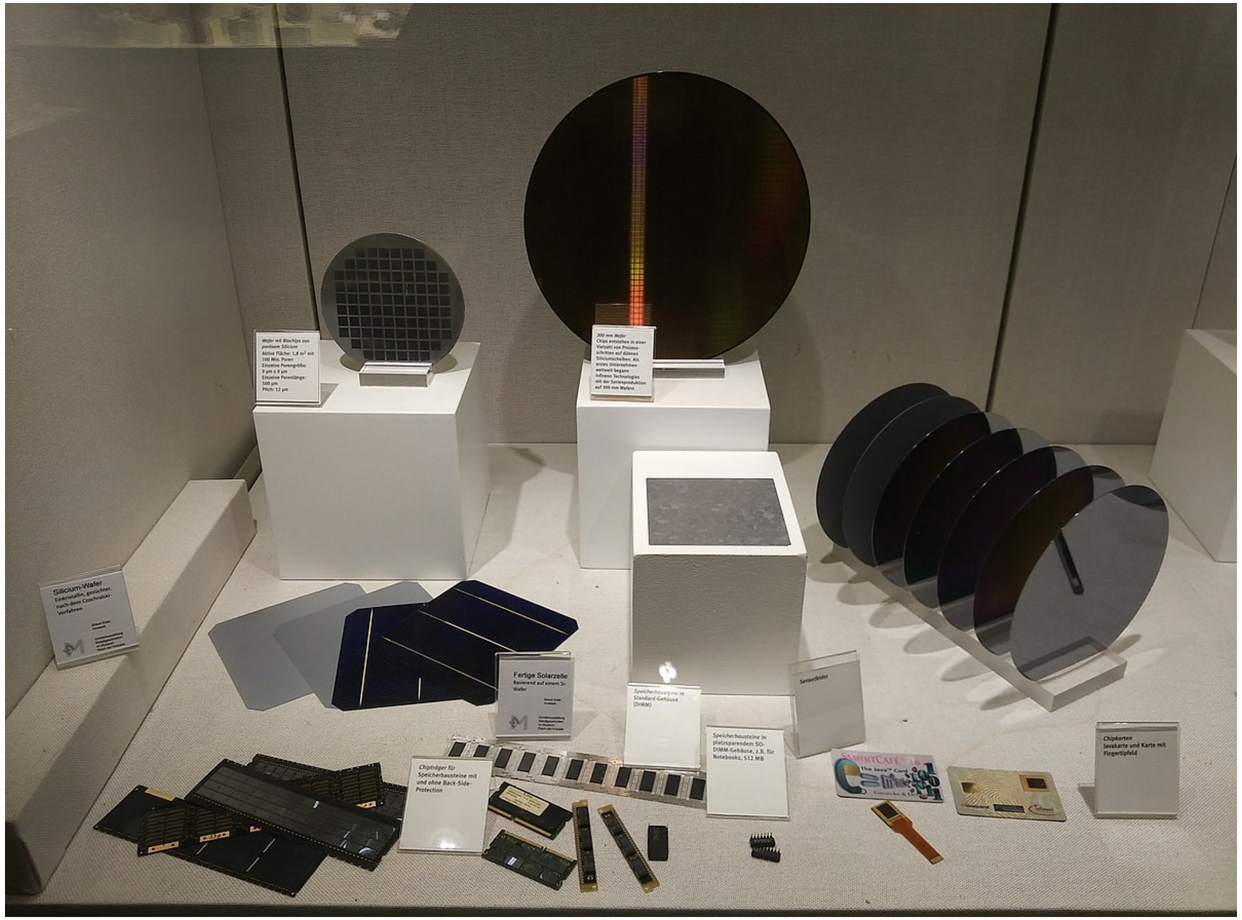
Corso «Fondamenti di Fisica delle Superfici»

Dr. Alberto Verdini

CNR-IOM

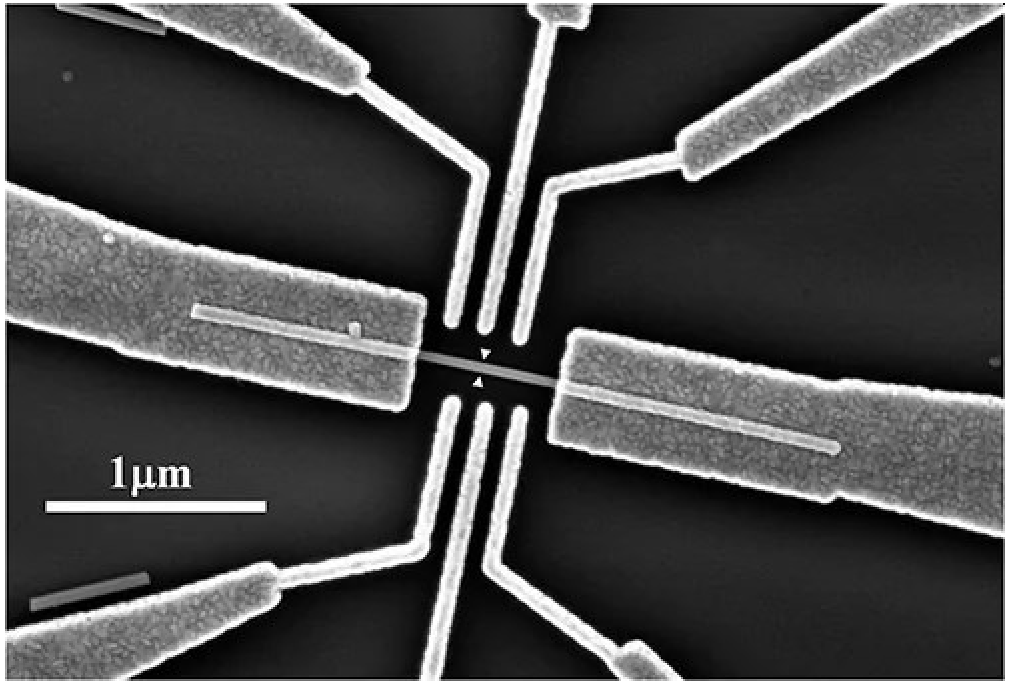
verdini@iom.cnr.it

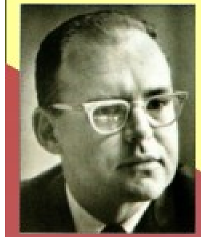
Perché studiare le superfici?



Wafer di Silicio – tecnologia anni ‘60

Transistor



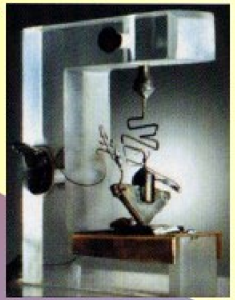


Gordon Moore's law: device dowsizing (1965)

The number of transitor that can be placed inexpensively on a chip doubles every two years on average.

First solid state device silicon transistor

Texas Instruments introduced the first Si tansistor in 1954

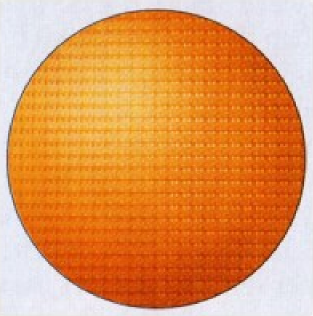


Size matters

Transitors in the first microprocessor (the Intel 4004) measured 10 µm.

