Fisica delle superfici e di film ultrasottili

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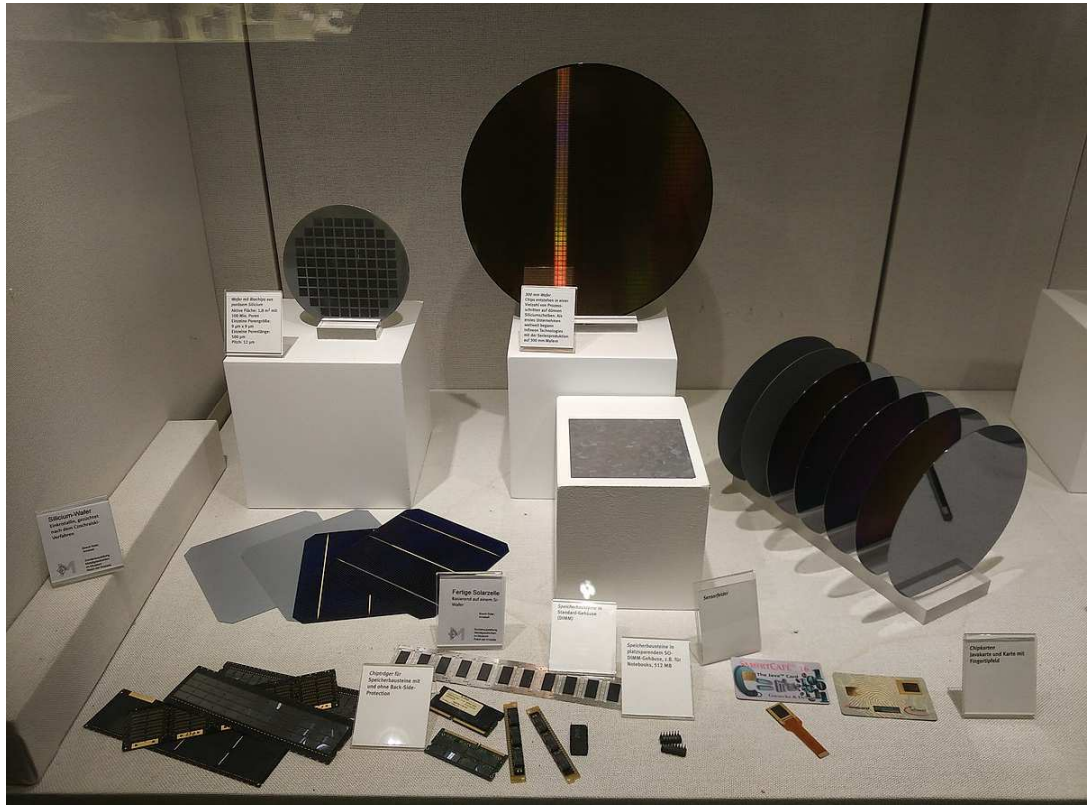
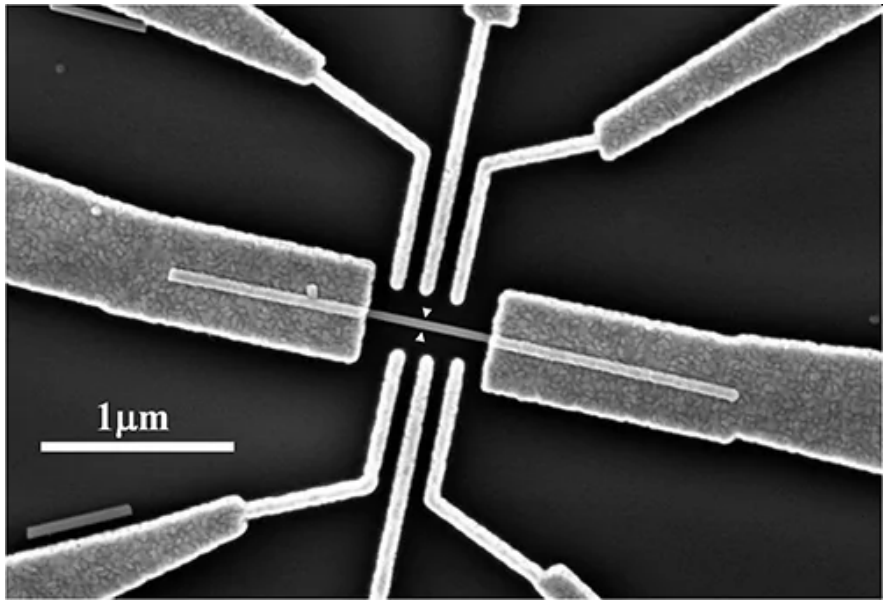
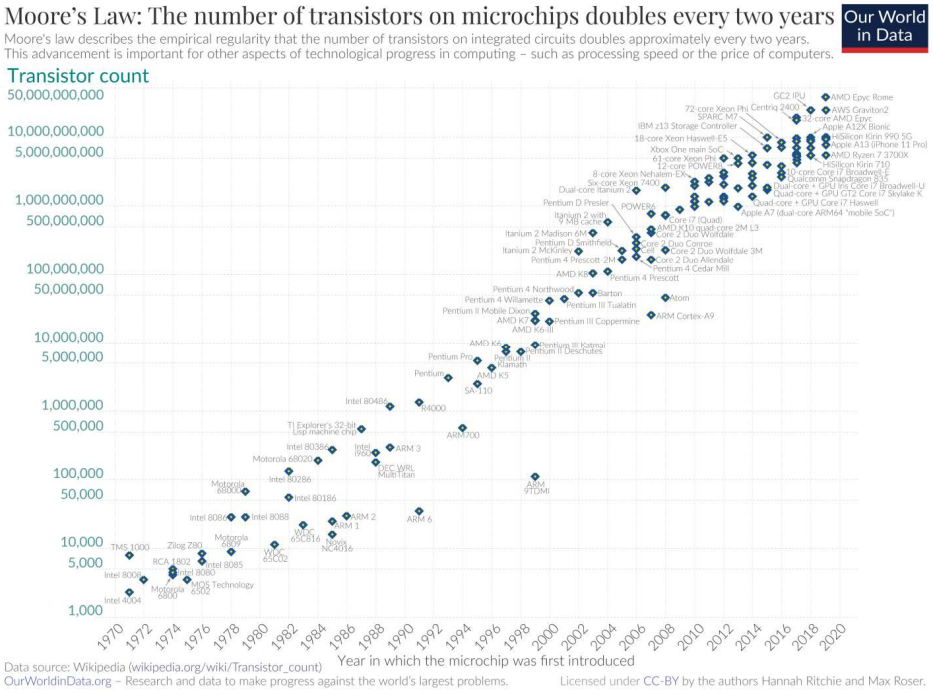
Perché studiare le superfici?



Wafer di Silicio – tecnologia anni ‘60

Transistor

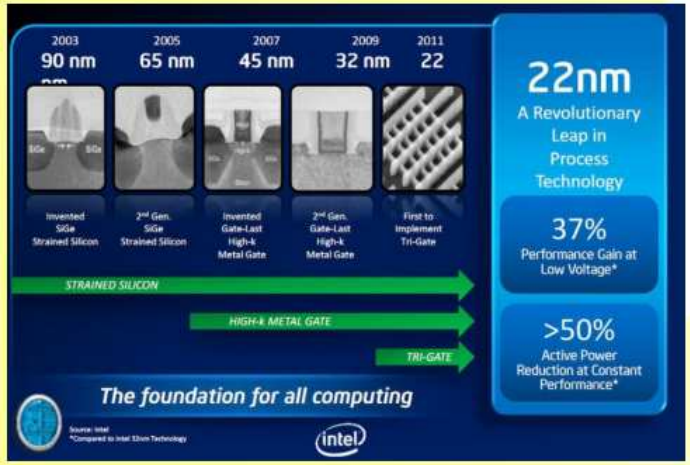


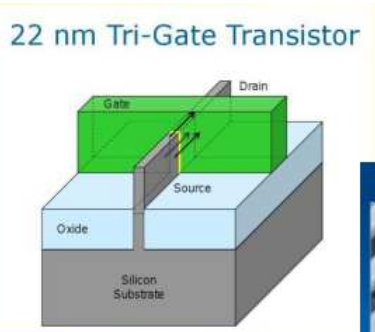


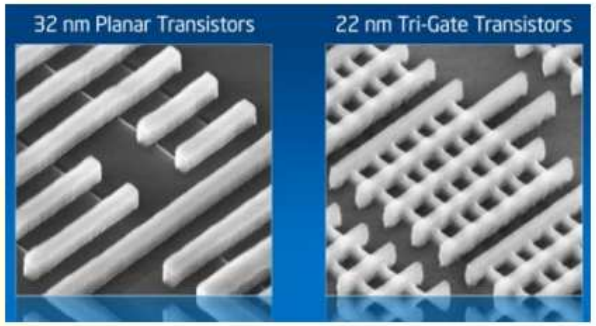
Legge di Moore:
Il numero di transistor nelle CPU raddoppia ogni due anni

