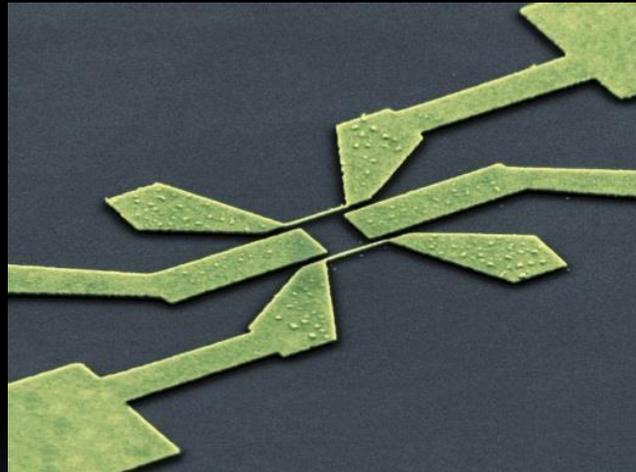




**Guido Goldoni**

Dipartimento di Scienze Fisiche, Informatiche e Matematiche, UNIMORE  
Centro di Ricerca sulle Nanoscienze CNR-NANO S<sub>3</sub>

[guido.goldoni@unimore.it](mailto:guido.goldoni@unimore.it)

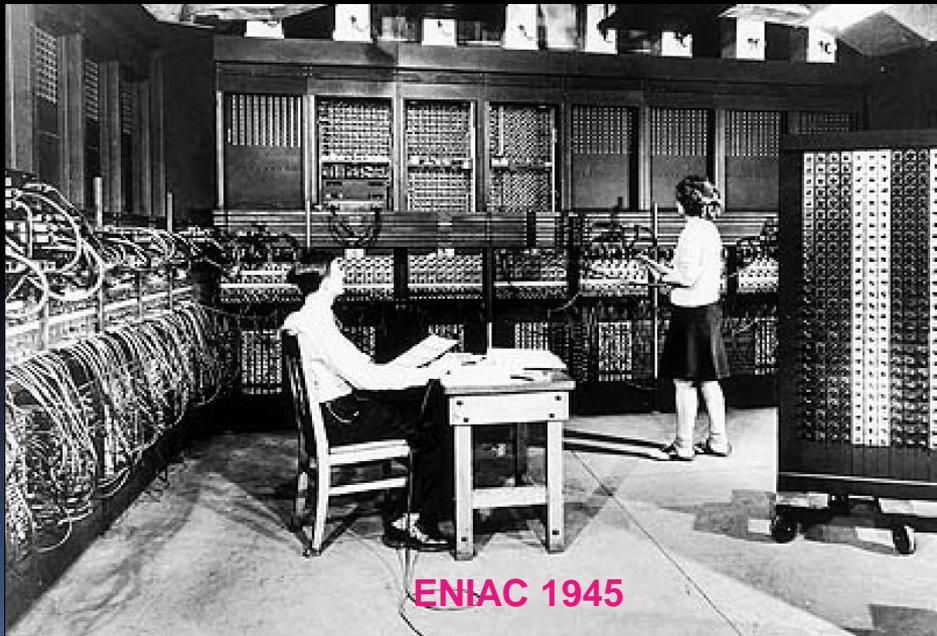


**DALLA FISICA DELLA MATERIA ALLA TECNOLOGIA**  
**UNO SGUARDO SULLE NANSCIENZE**

# LA POTENZA DELLE NUOVE IDEE

*“Penso che ci sia un mercato mondiale per, forse, cinque computer”*

*T.J.Watson, fondatore IBM, 1943*



ENIAC 1945



18000 valvole  
200 kW  
200 mq

# LA RIVOLUZIONE TECNOLOGICA

Nobel



W.B.Shockley, J.Bardeen  
W.H.Brattain, Nobel 1956



J. S. Kilby, Nobel 2000



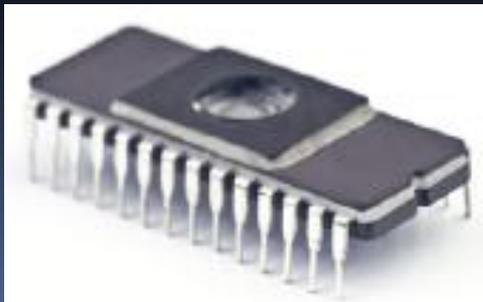
Valvola termoionica



Transistor a  
semiconduttore (1947)

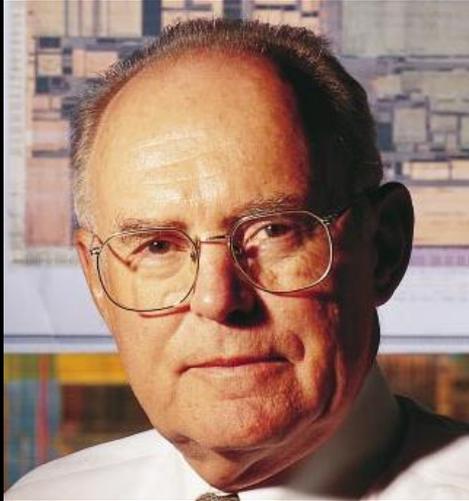


Circuito integrato (1958)



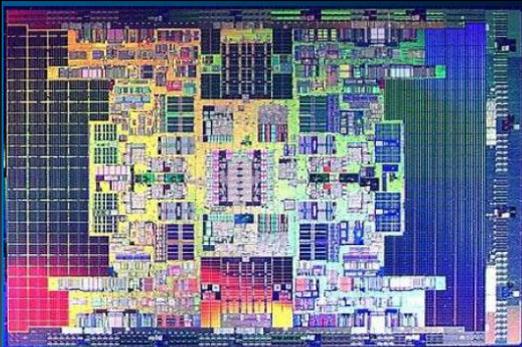
Information and  
Communication Technology

# LA LEGGE DI MOORE

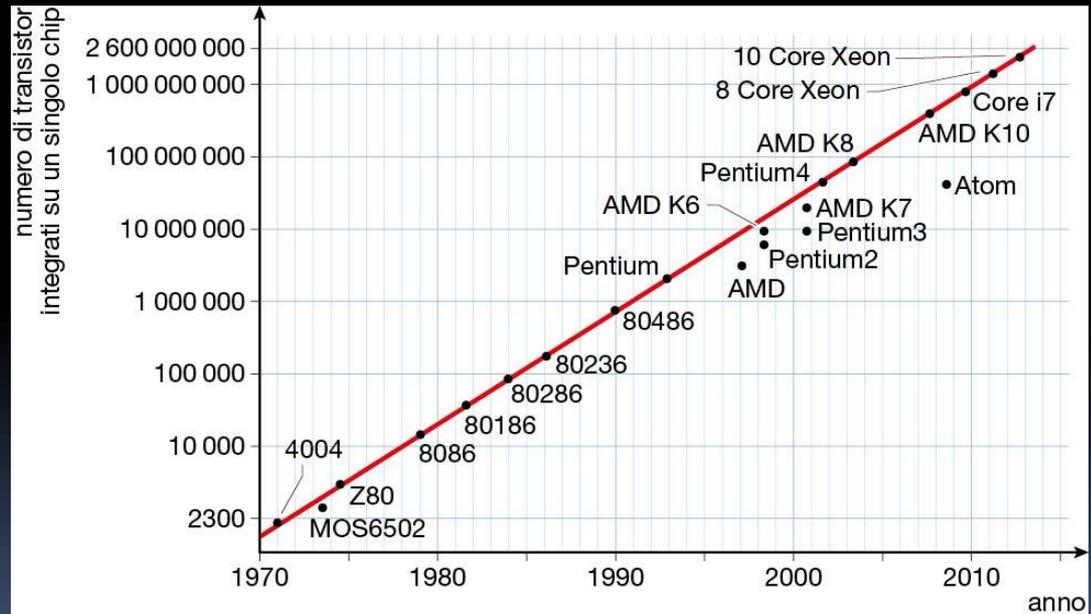


*"Ogni 2 anni la complessita' (il numero di transistor) raddoppia"*

*Gordon Moore*



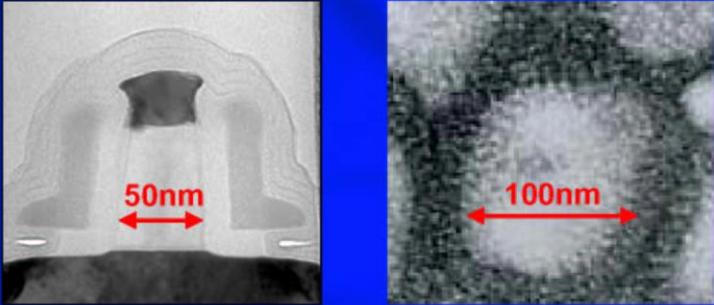
Intel Itanium (2008)



# LA NANOTECNOLOGIA IN TASCA

32nm technology

**Silicon Devices are Nanotechnology** intel.



The image contains two side-by-side microscopic views. The left view shows a transistor with a red double-headed arrow indicating a width of 50nm. The right view shows an influenza virus with a red double-headed arrow indicating a diameter of 100nm.

50nm

100nm

Transistor for 90 nm process

Influenza virus  
Source: CDC

Intel Research & Development

Page 10

Intel Developer Forum



# DI PIÙ O DIVERSO?

*"Che bisogno ha una persona di tenersi un computer in casa?"*

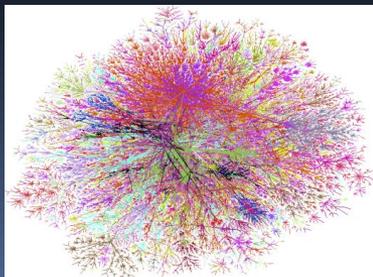
*K.Olsen, fondatore Digital, 1977*

*Apple II, 1977*



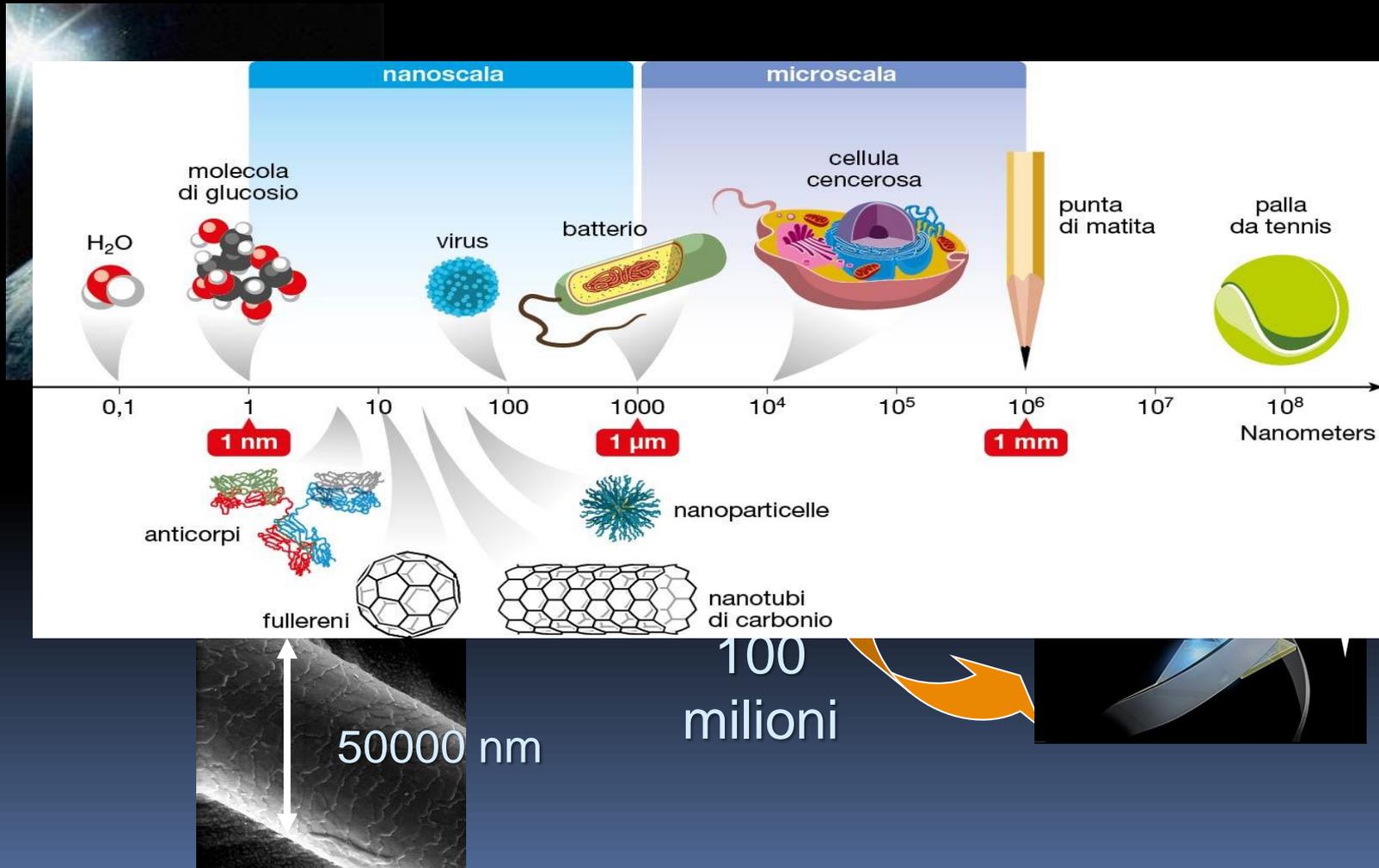
*"640K dovrebbero essere sufficienti per chiunque"*

