I SEMICONDUTTORI

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SEMICONDUTTORI

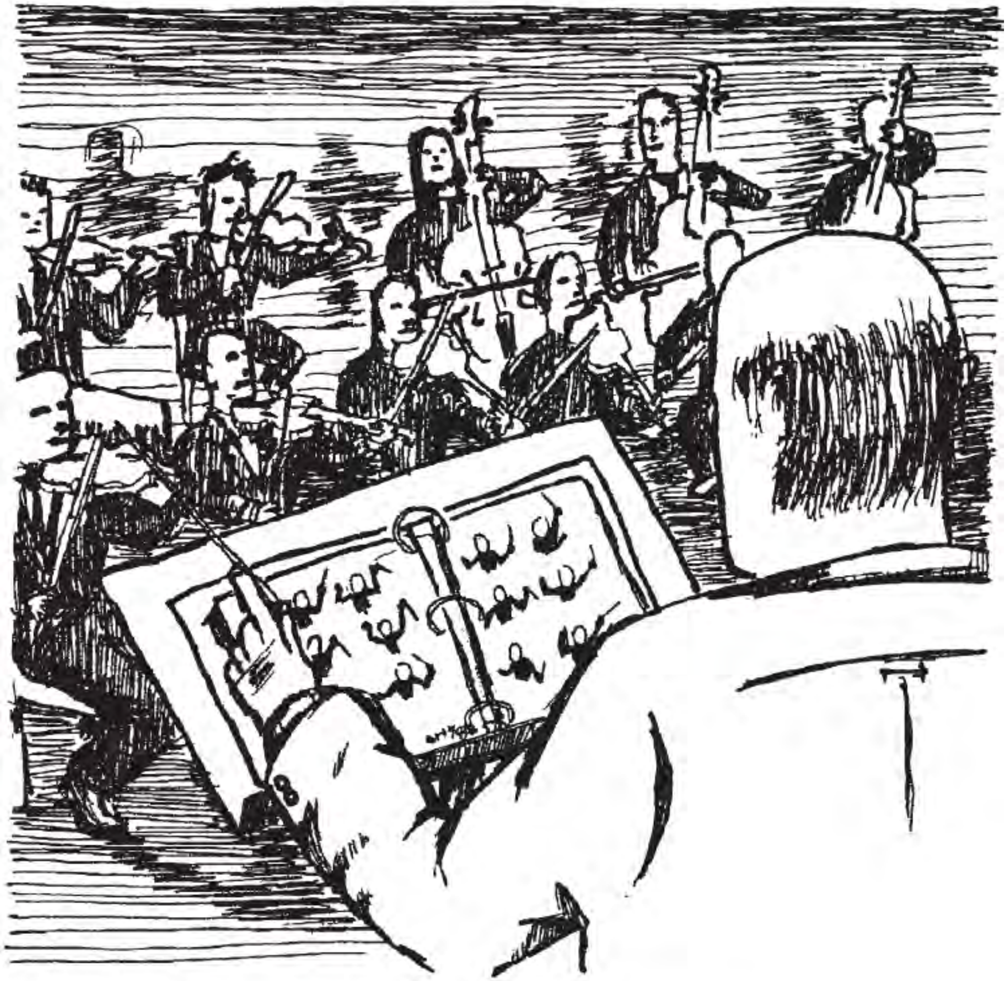
illuminazione

computazione

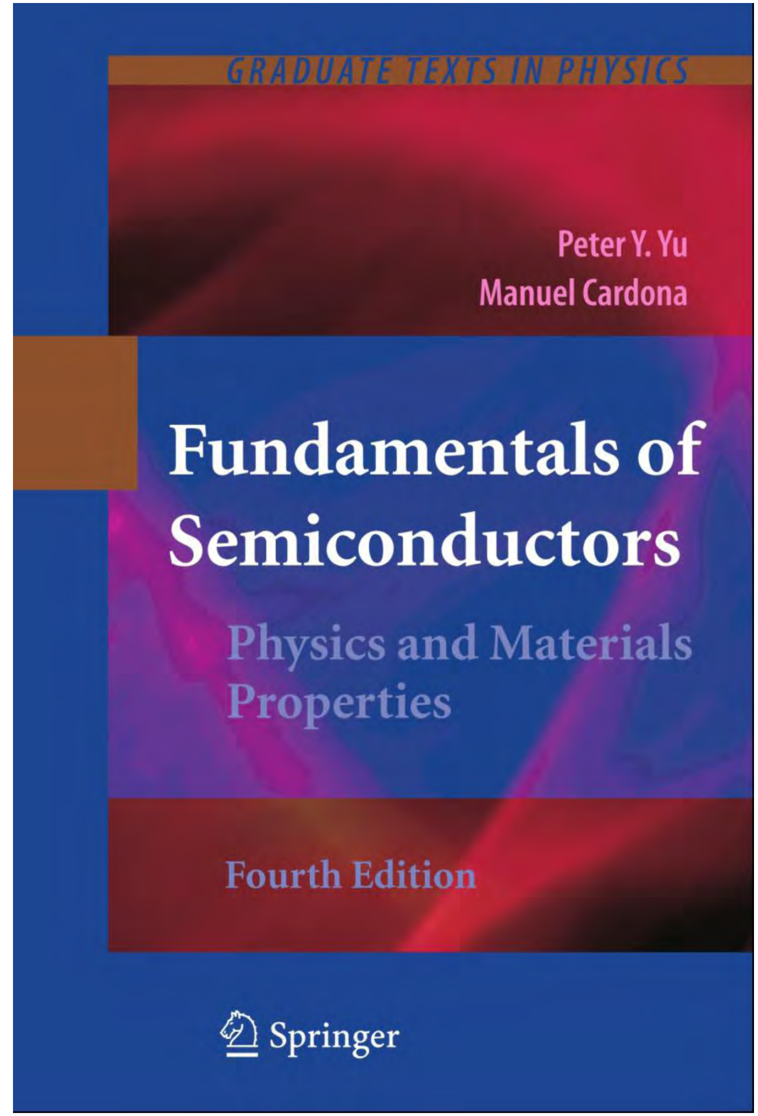
comunicazione

esplorazione

I SEMICONDUTTORI



A SEMI-CONDUCTOR

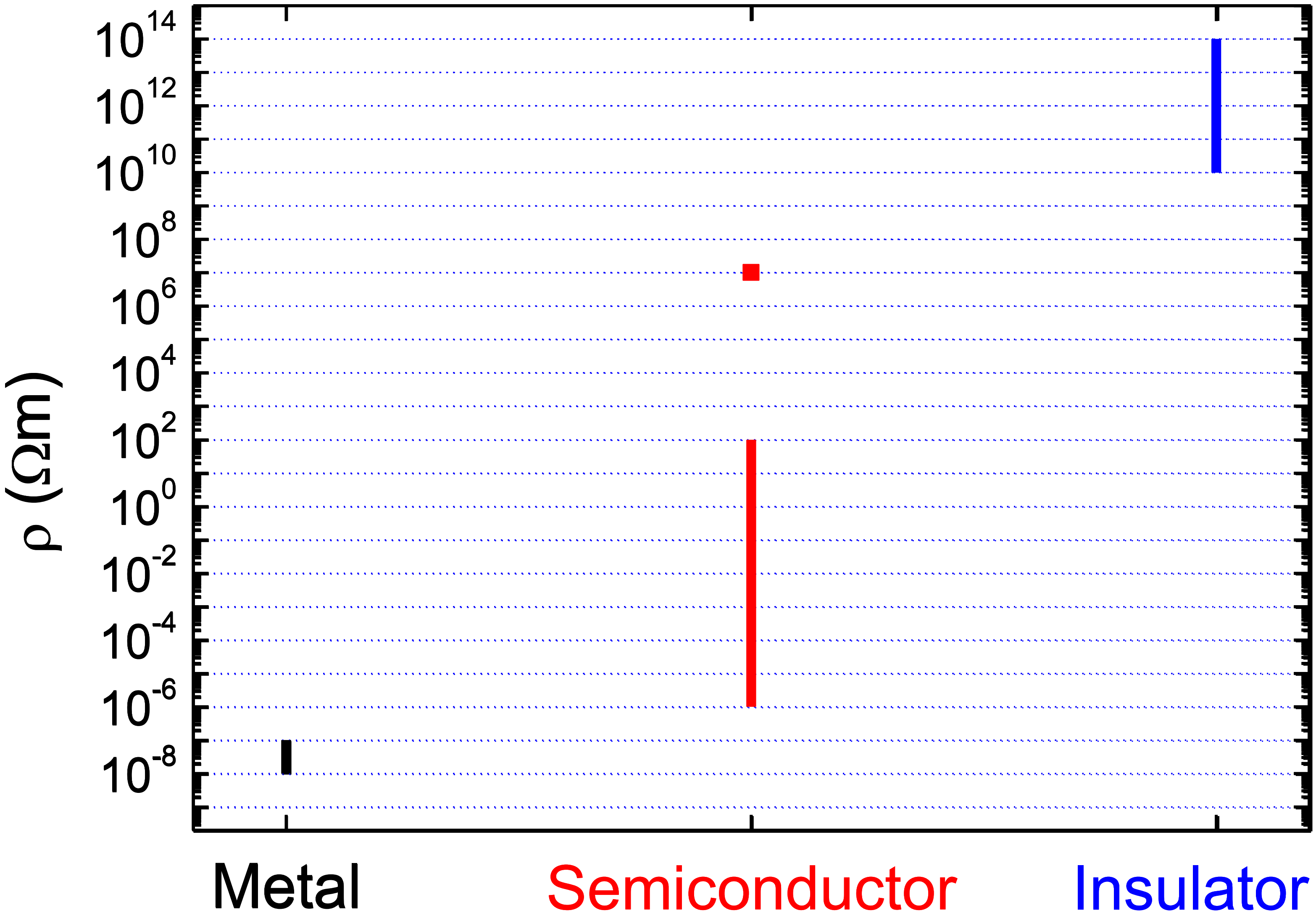


PROPRIETA’

- Coefficiente di temperatura della resisitività negativo

- Fotoconducibilità

- Rettificazione

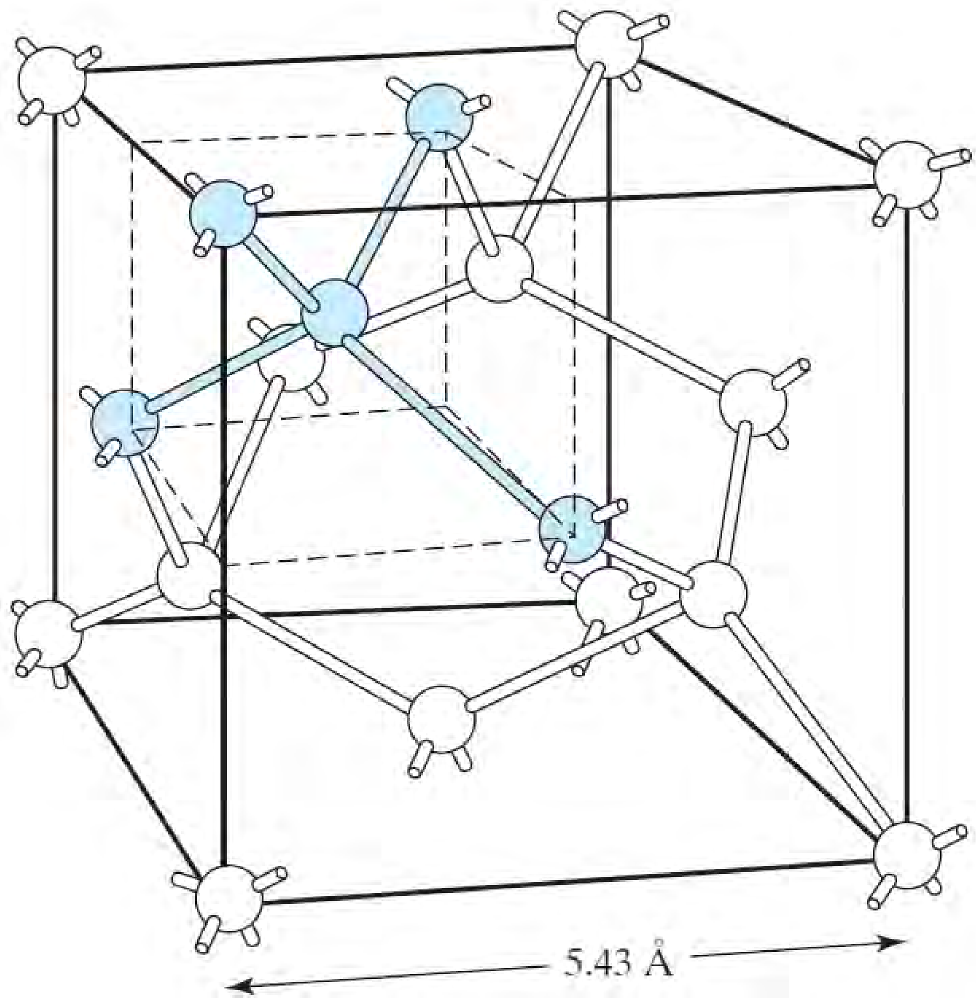


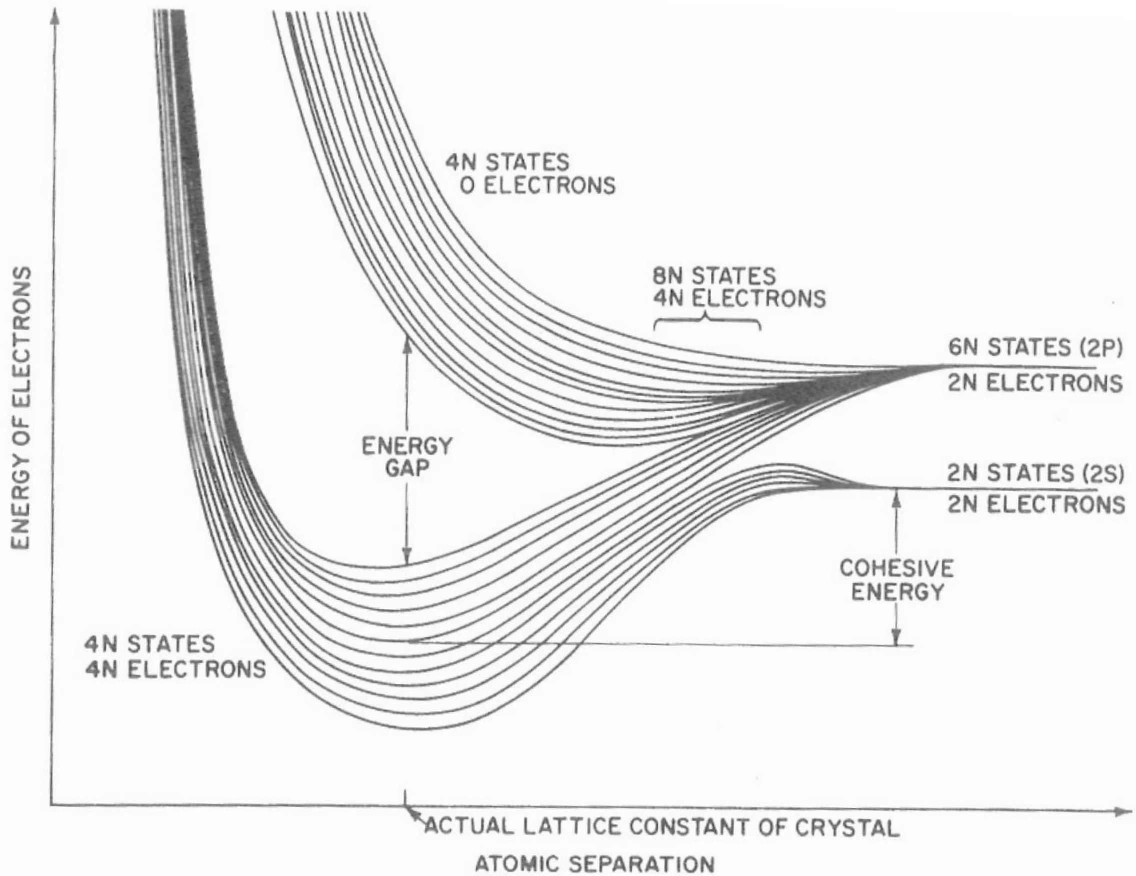
Variazione di circa **13** ordini di grandezza

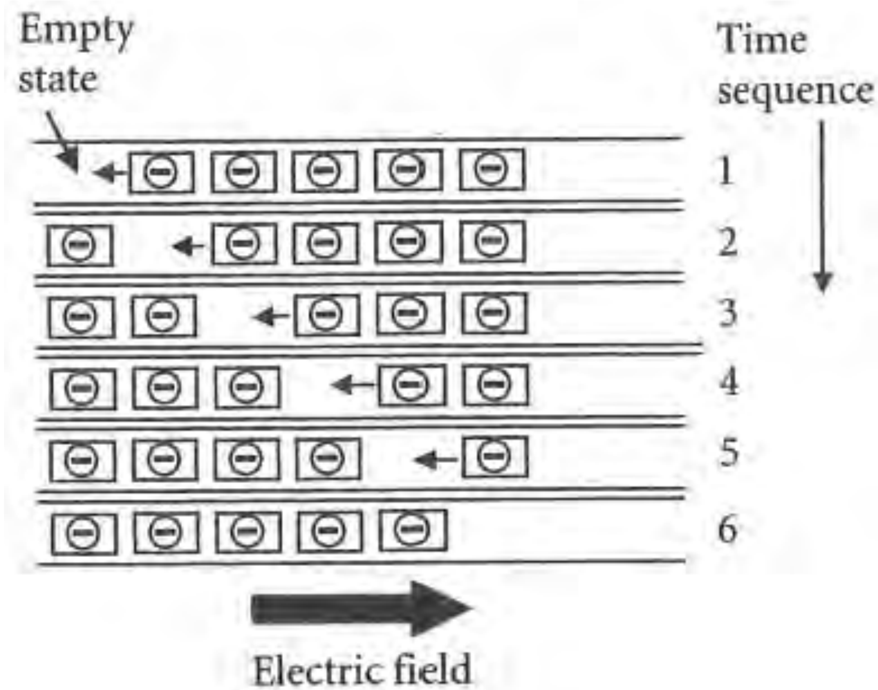
Group → / ↓ Period	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1 H																	2 He
2	3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
3	11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
4	19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
5	37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
6	55 Cs	56 Ba		72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
7	87 Fr	88 Ra		104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cn	113 Uut	114 Uuq	115 Uup	116 Uuh	117 Uus	118 Uuo

Lanthanides	57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu
Actinides	89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr

Configurazione elettronica: $1s^2 2s^2 2p^6 3s^2 3p^2$


5.43 Å


ENERGY OF ELECTRONS
4N STATES
0 ELECTRONS
8N STATES
4N ELECTRONS
6N STATES (2P)
2N ELECTRONS
ENERGY
GAP
2N STATES (2S)
2N ELECTRONS
COHESIVE
ENERGY
4N STATES
4N ELECTRONS
ACTUAL LATTICE CONSTANT OF CRYSTAL
ATOMIC SEPARATION