Logic/Foundry Process Roadmaps (for Volume Production)

	2016	2017	2018	2019	2020	2021	2022
Intel	14nm+	10nm (limited) 14nm++		10nm	10nm+	10nm++	7nm EUV
Samsung	10nm		8nm	7nm EUV 6nm EUV	18nm FDSOI 5nm	4nm	3nm GAA
TSMC	10nm	7nm 12nm		7nm+ EUV	5nm 6nm	5nm+	4nm 3nm
GlobalFoundries			22nm FDSOI 12nm finFET		12nm FDSOI	22nm+ FDSOI 12nm+ finFET	
SMIC				14nm finFET	12nm finFET	8-10nm finFET	
UMC		14nm finFET			22nm planar		

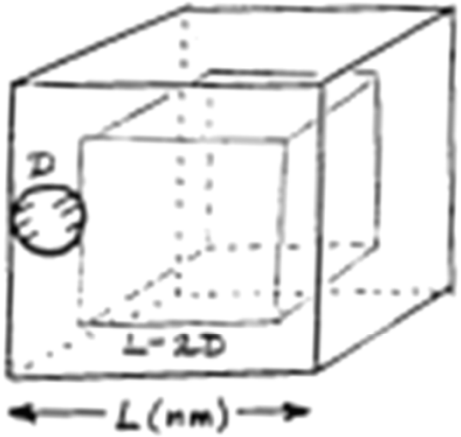






NANOTECHNOLOGIES!

FRACTION OF ATOMS ON THE SURFACE OF A CUBE: D = ATOMIC DIAM. ≈ 0.2 nm = 2 Å

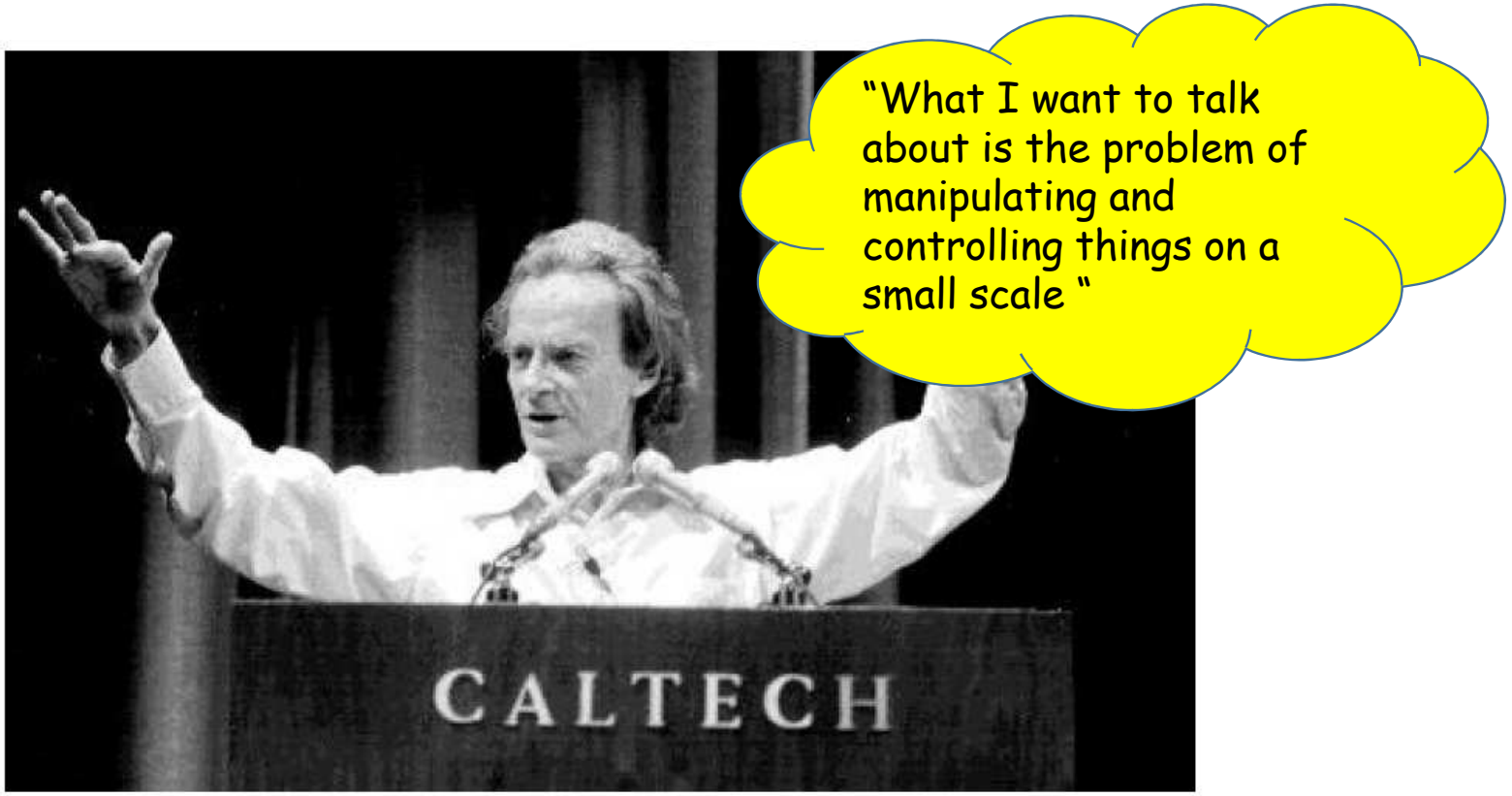


$$\text{SURFACE FRACTION} = \frac{L^3 - (L-2D)^3}{L^3}$$

L	FRACTION
1 μm = 1000 nm	0.001 = 0.1 %
0.1 μm = 100 nm	0.012 ≈ 1.2 %
0.01 μm = 10 nm	0.115 ≈ 11.5 %
0.001 μm = 1 nm	0.784 = 78.4 %

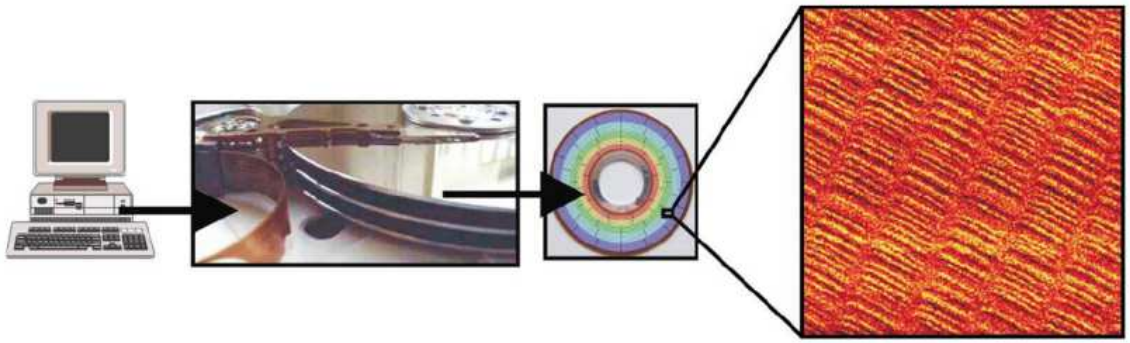
Prof. C. Fadley
School of Synchrotron Radiation
Miramare, Trieste Italy 1999

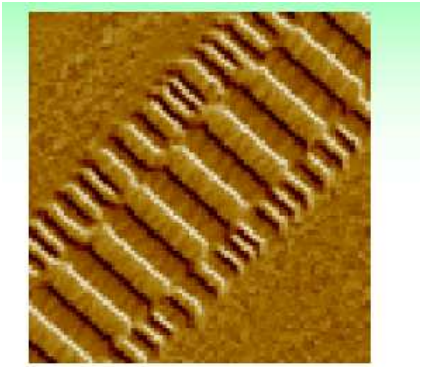
There's Plenty of Room at the Bottom è il titolo di una presentazione di Richard Feynmann alla riunione dell'APS al Caltech il 29 dicembre 1959.



NANOTECHNOLOGIES !

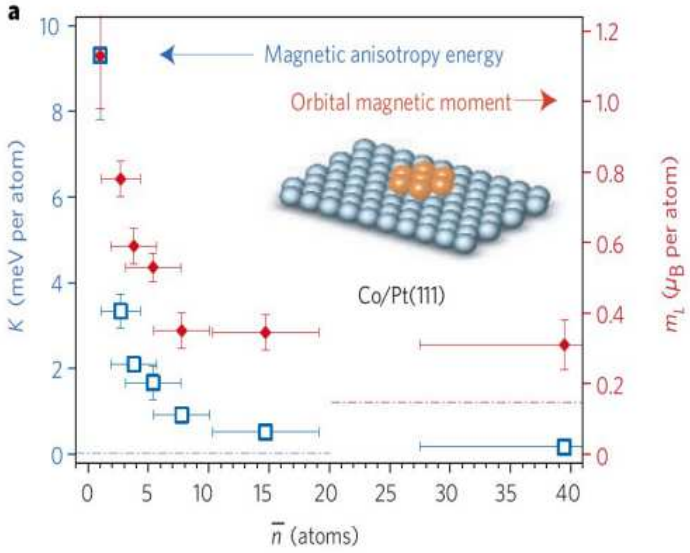
Perché studiare le superfici?