Small talk

The transistors in Intel's Pentium 4 were constructed with processes at 90 nm.



10^8 nm

10^7 nm

10^6 nm

10^5 nm

10^4 nm

10^3 nm

100 nm

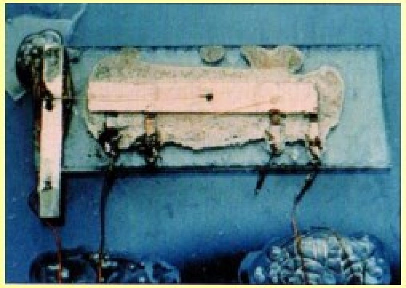
10 nm

Vacuum tube (thermoionic valve)

The first active electronic device

The first integrated circuit

Jack Kilby developed the first integrated circuit in 1958.



How low can we go?

Further downsizing may not prove to be economically viable

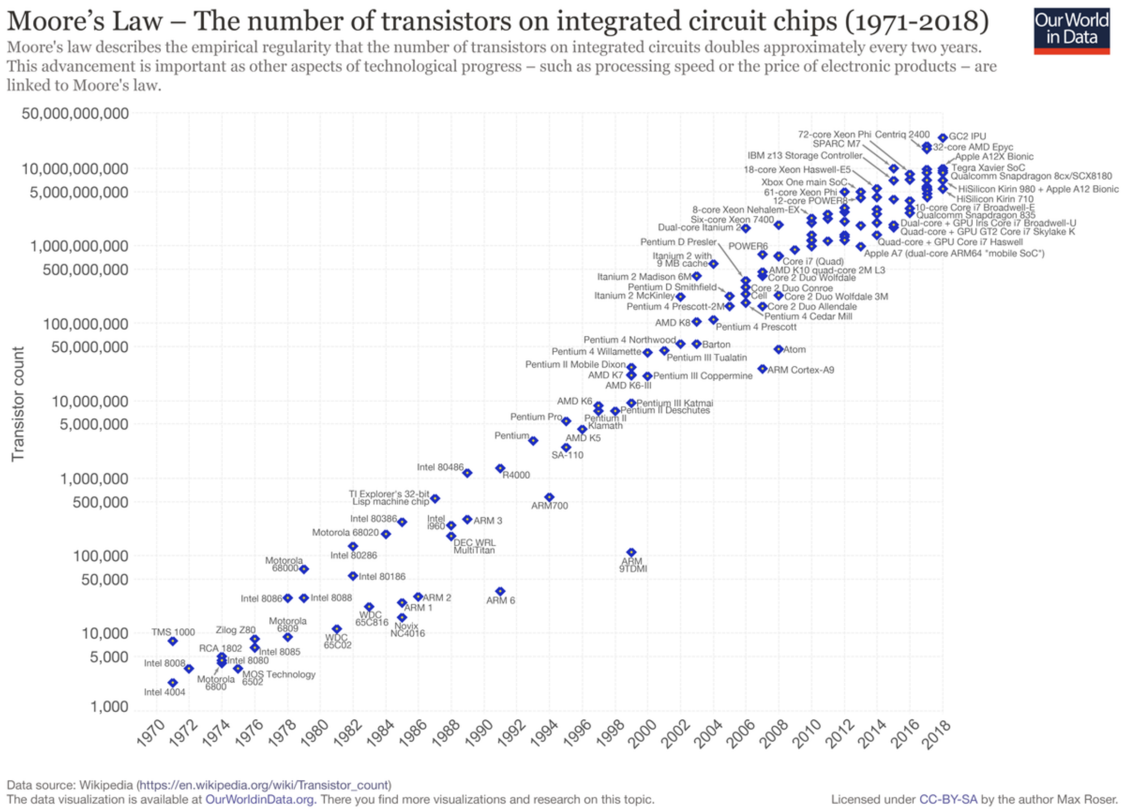
The smallest transistor that may be manufactured cost effectively is 9 nm

Limit of current manufacturing techniques is about 5 nm

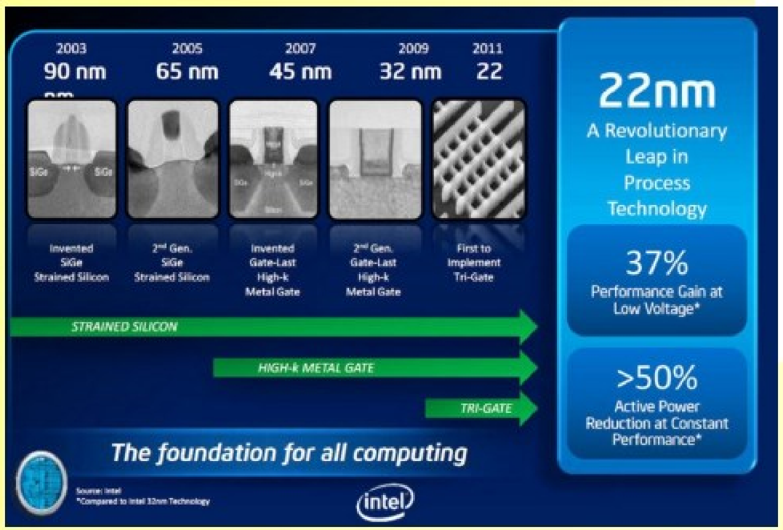
Fundamental physical limit is just below 1 nm

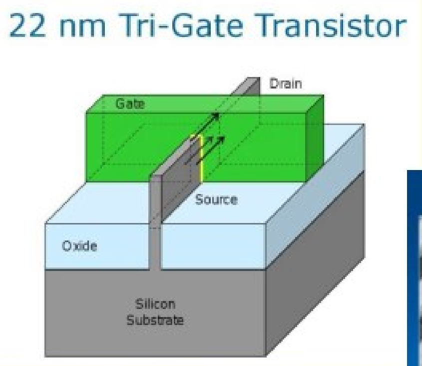
New technologies, such as spintronics, will be needed to go below these limits

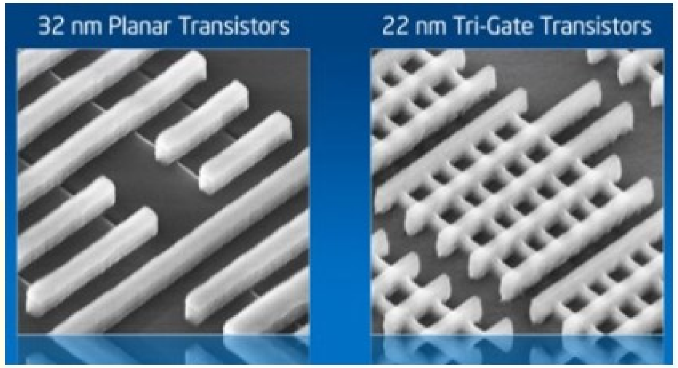
1900 1950 1960 1970 1980 1990 2000 2010 2020