Empty
state
Time
sequence
1
2
3
4
5
6
Electric field

Semiconduttore	Gap di Energia (eV)
Arseniuro di Indio (InAs)	0.354
Germanio (Ge)	0.664
Silicio (Si)	1.12
Arseniuro di Gallio (GaAs)	1.43
Seleniuro di Zinco (ZnSe)	2.70
Nitruro di Gallio (GaN)	3.43
Diamante (C)	5.5

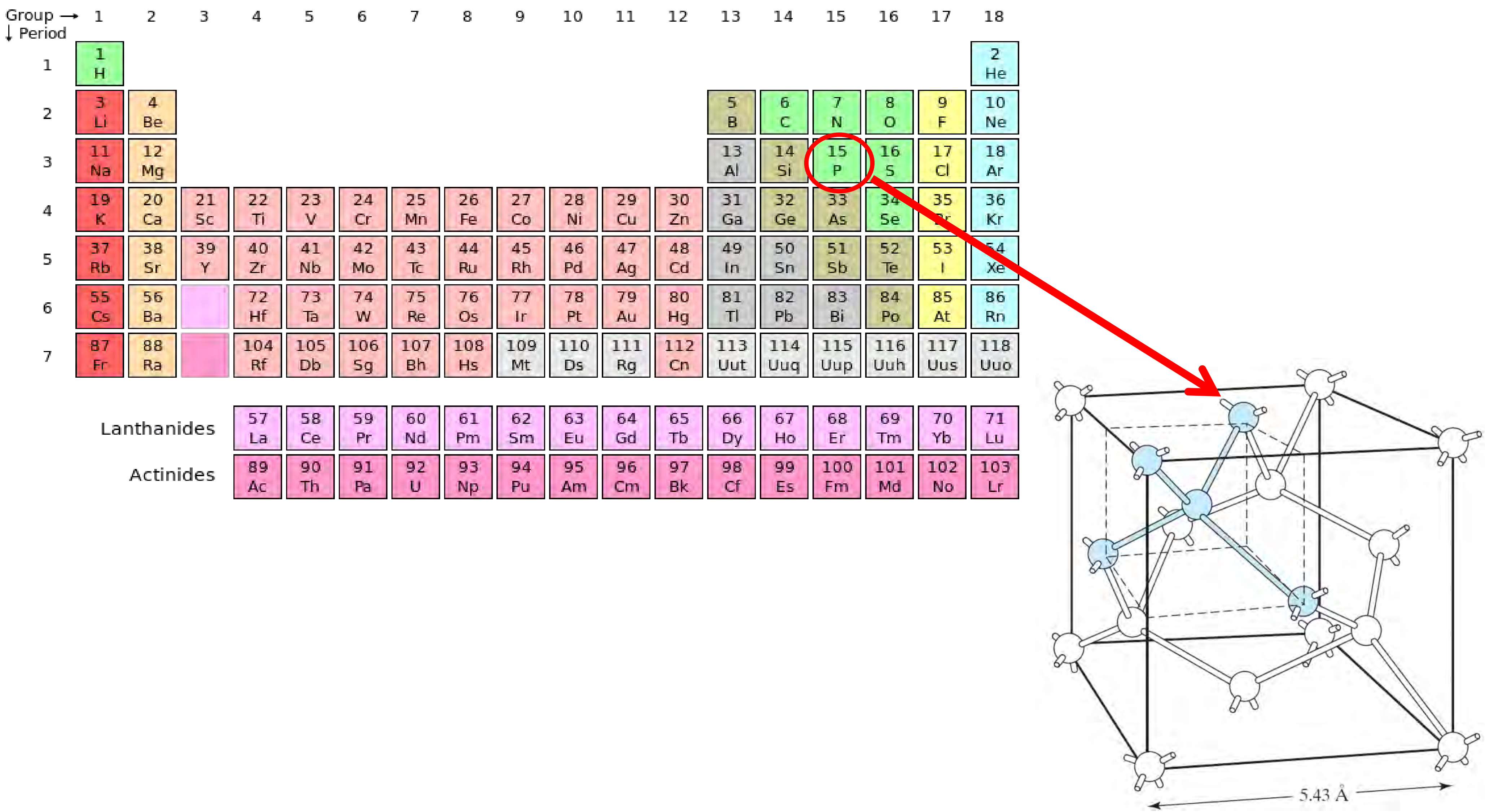
Eccitazione termica

$$n = p = \sqrt{N_C N_V} e^{-\frac{E_g}{2kT}}$$

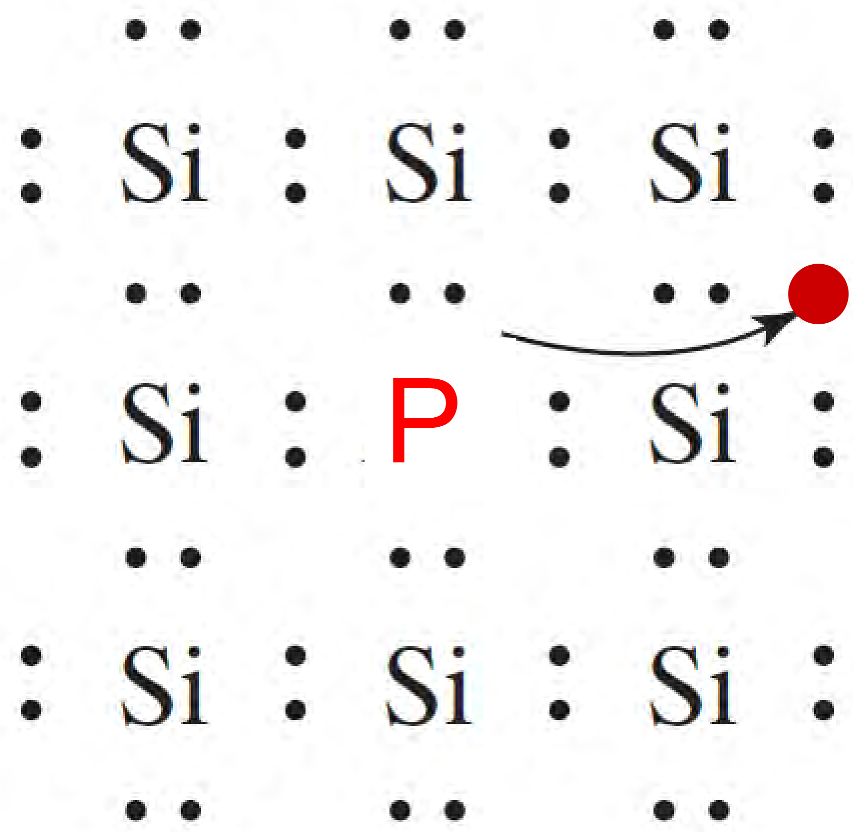
n = densità elettroni liberi
p = densità lacune libere
E_g = intervallo di energie proibite
k = costante Boltzmann
T è la temperatura
N_c e N_v parametri del materiale

Semiconduttore	n (m^{-3})
Ge	2.85×10^{19} (1 Ωm)
Si	4.43×10^{15}
GaAs	1.14×10^{13}
ZnSe	2.82×10^{2} (10^{7} Ωm)

DROGAGGIO

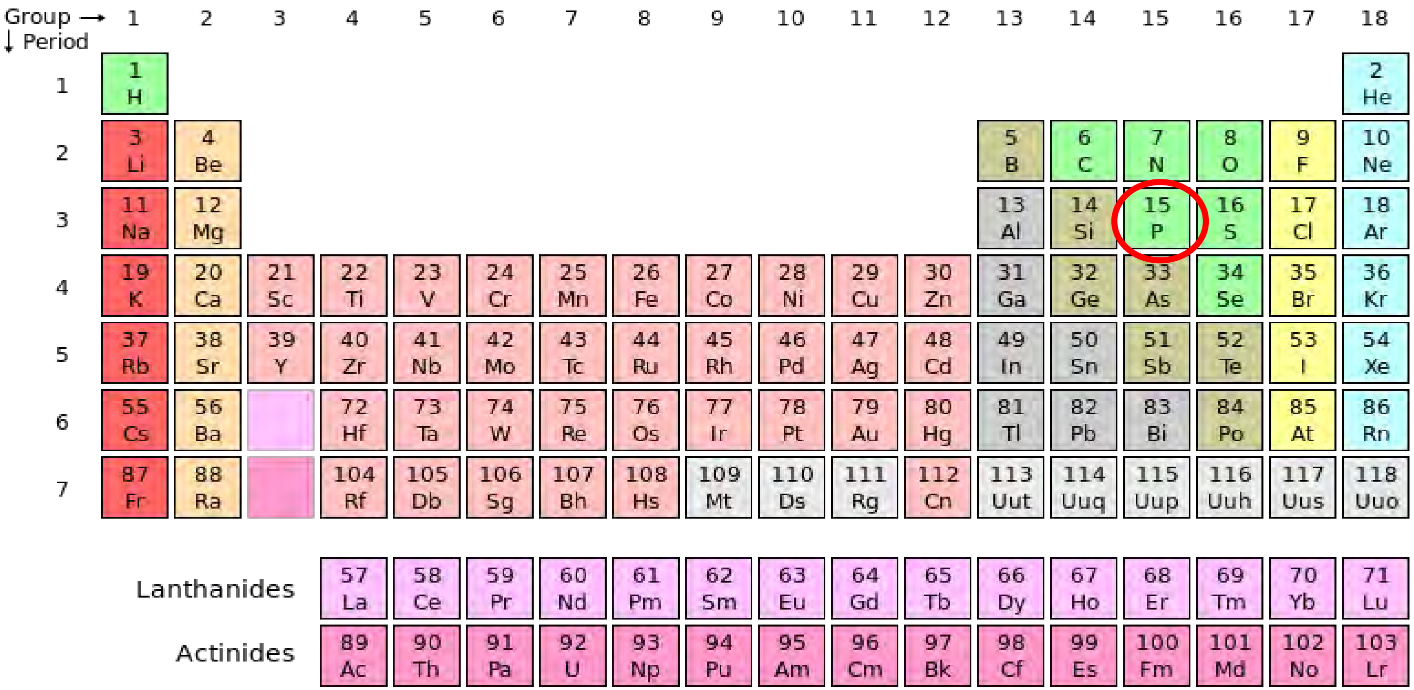

Group → 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
↓ Period
1 1 H 2 He
2 3 Li 4 Be 5 B 6 C 7 N 8 O 9 F 10 Ne
3 11 Na 12 Mg 13 Al 14 Si 15 P 16 S 17 Cl 18 Ar
4 19 K 20 Ca 21 Sc 22 Ti 23 V 24 Cr 25 Mn 26 Fe 27 Co 28 Ni 29 Cu 30 Zn 31 Ga 32 Ge 33 As 34 Se 35 Br 36 Kr
5 37 Rb 38 Sr 39 Y 40 Zr 41 Nb 42 Mo 43 Tc 44 Ru 45 Rh 46 Pd 47 Ag 48 Cd 49 In 50 Sn 51 Sb 52 Te 53 I 54 Xe
6 55 Cs 56 Ba 72 Hf 73 Ta 74 W 75 Re 76 Os 77 Ir 78 Pt 79 Au 80 Hg 81 Tl 82 Pb 83 Bi 84 Po 85 At 86 Rn
7 87 Fr 88 Ra 104 Rf 105 Db 106 Sg 107 Bh 108 Hs 109 Mt 110 Ds 111 Rg 112 Cn 113 Uut 114 Uuq 115 Uup 116 Uuh 117 Uus 118 Uuo
Lanthanides 57 La 58 Ce 59 Pr 60 Nd 61 Pm 62 Sm 63 Eu 64 Gd 65 Tb 66 Dy 67 Ho 68 Er 69 Tm 70 Yb 71 Lu
Actinides 89 Ac 90 Th 91 Pa 92 U 93 Np 94 Pu 95 Am 96 Cm 97 Bk 98 Cf 99 Es 100 Fm 101 Md 102 No 103 Lr
5.43 Å

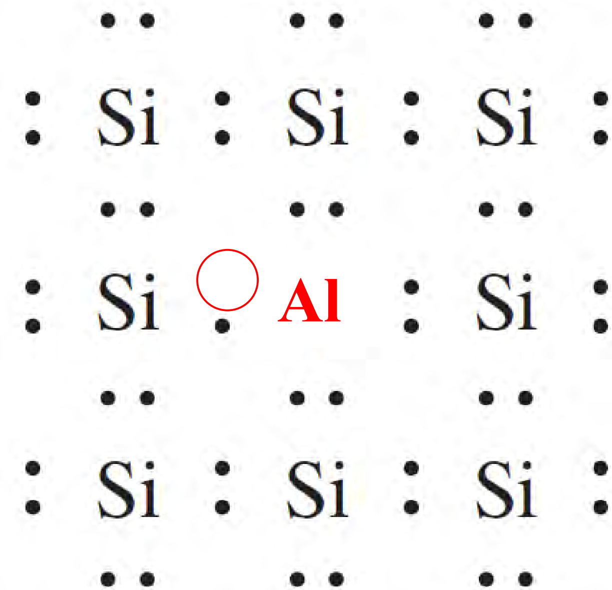
DROGAGGIO DI TIPO n



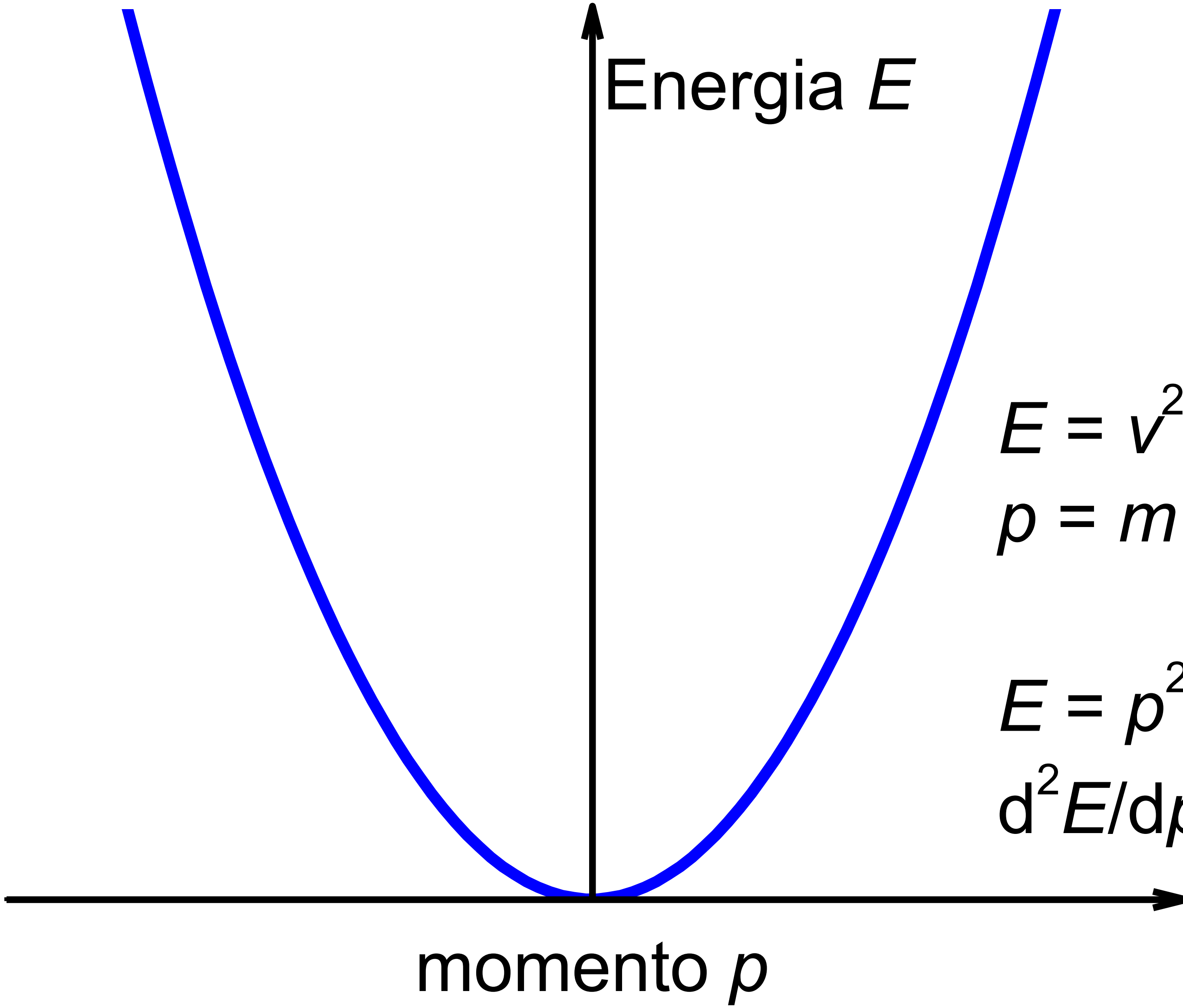
10^{20} atomi di silicio sostituiti (circa 1 ogni 10^9)
genera una densità di portatori liberi $n = 10^{20} m^{-3}$