Magnetic hard drive
(25 μm x 25 μm).
Wires are about 2000
atoms wide.

Data Storage Magnetico



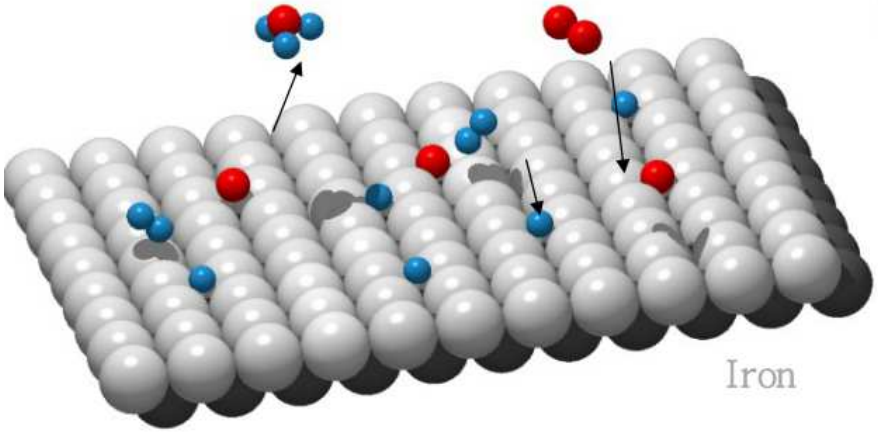
->Spintronica

Perché studiare le superfici?

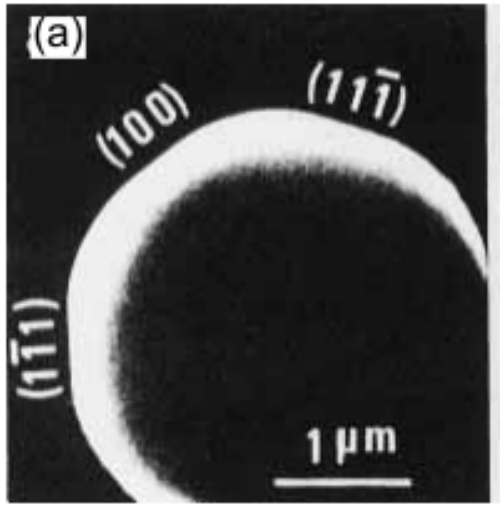
Processo Haber-Bosch (1910)

$3H_2+N_2 \rightarrow 2NH_3$

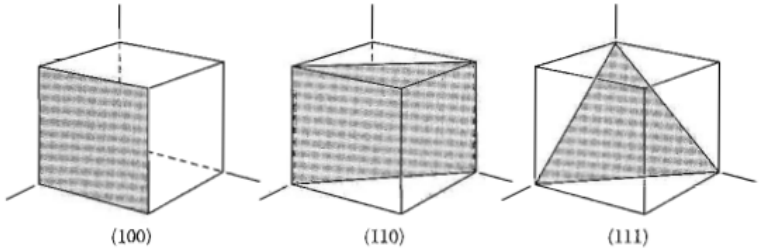
Catalisi eterogenea



Processo utile per fertilizzanti
usato ancora oggi mediante superfici di Fe

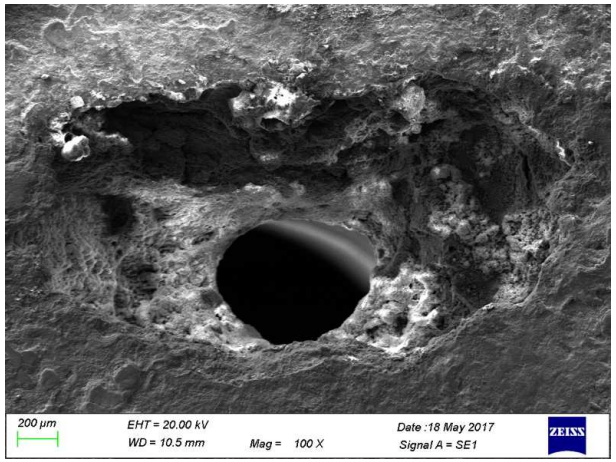


Particella di Pb

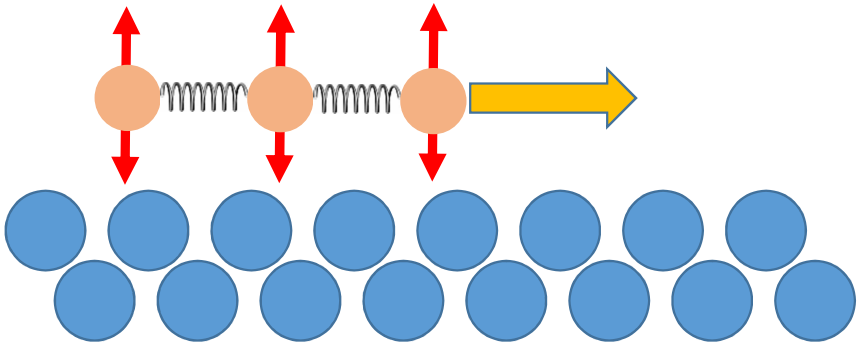


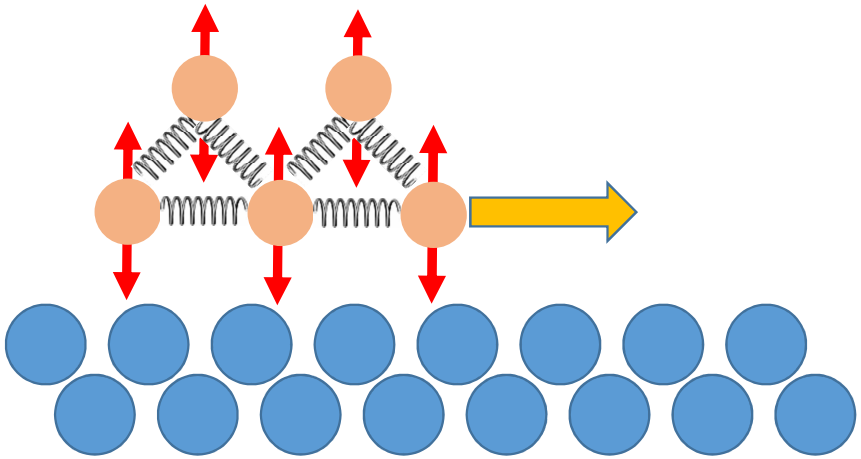
Perché studiare le superfici?

Corrosione

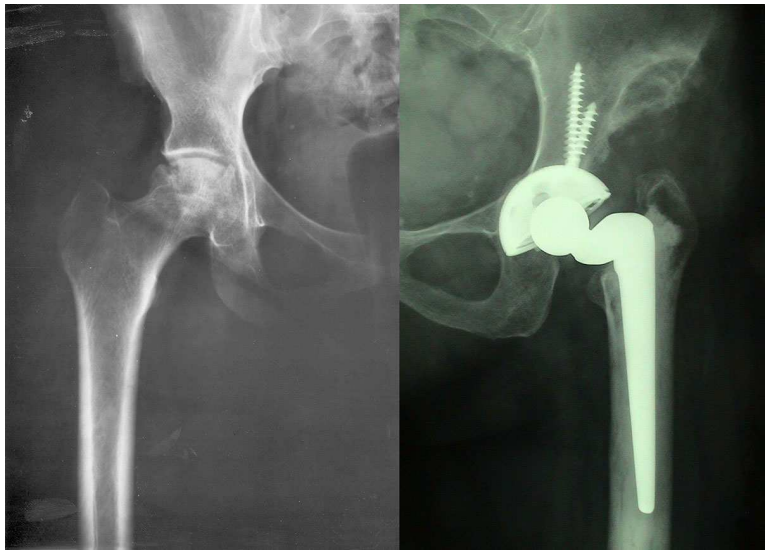


Attrito, adesione, Tribologia





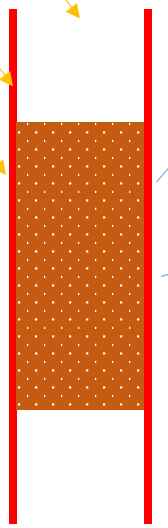
Perché studiare le superfici?



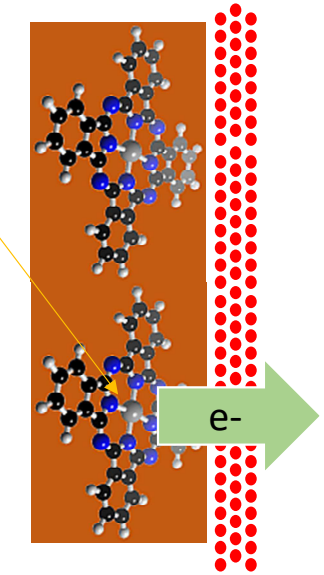
Scienza dei materiali

Medicina
Rivestimento di materiali avanzati in protesi (composizione (metalli/polimeri/ceramica), attrito, rugosità, tasso di usura, resistenza ai graffi, durezza, biocompatibilità, ecc.)