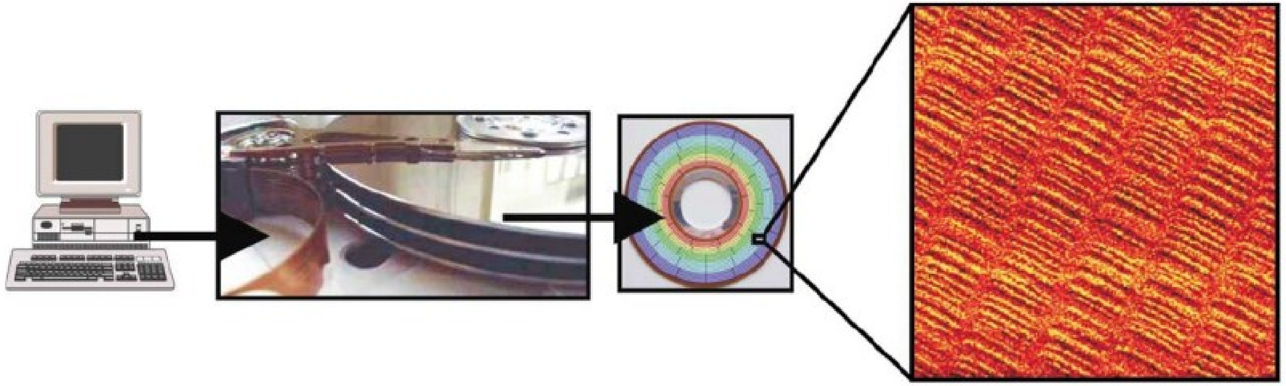
Legge di Moore:
Il numero di transistor nelle CPU raddoppia ogni due anni

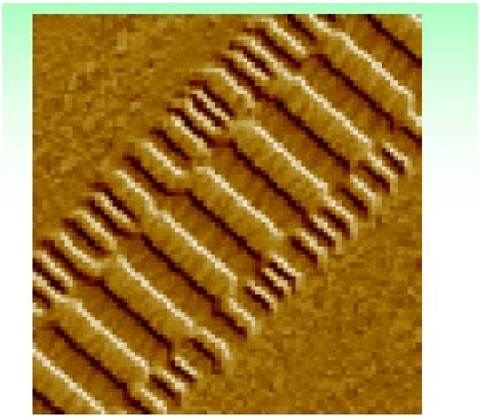






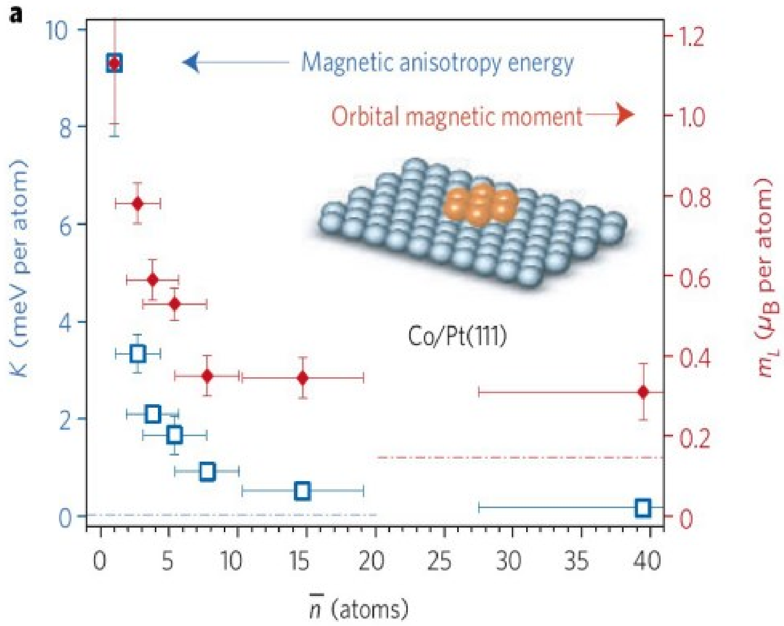
Perché studiare le superfici?





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

Data Storage Magnetico



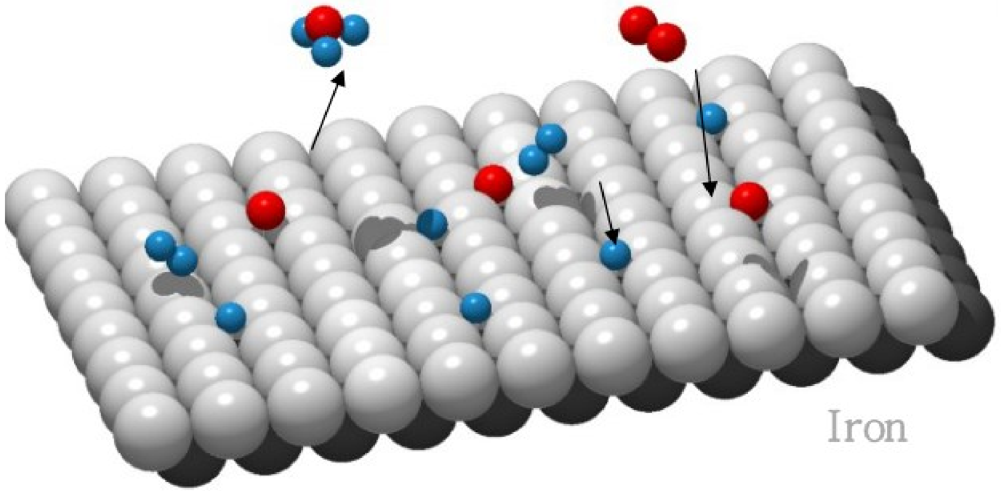
->Spintronica

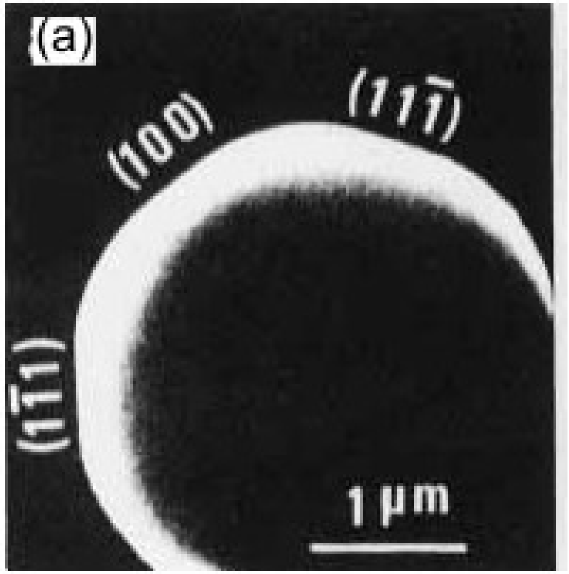
Perché studiare le superfici?