DROGAGGIO DI TIPO p





STRUTTURA A BANDE



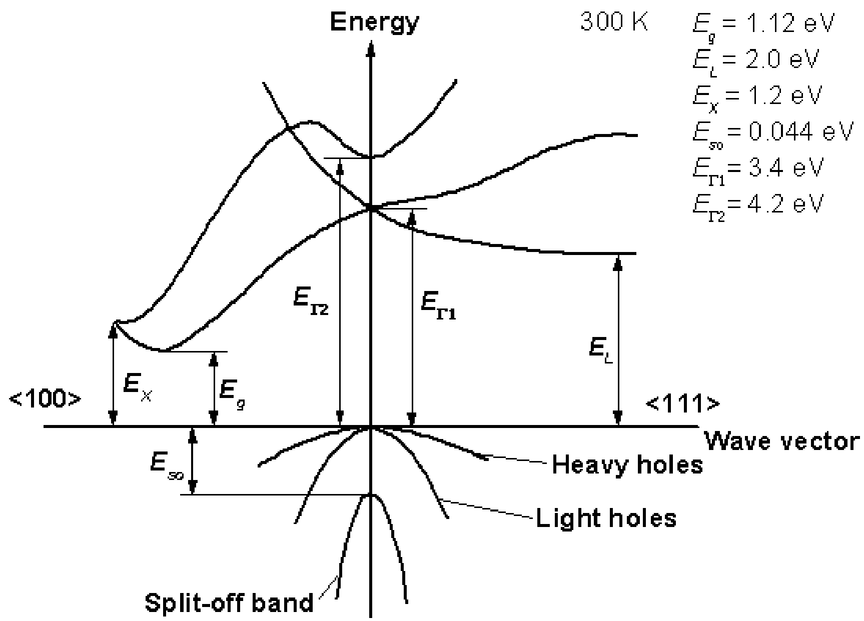
$E = v^2/2m$

$p = m\, v$

$E = p^2/2m$

$d^2E/dp^2 = m^{-1}$

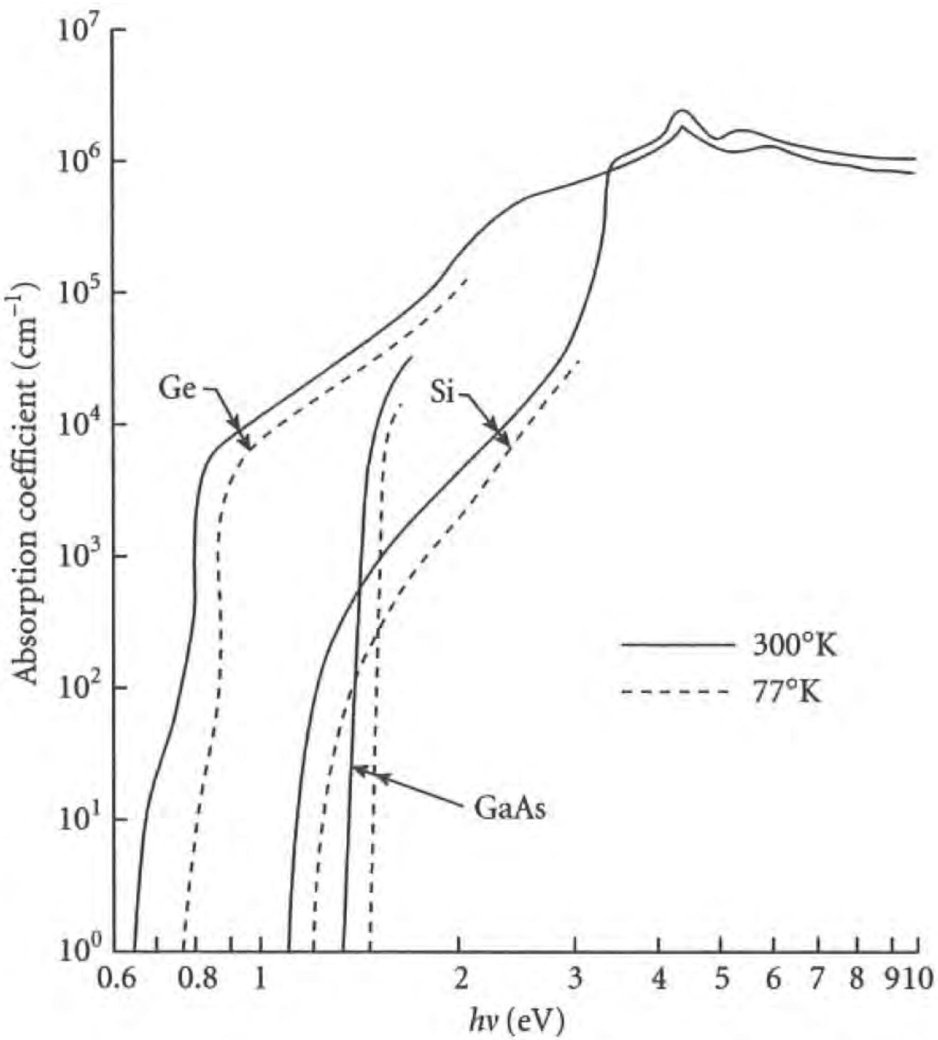
STRUTTURA A BANDE



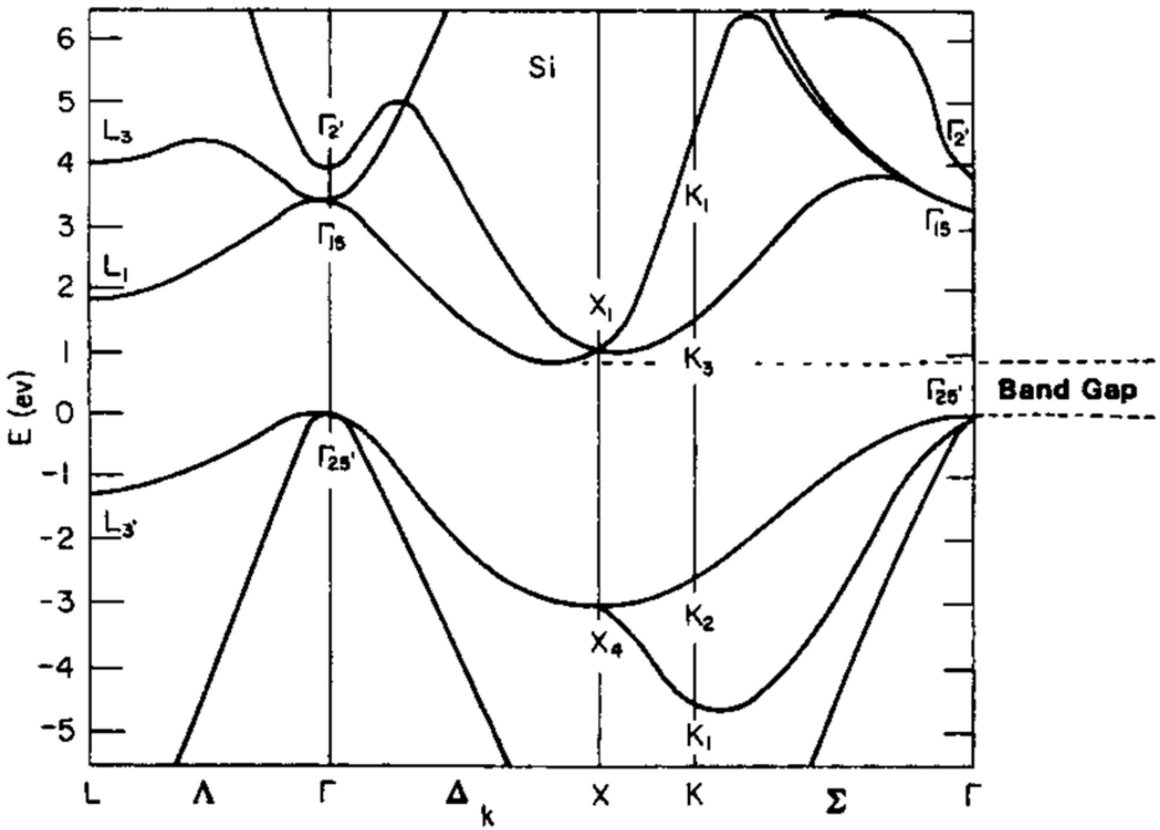
- **Massimo** banda valenza a **k= 0** nel punto **Γ**

•**Minimo** in banda di conduzione vicino al punto ***X*** al **bordo zona** lungo la direzione **(001)** dove **k=2π/a** con a passo reticolare

ASSORBIMENTO OTTICO



Si e Ge semiconduttori indiretti
GaAs semiconduttore diretto



Prima teoria 'adeguata' delle proprietà dei semiconduttori:
A. H. Wilson pubblicò due articoli nella rivista *Proceedings of the Royal Society* nel 1931.

LA RICERCA NEL DOPOGUERRA

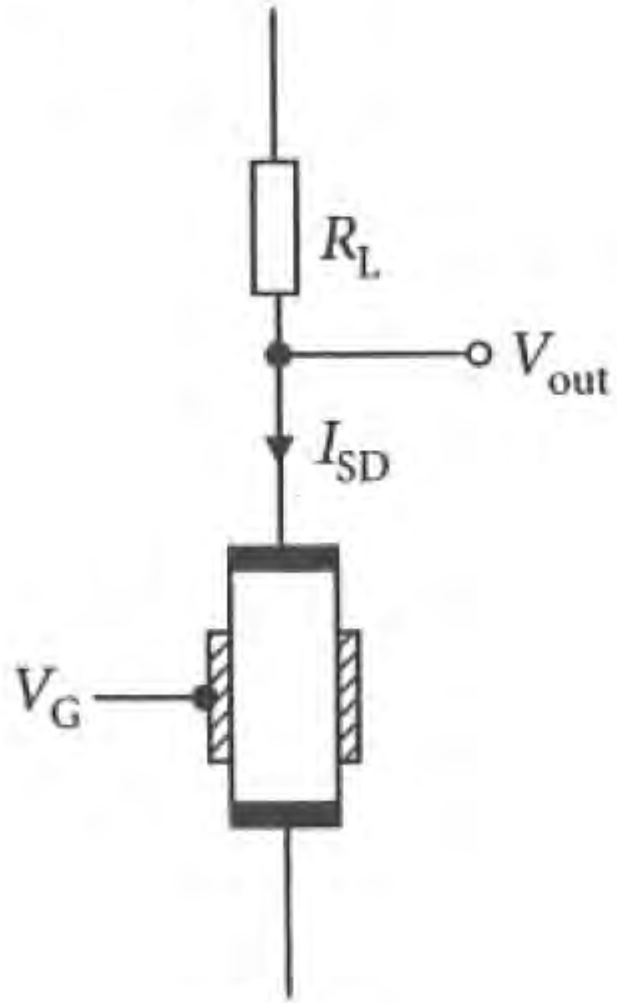
- Necessità di materiali con ‘elevati’ livelli di purezza
  - **Silicio** e **Germanio**

- Memorandum del 1945 di Vannevar Bush, chairman del National Defence Research Committee, al presidente Truman circa necessità di un **forte supporto alla ricerca base**.

- Bell Labs. Memorandum interno di Marvin Kelley sull’**importanza della ricerca sui semiconduttori**:
  - Willian Shockley (fisico) + Stanley Morgan (chimico)
  - John Bardeen e Walter Brattain

J.J. Thomson e la scoperta dell’elettrone nel 1897 **‘…and may it never be useful to anyone!...’**

TRANSISTOR A EFFETTO DI CAMPO



FET

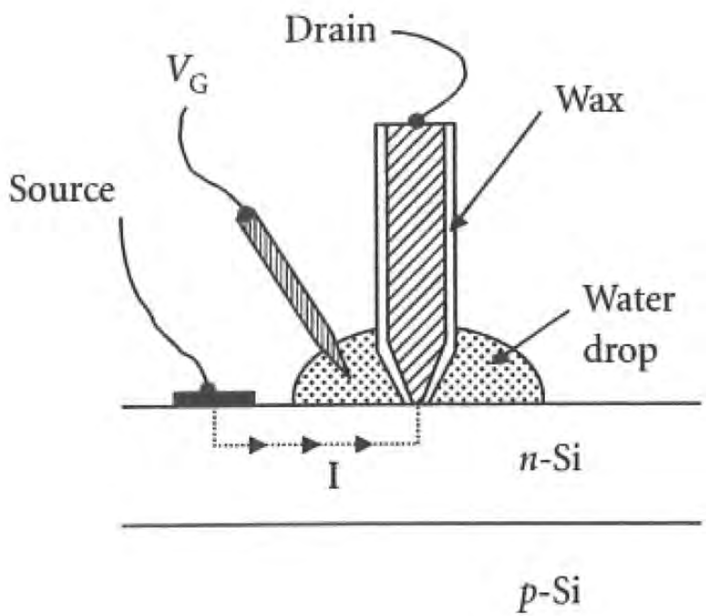
Field effect transistor: conducibilità modificabile attraverso tensione applicata a elettrodo

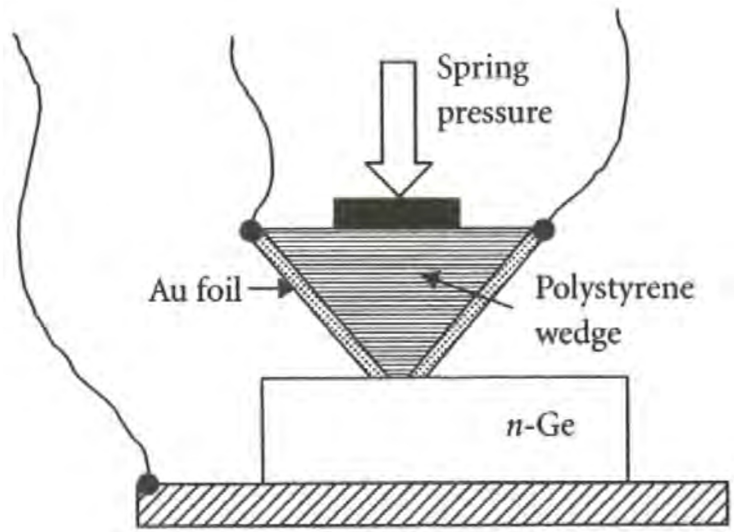
1947

Fisica delle superfici.

Autunno

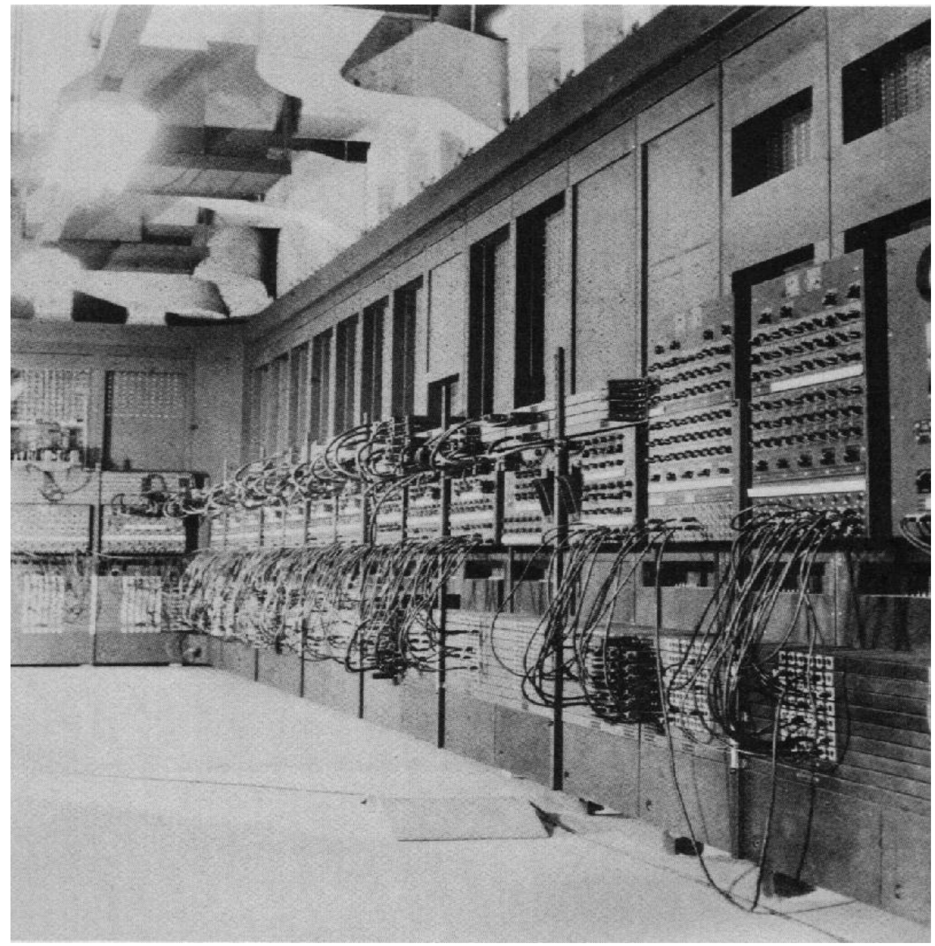
24.12

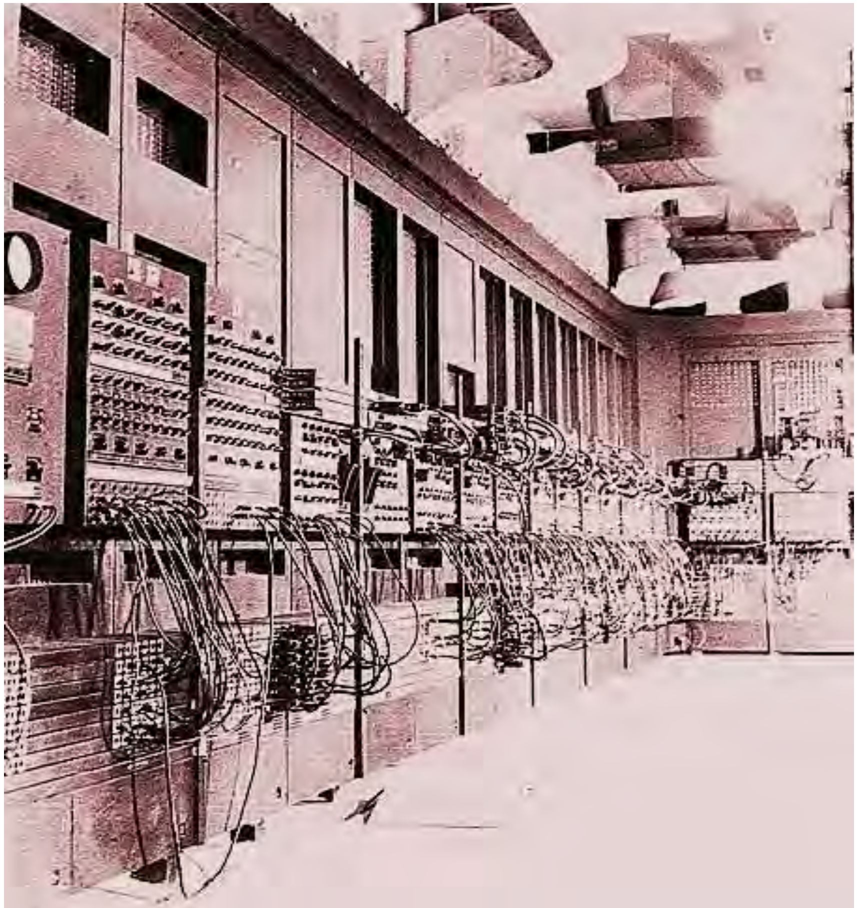


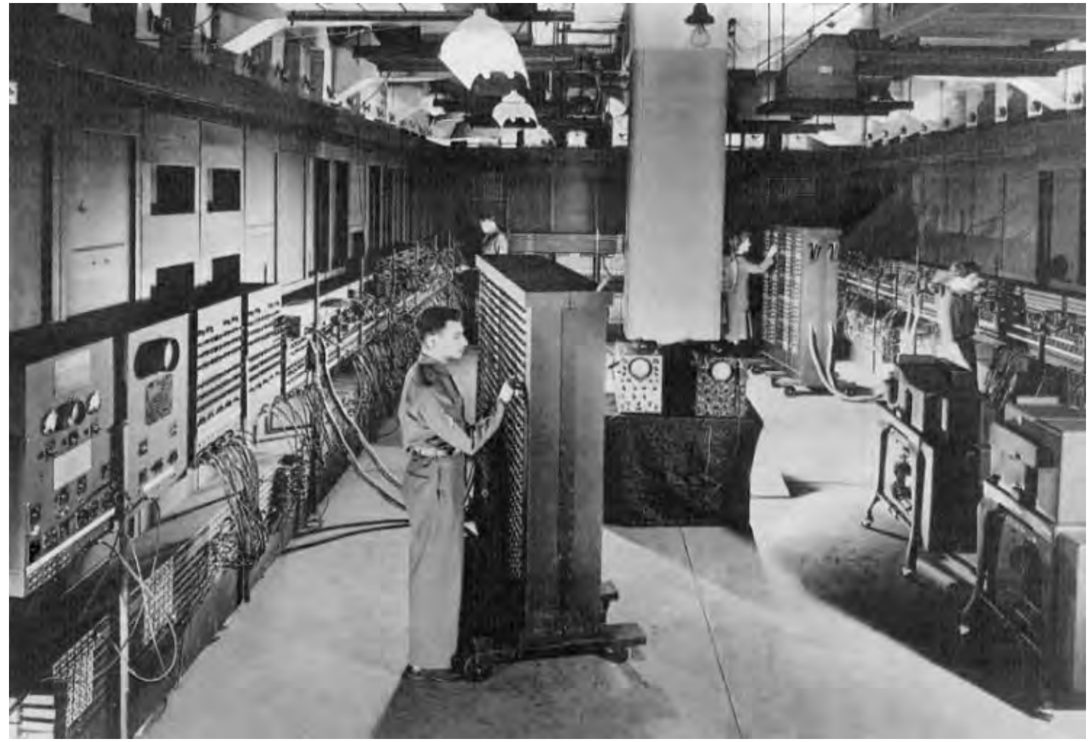


IL COMPUTER

- 1946: ENIAC (Electronic Numerical Integrator and Calculator)
- costruito con 17,000 valvole, 70,000 resistenze, 10,000 condensatori, peso di 30,000 kg.
- potenza assorbita: 174 kW; potenza di calcolo: 300 moltiplicazioni o 5000 addizioni al secondo
- usato per calcolare le tabelle balistiche per vari tipi di proiettili