Perché studiare le superfici?



Cella fotovoltaica
Materiale attivo
Molecole organiche



Ottimizzare il processo di trasferimento di carica alla superficie dell'elettrodo

Fisica delle Superfici e sistemi modello

- Le superfici reali sono molto complesse e mal definite: policristalli, disordine, difetti, ….
- Dipendono dall'ambiente in cui si trovano
- Impurezze

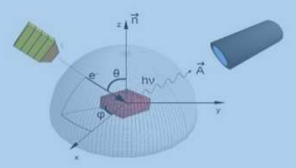
Come studiarle?

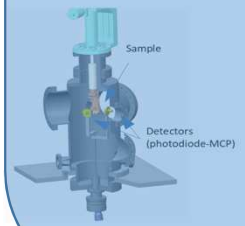
- Partire da sistemi semplici (UHV – ultra alto vuoto)
- Studiare le superfici a «basso indice» di cristalli singoli
- Capire bene queste superfici "ideali" e poi introdurre difetti/irregolarità/disordine in modo controllato
- Rendere i sistemi gradualmente più complessi nello speranza di avere modelli sempre più vicini alla realtà

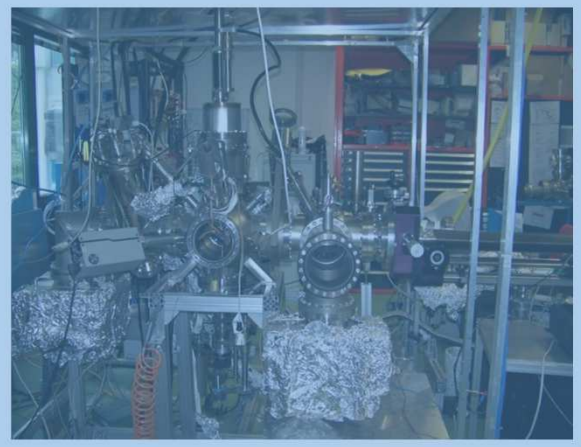
Attività di Ricerca @ Laboratorio Congiunto Superfici e Nanostrutture

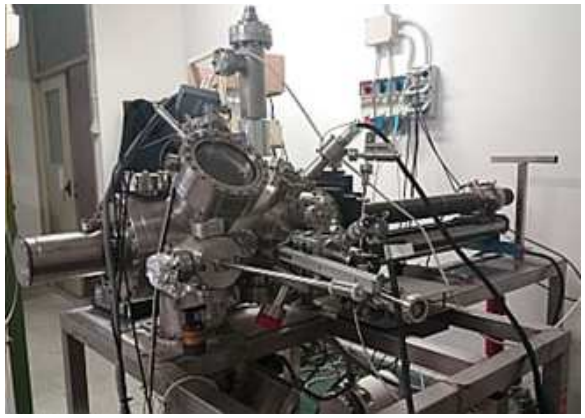
Dr. Alberto Verdini, Dr.ssa Maddalena Pedio, Prof. Giovanni Carlotti

SIPE-
nanoStructures
Inverse
Photoemission
and Excitation
dynamic









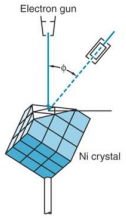
ACROSS –Surfaces, Nanostructures,
Electron Diffraction, Auger and UV
Photoemission Spectroscopy

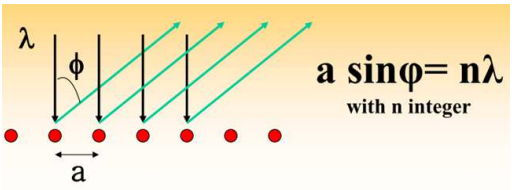
https://www.iom.cnr.it/research-facilities/facilities-labs/analytical-microscopy-and-spectroscopy/sipe/

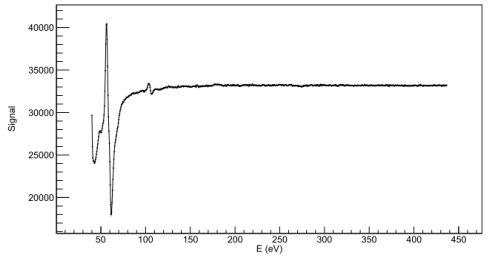
https://www.iom.cnr.it/research-facilities/facilities-labs/analytical-microscopy-and-spectroscopy/across/

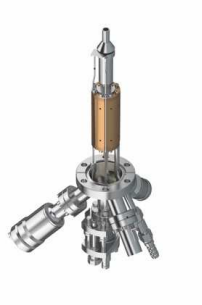
Advanced ChambeR fOr Surface Studies -> ACROSS

- Low Energy Electron Diffraction - LEED + Auger
- Reflection High Energy Electron Diffraction - RHEED
- Electron Bombardment Cell for metals
- Cooled Multicell for organic molecules deposition
- Electron Analyzer + 2D detector
- UV Source
- (Monochromatized) X-ray Source