Processo Haber-Bosch (1910)

$3H_2+N_2 \rightarrow 2NH_3$

Catalisi eterogenea

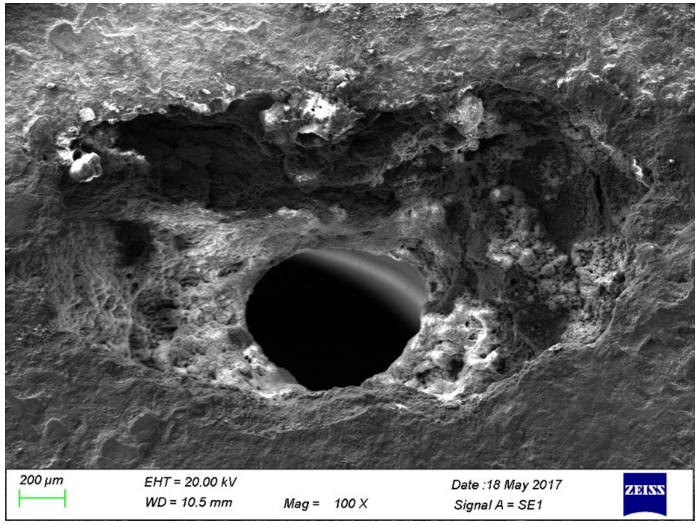




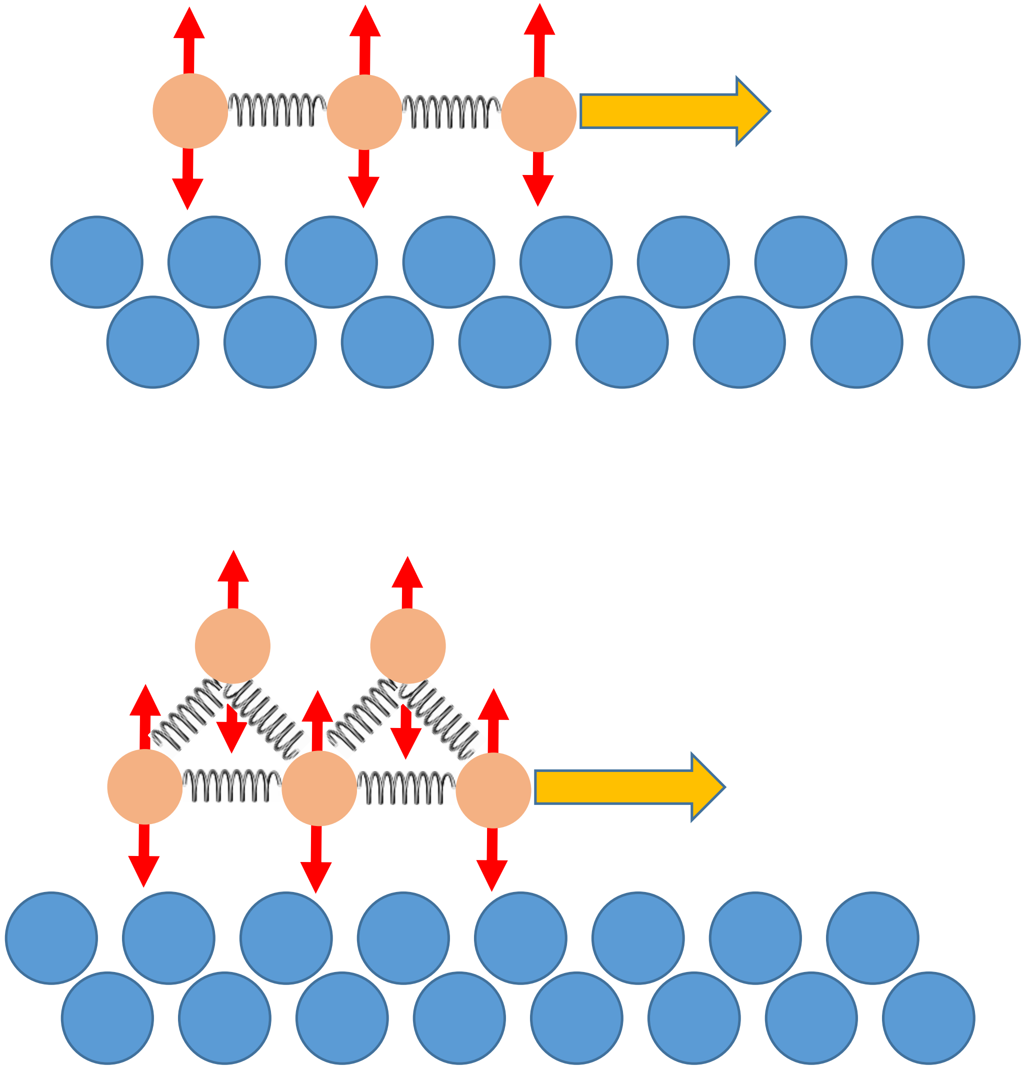
Processo utile per fertilizzanti
usato ancora oggi mediante superfici di Fe

Perché studiare le superfici?

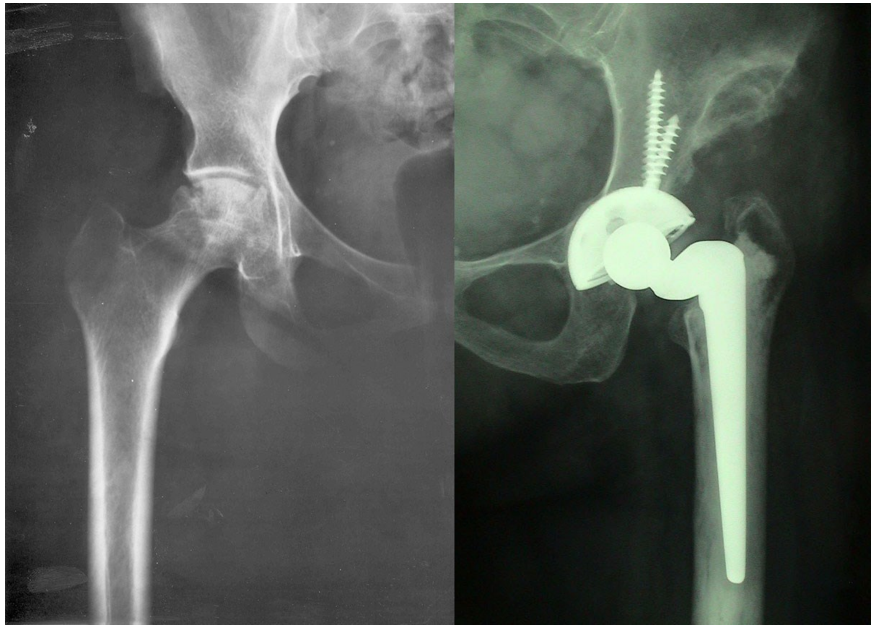
Corrosione



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.)

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.

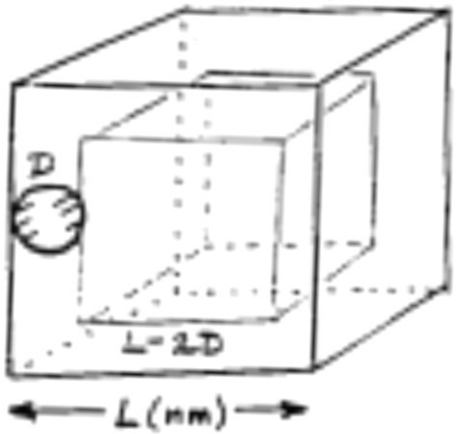
"What I want to talk about is the problem of manipulating and controlling things on a small scale "

NANOTECHNOLOGIES !

Perché studiare le superfici?

NANOTECHNOLOGIES !