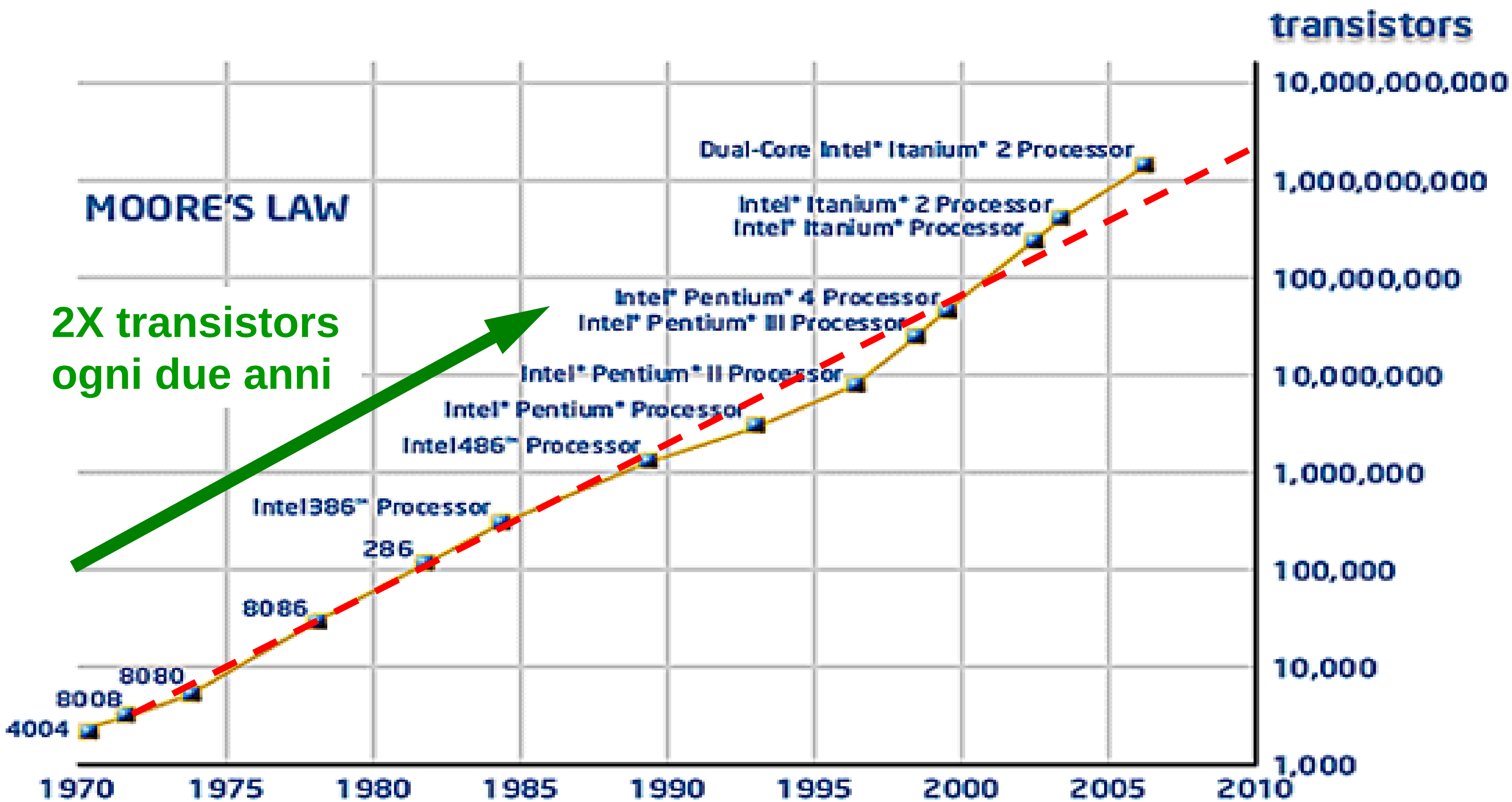


1954 - TRADIC (Bell per US Army) 700 transitor
1955-Computer commerciale IBM 2000 transistor

PUT A MAN ON THE MOON!

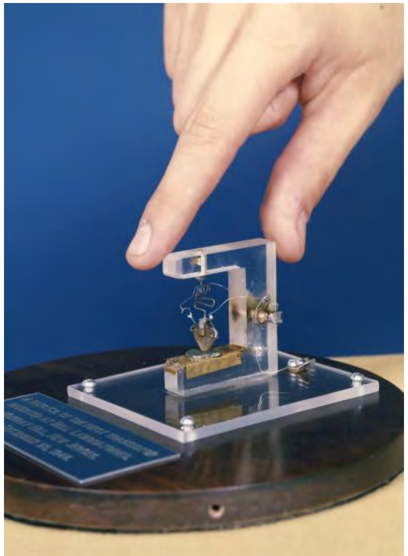
- 1955-1963, 35%-50% produzione annuale semiconduttori destinata usi militari
- 1958, Texas Instruments, Jack Kilby realizza primo circuito integrato in germanio.
- 1961, Fairchild, Robert Noyce realizza circuito integrato usando Silicio, formando interconnessioni metalliche evaporando film metallici ed usando litografia.
- 1961, Kennedy decisione di intraprendere intensivo programma spaziale.