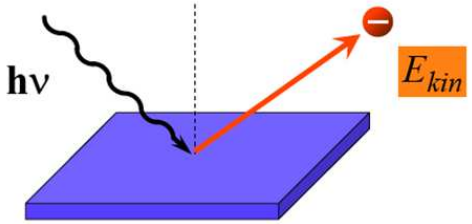






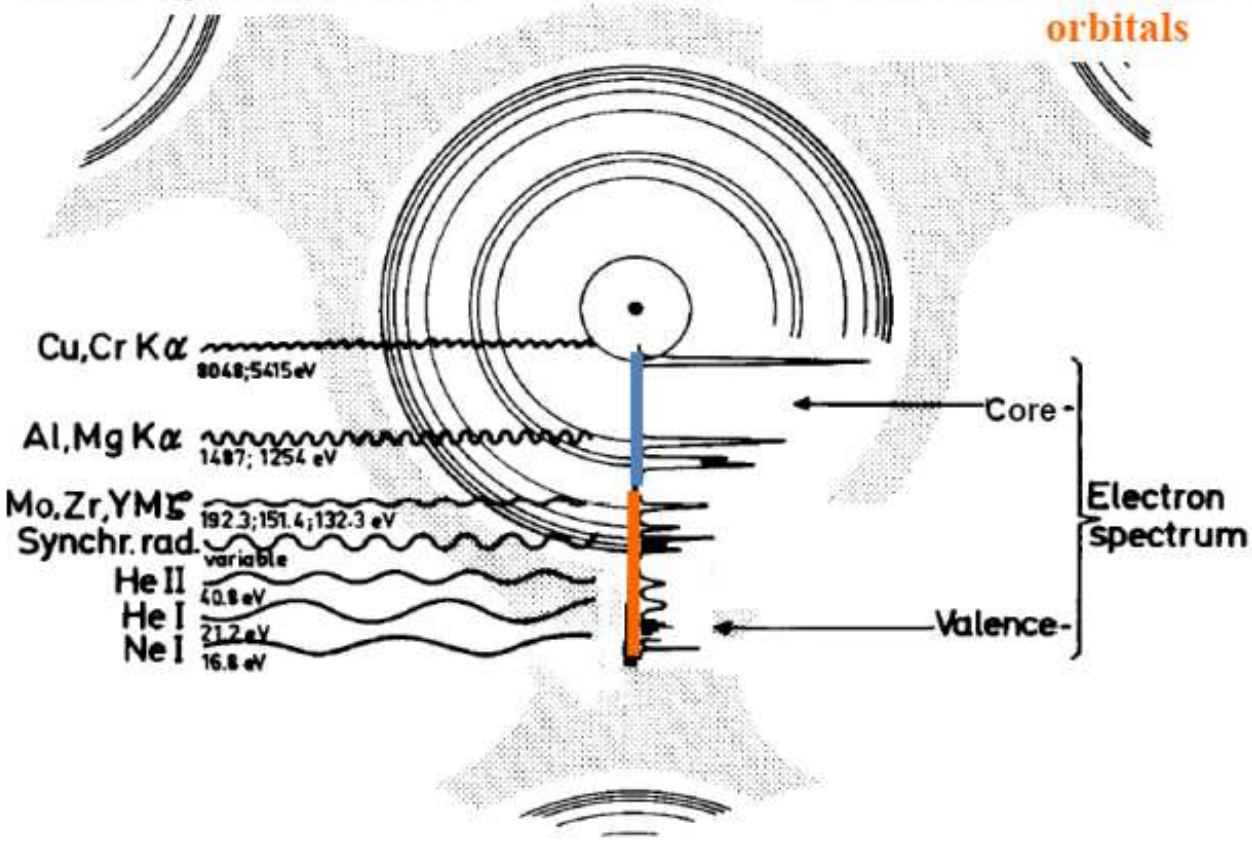


$$E_{kin} = h\nu - E_B - \Phi$$

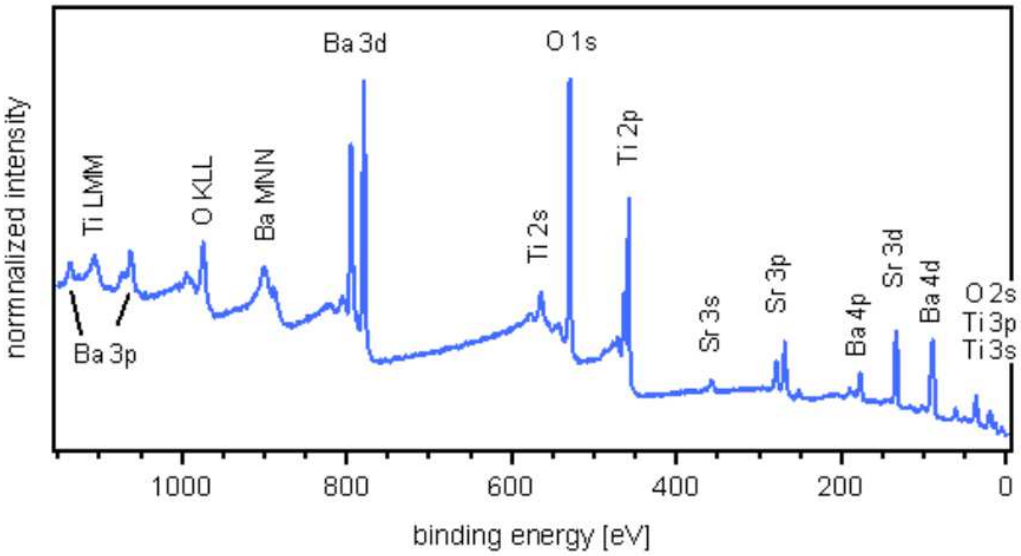


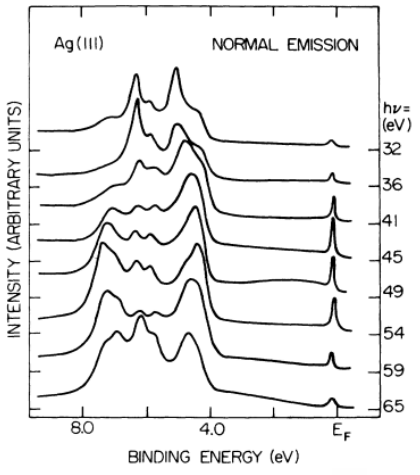
Localized levels, atomic orbitals

More delocalized levels, molecular orbitals



X-ray Photoemission Spectroscopy - XPS

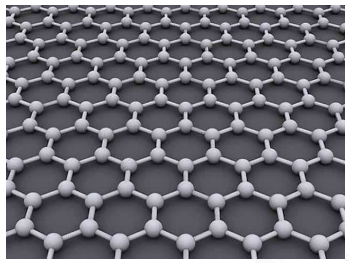




- Specificità specie atomica
- Stato chimico
- Proprietà elettroniche

Attività di Ricerca

Materiali 2D Monoatomici



Graphene

Silicene

Germanene

Stanene

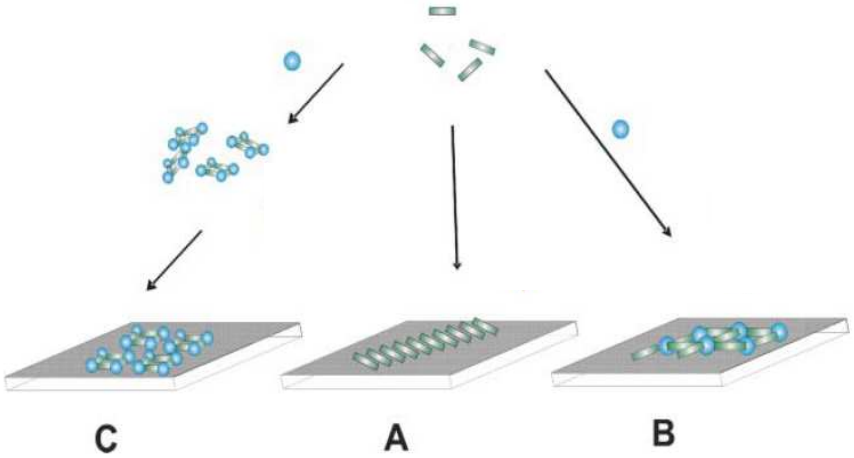
Plumbene

					helium 2 He 4.0026
boron 5 B 10.811	carbon 6 C 12.011	nitrogen 7 N 14.007	oxygen 8 O 15.999	fluorine 9 F 18.998	neon 10 Ne 20.180
aluminium 13 Al 26.982	silicon 14 Si 28.086	phosphorus 15 P 30.974	sulfur 16 S 32.065	chlorine 17 Cl 35.453	argon 18 Ar 39.948
gallium 31 Ga 69.723	germanium 32 Ge 72.61	arsenic 33 As 74.922	selenium 34 Se 78.96	bromine 35 Br 79.904	krypton 36 Kr 83.80
indium 49 In 114.82	tin 50 Sn 118.71	antimony 51 Sb 121.76	tellurium 52 Te 127.60	iodine 53 I 126.90	xenon 54 Xe 131.29
thallium 81 Tl 204.38	lead 82 Pb 207.2	bismuth 83 Bi 208.98	polonium 84 Po [209]	astatine 85 At [210]	radon 86 Rn [222]

Borophene

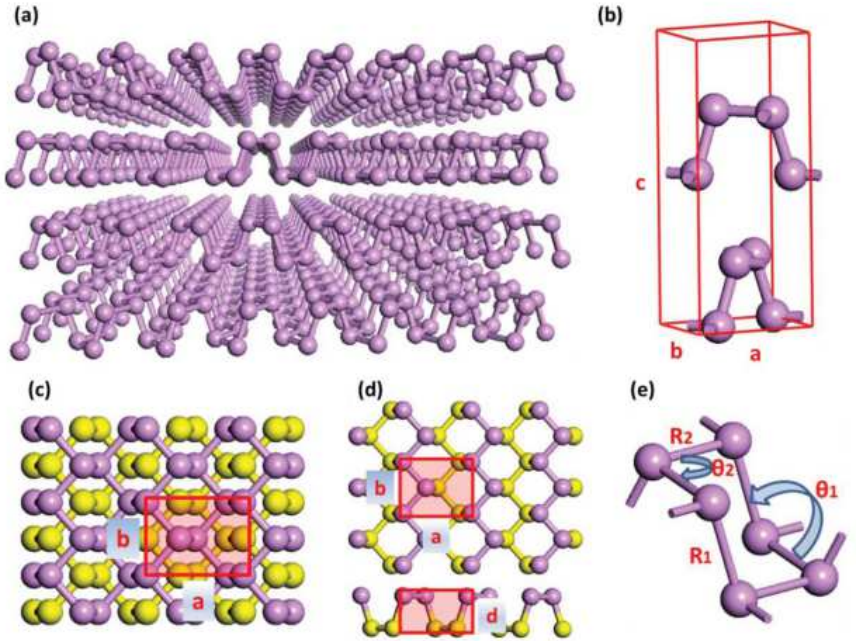
Phosphorene

Crescita pilotata dalla superficie



N. Lin et al., Dalton Trans., 2006, 2794–2800

Black Phosphorous



V. Sorkin et al. Critical Reviews in Solid State and Materials Sciences, 42, 1 (2016)

PHYSICAL REVIEW B **93**, 035448 (2016)

Surface structure determination of black phosphorus using photoelectron diffraction

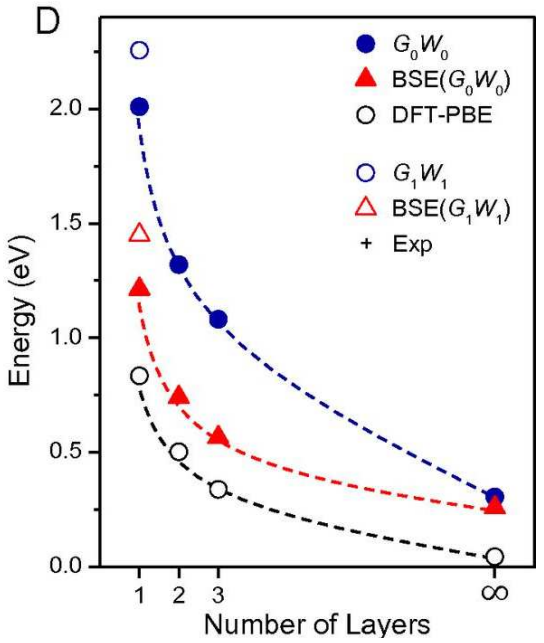
Luis Henrique de Lima,[1,*] Lucas Barreto,[1,2] Richard Landers,[1] and Abner de Siervo[1,†]
[1]*Instituto de Física Gleb Wataghin, Universidade Estadual de Campinas, Campinas 13083-859, São Paulo, Brazil*
[2]*Centro de Ciências Naturais e Humanas, Universidade Federal do ABC, Santo André 09210-580, São Paulo, Brazil*
(Received 16 November 2015; revised manuscript received 11 January 2016; published 26 January 2016)

