	cerium Db (230)	praseodymium Sg (231)	neodymium Bh (232)	seaborgium Hs (233)	promethium Mt (234)	hafnium Ds (235)	thulium Rg (236)	cerium Tb (237)	europium Dy (238)	terbium Tb (239)	dysprosium Dy (240)	holmium Ho (241)	erbium Er (242)	thulium Tm (243)	yterbium Yb (244)								
lanthanoids Actinoids	lanthanum La 138.9055(2)	cerium Ce 140.116(1)	praseodymium Pr 140.90765(2)	neodymium Nd 144.24(3)	promethium Pm 145(1)	samarium Sm 150.36(3)	europeum Eu 151.964(1)	gadolinium Gd 157.29(3)	terbium Tb 158.92534(2)	dysprosium Dy 162.500(1)	holmium Ho 164.93032(2)	erbium Er 167.259(3)	thulium Tm 168.9342(1)	yterbium Yb 173.954(5)	cerium Th 173.038(1)	praseodymium Pa 173.03589(2)	neodymium U 173.02891(3)	promethium Np 173(1)	samarium Pu 174(1)	europeum Am 174(1)	gadolinium Cm 174(1)	terbium Bk 174(1)	dysprosium Cf 175(1)	holmium Es 175(1)	erbium Fm 176(1)	thulium Md 176(1)	yterbium No 176(1)

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Semiconductor Nanostructures

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Semiconductor Materials

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
hydrogen H 1.00794(7)	beryllium Be 6.941(2)	boron B 10.811(7)	carbon C 12.0107(7)	nitrogen N 14.0067(7)	oxygen O 15.999403(5)	fluorine F 18.998403(5)	neon Ne 20.1797(6)										
lithium Li 6.941(2)	magnesium Mg 24.3059(9)	aluminum Al 26.9815(8)	silicon Si 28.0555(3)	phosphorus P 30.9737(12)	sulfur S 32.055(5)	chlorine Cl 35.453(2)	argon Ar 36.968(1)										
sodium Na 22.98970(2)	calcium Ca 40.0770(4)	titanium Ti 47.9571(1)	vanadium V 50.9151(1)	chromium Cr 51.9951(6)	manganese Mn 54.935045(9)	iron Fe 55.845(3)	cobalt Co 58.933000(9)	nickel Ni 58.9524(4)	copper Cu 63.545(3)	zinc Zn 65.38(2)	gallium Ga 69.723(1)	germanium Ge 72.641(1)	arsenic As 74.9216(2)	seleium Se 78.95(3)	bromine Br 79.904(1)	krypton Kr 83.773(2)	
potassium K 39.0923(1)	calium Ca 44.9555(8)	scandium Sc 44.9555(8)	yttrium Y 47.9571(1)	zirconium Zr 91.224(2)	rhenium Ru 91.963(2)	ruthenium Rh 92.963(2)	osmium Os 95.95(2)	rhodium Pd 101.07(2)	platinum Ag 102.955(2)	osmium Pt 107.868(2)	iridium Pt 112.411(8)	tin In 114.818(3)	antimony Sb 118.715(7)	tellurium Te 121.760(1)	iodine I 127.60(3)	xenon Xe 131.93(6)	
rubidium Rb 85.467(3)	strontium Sr 87.62(1)	barium Ba 88.9055(2)	lanthanum Lu 137.327(7)	cerium Hf 174.9565(1)	europium Tb 180.5479(1)	neodymium Dy 183.84(1)	praseodymium Ho 186.207(1)	promethium Mt 190.43(3)	samarium Gd 192.217(3)	neptunium Tb 195.078(2)	neptunium Dy 196.9555(2)	neptunium Ho 202.59(2)	neptunium Er 204.383(2)	neptunium Tm 207.2(1)	neptunium Yb 208.9535(2)	neptunium Uuh 209(1)	neptunium Uuo 210(2)
cesium Cs 132.90545(2)	barium Fr 137.327(7)	lanthanum Ra 143.9555(2)	cerium Lr (262)	europium Rf (267)	neodymium Db (268)	praseodymium Sg (271)	neodymium Bh (272)	neodymium Hs (270)	neodymium Mt (275)	neodymium Ds (281)	neodymium Rg (280)	neptunium Uub (285)	neptunium Uut (284)	neptunium Uuo (285)	neptunium Uup (286)	neptunium Uuh (287)	neptunium Uuo (288)
francium Fr [223]	radon Ra [226]	lanthanum La [227]	cerium Ce [232]	europium Pr [232]	neodymium Nd [231]	praseodymium Pm [237]	neodymium Sm [243]	neodymium Eu [243]	neodymium Gd [247]	neodymium Tb [247]	neodymium Dy [247]	neodymium Ho [251]	neodymium Er [257]	neodymium Tm [253]	neodymium Yb [254]	neptunium Uuo —	
lanthanoids	cerium La 132.9555(2)	europium Ce 142.116(1)	praseodymium Pr 140.97795(2)	neodymium Nd 144.24(3)	neodymium Pm 145(1)	neodymium Sm 151.954(1)	neodymium Eu 157.55(1)	neodymium Gd 162.55(1)	neodymium Tb 162.55(1)	neodymium Dy 164.333(2)	neodymium Ho 167.25(3)	neodymium Er 168.942(1)	neodymium Tm 173.05(5)	neodymium Yb 180(1)	neptunium Uuo —		
actinoids	thorium Th [227]	protactinium Pa [232]	protactinium U [238]	neptunium Np [237]	neptunium Pu [244]	americium Am [243]	curium Cm [247]	curium Bk [247]	curium Tb [251]	curium Dy [251]	curium Ho [251]	curium Es [257]	curium Fm [257]	curium Md [258]	curium No [259]		

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