Legge di Moore

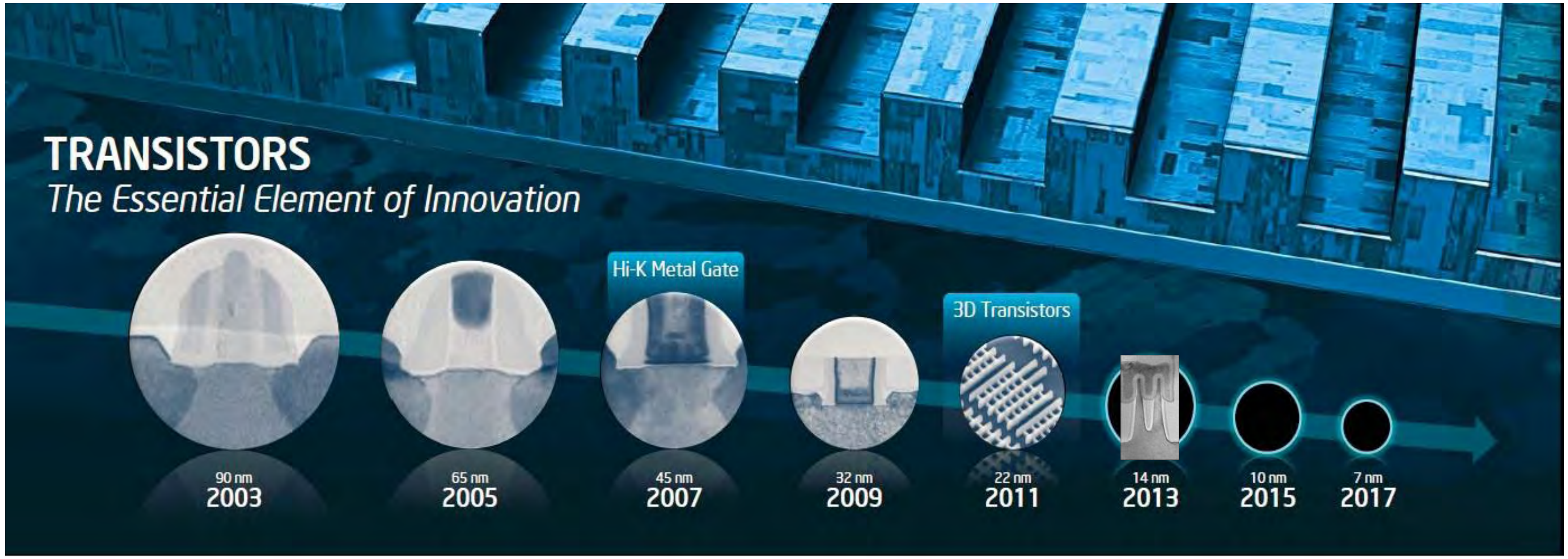


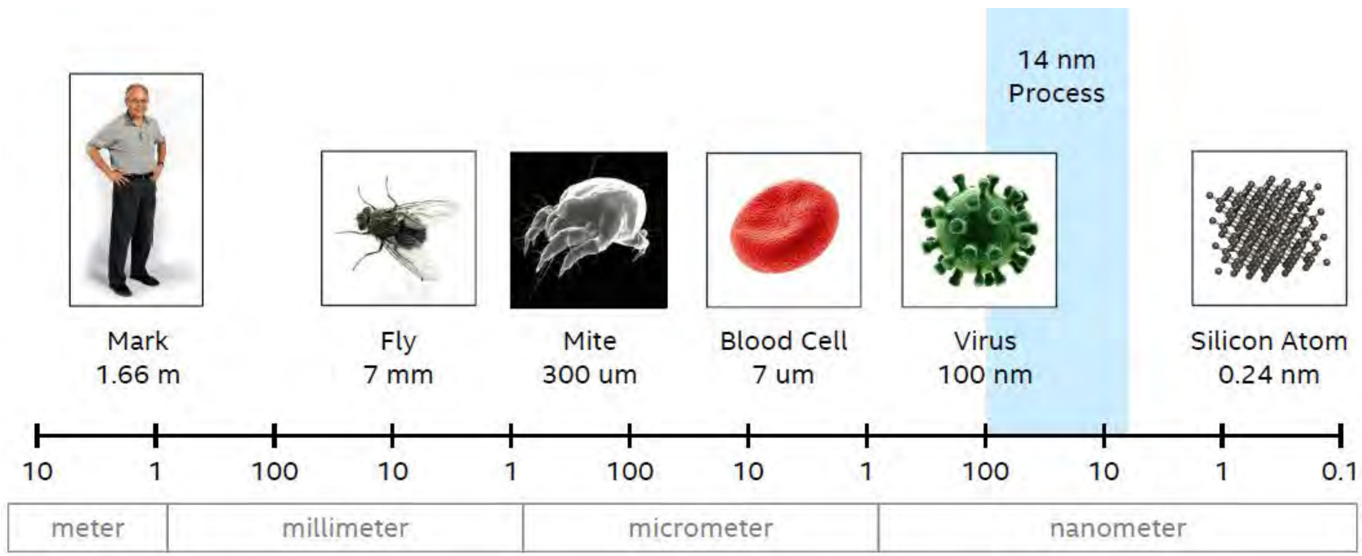
Transistor duplicati ogni due anni

MINIATURIZZAZIONE DEI TRANSISTOR

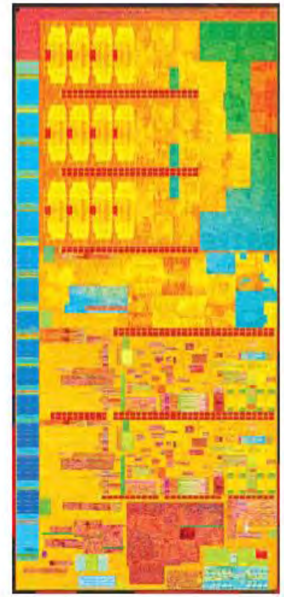


1947





14 nm Intel® Core™ M Processor

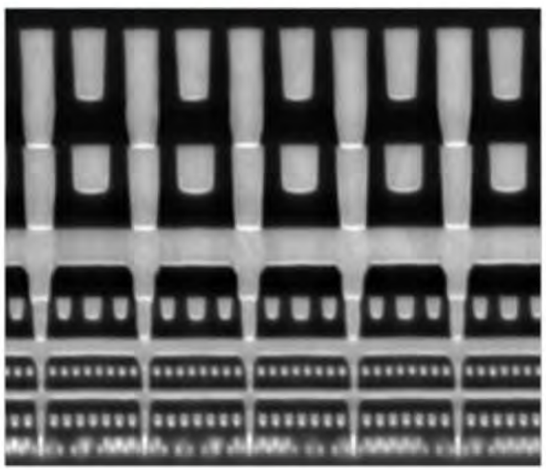


1.3 billion transistors

82 mm^2 die size

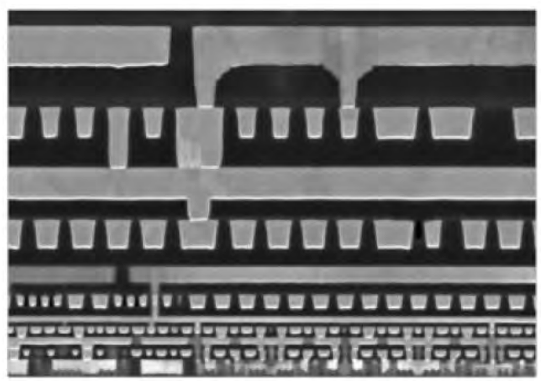
Interconnects

22 nm Process



80 nm minimum pitch

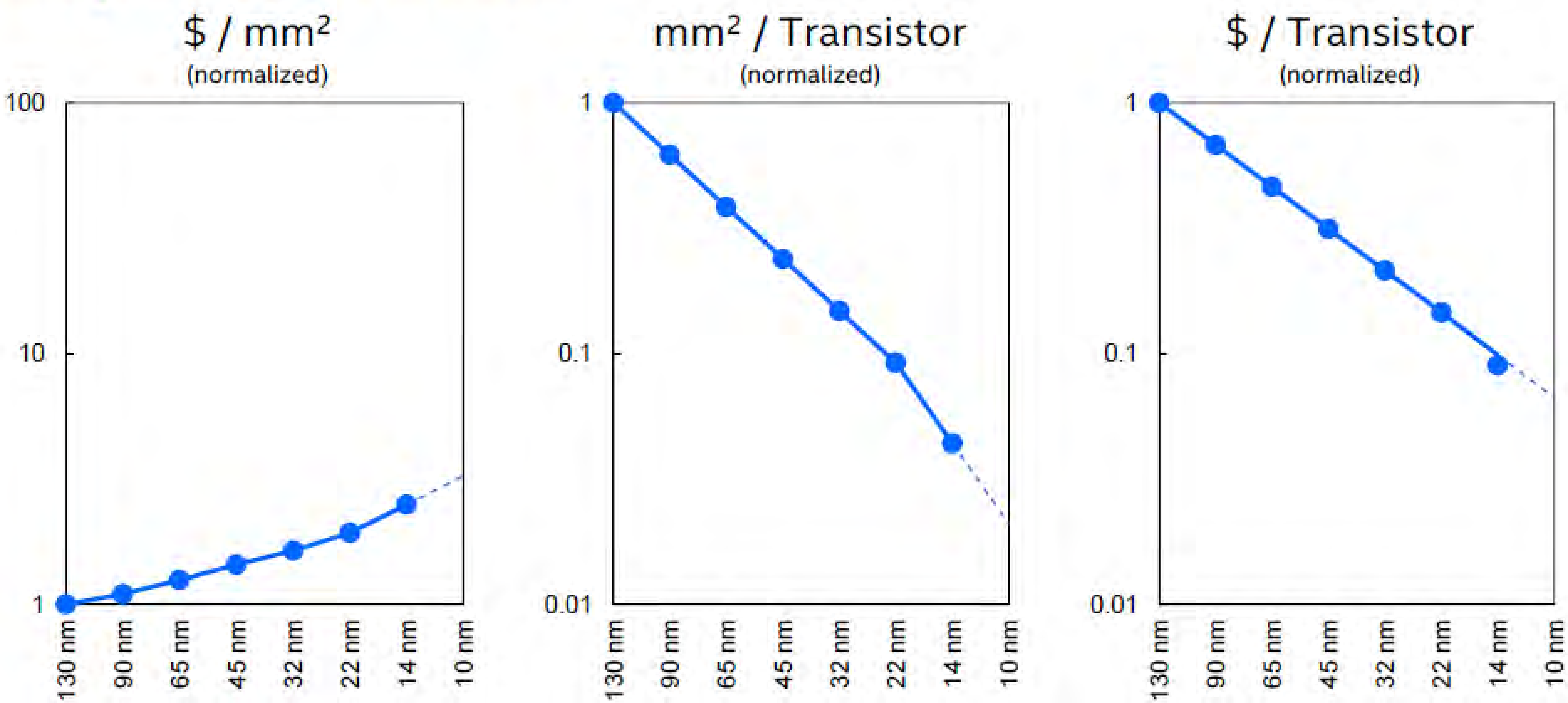
14 nm Process



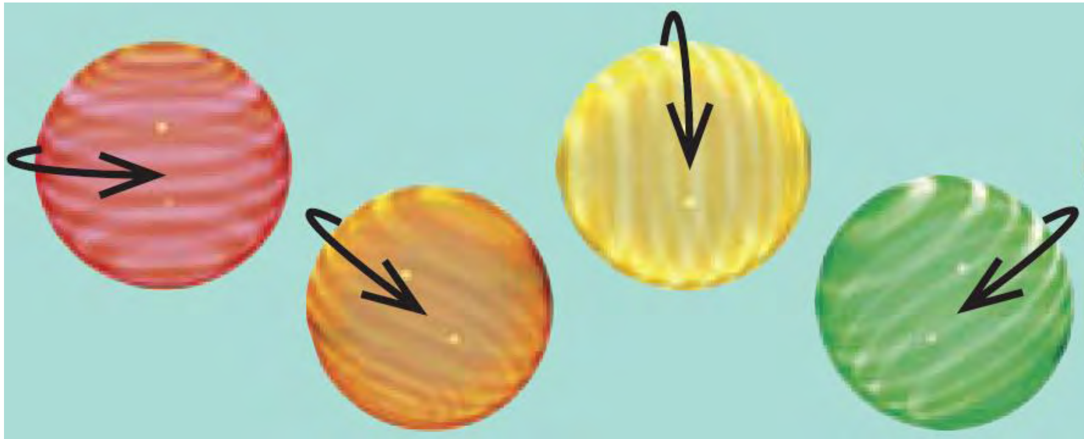
52 nm (0.65x) minimum pitch

M. Bohr, IDF 2014

Cost per Transistor

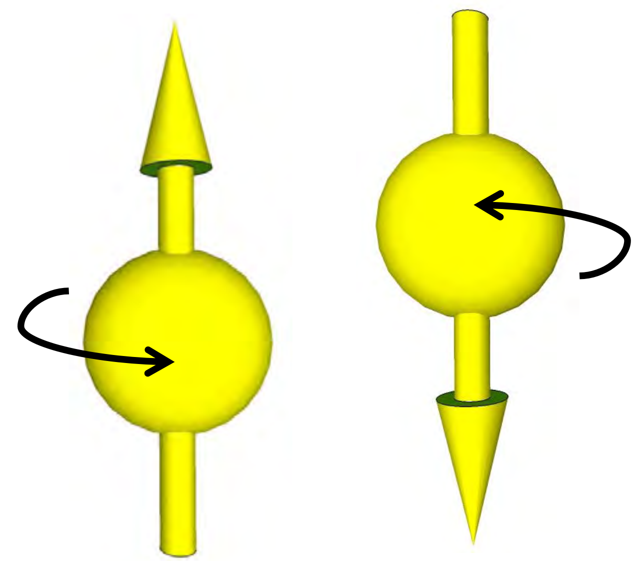


M. Bohr, IDF 2014

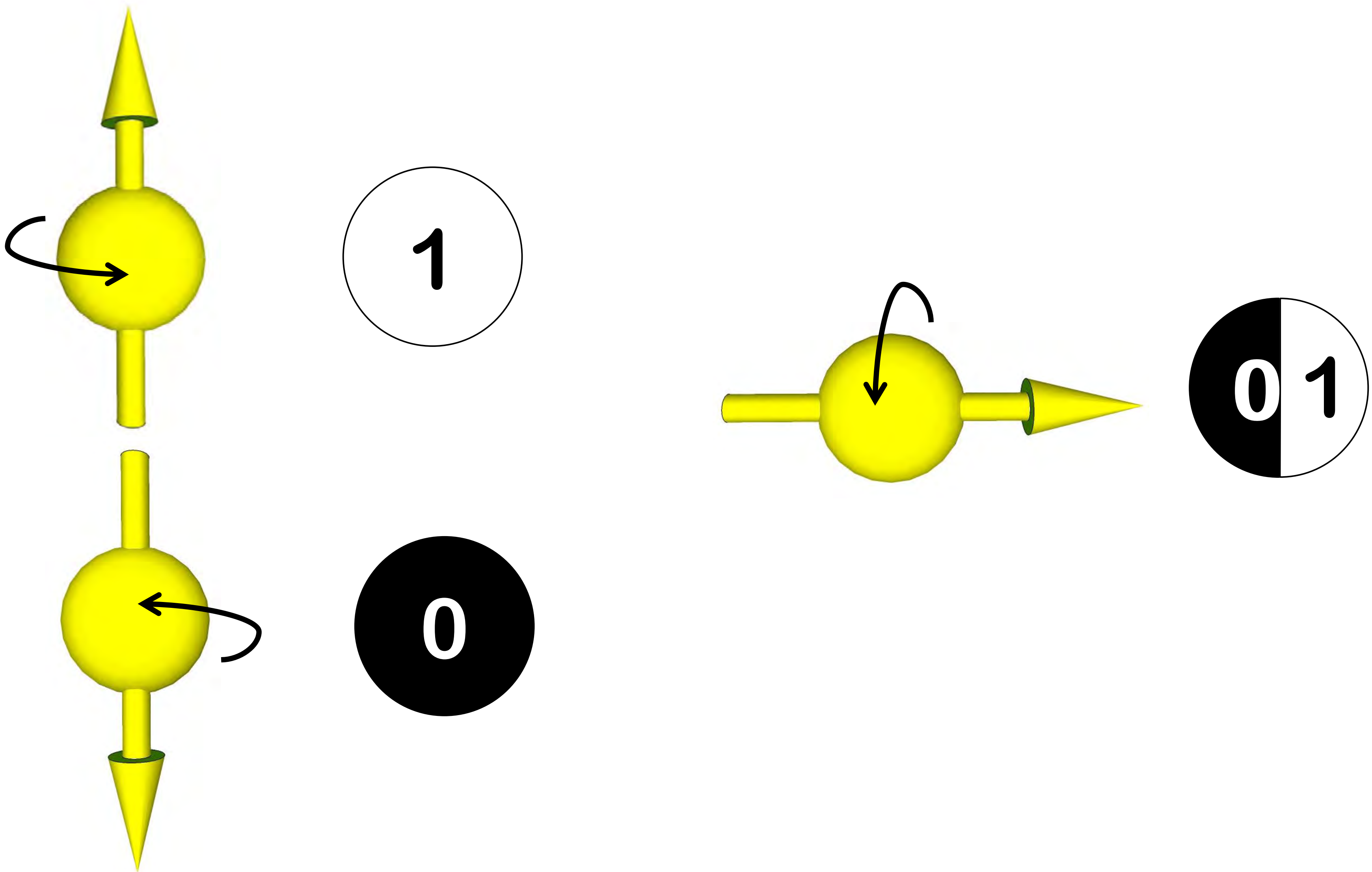


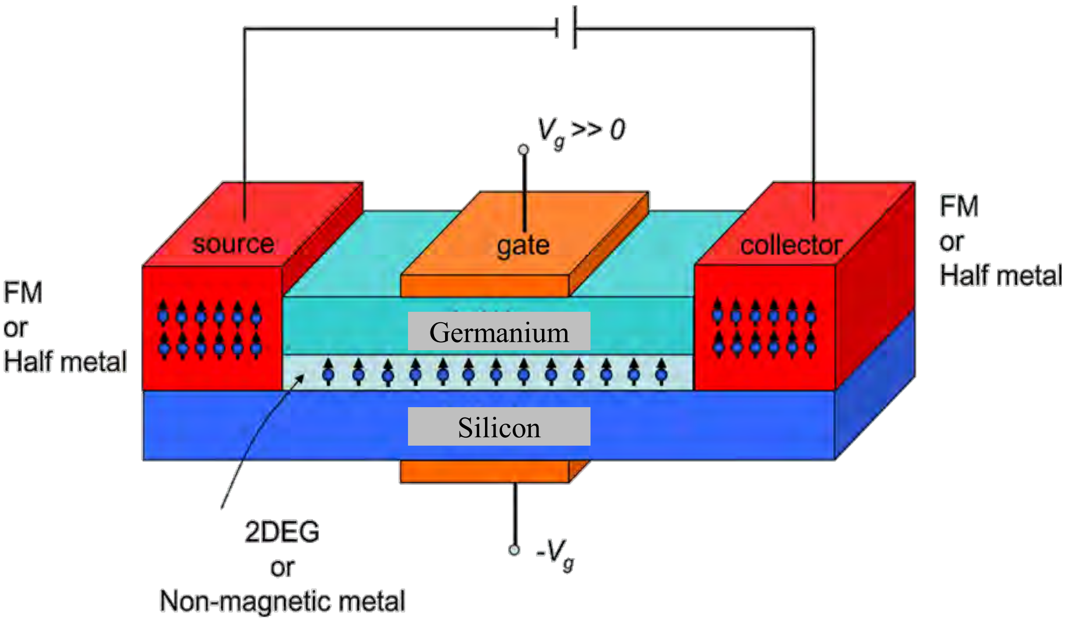
Oltre alla massa e alla carica elettrica elettroni hanno un momento angolare denominato spin

Lo spin può essere rappresentato come un vettore. Per una sfera che ruota ovest-est, il vettore punta verso nord o su.



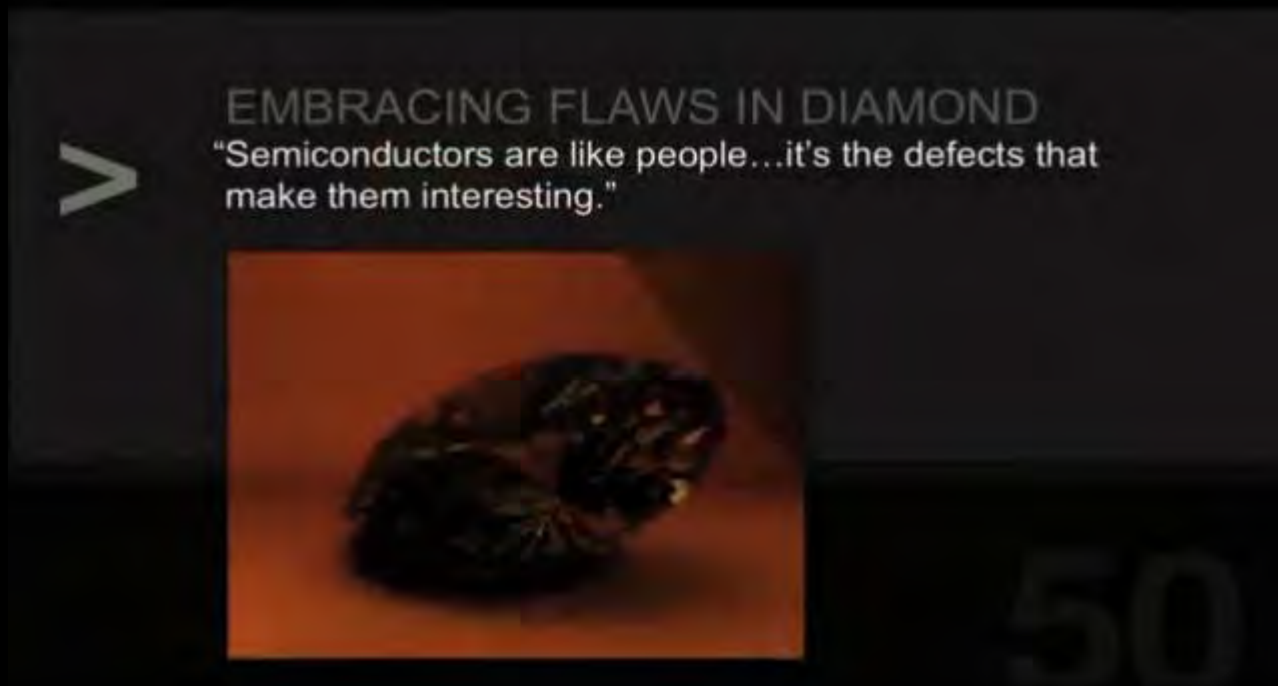
SOVRAPPOSIZIONE QUANTICA





→ **Dispositivi più efficienti** → **computazione quantistica**

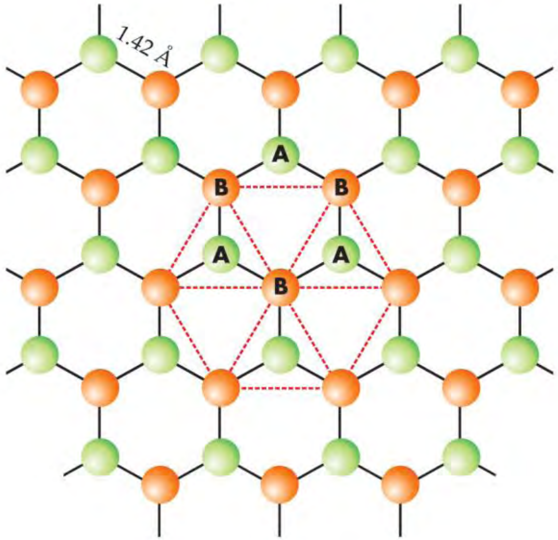
Impatto dei dispositivi quantistici:
- ridisegnare materiali a farmaci
- human brain
- test quantum gravity and oggetti quantistici

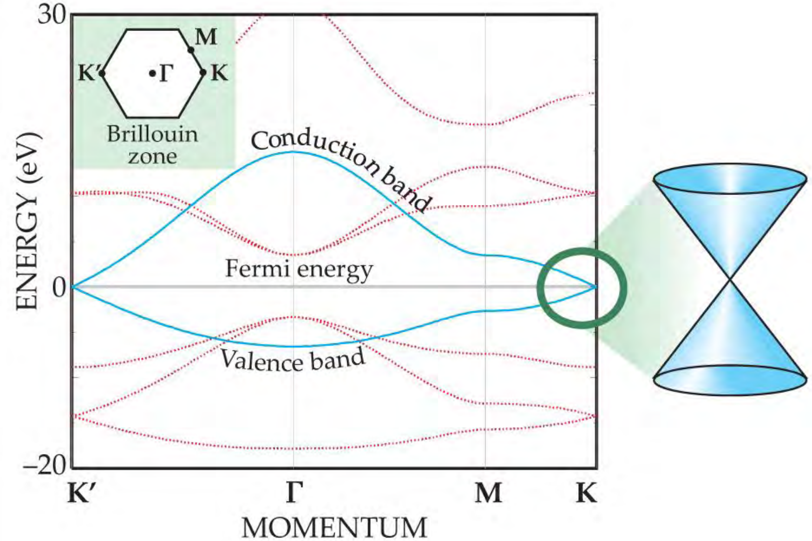


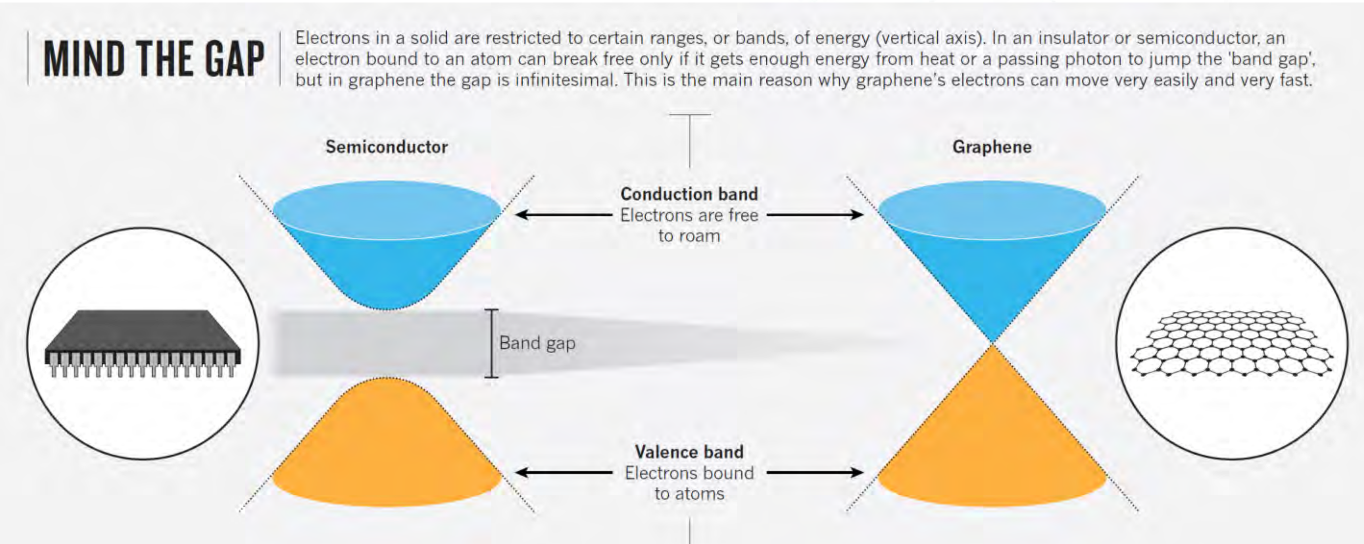
adattato da D. Awshalom

GRAFENE

K. Geim and A. H. MacDonald, Phys. Today. Agosto 2007 p35







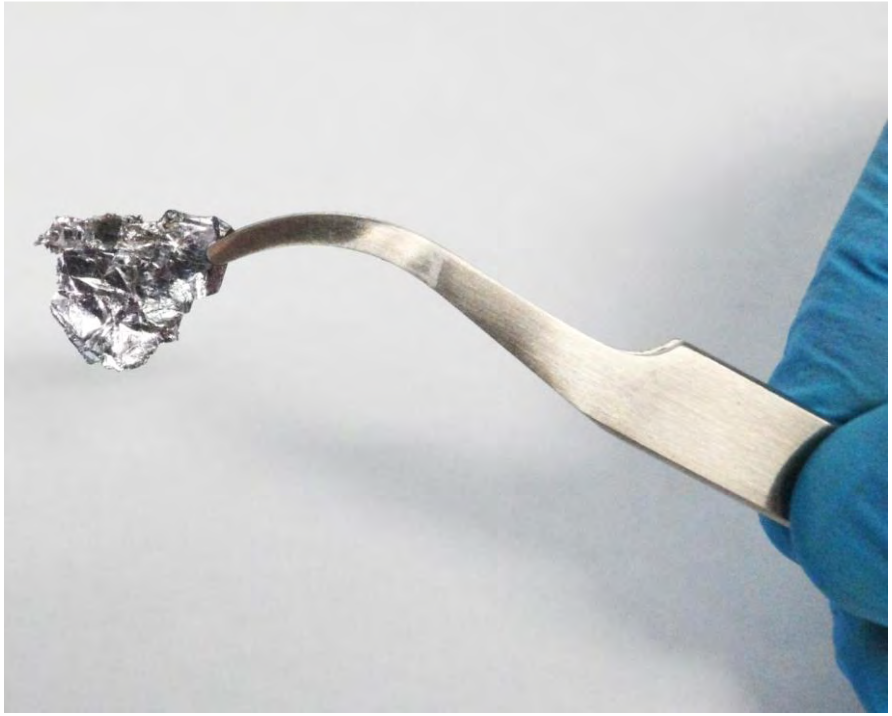
M. Peplow, Nature, 503, 327 (2013)

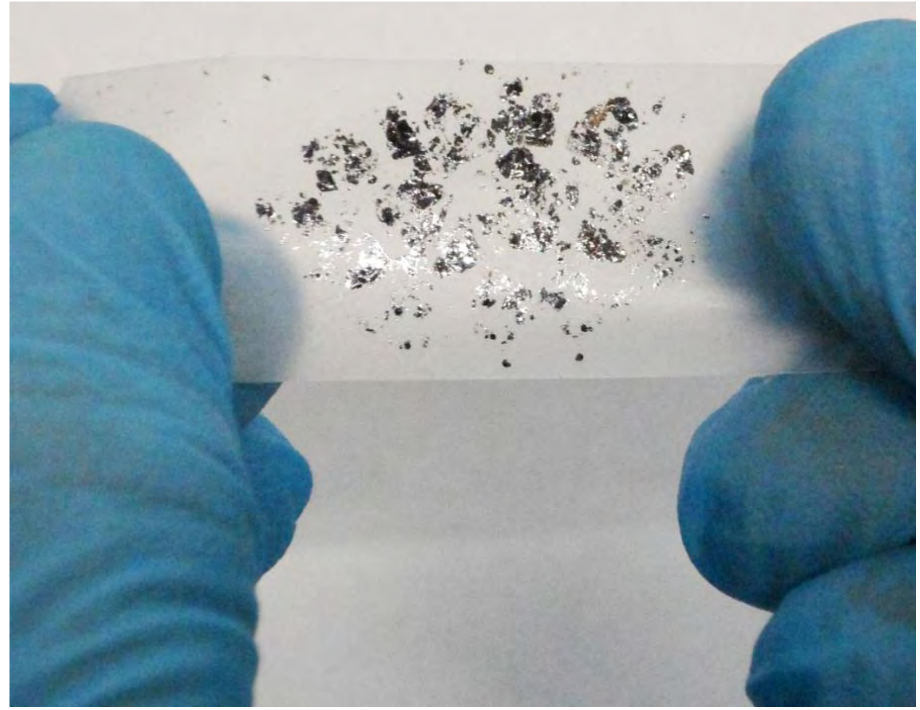
DISOLFURO DI MOLIBDENO

Ottime caratteristiche di estrema pressione per assicurare la resistenza degli organi meccanici sottoposti a carichi elevati.