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

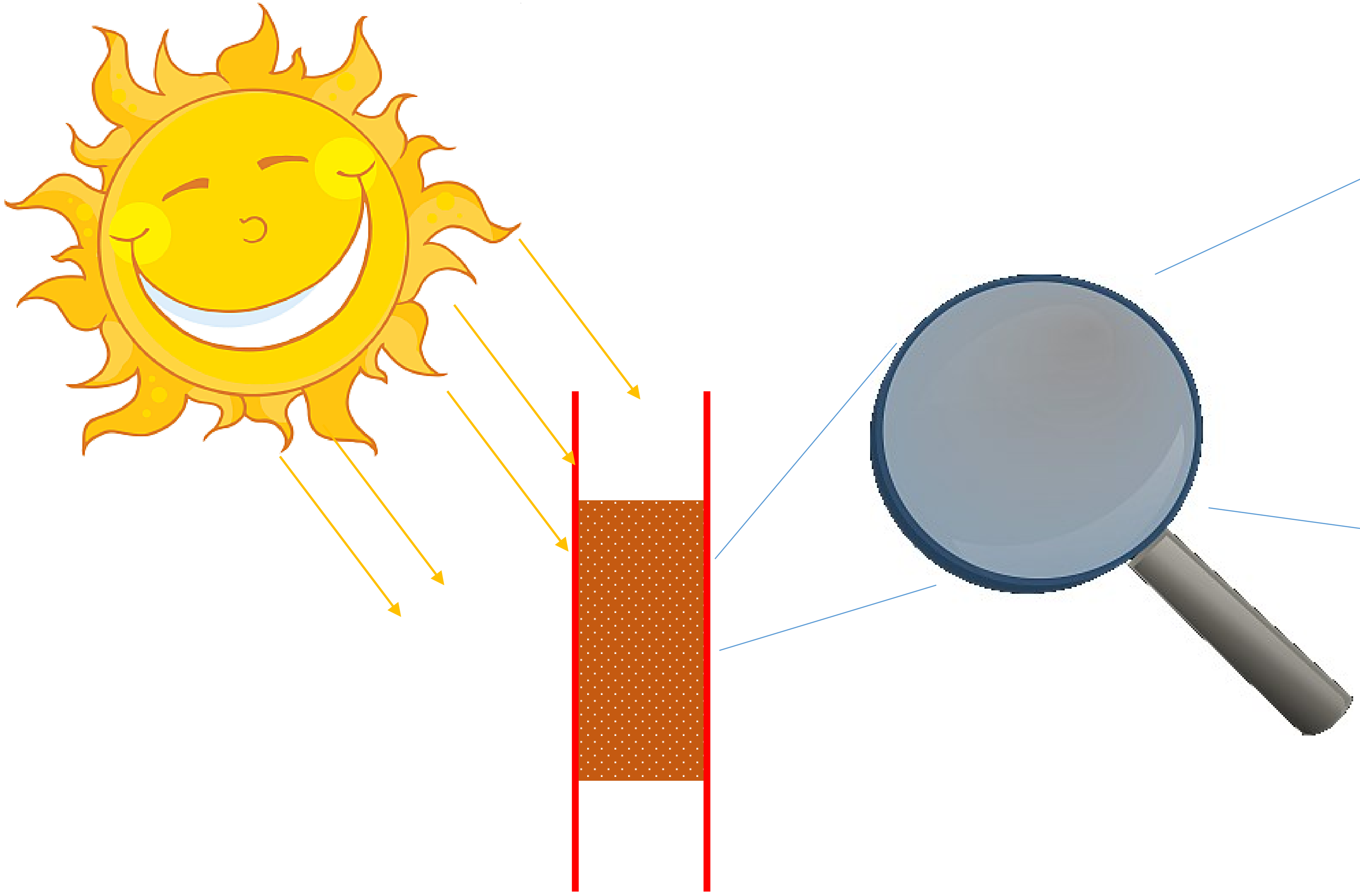


SURFACE FRACTION = $\frac{L^3 - (L-2D)^3}{L^3}$

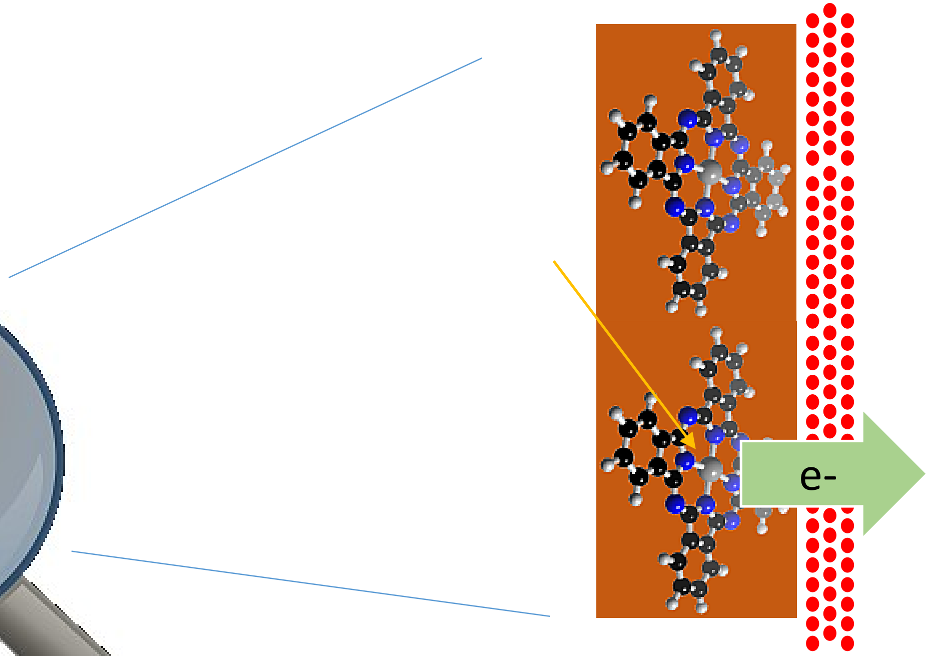
L	FRACTION
1 μm = 1000 nm	0.001 = 0.1 %
0.1 μm = 100 nm	0.012 = 1.2 %
0.01 μm = 10 nm	0.115 = 11.5 %
0.001 μm = 1 nm	0.784 = 78.4 %