Applicazioni

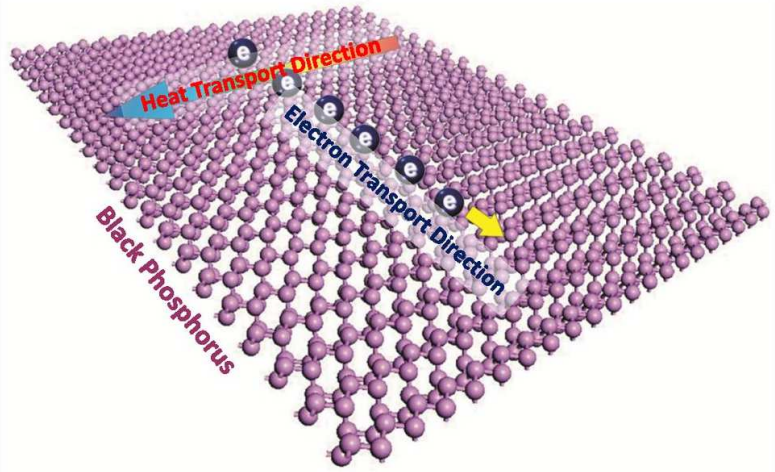
- Transistor FET
- Dispositivi Optoelettronici
- Celle solari
- Scissione fotocatalitica dell'acqua
- Batterie Li-ion
- Materiali termoelettrici
- Sensori

Black phosphorous principali proprietà interessanti:

- La gap dipende dal numero di strati

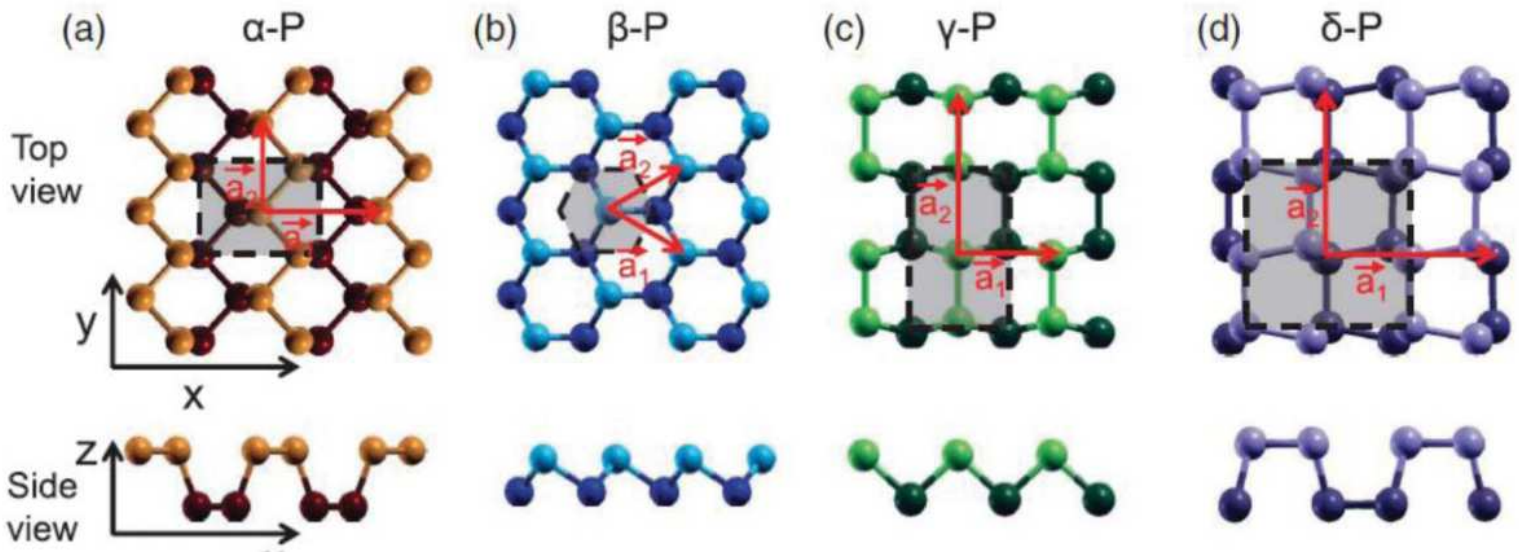


- Anisotropia sul piano del trasporto di calore e di elettroni



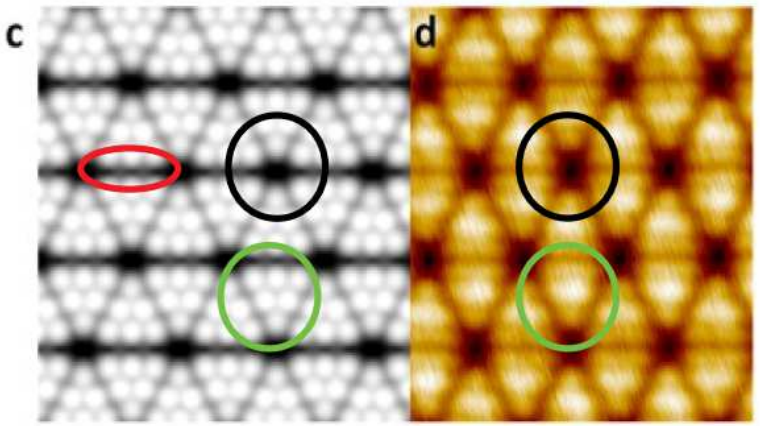
X. Ling et al., PNAS - April 14, 2015 112 (15) 4523-4530

Molti possibili monostrati con diverse strutture

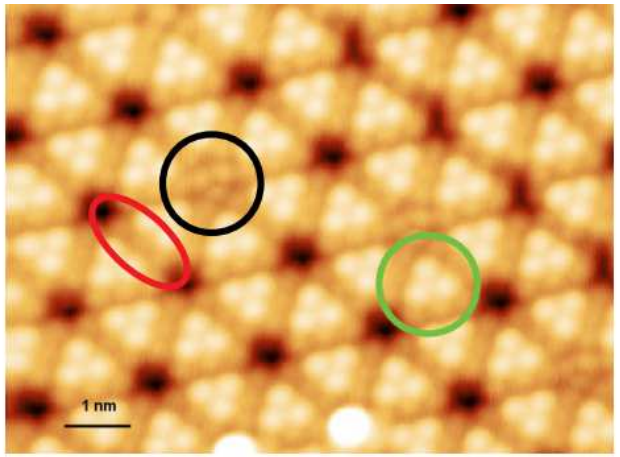


Fasi calcolate per un singolo strato di P

J. Guan et al, PRL 113, 046804 (2014)

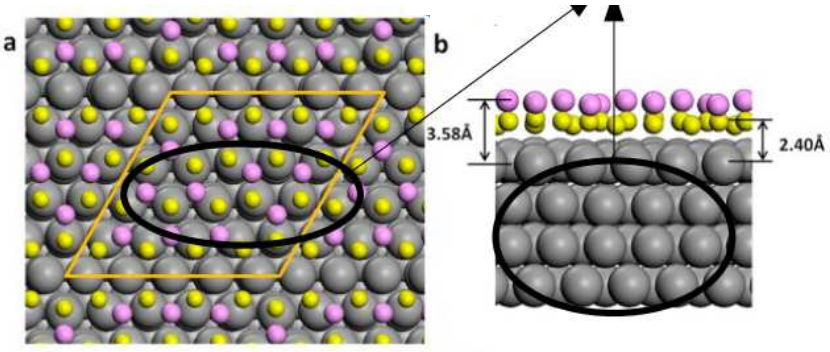


[1]J.L. Zhang et al., Epitaxial Growth of Single Layer Blue Phosphorus: A New Phase of Two-Dimensional Phosphorus, Nano Lett. 16, 4903-4908 (2016)