Il prodotto si presenta di colore nero e di aspetto pomatoso e filante.

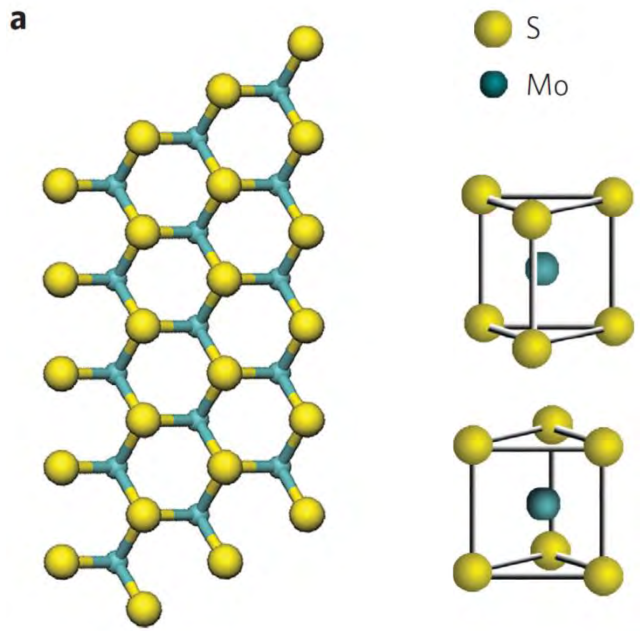
http://arexons.it/it/

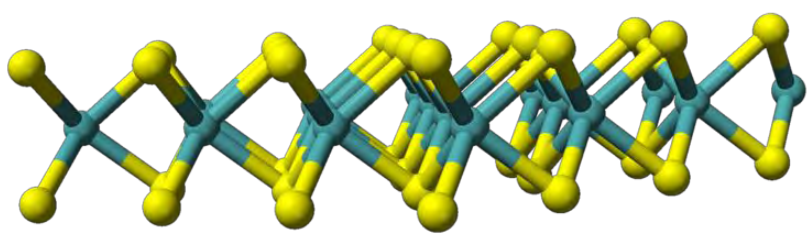


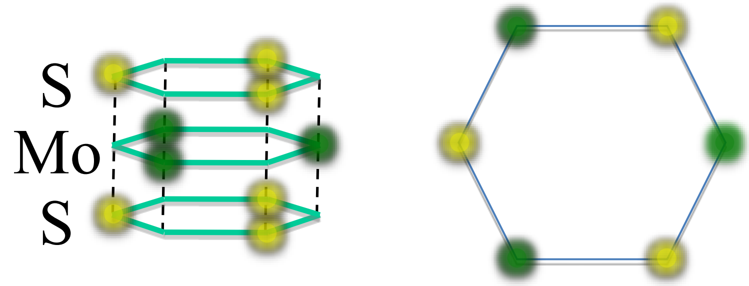


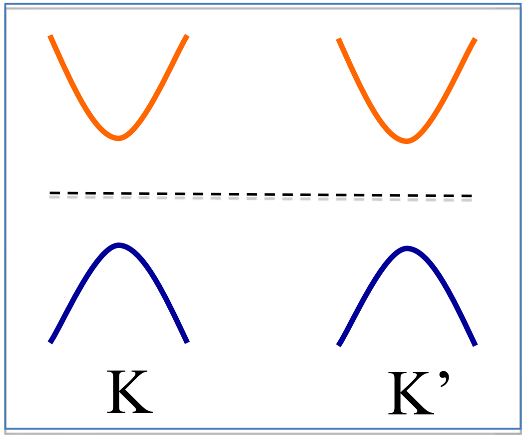
Produzione di lamelle spesse **1** solo **strato atomico** per **esfoliazione** meccanica

Honeycomb lattice with broken sublattice symmetry









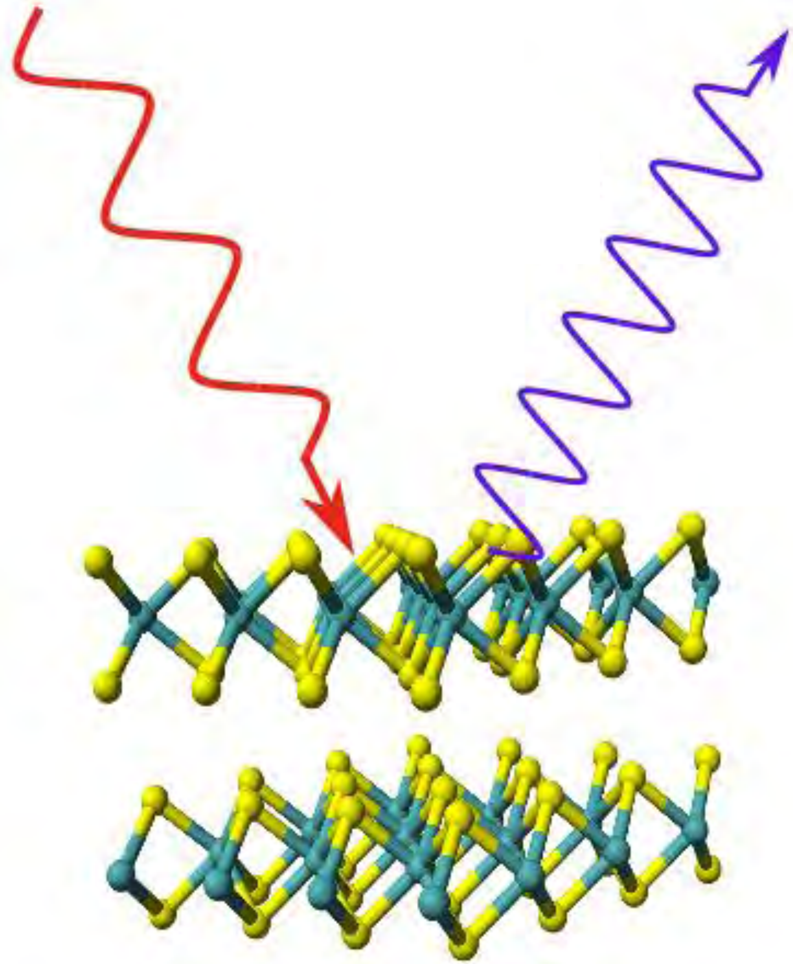
MONOLAYER MoS2

PRL **105,** 136805 (2010) PHYSICAL REVIEW LETTERS week ending 24 SEPTEMBER 2010

Atomically Thin MoS_2: A New Direct-Gap Semiconductor

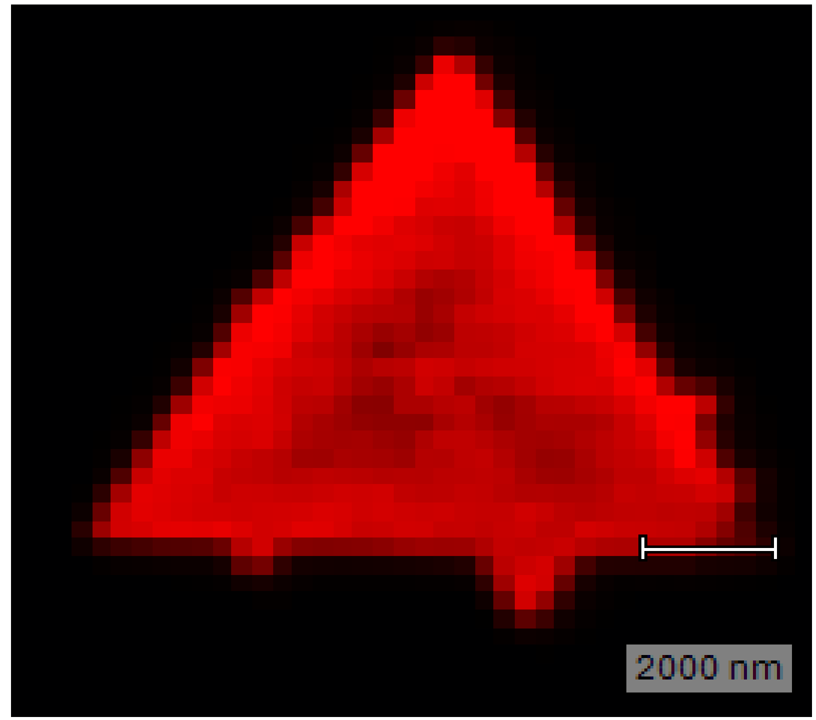
Kin Fai Mak,[1] Changgu Lee,[2] James Hone,[3] Jie Shan,[4] and Tony F. Heinz[1,*]
[1]*Departments of Physics and Electrical Engineering, Columbia University, 538 West 120th Street, New York, New York 10027, USA*
[2]*SKKU Advanced Institute of Nanotechnology (SAINT) and Department of Mechanical Engineering, Sungkyunkwan University, Suwon 440-746, Korea*
[3]*Department of Mechanical Engineering, Columbia University, New York, New York 10027, USA*
[4]*Department of Physics, Case Western Reserve University, 10900 Euclid Avenue, Cleveland, Ohio 44106, U*
(Received 2 April 2010; published 24 September 2010)

The electronic properties of ultrathin crystals of molybdenum disulfide consisting of $N = 1, 2, \ldots, 6$ S-Mo-S monolayers have been investigated by optical spectroscopy. Through characterization by absorption, photoluminescence, and photoconductivity spectroscopy, we trace the effect of quantum confinement on the material's electronic structure. With decreasing thickness, the indirect band gap, which lies below the direct gap in the bulk material, shifts upwards in energy by more than 0.6 eV. This leads to a crossover to a direct-gap material in the limit of the single monolayer. Unlike the bulk material, the MoS_2 monolayer emits light strongly. The freestanding monolayer exhibits an increase in luminescence quantum efficiency by more than a factor of 10^4 compared with the bulk material.

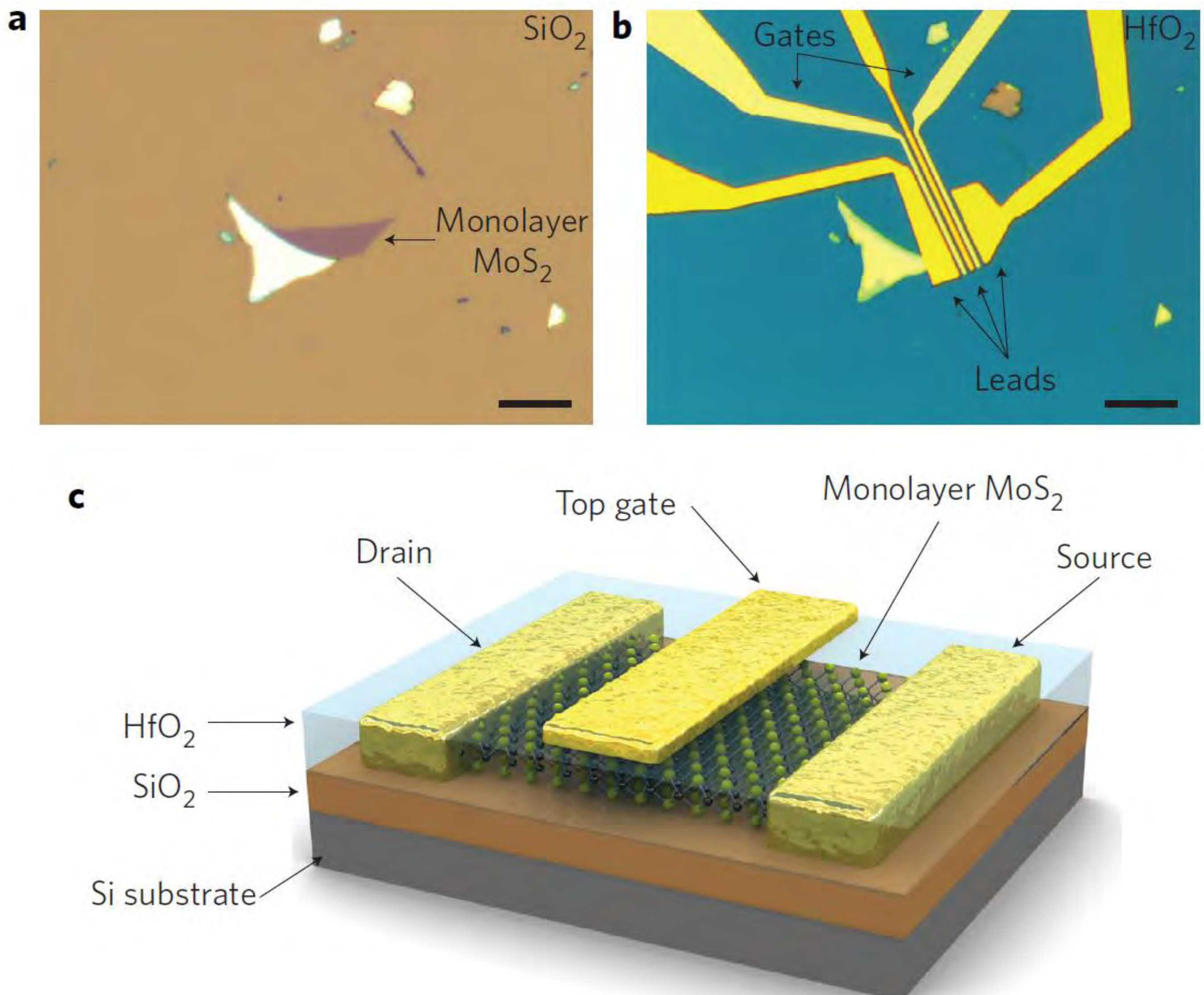


Microscopio ottico

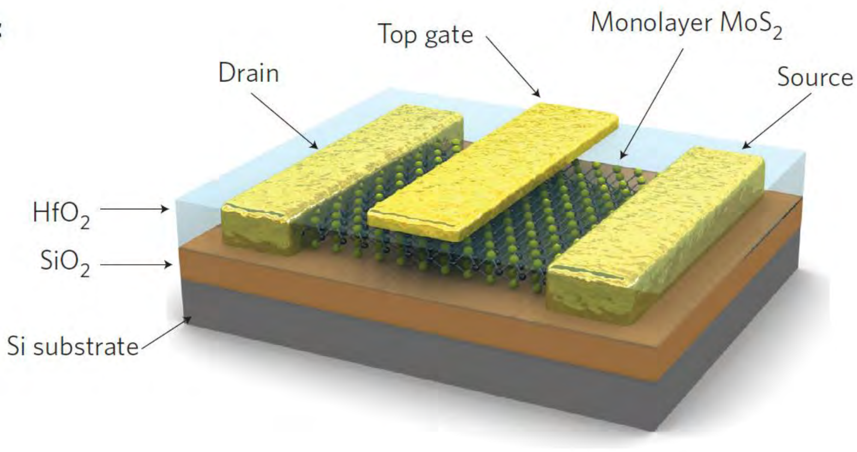
Intensità di luminescenza



Nature Materials 2013



B. Radisavljevic et al, Nature Nanotech.(2011)



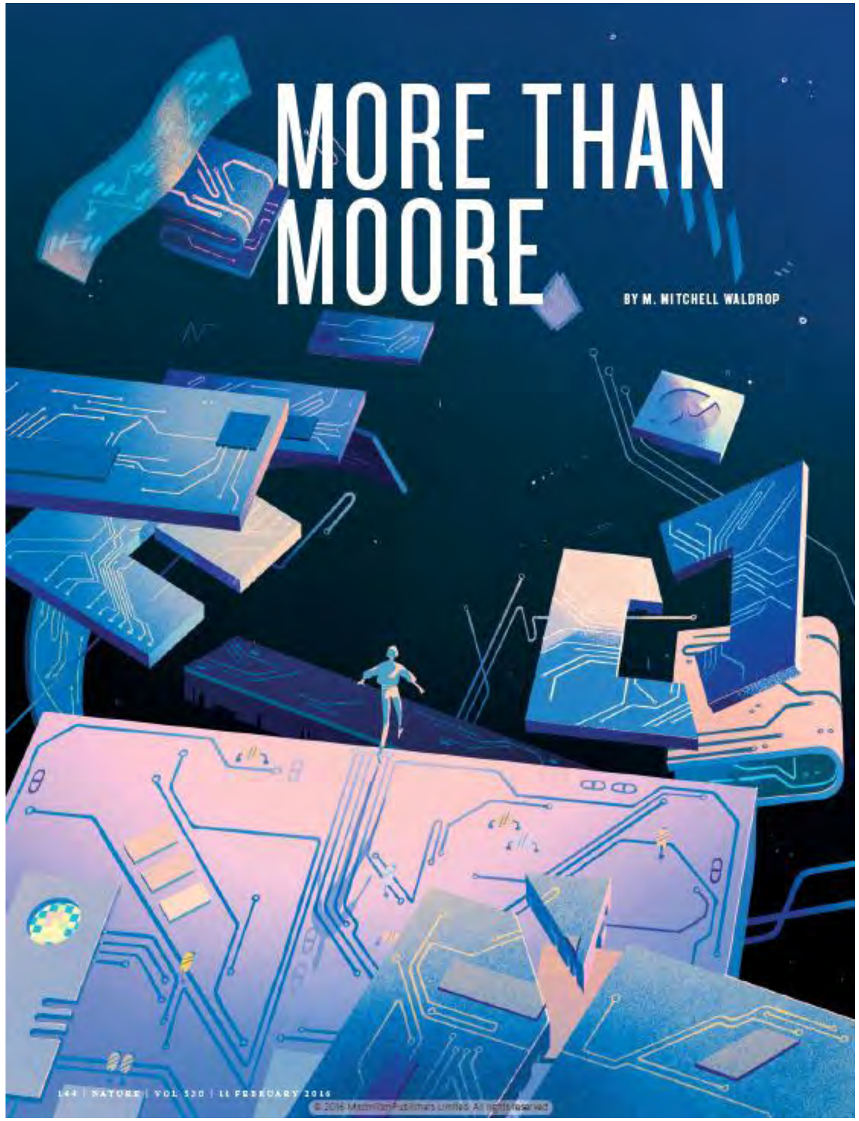
Elettronica flessibile

nel 1931 Pauli in una lettera a Rudolf Peierls afferma che:

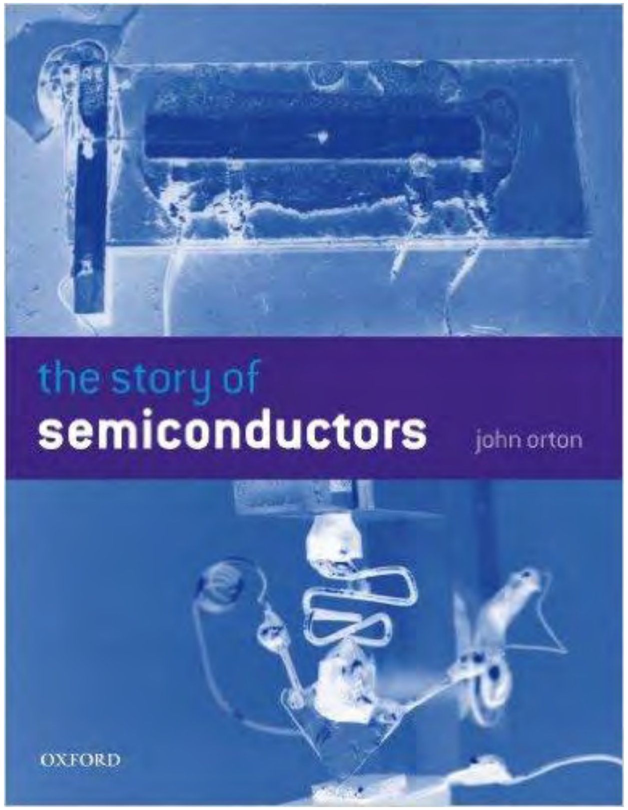
"…uno non deve lavorare sui semiconduttori: sono un pasticcio; chi sa se addirittura i semiconduttori esistono…"

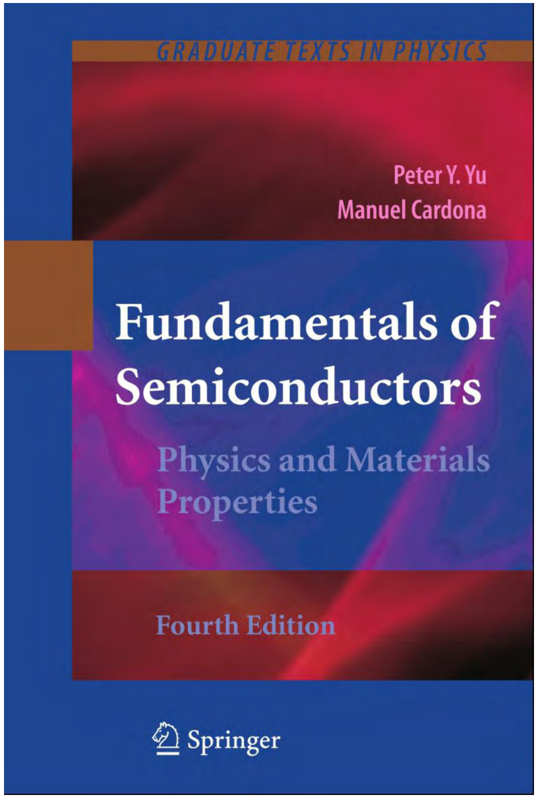
Pauli, premio nobel nel 1945

BIBLIOGRAFIA



BIBLIOGRAFIA





L'educazione ha prodotto molte persone in grado di leggere,

ma non in grado di distinguere che cosa è bene leggere

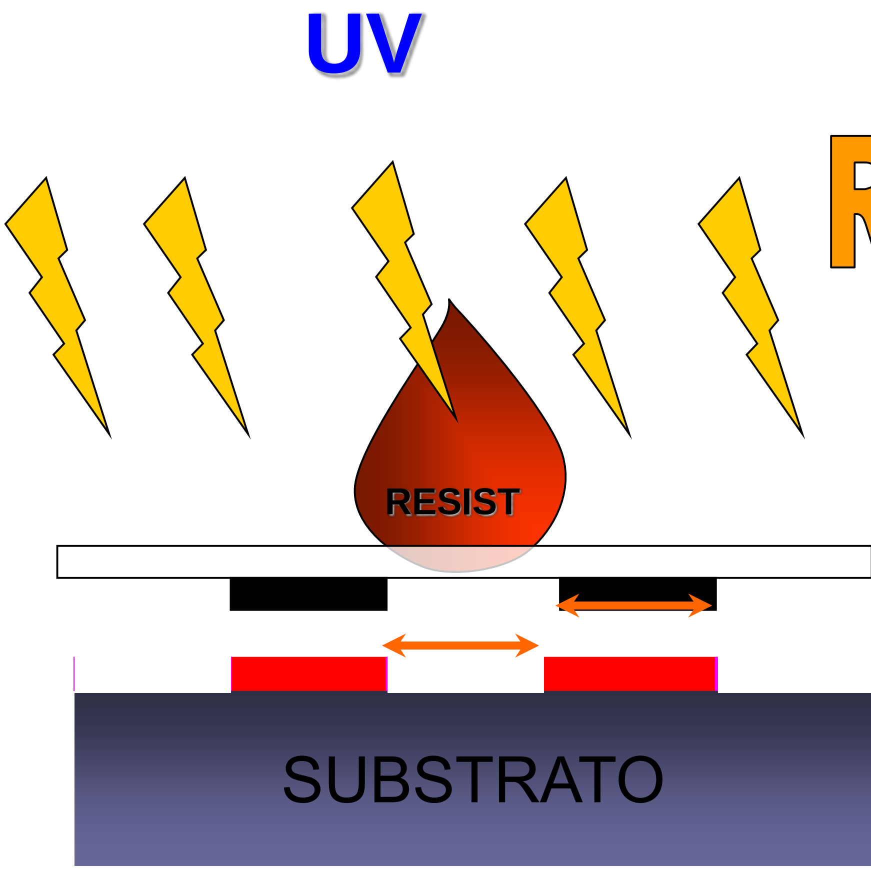
G.M Trevelyan

L'educazione scientifica sta producendo molte persone in grado di far scienza,

ma incapaci di distinguere cosa è bene fare con la scienza.

Balzani

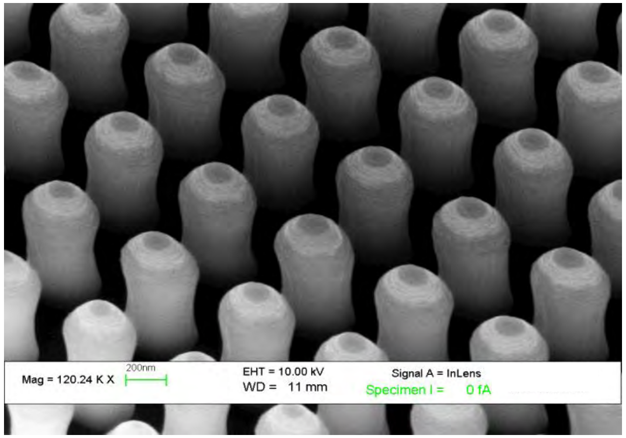
LITOGRAFIA



RISOLUZIONE?!?!

MASCHERA

DEVELOPER


Mag = 120.24 K X
200nm
EHT = 10.00 kV
WD = 11 mm
Signal A = InLens
Specimen I = 0 fA


SUBSTRATO

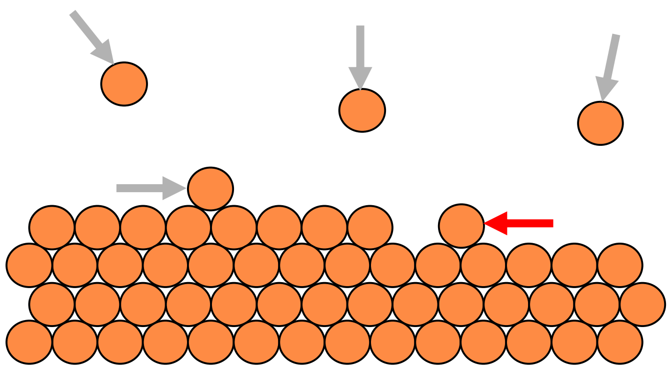
AUTOORGANIZZAZIONE

Comune denominatore = Natura → minimizzare l'energia attraverso l'organizzazione

Esempi? Materia allo stato solido, in particolare = CRESCITA CRISTALLI

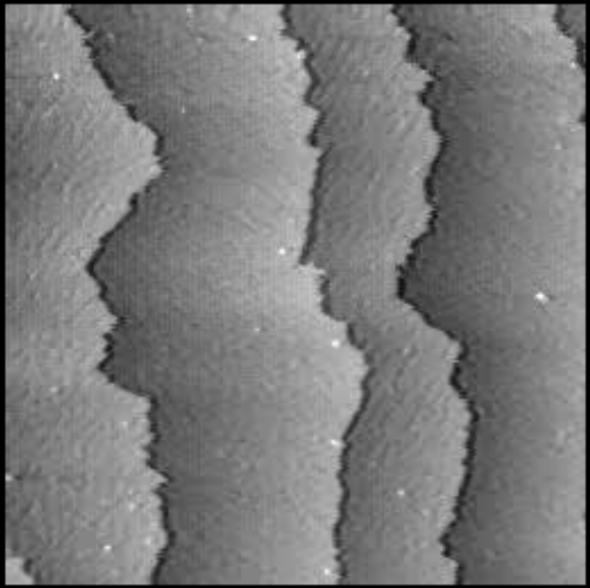
Atomi o molecole

In fase vapore o in soluzione liquida



L'atomo indicato dalla freccia rossa ha VERAMANTE una buona idea:

Se raggiunge l'angolo può legarsi ad altri tre atomi → *veramente* bassa energia



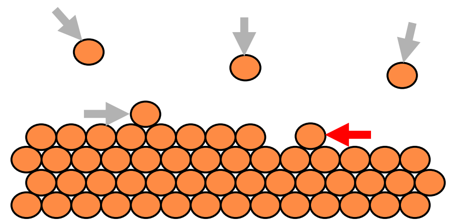
http://www.fz-juelich.de/video/voigtlaender

EPITASSIA DA FASCI MOLECOLARI

Gettare atomi in una camera da vuoto (ad esempio mediante evaporazione)

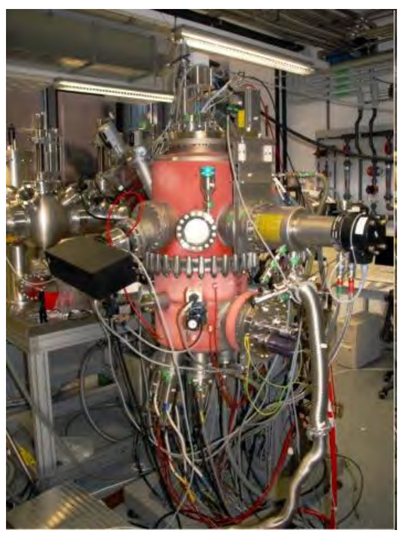
Questi *atterreranno* su un substrato riscaldato (il che gli consente di muoversi sulla superficie)

Il Processo è del tipo:



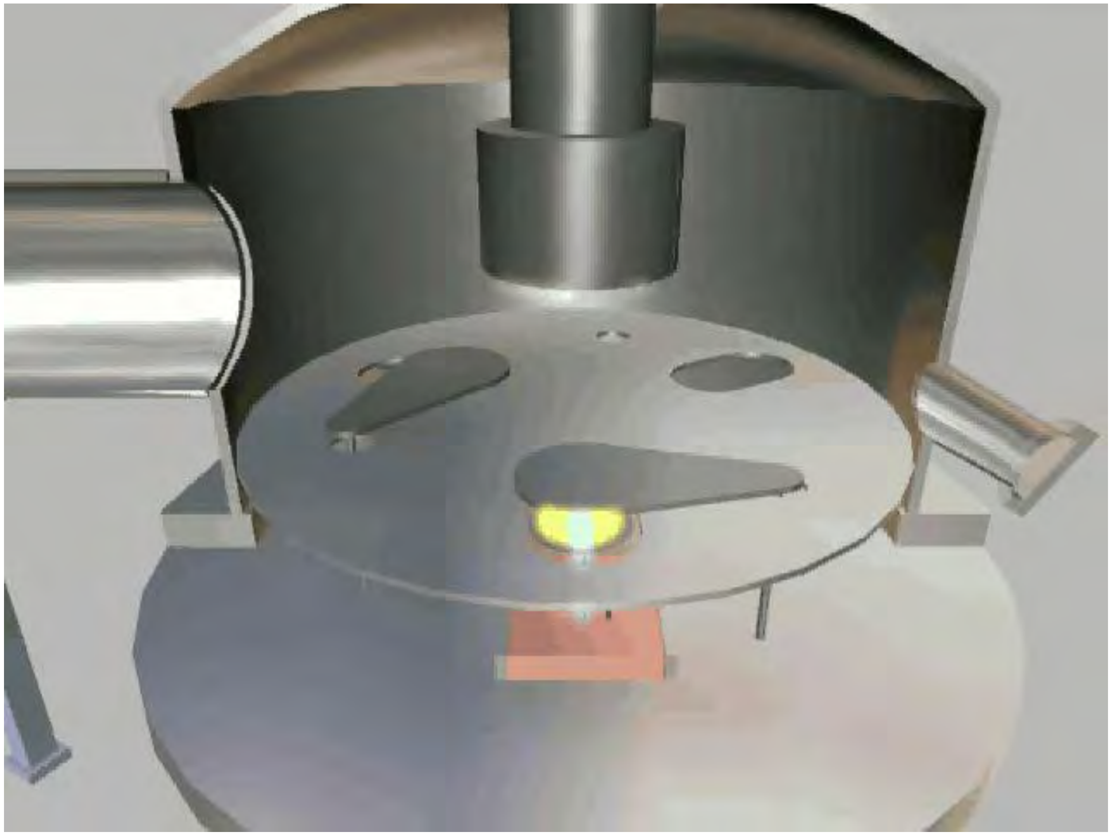
Tranne il fatto che richiede in più un sistema da vuoto dal valore <M€ per renderlo "semplice"

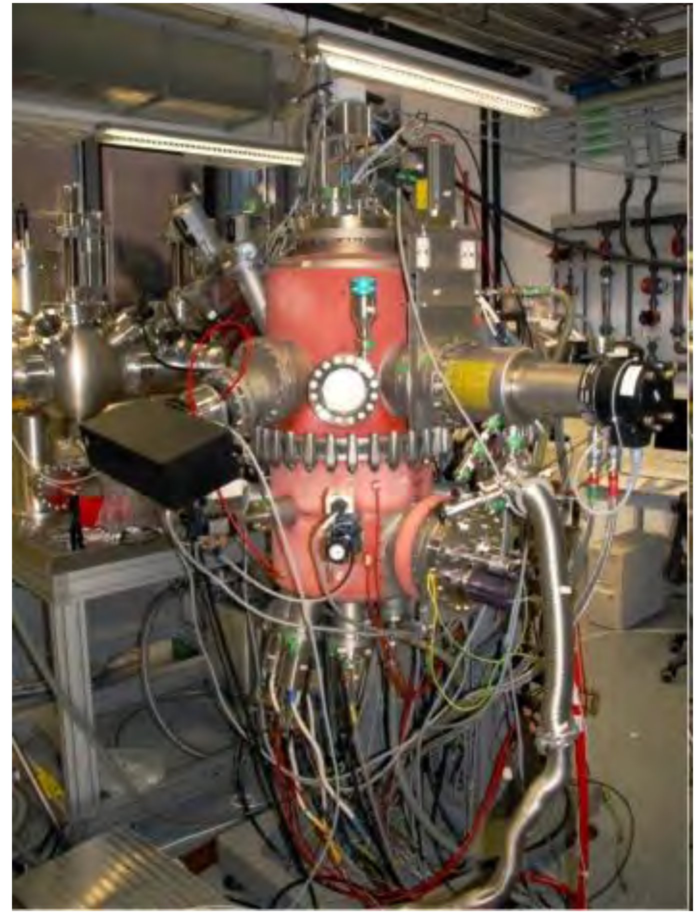
Il mio primo sistema:



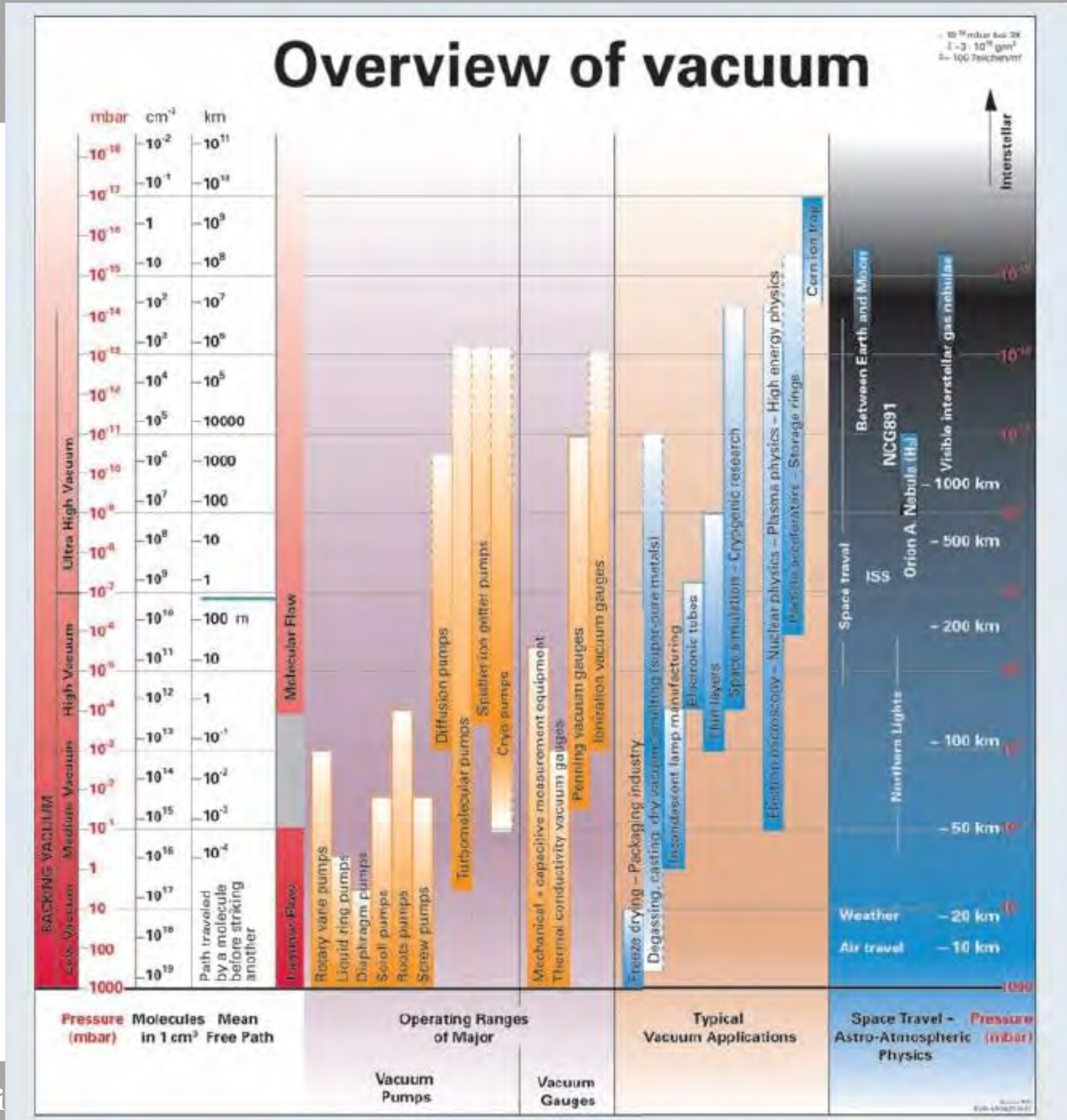
Leibniz-Institut
für Festkörper- und
Werkstoffforschung
Dresden