*B. Gates, fondatore Microsoft, 1981*



*World Wide Web*

# LA NANO SCALA



# LE NANOSCIENZE

- ▶ Studiano le proprietà di sistemi con dimensioni intorno a 10 – 100 nm (da poche migliaia a un milione di atomi)

Un oggetto nanometrico non è solo “molto piccolo”

Le caratteristiche di un materiale alla nanoscala ne determinano le proprietà

Modificare un materiale in modo controllato alla nanoscala significa pre-determinarne le proprietà

*“There is plenty of room at the bottom.”*

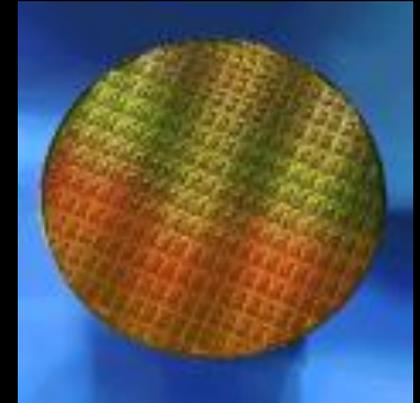
R. Feynmann, 1959



R Feynmann  
Nobel 1965

# AUREA MEDIOCRITAS – I SEMICONDUTTORI

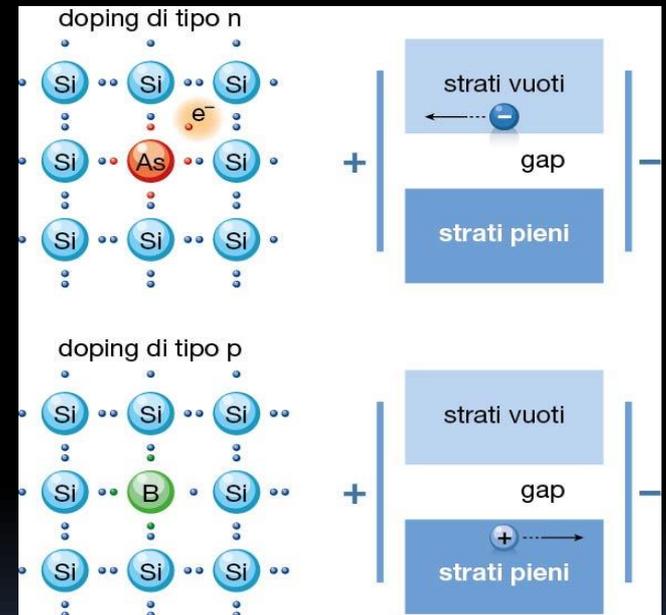
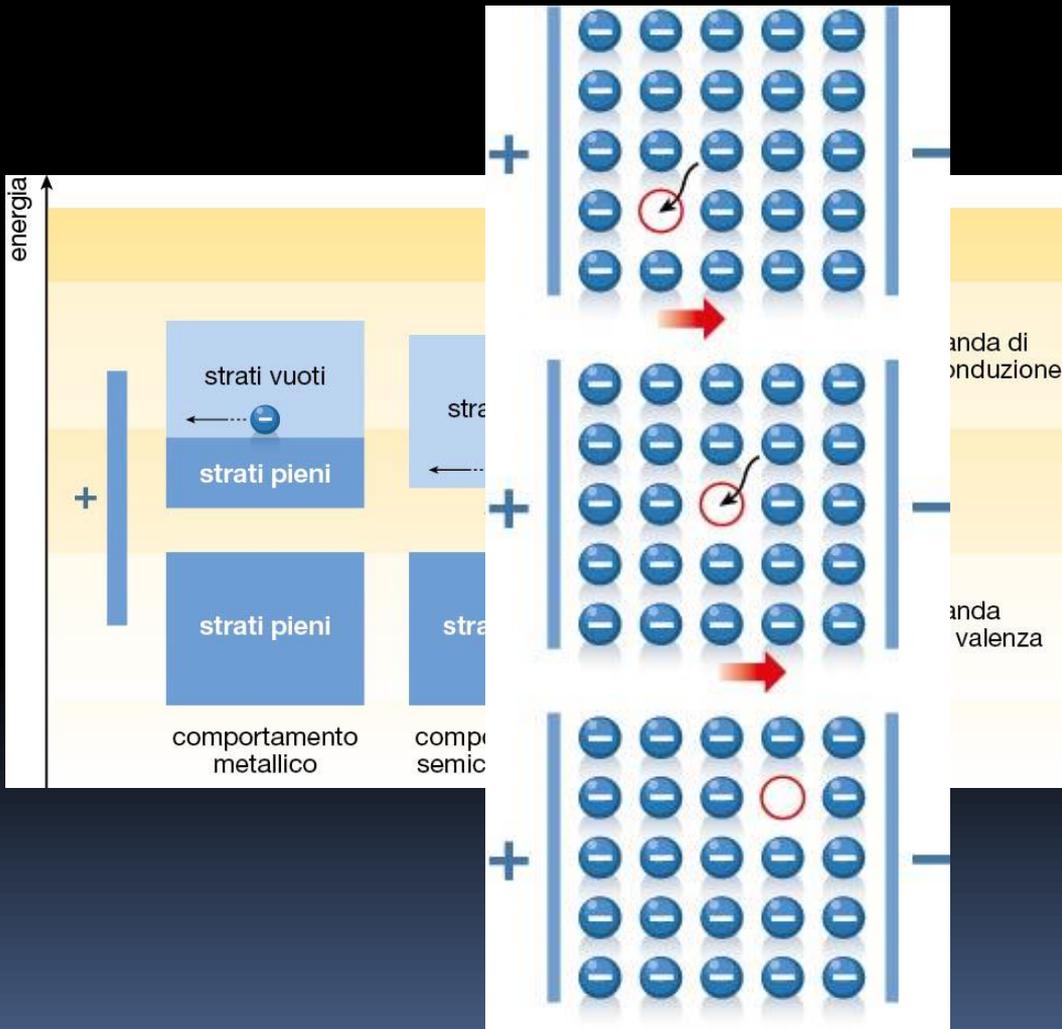
- Ne' buoni conduttori, ne' buoni isolanti



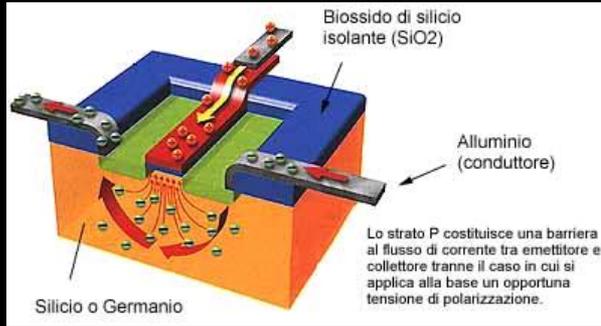
1																	2
H																	He
3	4											5	6	7	8	9	10
Li	Be											B	C	N	O	F	Ne
11	12											13	14	15	16	17	18
Na	Mg											Al	Si	P	S	Cl	Ar
19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
37	38	39	40	41	42	43	44	45	46	47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

5	6	7	8
B	C	N	O
13	14	15	16
Al	Si	P	S
31	32	33	34
Ga	Ge	As	Se

# LA TEORIA QUANTISTICA DEI SOLIDI



# IL MATTONE - IL TRANSISTOR



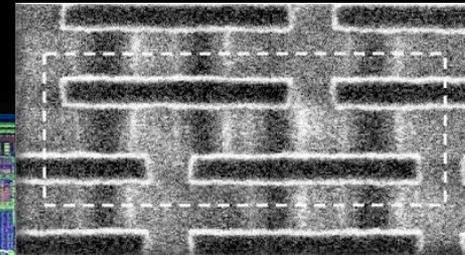
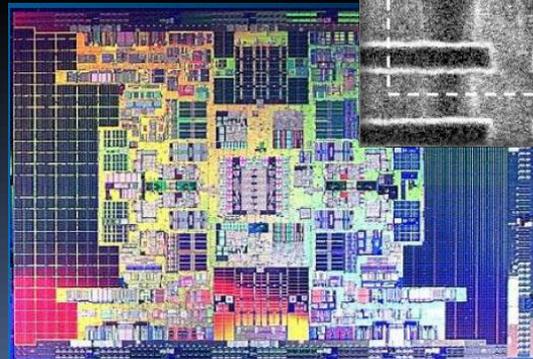
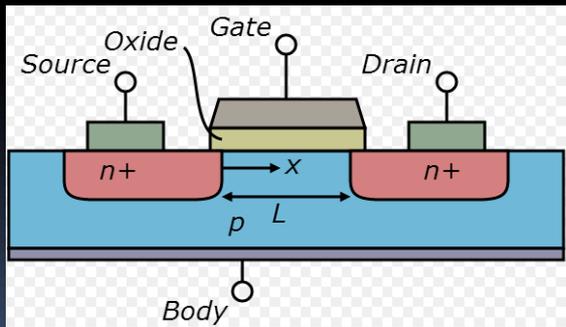
0

+V

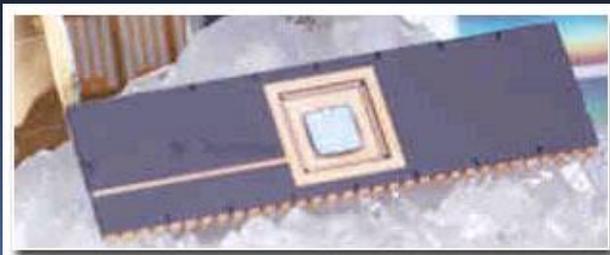
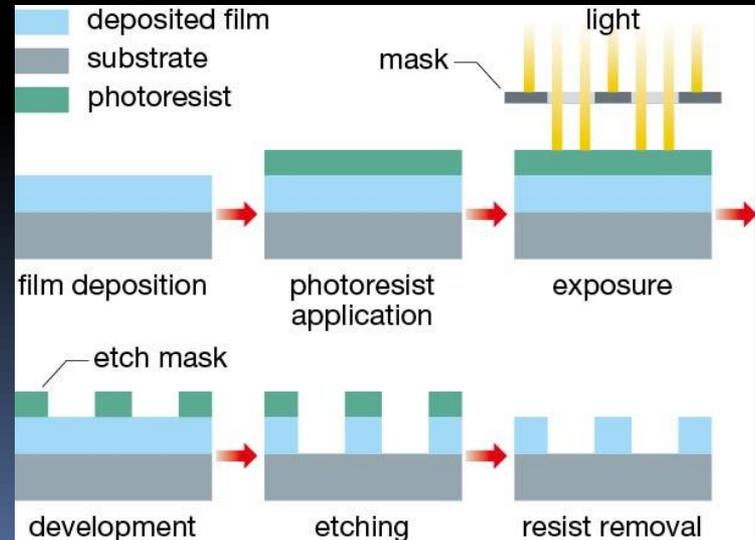
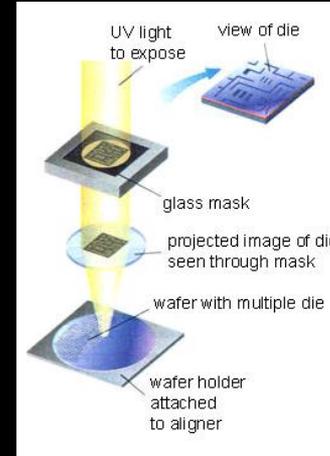
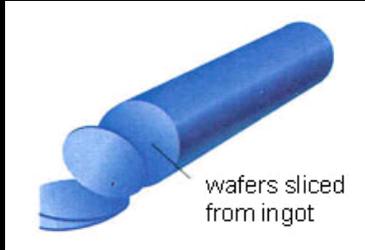
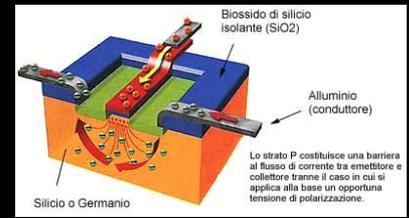