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

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

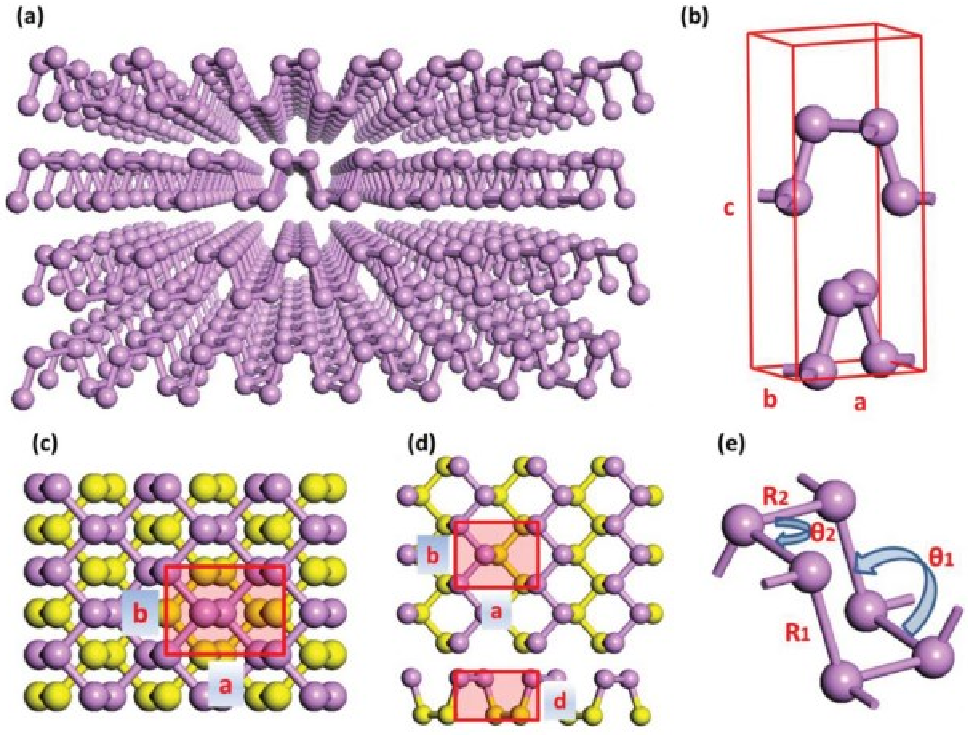
Come studiarle?

- Partire da sistemi semplici (UHV)
- 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

Materiali 2D

- Graphene -> Nobel
- Altri sistemi monostrato? …. Silicene, Germanene, Stanene
- Borophene and Phosphorene

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*

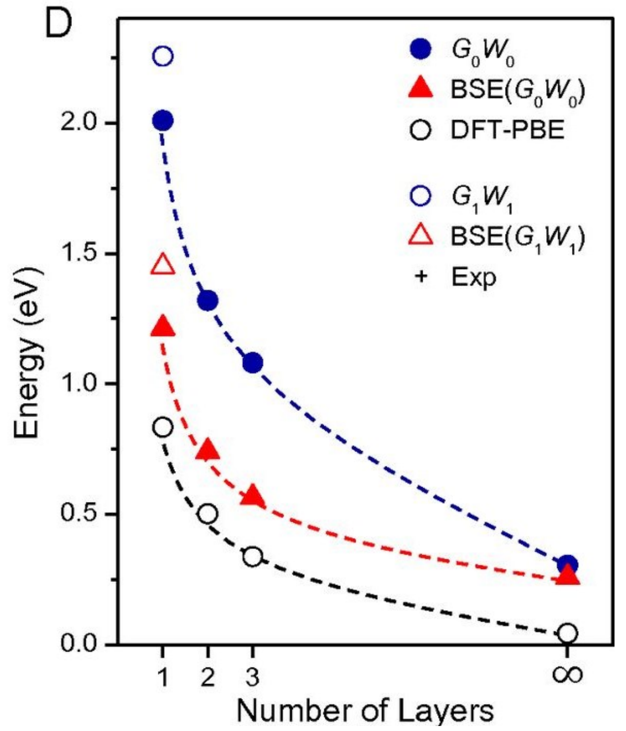
[2]*Centro de Ciências Naturais e Humanas, Universidade Federal do ABC, Santo André 09210-580, São Paulo, Brazil*

(Received 16 November 2015; revised manuscript received 11 January 2016; published 26 January 2016)

Applicazioni

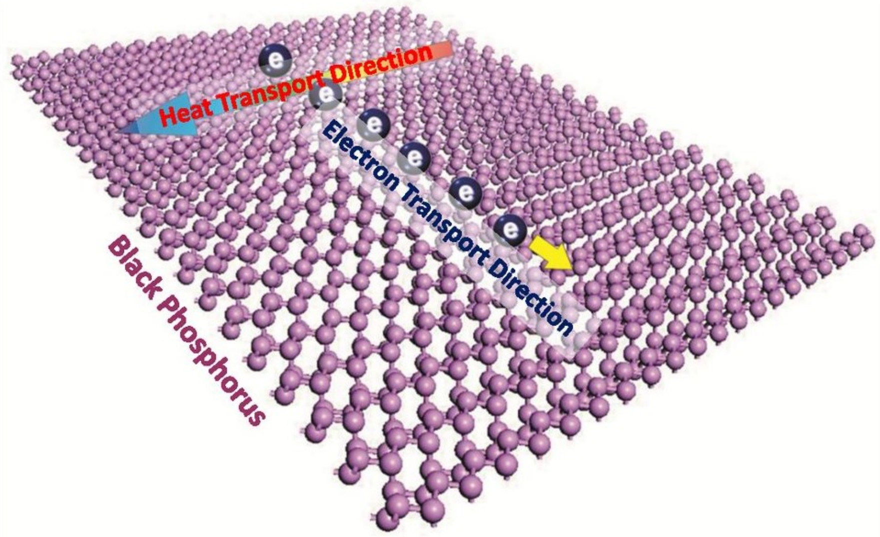
- Transistor FET
- Dispositivi Optoelettronici
- Celle solari
- Scissione fotocatalitica dell'acqua
- Batterie Li-ion
- Materiali termoelettrici
- Sensori

Black phosphorous principali proprietà interessanti:



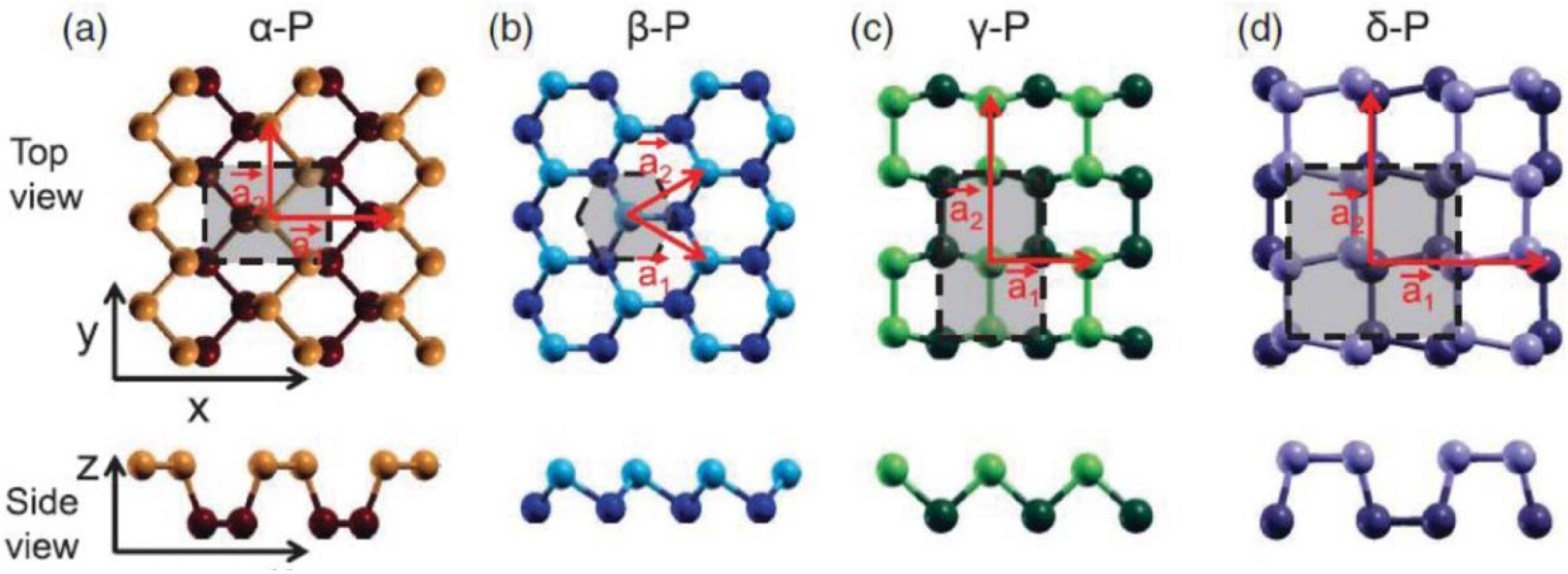
- La gap dipende dal numero di strati

- 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



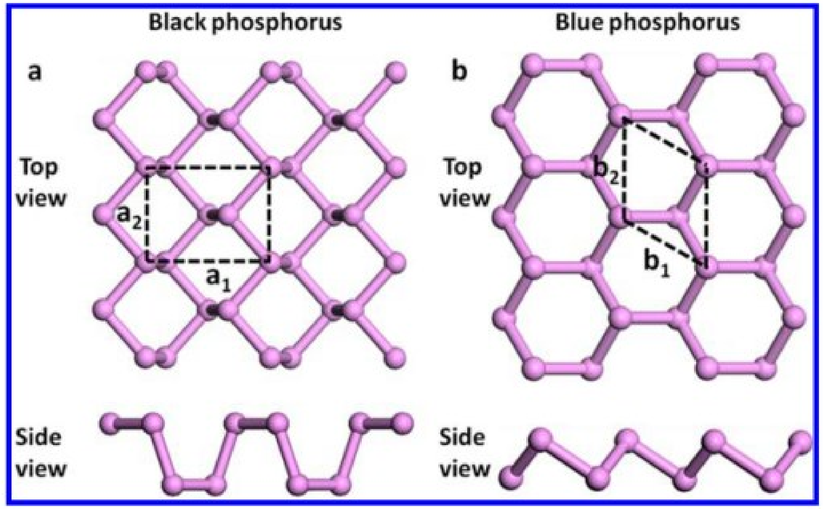
Fasi calcolate per un singolo strato di P

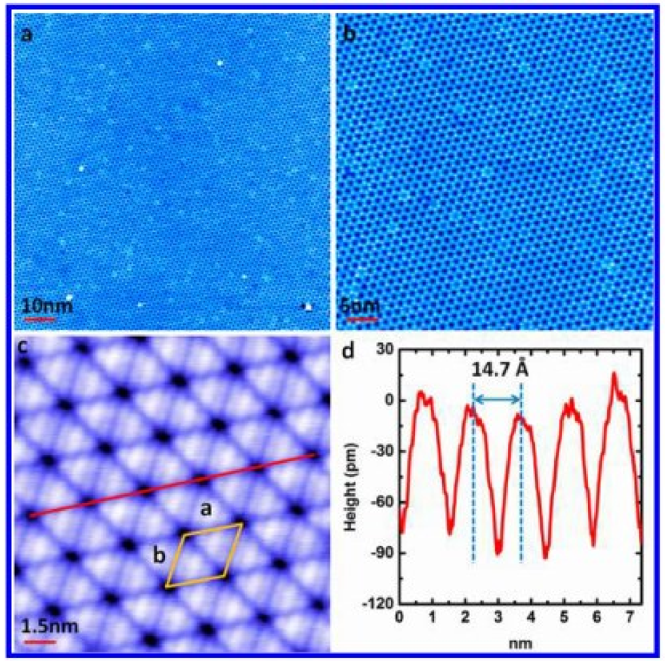
J. Guan et al, PRL 113, 046804 (2014)

NANO LETTERS
Letter
pubs.acs.org/NanoLett

Epitaxial Growth of Single Layer Blue Phosphorus: A New Phase of Two-Dimensional Phosphorus

Jia Lin Zhang,[†,‡] Songtao Zhao,[§] Cheng Han,[†,‡,∥] Zhunzhun Wang,[§,⊥] Shu Zhong,[†] Shuo Sun,[‡] Rui Guo,[†] Xiong Zhou,[†] Cheng Ding Gu,[†] Kai Di Yuan,[‡] Zhenyu Li,[*,§] and Wei Chen[*,†,‡,∥,#]





Blue Phosphorene/Au(111)

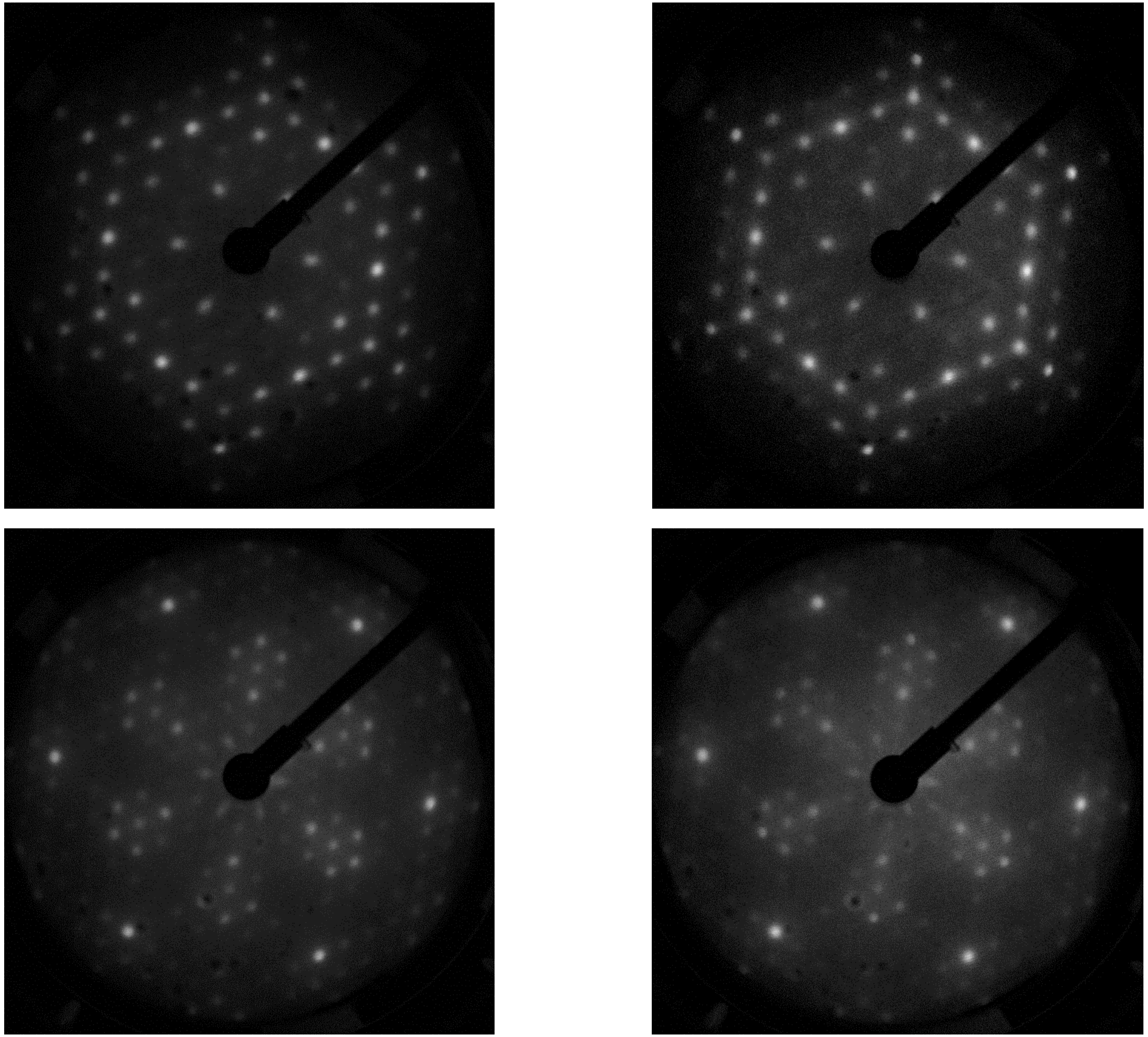
Perché non usare il fosforo rosso (molto molto economico) invece di quello nero (molto costoso)?