Epitassia da fascio molecolare: J. R. Arthur and Alfred Y. Cho (fine anni 60)





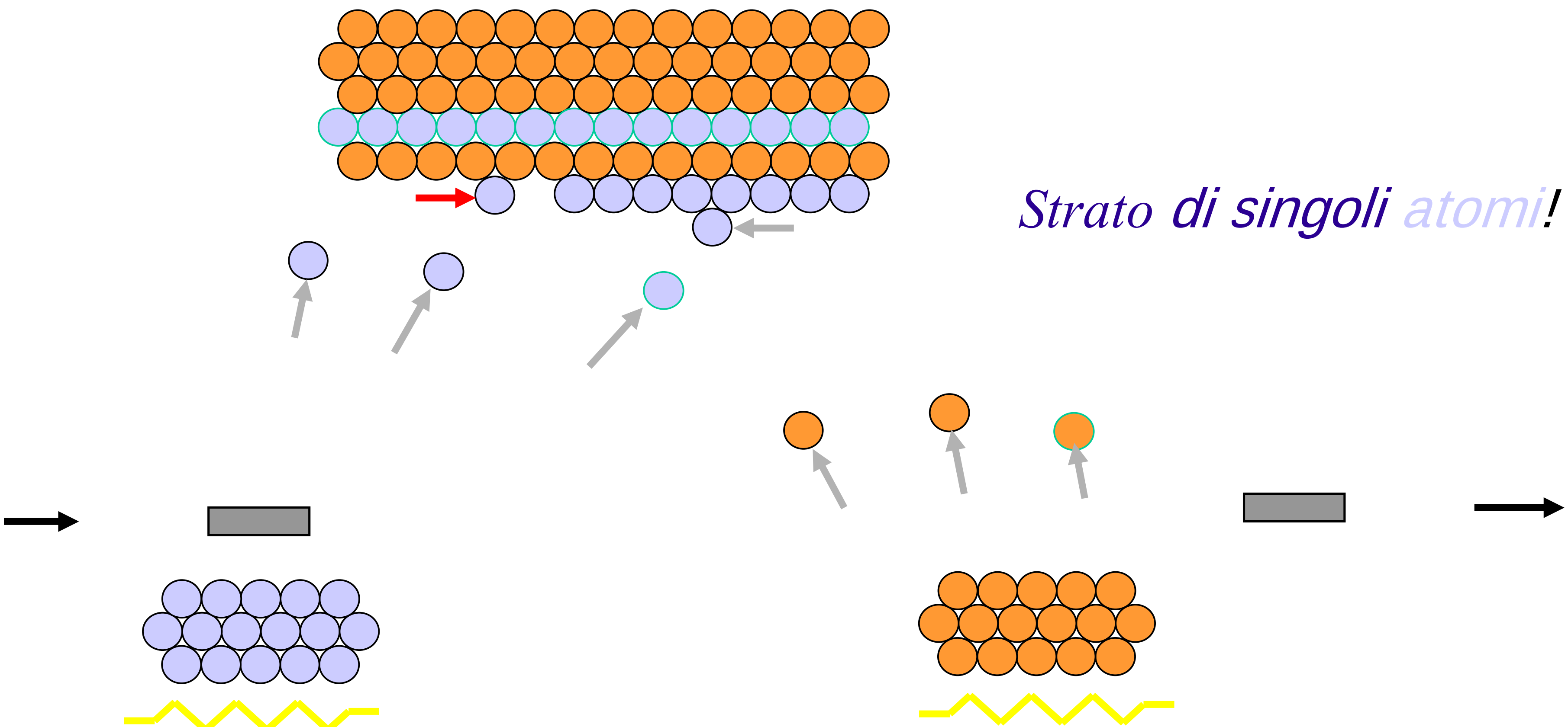
Da "UVA Virtual Lab" http://www.virlab.virginia.edu/VL/MBE.htm



Overview of vacuum
mbar
cm⁻³
km
Interstellar
Ultra High Vacuum
High Vacuum
Medium Vacuum
Low Vacuum
BACKING VACUUM
Molecular Flow
Laminar Flow
Path traveled by a molecule before striking another
Rotary vane pumps
Liquid ring pumps
Diaphragm pumps
Scroll pumps
Roots pumps
Screw pumps
Turbomolecular pumps
Diffusion pumps
Sputter ion getter pumps
Cryo pumps
Mechanical + capacitive measurement equipment
Thermal conductivity vacuum gauges
Penning vacuum gauges
Ionization vacuum gauges
Freeze drying - Packaging industry
Degassing, casting, dry vacuum smelting (super-pure metals)
Incandescent lamp manufacturing
Electronic tubes
Thin layers
Space simulation - Cryogenic research
Electron microscopy - Nuclear physics - Plasma physics - High energy physics
Particle accelerators - Storage rings
Cern ion trap
Between Earth and Moon
NCG891
Orion A. Nebula (H₂)
Visible interstellar gas nebulae
Space travel
ISS
Northern Lights
Weather
Air travel
1000 km
500 km
200 km
100 km
50 km
20 km
10 km
Pressure (mbar)
Molecules in 1 cm³
Mean Free Path
Operating Ranges of Major
Vacuum Pumps
Vacuum Gauges
Typical Vacuum Applications
Space Travel - Astro-Atmospheric Physics
Pressure (mbar)

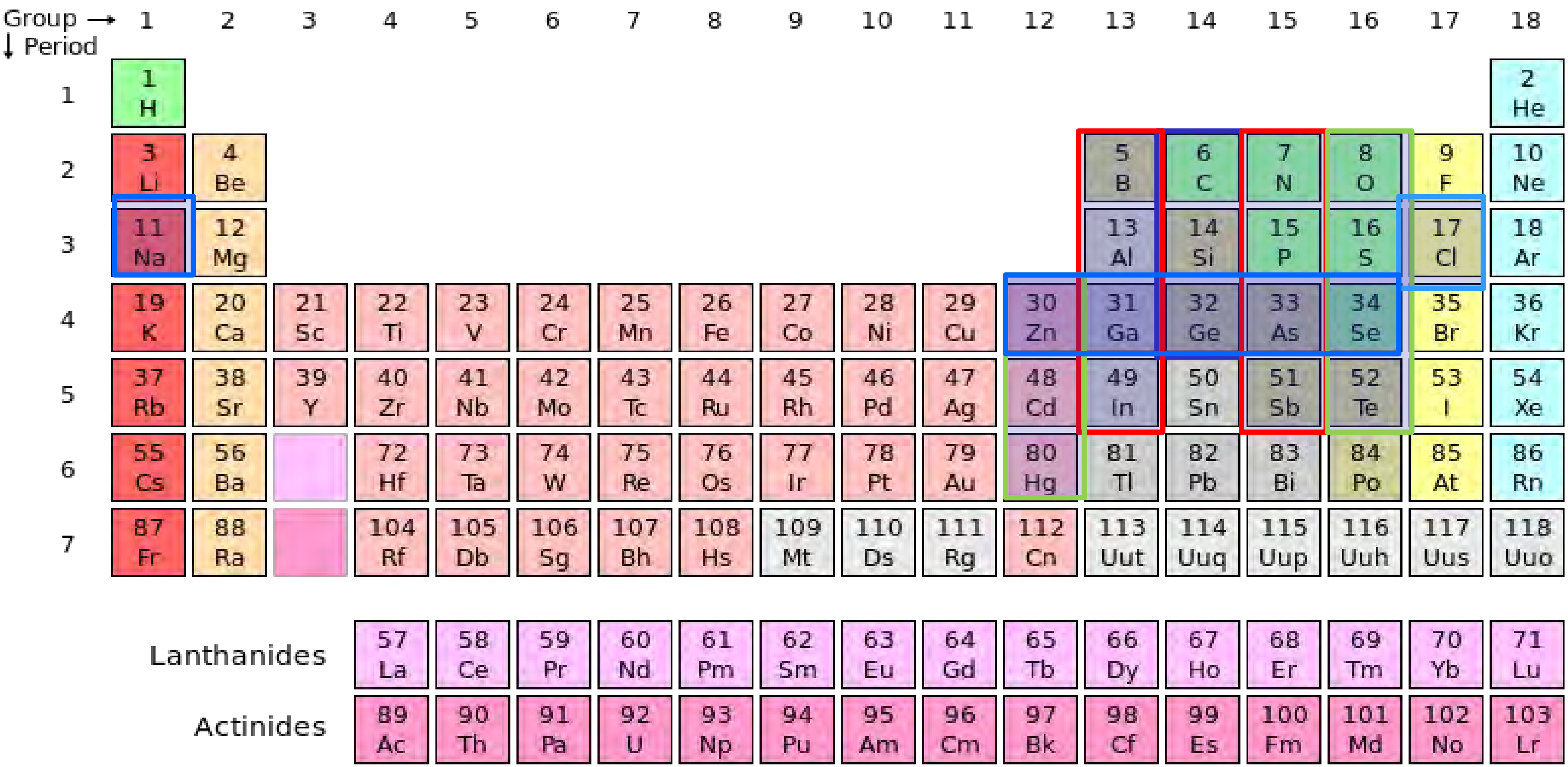
Come produrre nano-cose?

Capovolgete il campione, istallate 2 sorgenti d'evaporazione, e poi alternate gli atomi:



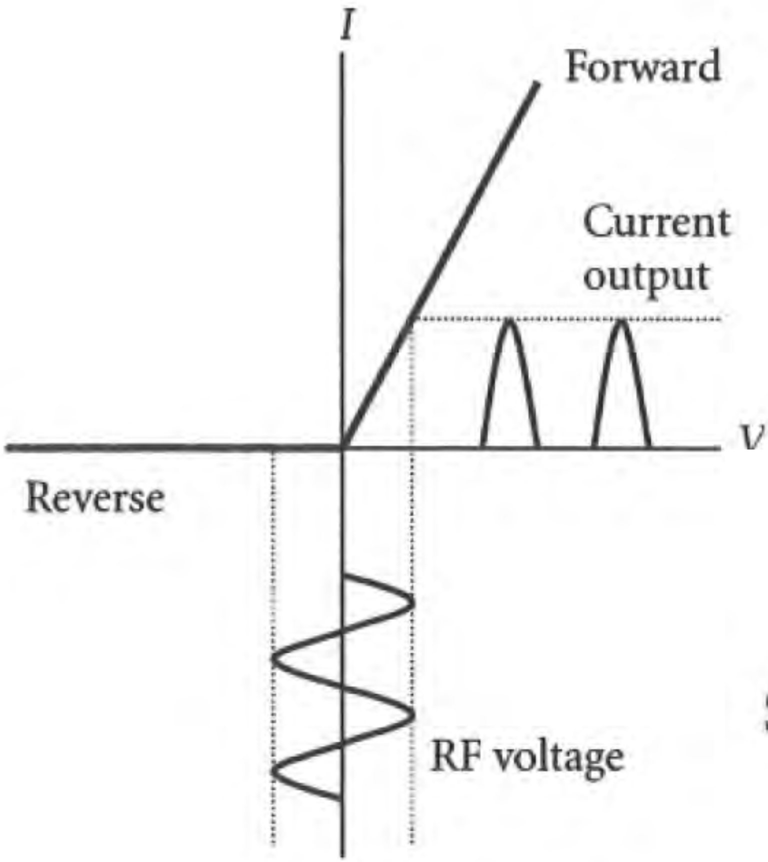
Strato di singoli atomi!

SEMICONDUTTORI NOTI E MENO NOTI

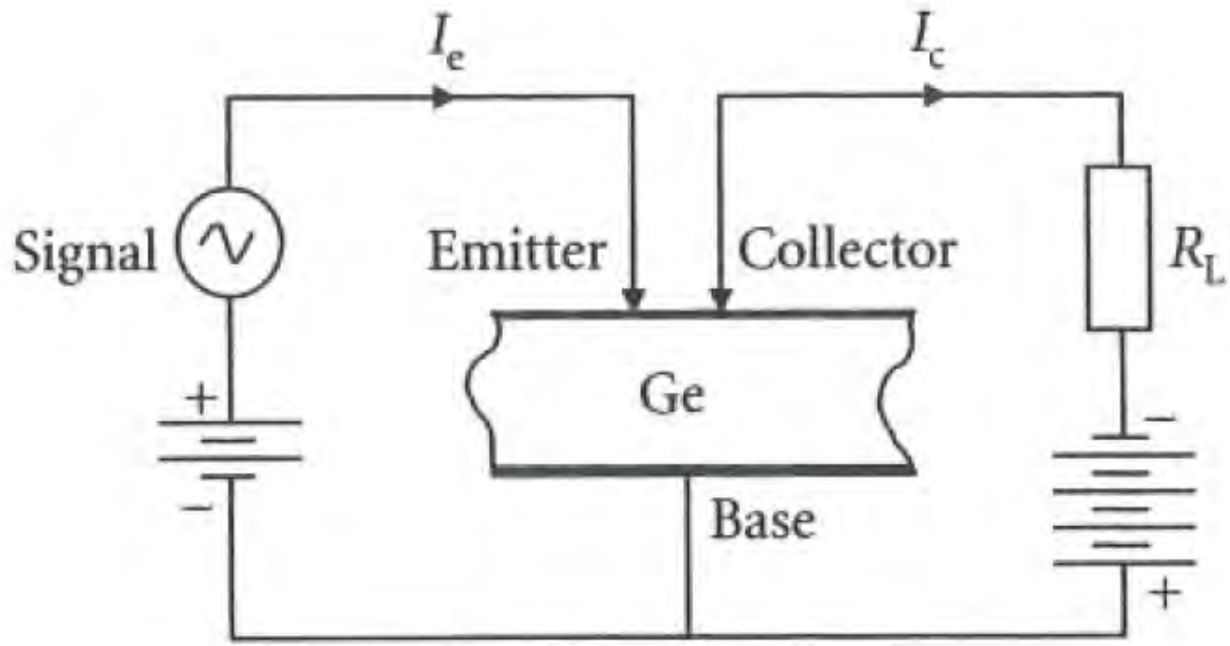


CuInSe, AgInS, PbSe, GaSe…

Composti I-VII fortemente ionici, Ge (0.66eV)→GaAs(1.43eV)→ZnSe (2.7eV)



I
Forward
Current
output
V
Reverse
RF voltage

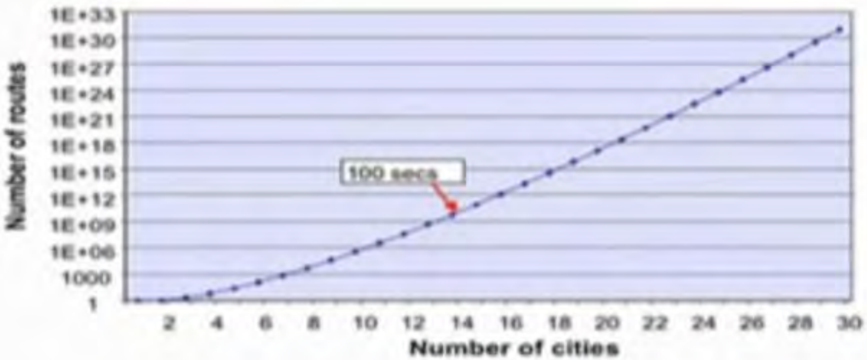


I_e
I_c
Signal
Emitter
Collector
R_L
Ge
Base
+
–
–
+

Difficult problems: the travelling salesman

Problem: A salesman has to travel to many cities and wants to work out the shortest possible route

Difficult problems: the travelling salesman

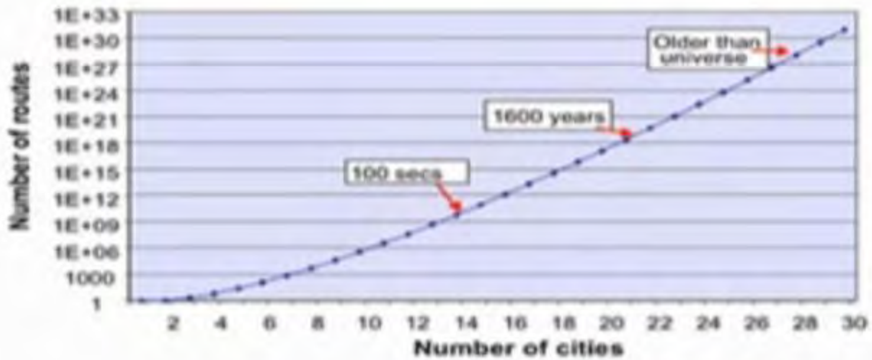


14 cities: 10^{11} routes

for a classical 1GHz computer (10^{9} operations/sec)

it would take 100 seconds

Difficult problems: the travelling salesman



14 cities: 10^{11} routes

for a classical 1GHz computer (10^{9} operations/sec)

it would take 100 seconds

22 cities: 10^{19} routes

it would take 1600 years

28 cities

Classical versus quantum computation

Classical computer - can check many different possibilities in *rapid succession*

1 computer -
search A, B, C, ... Z

2 computers - twice as fast.
One searches A-L, other M-Z.

3 computers - 3 × as fast.

Classical versus quantum computation

Classical computer - can check many different possibilities in *rapid succession*
Quantum computer - can check many different possibilities *in parallel*

Superposition, 1 spin: $\Psi = \alpha_1|0\rangle + \alpha_2|1\rangle$

# qubits	classical possibilities	power
1	0 or 1	2
2	00, 01, 10, 11	4
3	000, 001, 010, 011 100, 101, 110, 111	8
N		2^N

Quantum computer's power ***doubles*** every time another qubit is added

A 30-qubit quantum computer would be more powerful than a supercomputer..

As for 300 qubits....