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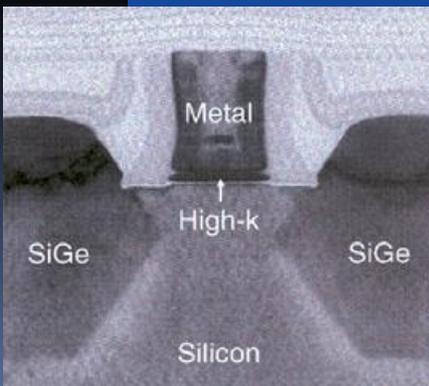
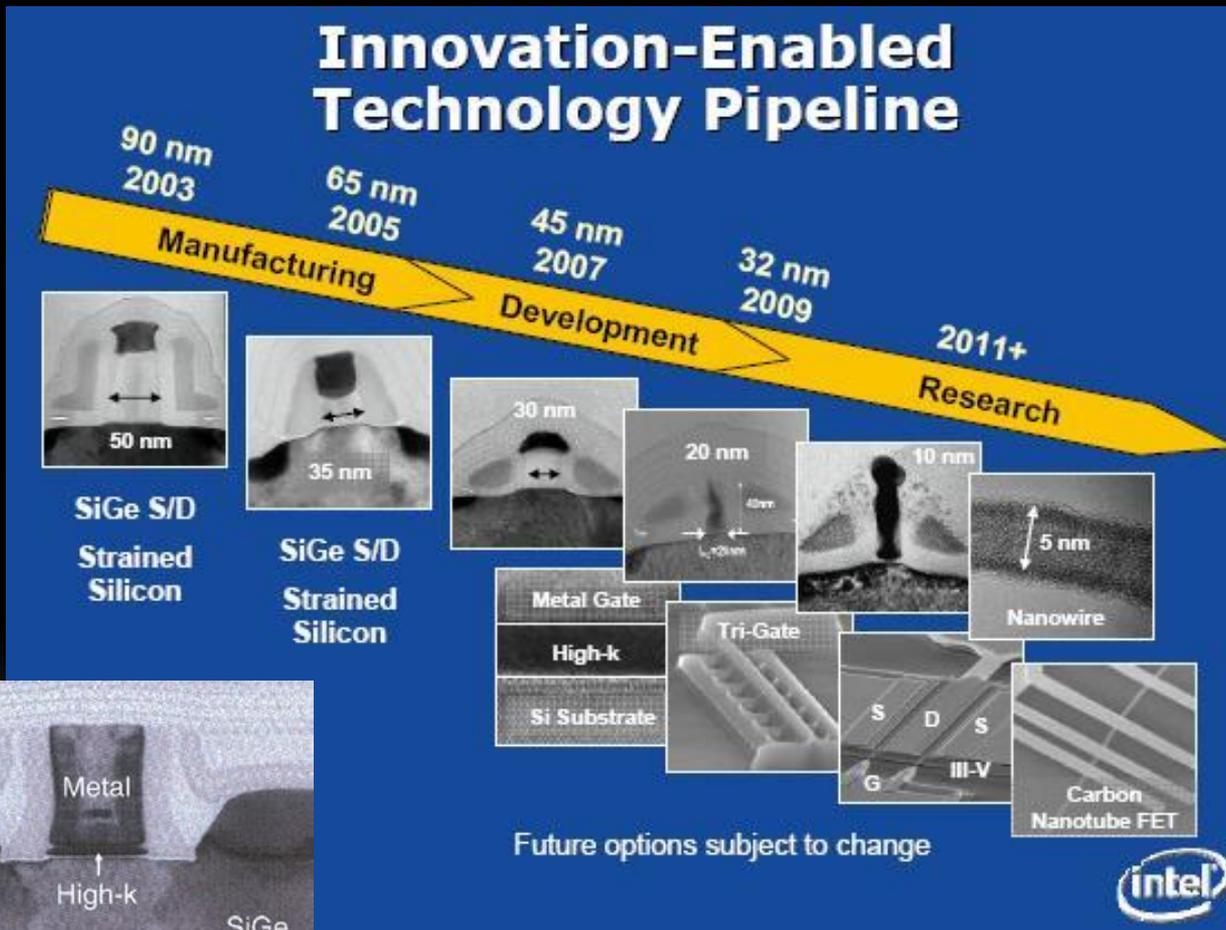
1



# DAL GRANDE AL PICCOLO



# FISICA O NANOTECNOLOGIA?



### Semiconductor manufacturing processes

- 10  $\mu\text{m}$  — 1971
- 3  $\mu\text{m}$  — 1975
- 1.5  $\mu\text{m}$  — 1982
- 1  $\mu\text{m}$  — 1985
- 800 nm — 1989
- 600 nm — 1994
- 350 nm — 1995
- 250 nm — 1997
- 180 nm — 1999
- 130 nm — 2002
- 90 nm — 2004
- 65 nm — 2006
- 45 nm — 2008
- 32 nm — 2010
- 22 nm** — 2012
- 14 nm — est. 2015
- 10 nm — est. 2017
- 7 nm — est. 2020
- 5 nm — est. 2022

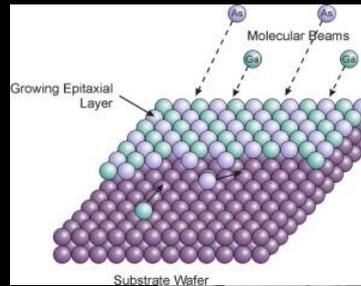
Half-nodes

Nobel

# UNA GRANDE OPPORTUNITA', NUOVI MATERIALI QUANTISTICI



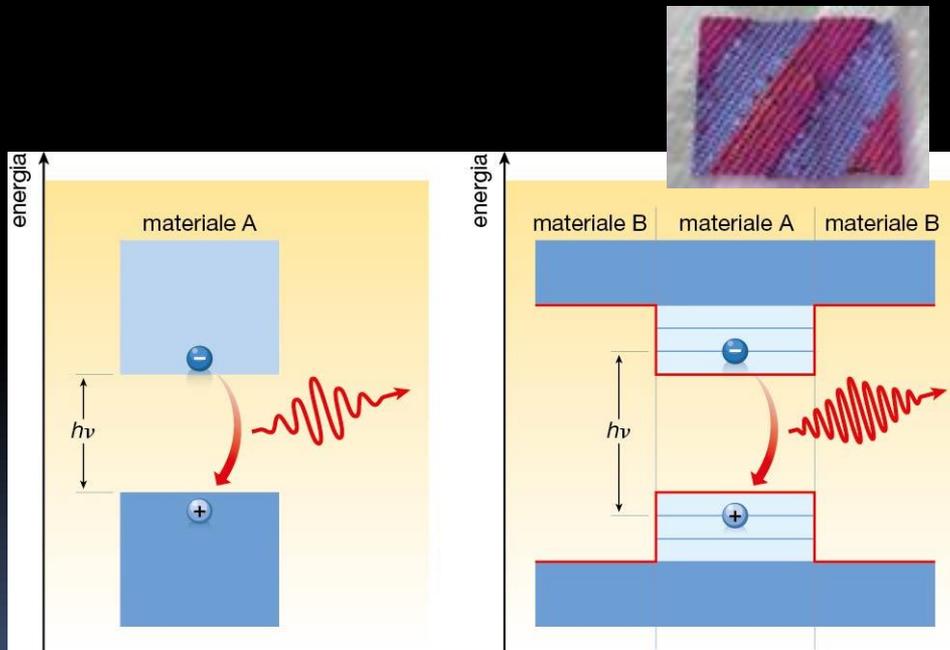
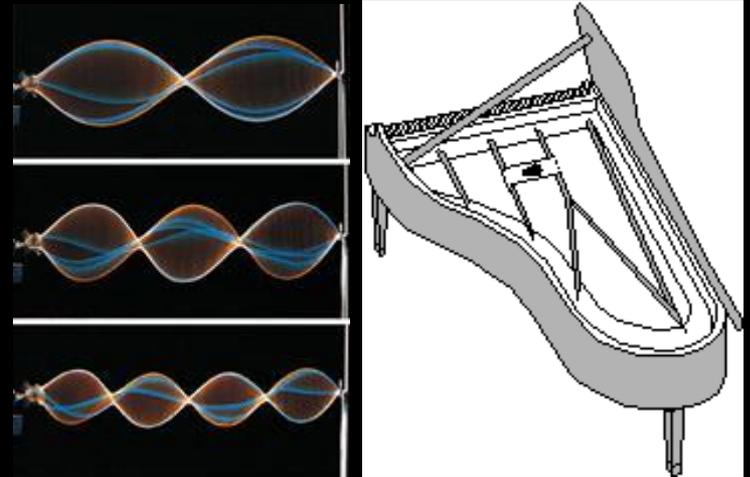
Leo Esaki  
Nobel 1973



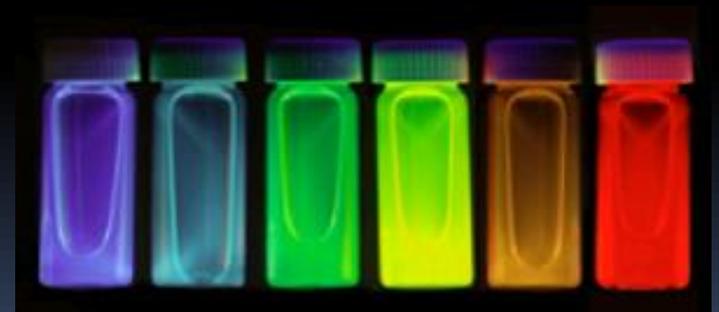
# ONDE DI ELETTRONI

I principi della meccanica quantistica

Gli elettroni alla nano-scala si comportano come onde



Il 'suono' degli elettroni: la luce



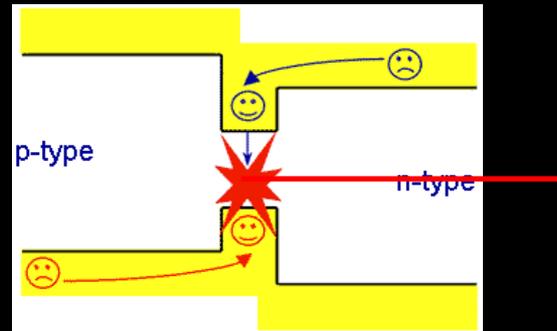
Nobel

# UNA NUOVA GENERAZIONE DI LASER

LASER e LED a pozzi quantici



AlGaAs  
GaAs



Emissione alla frequenza desiderata  
Alta efficienza

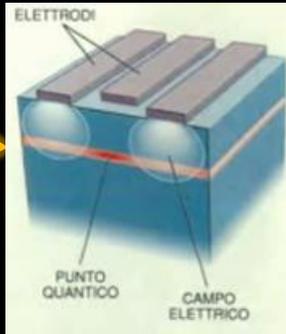


Alferov Kroemer  
Nobel 2000

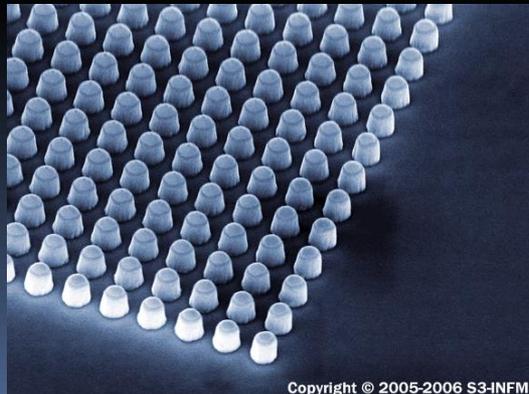
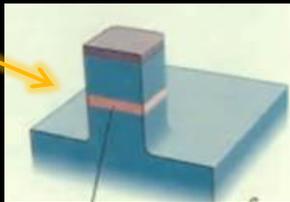


# PUNTI QUANTICI

pozzo  
quantico

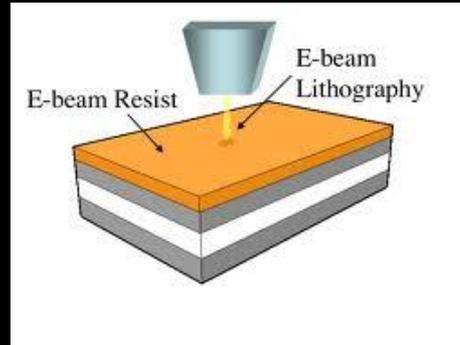


punto  
quantico

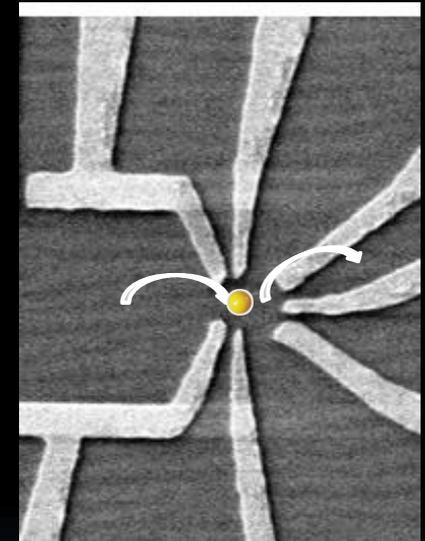
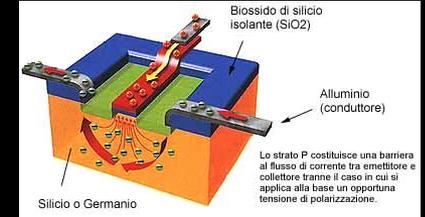


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## Litografia a fascio elettronico



## Transistor a singolo elettrone



## Trappole elettroniche

# DAL GRANDE AL PICCOLO

## TOP-DOWN

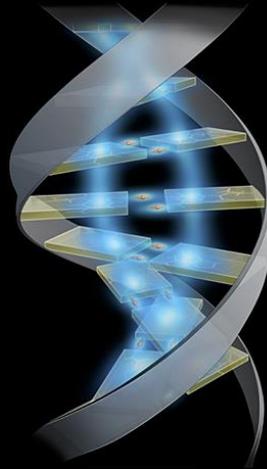
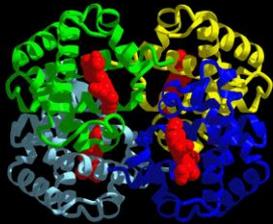
“Scolpire” i  
dispositivi  
dal materiale