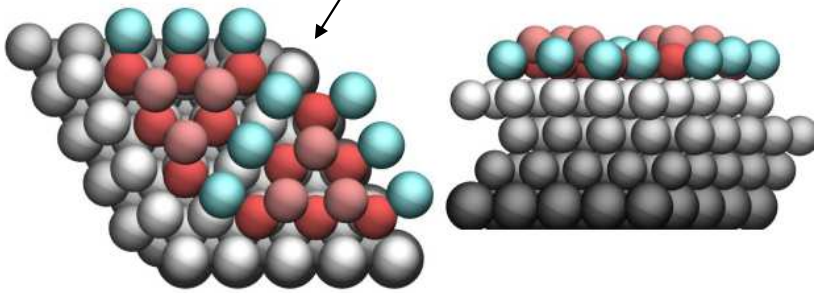


Our expSTM image - P_{16} x 2 model

Struttura non stabile

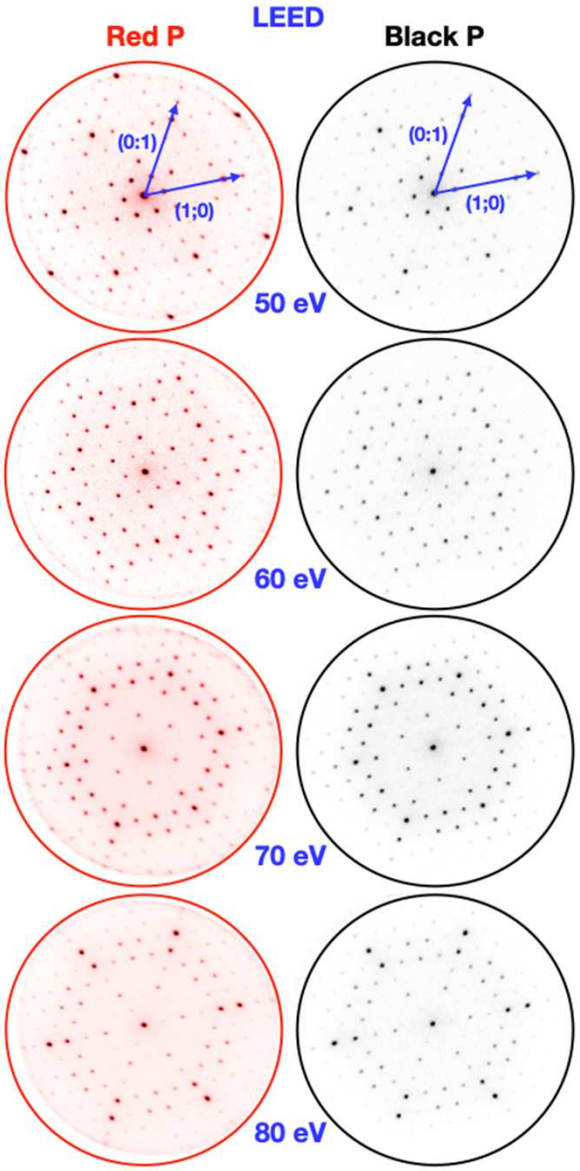


? P o Au ?



A. Sala @ IOM TS
M. Peressi S. Dal Puppo @UniTS

Electron Diffraction



Perché non usare il fosforo rosso (molto molto economico) invece di quello nero (molto costoso)?

Stesse Strutture

⇩

SI!

⇩

Abbassamento dei costi (anche ambientali) per la produzione di dispositivi

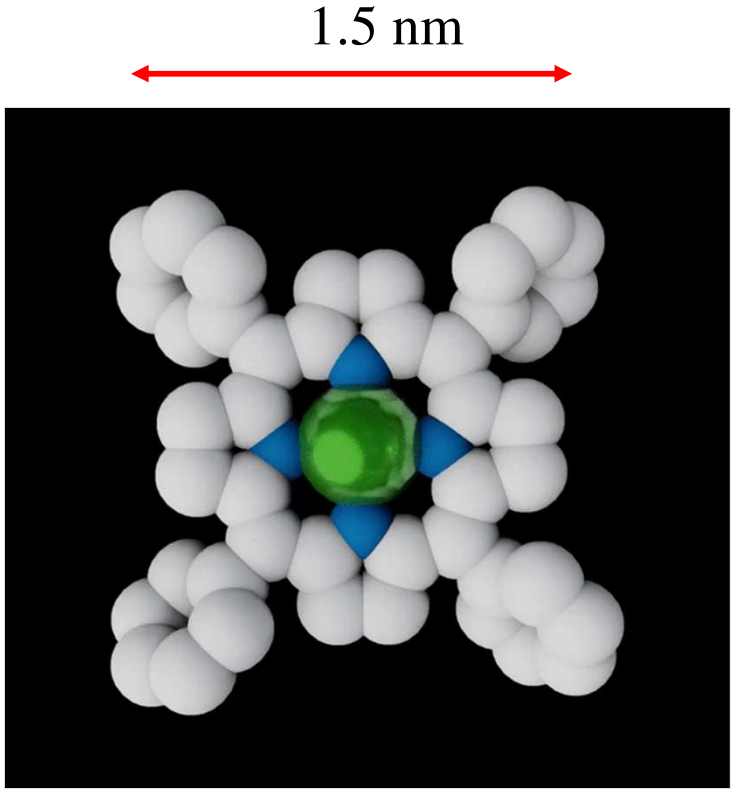
A. Sala et al. Nanoscale,14,16256(2022)
https://doi.org/10.1039/D2NR02657K

Porfirina (tetrapirrolo), molecola metallorganica -> semiconduttori organici

Funzionalizzabile mediante diversi ligandi
Metallo al centro: Cu, Zn, Ni, Fe, Pd, ….

Applicazioni:

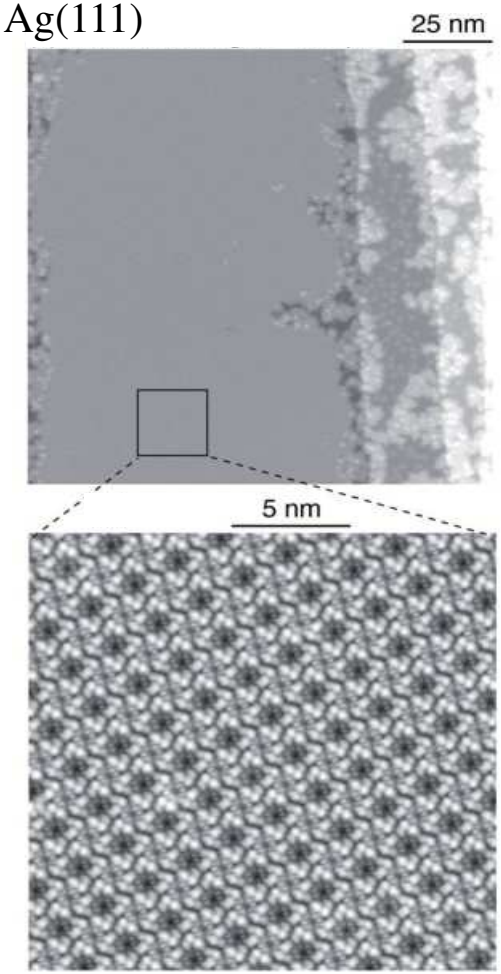
- Celle Solari
- Dispositivi elettronici a basso consumo
- Transistor molecolari
- Spintronica
- H_2 da Water Splitting
- Sensori
- Quantum Computing
- Terapie anti tumorali



Presente nei sistemi biologici fondamentali
Emoglobina, Clorofilla, F430,…

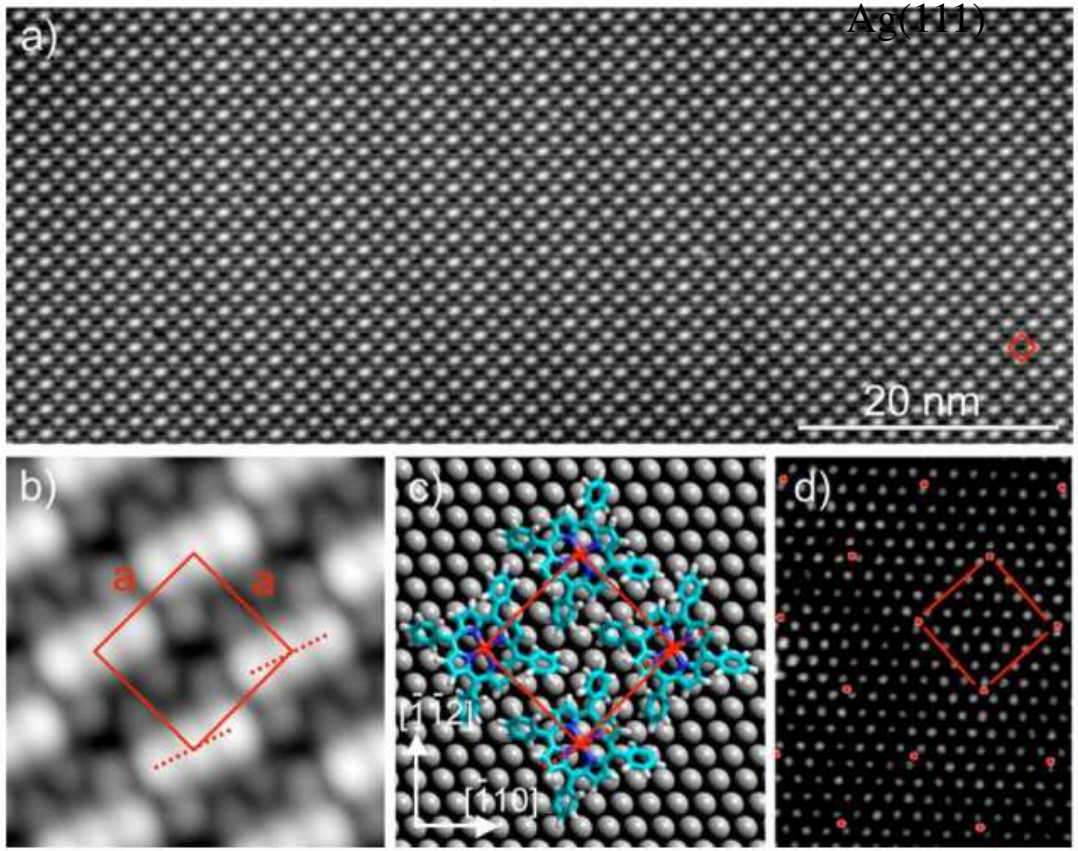
Autoassemblamento sulle superfici

$TbPc_2$/ Ag(111)