Red phosphorus

Black phosphorus

60 eV

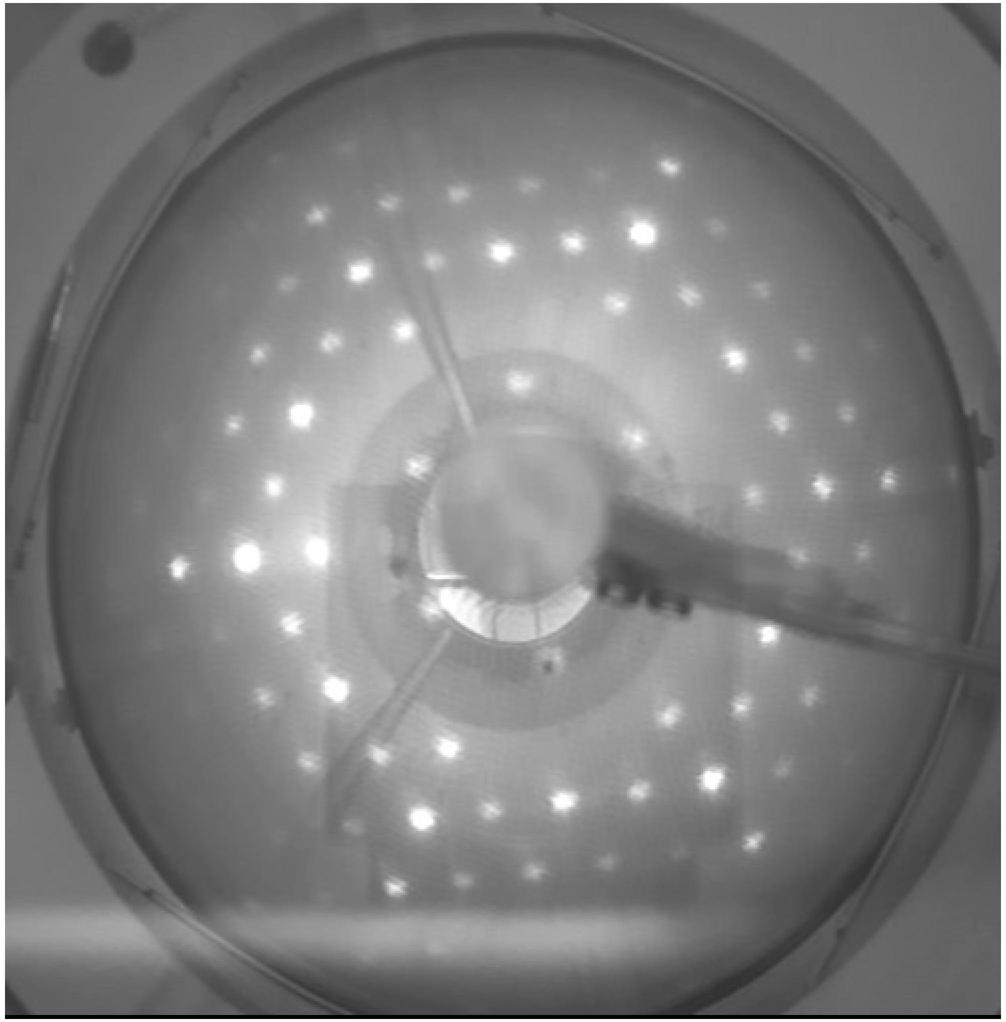
60 eV



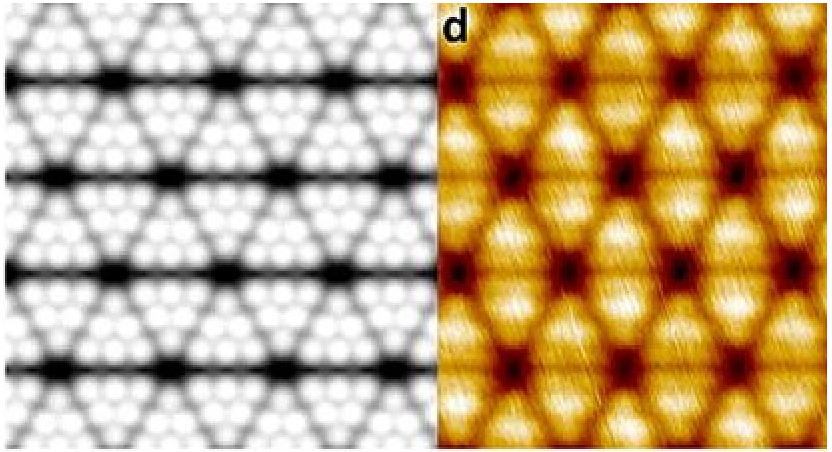
120 eV

120 eV

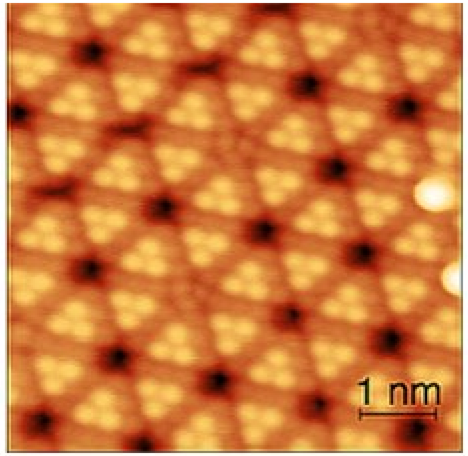
LEED measurments for Red (Left) and Black (Right) Phosphorous deposited on Au(111) in the VISP lab of University of Trieste. Paper in preparation



Ek=66 eV



STM image of Black Phosphorous/Au(111) from J.L. Zhang et al. Nano Lett. 16, 4903 (2016)



STM image of Red Phosphorous/Au(111) taken in the STM lab of TASC-IOM-CNR in Trieste

- Diffrazione di raggi X da superfici (SXRD) per controllare il modello
- beamline SIXS a Soleil (Parigi, Francia) a luglio