**Attuale tecnologia  
dei semiconduttori**



# DAL PICCOLO AL GRANDE



## BOTTOM-UP

“Assemblare”  
mattoncini (unità  
funzionali)  
nanoscopici



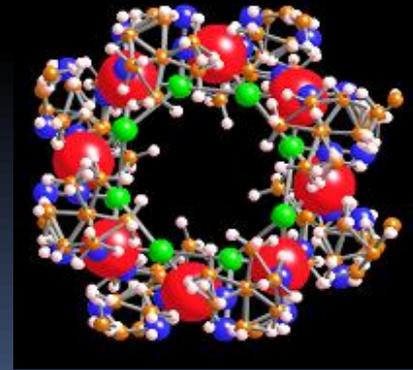
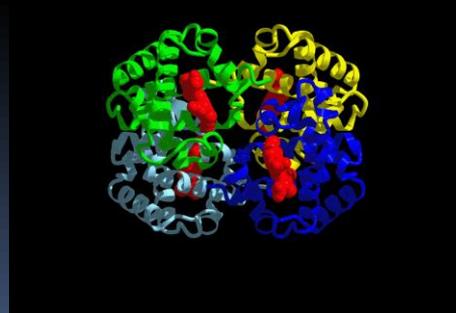
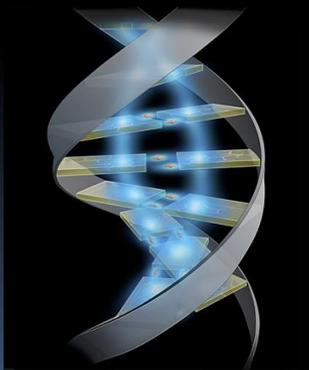
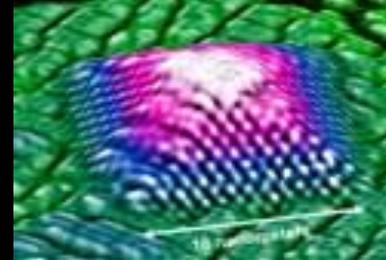
Futura tecnologia  
elettronica ?

# FUNZIONI

autoaggregazione

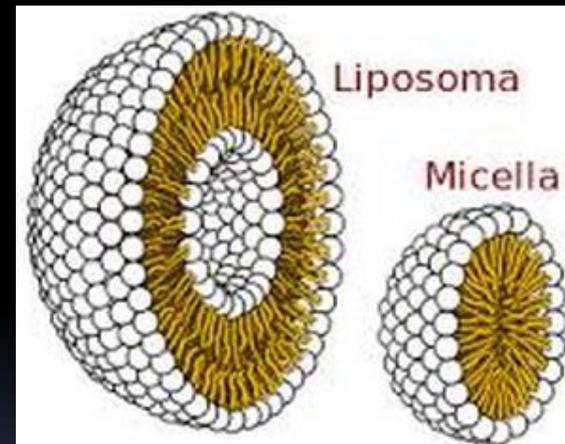
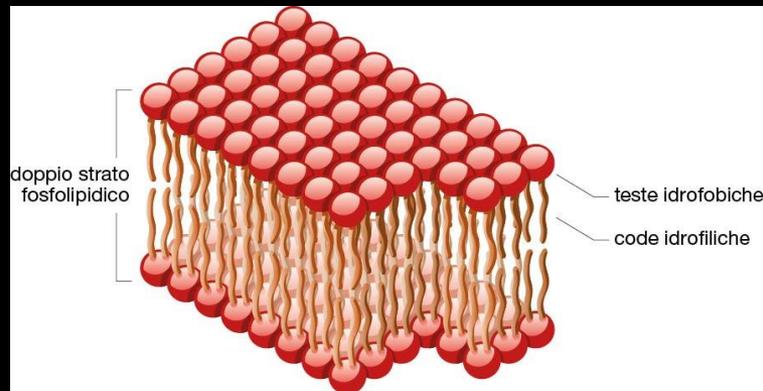
funzioni elettriche

riconoscimento



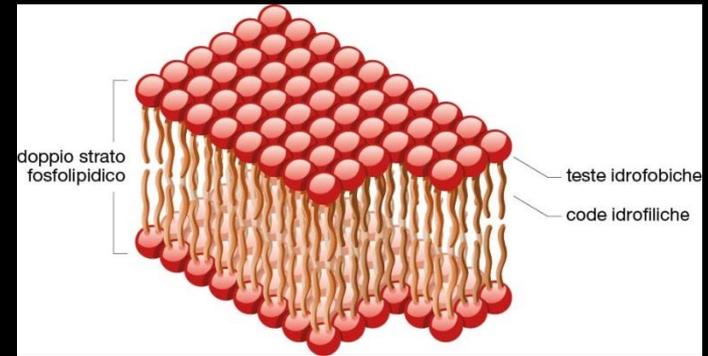
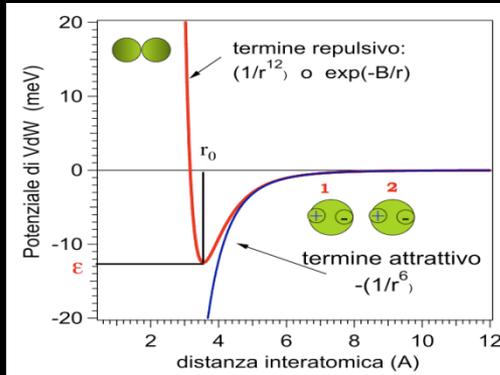
# NANOSTRUTTURE MOLECOLARI AUTOASSEMBLATE

## Membrana cellulare



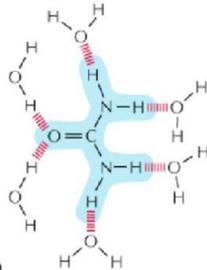
# DRIVING FORCES

## Forze dipolari

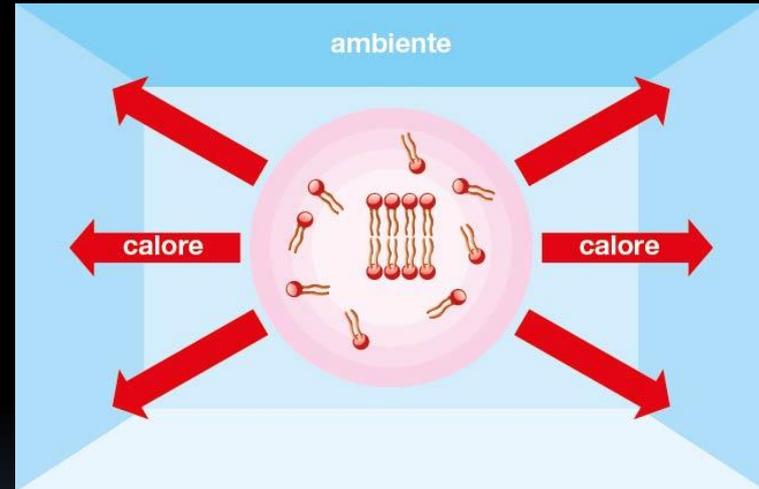


## Idrofilia

Hydrophilic molecules: Polar



Panel 2-2 page 50



## Trasformazione esotermica

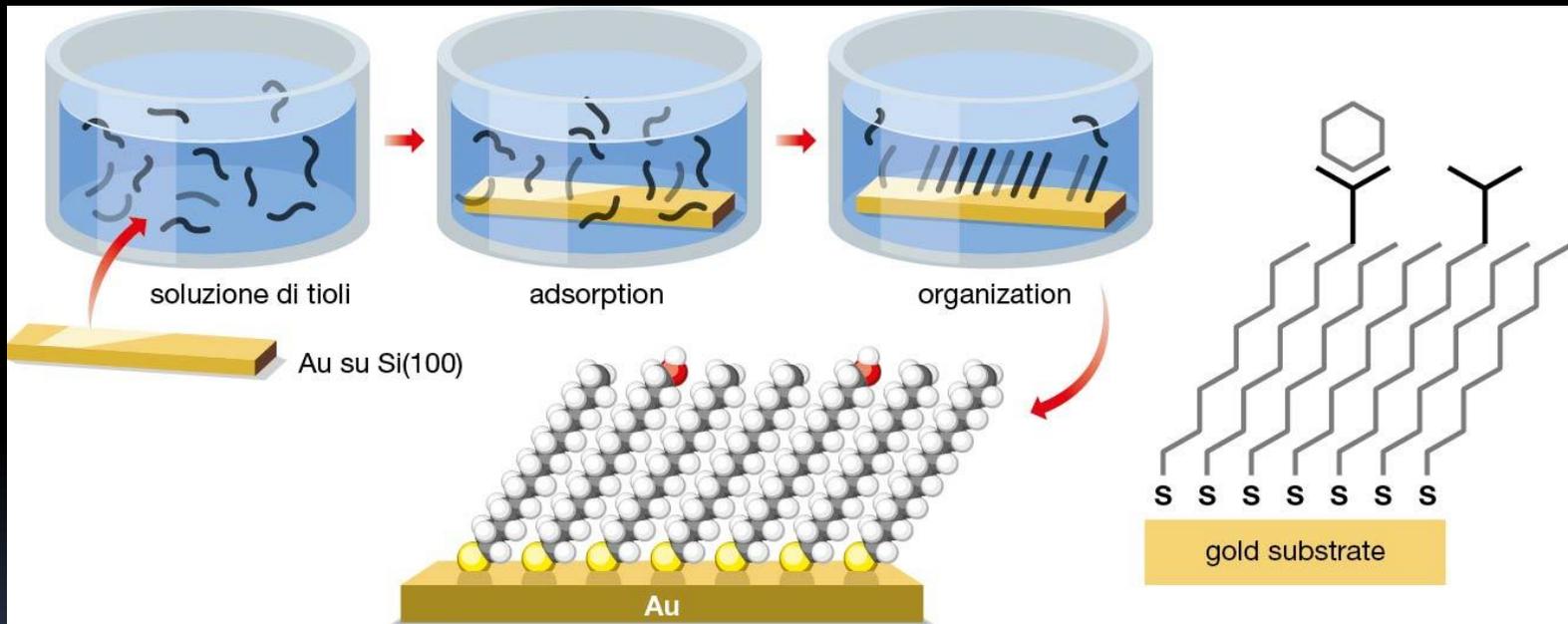
- diminuisce l'entropia del sistema
- aumenta l'entropia dell' «universo»

# UNA PIATTAFORMA MOLECOLARE

Autoaggregazione

Funzionalizzazione

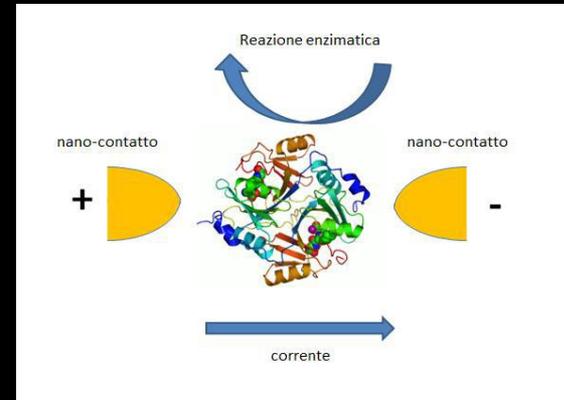
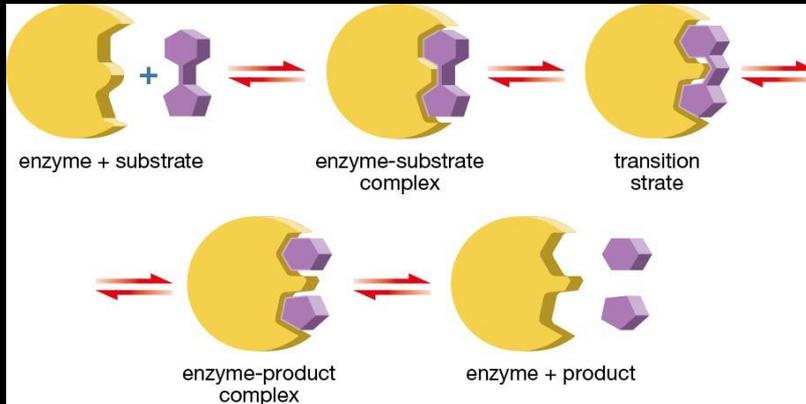
Riconoscimento



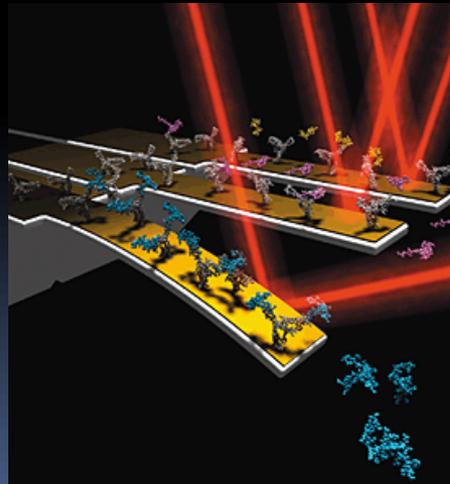
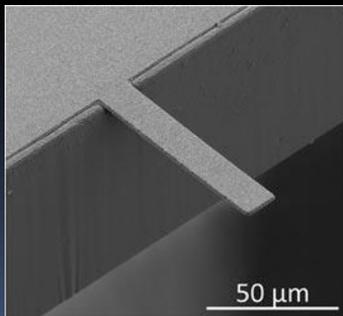
Self-assembled monolayer