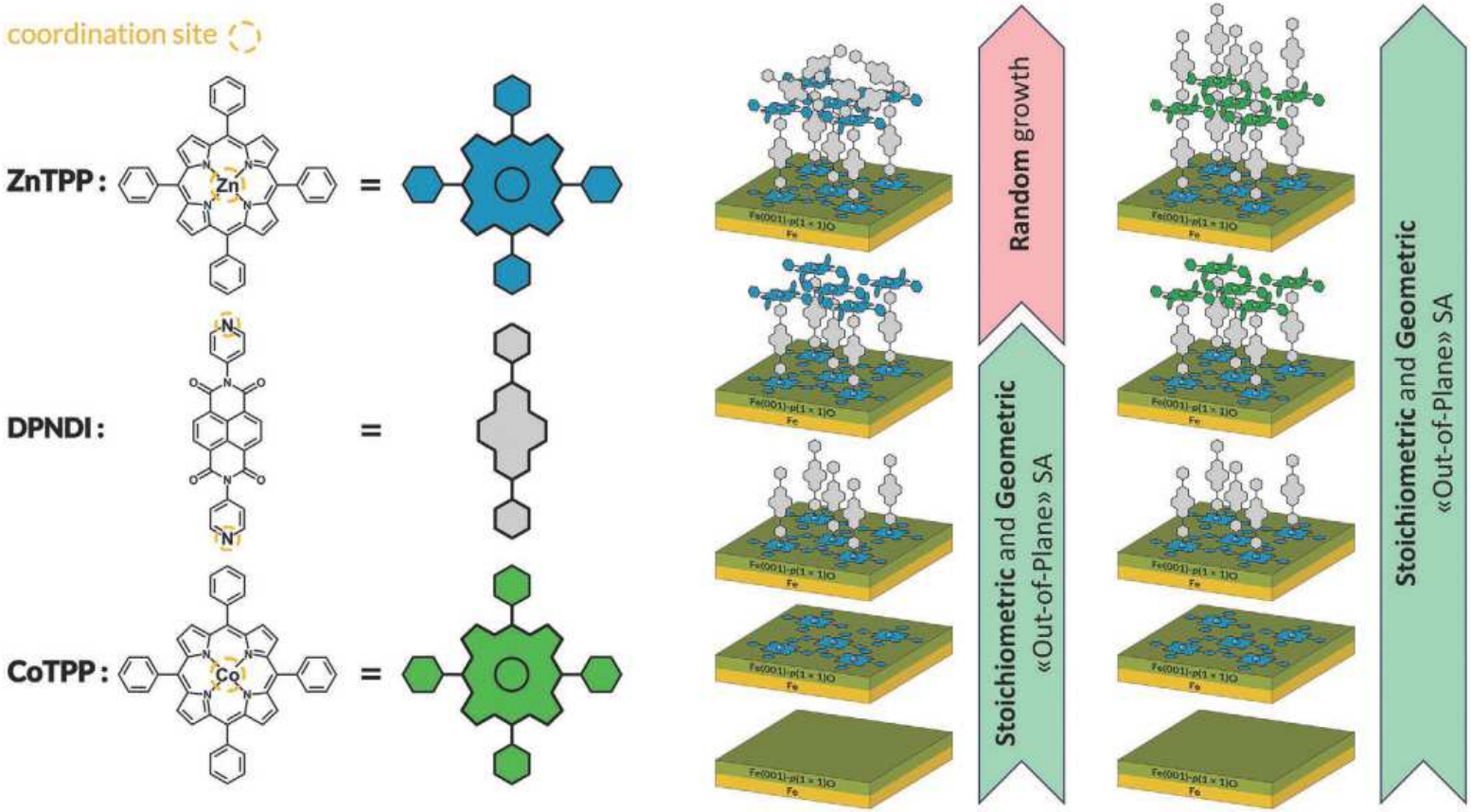
K. Diller et al. RSC Adv., 9, 34421 (2019)
DOI: 10.1039/c9ra06803a

CoTPP/
Ag(111)



W. Auwarter et al. PRB 81, 245403 (2010,
http://dx.doi.org/10.1103/PhysRevB.81.245403

Autoassemblamento in 3D



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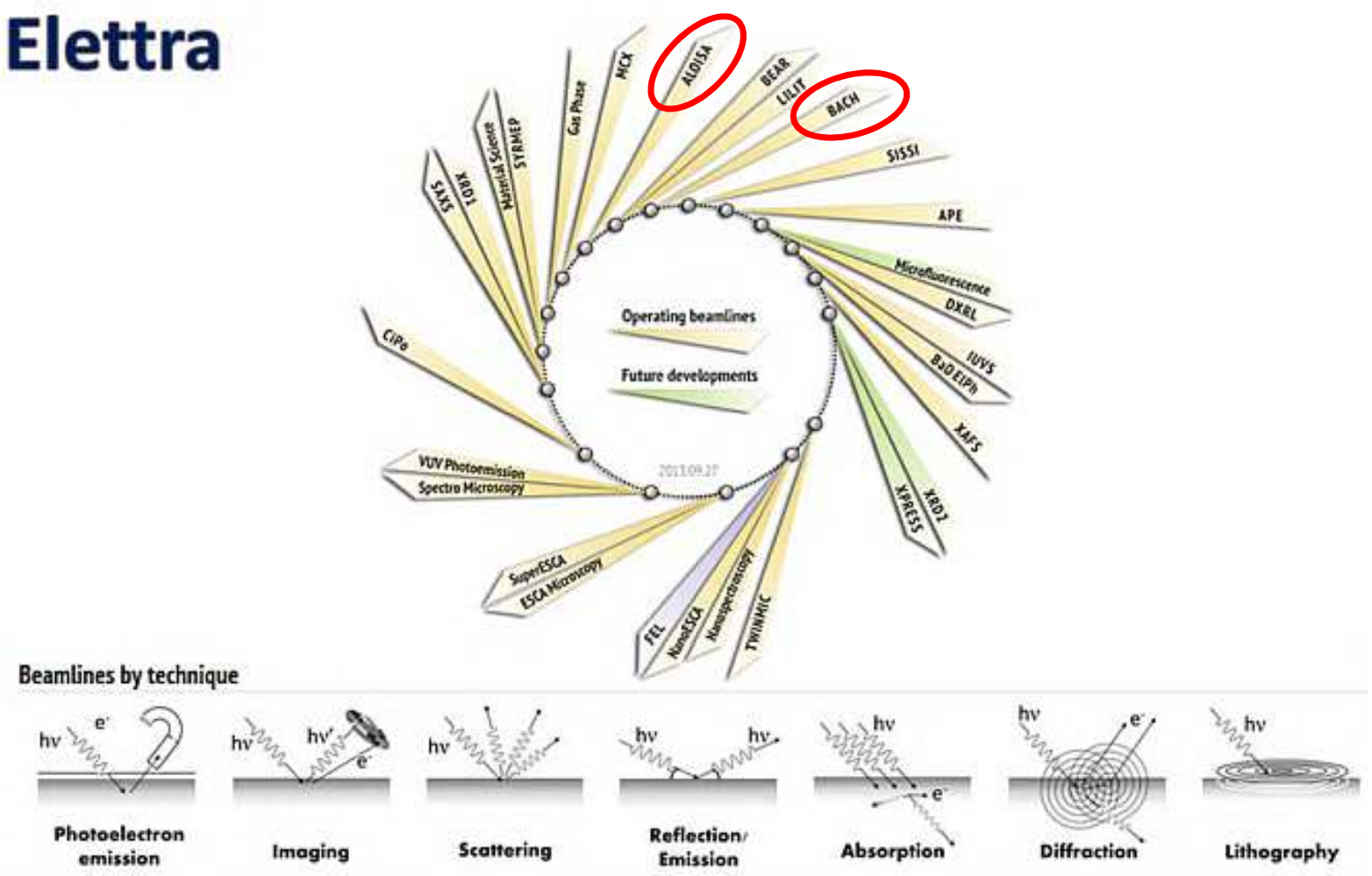
Adv. Funct. Mater. 2021, 31, 2011008

Attività presso Sincrotrone Elettra - Trieste



Possibili argomenti per le tesi triennali e magistrali

- Studio della crescita di P su superfici metalliche:
  Cu(111), Cu(100), Ni(111), Pt(111),….
- Studio delle interazioni monostrato di P con tetrapirroli

Laboratorio/sincrotroni

- Ottimizzazione della tecnica di spettroscopia UPS e XPS
- Ottimizzazione della strumentazione delle camere sperimentali – motorizzazioni, acquisizione dati, automazione,…

Grazie per la vostra attenzione