# SENSORI MOLECOLARI

## Attività enzimatica

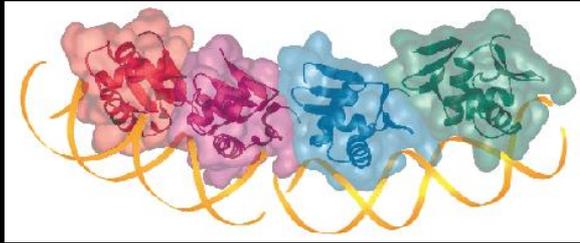


## Micro bilance

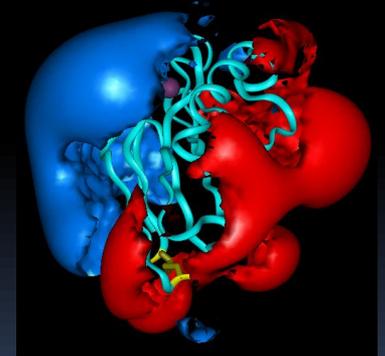
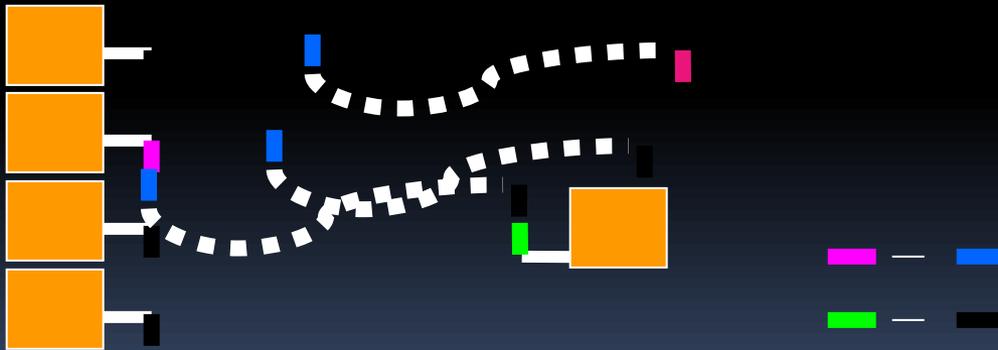
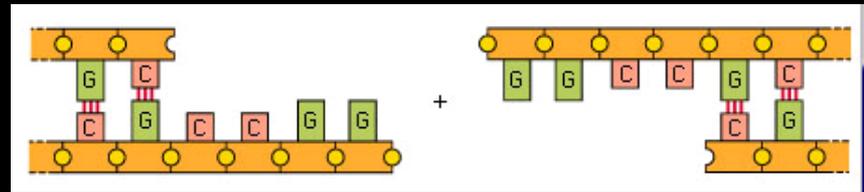


# ELETTRONICA BIO-MOLECOLARE

FUNZIONE



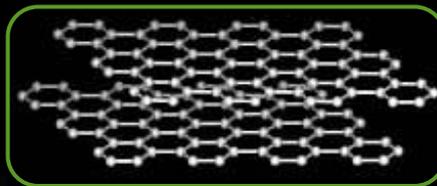
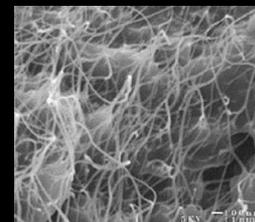
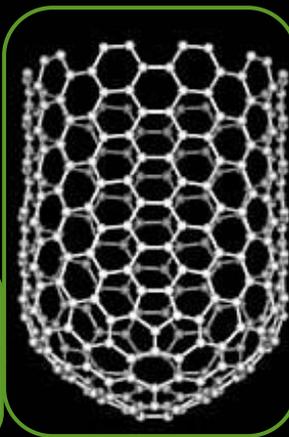
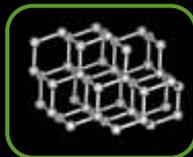
RICONOSCIMENTO



# ALLA NANO-SCALA...

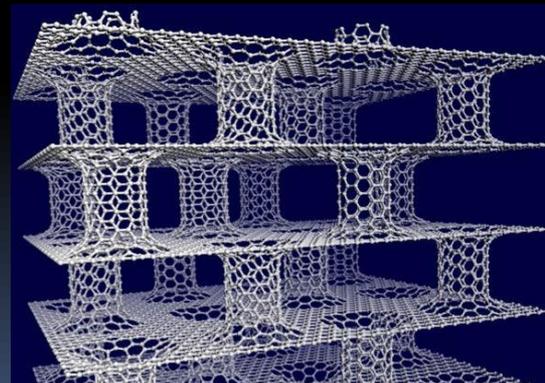
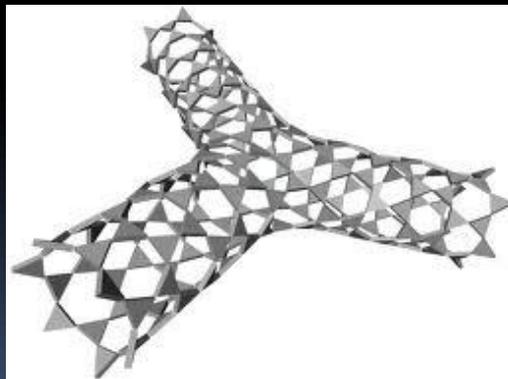
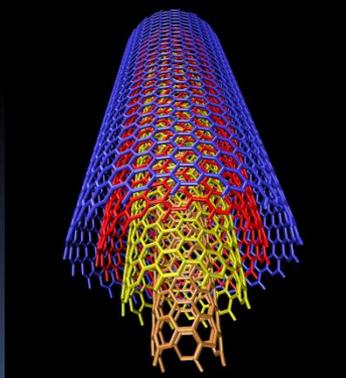
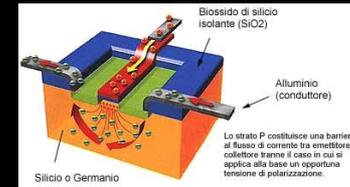
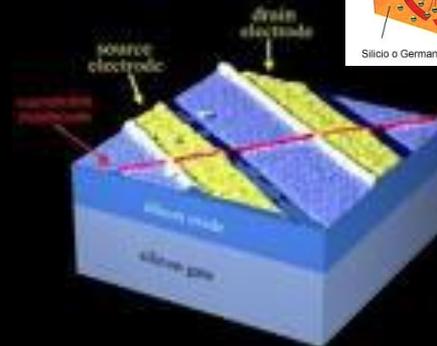
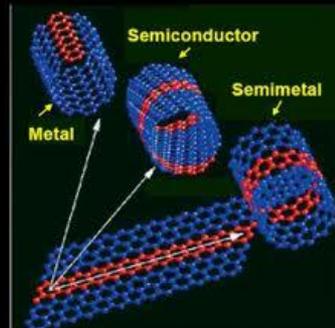
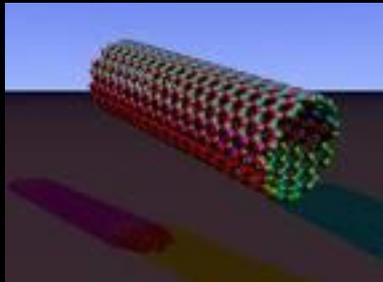
... si determinano molte proprietà macroscopiche

conduttività  
durezza  
attrito  
colore



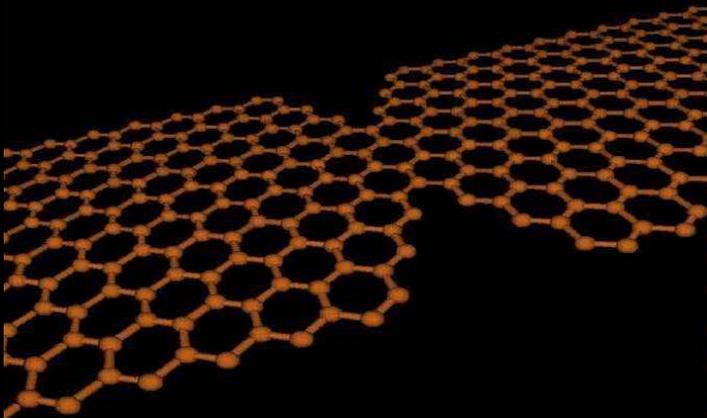
# UNA NUOVA ETA' DEL CARBONIO ?

nano-tubi



# AND THE WINNER IS ...

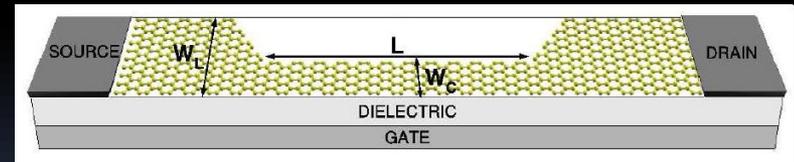
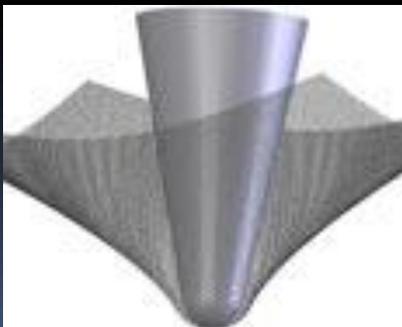
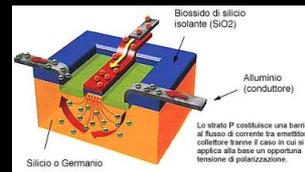
## grafene



### Nobel



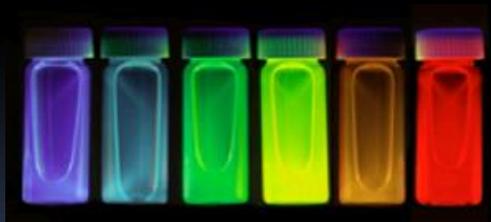
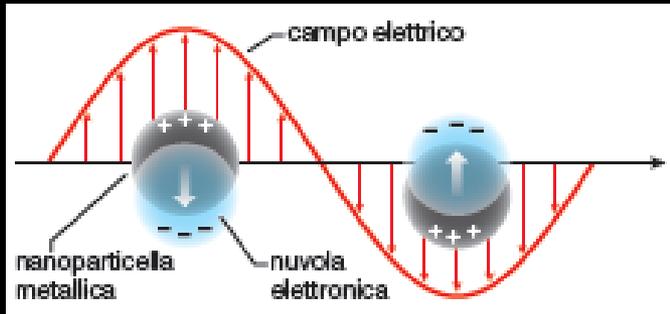
A Geim, K Novoseov,  
Nobel 2010



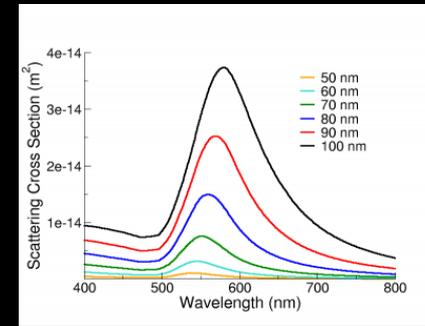
➔ Geim, Kim Le Scienze 478 (2008)

# GIALLO COME L'ORO

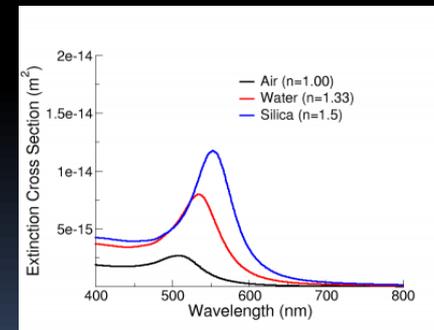
## Localized Plasmon Resonance (LPR)



## Dimensione

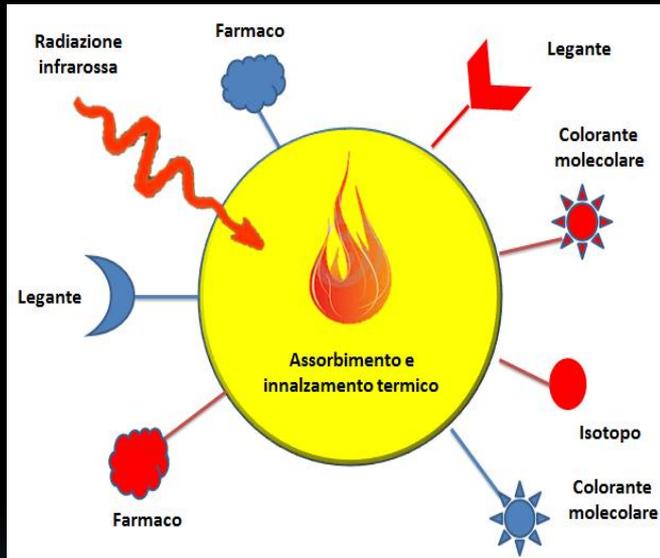


## Ambiente

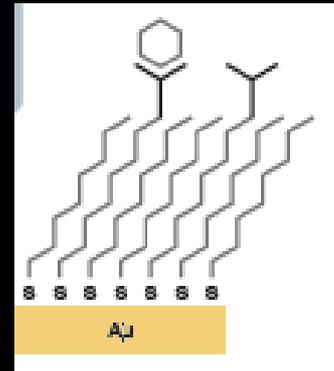


# NANO-MEDICINA

## Funzionalizzazione



Piattaforma teragnostica



## Terapia fototermica

Accumulazione in tessuti patologici

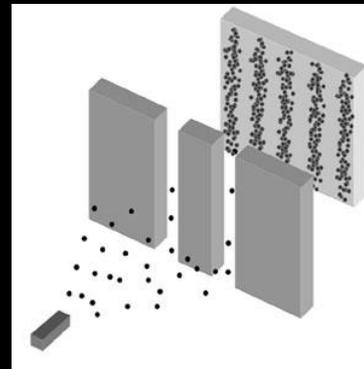
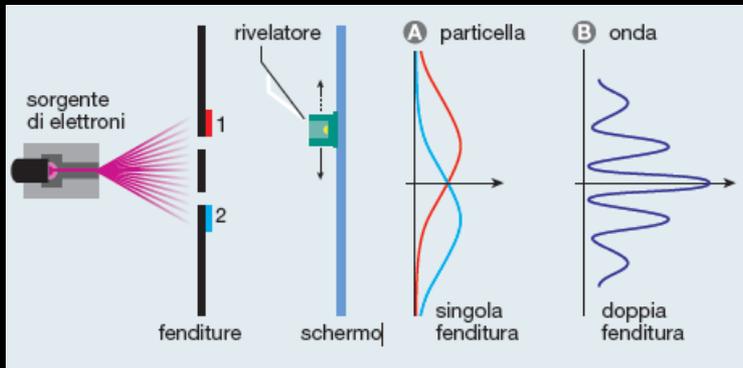
Pelle trasparente a frequenze NIR -> assorbimento LPR e riscaldamento

Distruzione selettiva tessuti

Rilascio controllato di farmaci

Tracciamento selettivo per imaging diagnostico

# IL PRINCIPIO DI SOVRAPPOSIZIONE



*Due livelli di un atomo, il valore dello spin di un elettrone, ecc.*



$$|0\rangle$$

$$|1\rangle$$

$$|Q\rangle = \alpha|0\rangle + \beta|1\rangle$$

# IL SACRO GRAAL - COMPUTER QUANTISTICI

Computazione classica

$$Q = 0,1$$

*bit*

0,+V



Computazione quantistica

$$|Q\rangle = \alpha|0\rangle + \beta|1\rangle$$

*qu-bit*

*N qu-bit:  $2^N$  configurazioni*

$$|000\rangle, |001\rangle, |010\rangle, |011\rangle, |100\rangle, |101\rangle, |110\rangle, |111\rangle$$



# IL “CQ” ESISTE



*Compiti eseguiti fino ad ora*

*Fattorizzazione del numero 15*

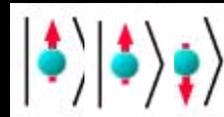
*Correzione di un bit (5 qu-bit)*

*Per avere la potenza di calcolo di un  
moderno PC occorrono alcune decine di  
qu-bit*

# PERCHE' NON HO UN "CQ" SUL TAVOLO

COERENZA

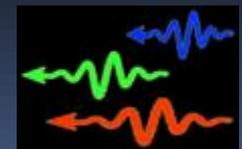
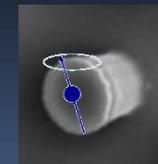
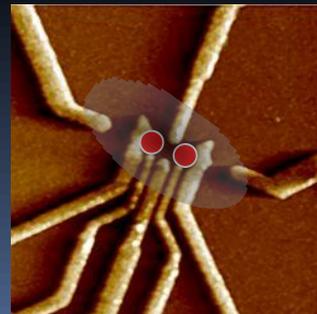
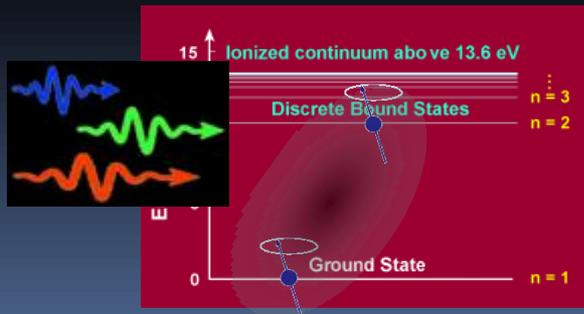
*L'interazione con l'ambiente (compreso il processo di misura) distrugge la coerenza quantistica*



SCALABILITA'

$|1\rangle$

$|0\rangle$



# IDEE-CHIAVE

Il ruolo della meccanica quantistica  
Da schema interpretativo a strumento di  
progettazione di nuovi materiali

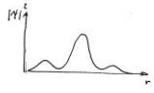
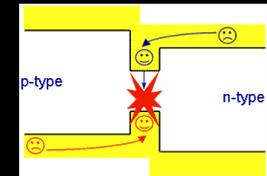
Funzione d'onda:  $\Psi(\vec{r})$

Eq. di Schrödinger

$$i\hbar \frac{\partial \Psi(\vec{r})}{\partial t} = \hat{H} \Psi(\vec{r})$$

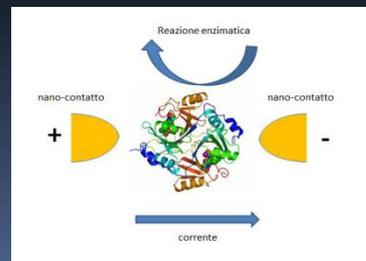
$$\hat{H} = -\frac{\hbar^2}{2m} \nabla^2 + V(\vec{r})$$

Particella libera  $V(\vec{r})=0$  Particella in una barriera

$$\begin{cases} \Psi(\vec{r}, t) = \frac{1}{\sqrt{V}} e^{i(\vec{k}\cdot\vec{r} - \omega t)} \\ E(\vec{k}) = \frac{\hbar^2 k^2}{2m} \end{cases} \quad \begin{cases} \Psi(x,y) = \sin(k_x x) e^{i(k_y y - \omega t)} \\ k_x = n \frac{\pi}{L} \end{cases}$$



Le proprietà dipendono dalle dimensioni  
Un nuovo asse nella tavola di Mendeleev

La (nano) struttura dei materiali ne determina la  
funzione



# www.NANOLAB.unimore.it

Portare le nanoscienze in classe

Hands-on, inquiry based science education

Ogni modulo incentrato su una idea-chiave  
delle nanoscienze

Sito web – video guide, indicazioni didattiche,  
background reading

Kit e corsi di aggiornamento

Temi

**Nanoparticelle** – Size matters

**Superfici nanostrutturate** – La gerarchia delle forze

Materiali intelligenti – Struttura e funzione

Polimeri conduttivi a effetto tunnel – Il ruolo della meccanica quantistica



Immagini (\*) estratte dal testo

# outreach.fim.unimore.it

The screenshot shows the homepage of the outreach.fim.unimore.it website. At the top left is the logo for the 'PIANO LAUREE SCIENTIFICHE' (Scientific Degree Plan) with a colorful sun-like icon. Next to it is the text 'Dipartimento di Scienze Fisiche, Informatiche e Matematiche con e per la scuola e la società'. On the top right is the 'UNIMORE' logo (Università degli Studi di Modena e Reggio Emilia) and its official seal. Below the header is a navigation menu with items: 'Chi siamo', 'Stage & Scuole estive', 'Divulgazione', 'Gare & Olimpiadi', 'Orientamento', and 'Aggiornamento insegnanti'. A horizontal banner features six images: a sailboat, a person in a lab coat, a computer keyboard, a fractal, a green crystalline structure, and blue puzzle pieces. The main content area is divided into three columns. The first column, 'News e seminari del FIM', has an RSS icon and a news item dated 15-04-2014 about a conference cycle. The second column, 'In evidenza', has an RSS icon and a featured item for the 'Scuola Estiva InforM@th 2014' with a date of 14-03-2014 and a small circular logo. The third column, 'Accesso diretto', has three links: 'Iscriviti alla Newsletter', 'Iscrizione a FareFisica 2014', and 'Iscrizione a InforM@th 2014'.

**PIANO LAUREE SCIENTIFICHE**

Dipartimento di  
**Scienze Fisiche, Informatiche e Matematiche**  
*con e per la scuola e la società*

**UNIMORE**  
UNIVERSITÀ DEGLI STUDI DI  
MODENA E REGGIO EMILIA

Chi siamo ▾ Stage & Scuole estive ▾ Divulgazione ▾ Gare & Olimpiadi ▾ Orientamento ▾ Aggiornamento insegnanti ▾

News e seminari del FIM 

15-04-2014  
**Ciclo di conferenze: "Nuovi orizzonti della Fisica, dell'Informatica e della Matematica"**

In evidenza 

**Scuola Estiva InforM@th 2014**

 14-03-2014 - Sono aperte le iscrizioni alla Scuola Estiva InforM@th 2014. Le iscrizioni si chiuderanno il 5 maggio 2014.

Accesso diretto

- » **Iscriviti alla Newsletter**
- » Iscrizione a FareFisica 2014
- » Iscrizione a InforM@th 2014

Stage

Prepa

Innov

Orientamento

Divulgazione scientifica, laboratori, seminari

Newsletter

# COSA PUO' FARE DI PIU' UN "CQ"

*Un computer quantistico può eseguire più velocemente*

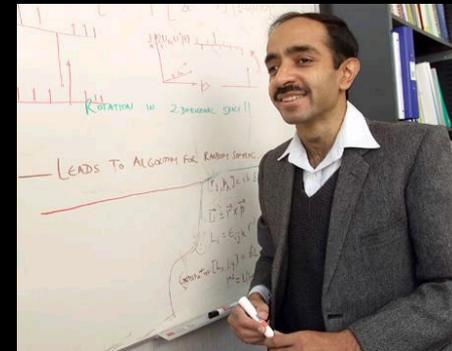
*ricerca in una lista*

**classico**

$$O(\exp(N^{1/3}))$$

**quantistico**

$$O(N^3)$$



*Lov Grover*

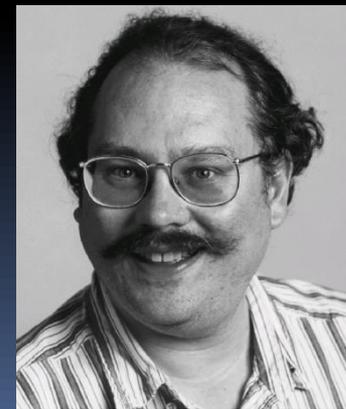
*fattorizzazione di numeri interi*

**classico**

$$O(N)$$

**quantistico**

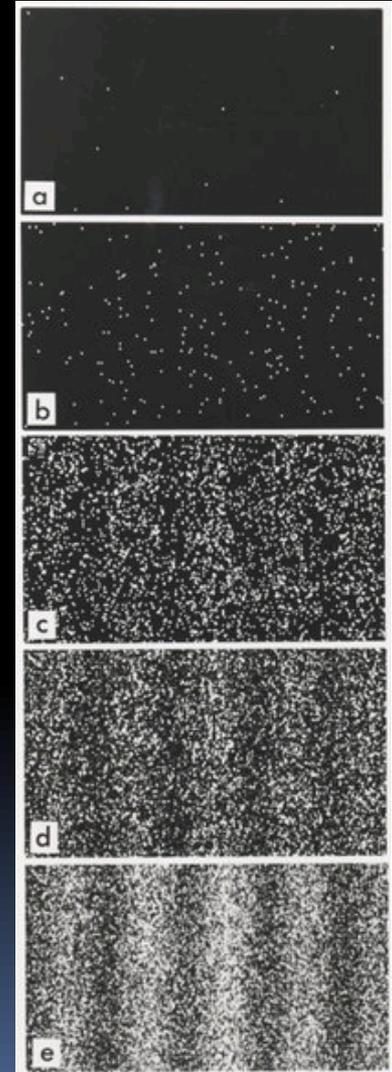
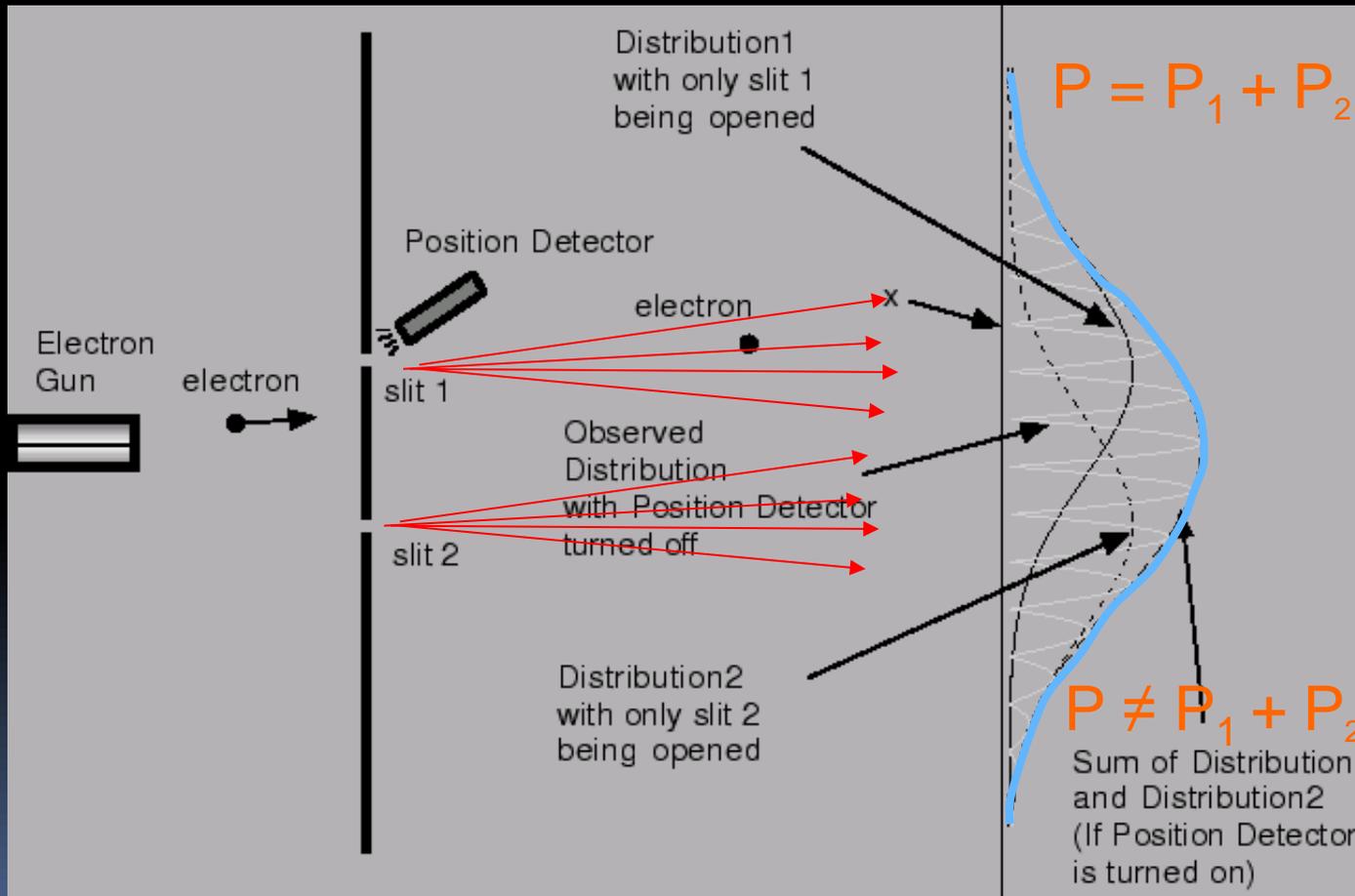
$$O(N^{1/3})$$



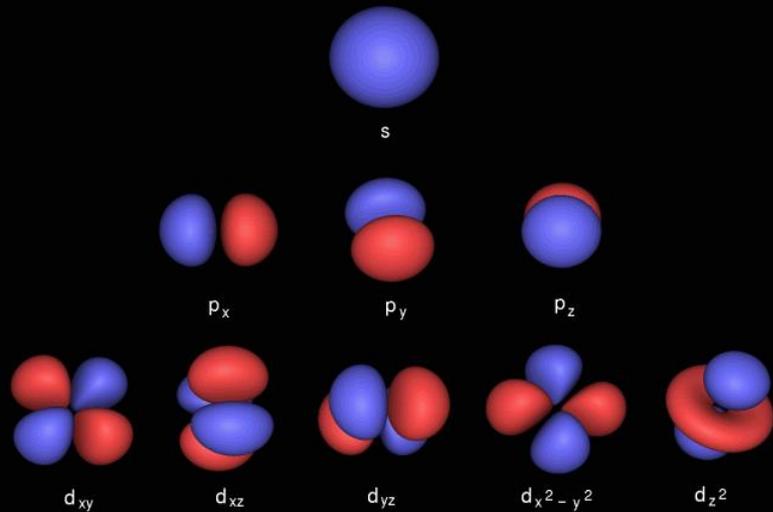
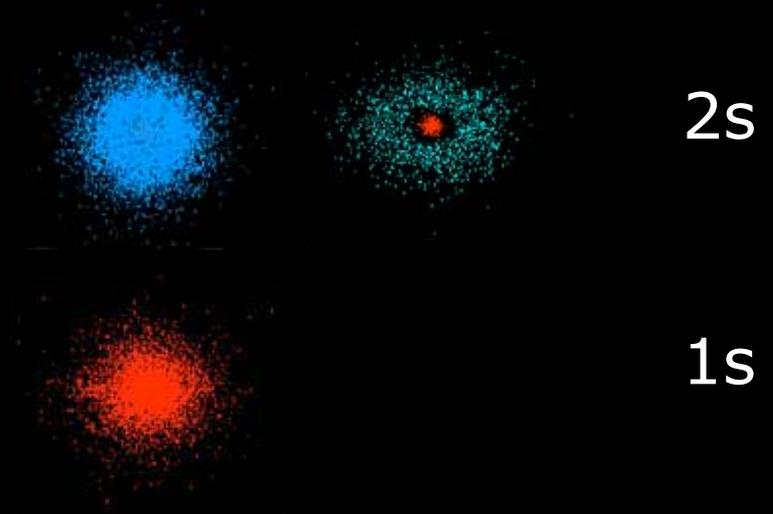
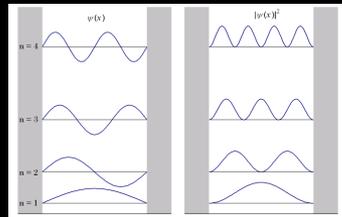
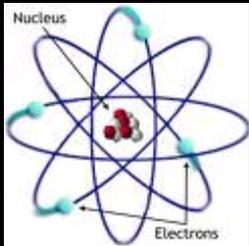
*Peter Shor*

# L'ESPERIMENTO PIU' BELLO DEL MONDO

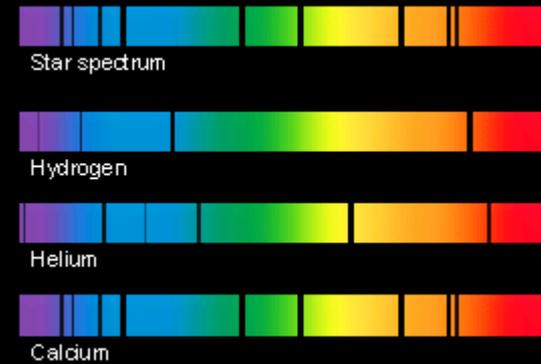
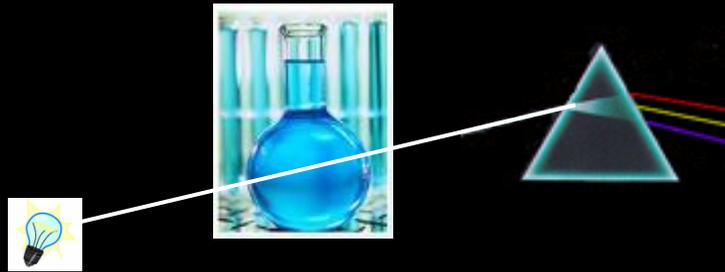
Gli elettroni formano una figura di interferenza come delle onde!



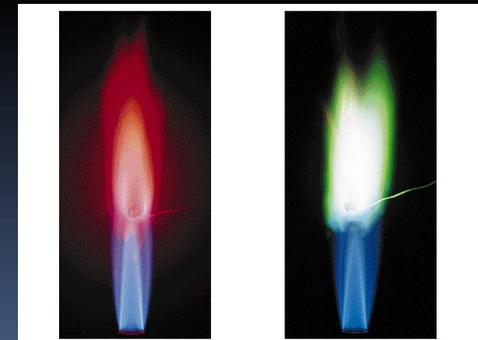
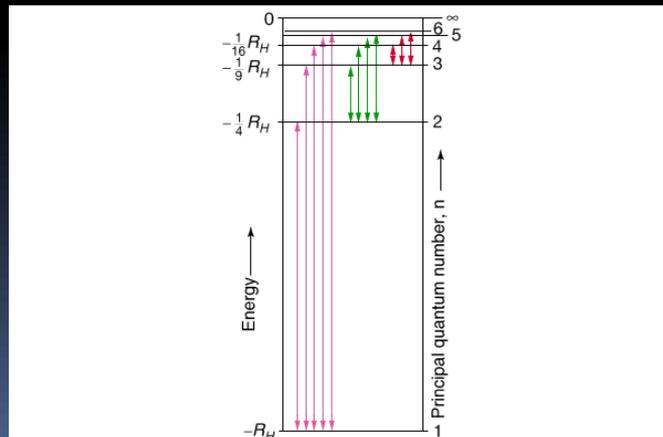
# I LIVELLI ATOMICI



# SPETTRI ATOMICI



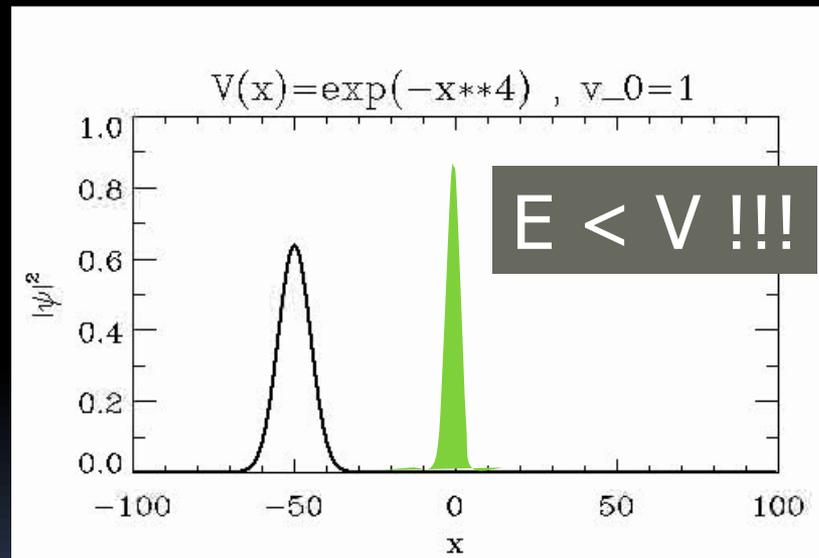
Ora sappiamo perche' gli atomi assorbono solo specifiche frequenze e possiamo calcolarne le frequenze con estrema precisione



# PALLINE CHE ATTRAVERSANO I MURI

## IL TUNNELING QUANTISTICO

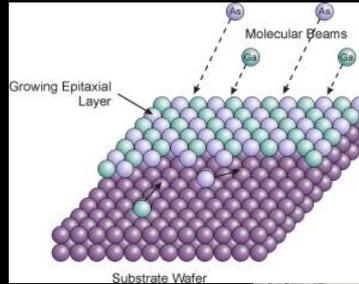
Tunneling della funzione d'onda



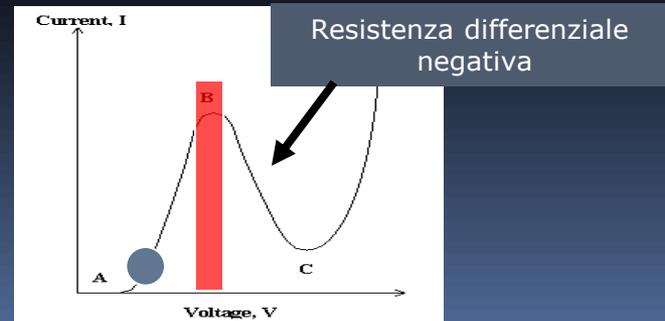
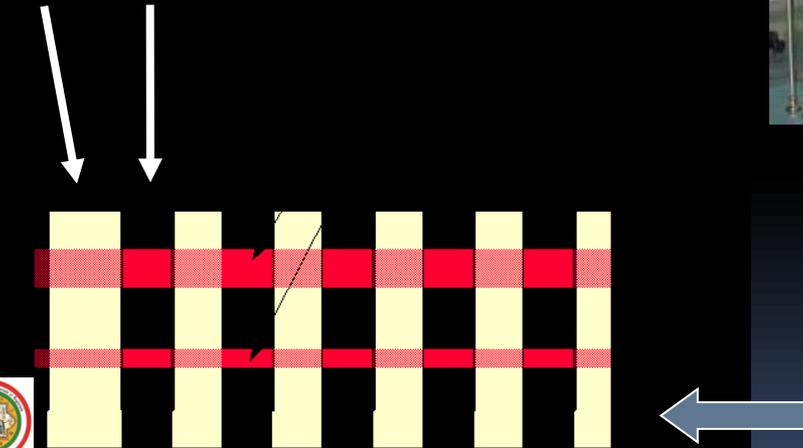
# I SUPER-RETICOLI DI ESAKI



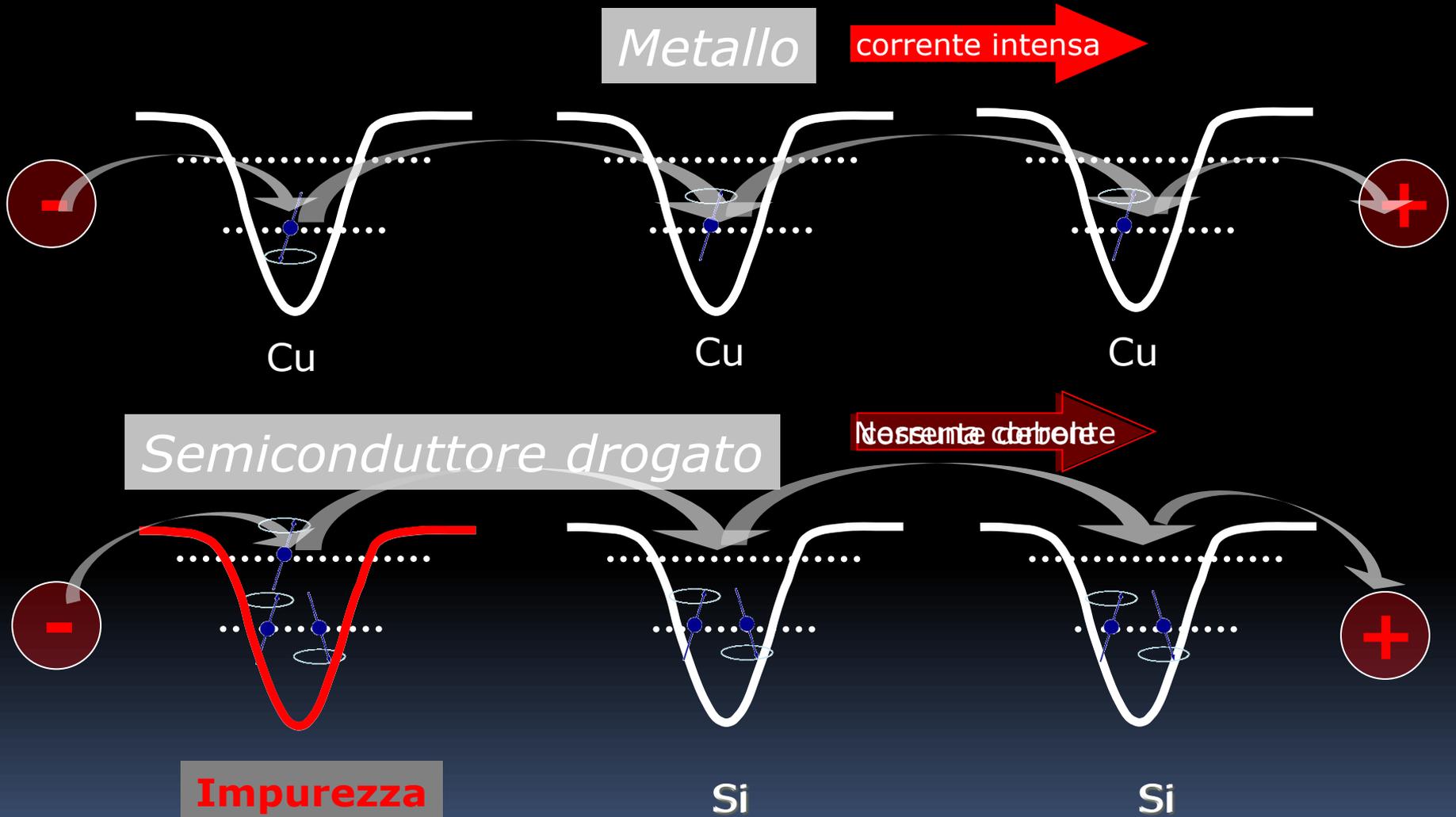
Leo Esaki  
Nobel 1973



TASC-Trieste



# LA TEORIA QUANTISTICA DEI SOLIDI



# IL RUOLO DELLA MECCANICA QUANTISTICA

- ▶ Perché alcuni materiali conducono bene, altri male o nulla
- ▶ Perché alcuni materiali SUPER-conducono
- ▶ Cosa limita la conduzione, come possiamo cambiare questo stato di cose e trarne vantaggio
  
- ▶ Perché alcuni materiali assorbono la luce e altri no
- ▶ Perché la luce che assorbono o emettono ha un determinato colore

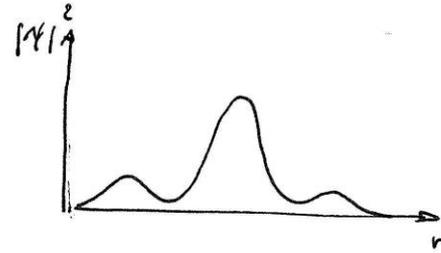
# IN MEDIAS RES - LA MECCANICA QUANTISTICA

Funzione d'onda:  $\psi(\vec{r})$

Eq. di Schrödinger

$$i\hbar \frac{\partial \psi(\vec{r})}{\partial t} = \hat{H} \psi(\vec{r})$$

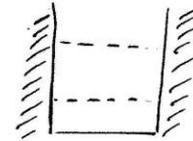
$$\hat{H} = -\frac{\hbar^2}{2m} \nabla^2 + V(\vec{r})$$



Particella libera  $V(\vec{r}) = 0$

$$\begin{cases} \psi(\vec{r}, t) = \frac{1}{\sqrt{V}} e^{i(\vec{k} \cdot \vec{r} - \omega t)} \\ E(\vec{k}) = \frac{\hbar^2 k^2}{2m} \end{cases}$$

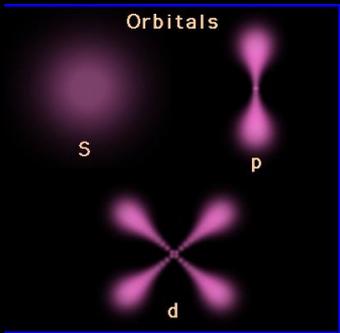
Particella in una scatola



$$\begin{cases} \psi(x, t) = \frac{1}{\sqrt{2}} \sin k_n x \exp i \omega_n t \\ k_n = n \frac{\pi}{L} \end{cases}$$

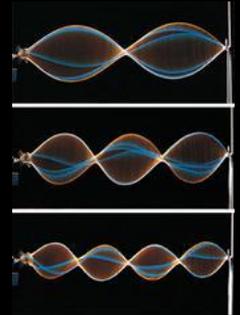
"I think that I can safely say that nobody understands quantum mechanics." R. Feynmann, Nobel 1965

# I PRINCIPI DELLA MECCANICA QUANTISTICA



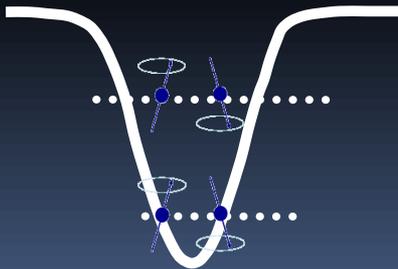
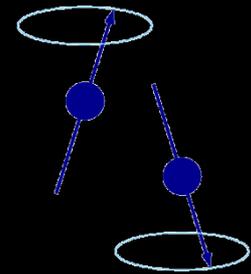
## *Principio di quantizzazione dell'energia*

- ▶ In un atomo sono permesse solo certe orbite/energie



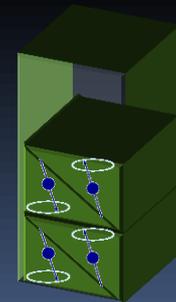
## *Ogni elettrone è dotato di spin*

- ▶ Lo spin può assumere solo due valori



## *Principio di esclusione di Pauli*

- ▶ Ogni livello può essere occupato da un solo elettrone per spin



# PUNTI QUANTICI COLLOIDALI

*Ampio spettro di eccitazione*

*Emissione a singole frequenze*

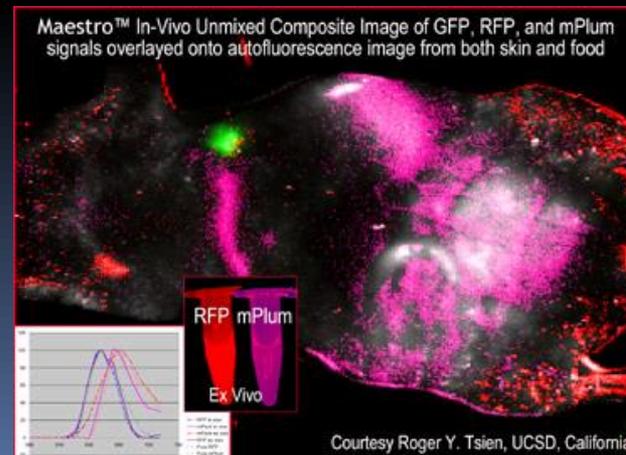
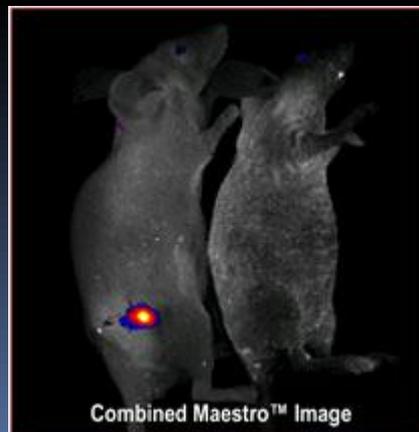
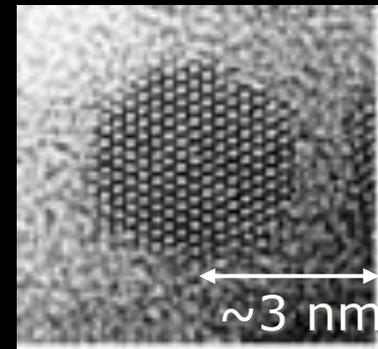
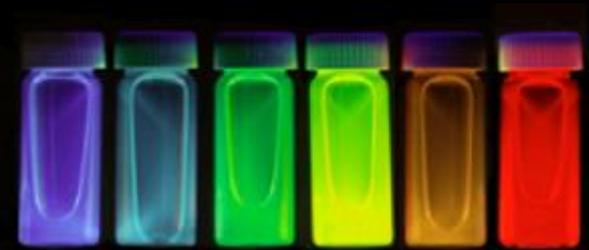
*Emissione alla frequenza desiderata*

*Lunghi tempi di fluorescenza*

*bio-compatibilità*

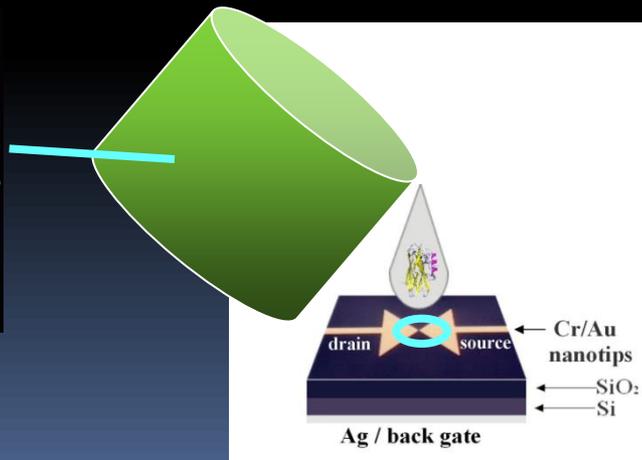
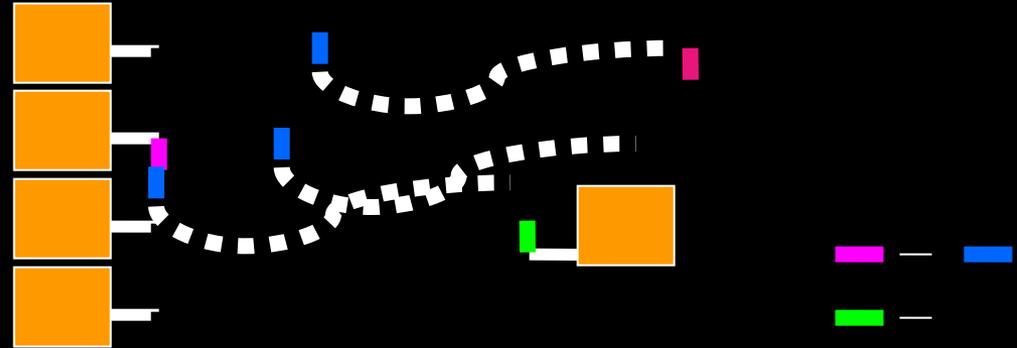
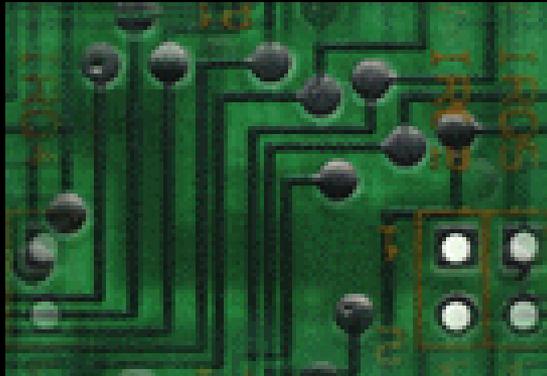
*Rivelazione di singole molecole in-vivo*

*Colorazione cellulare per fluorescenza*



Courtesy Roger Y. Tsien, UCSD, California

# ELETTRONICA BIOMOLECOLARE



RIDONDANZA  
AUTO-AGGREGAZIONE