

Dal sole alle nanostrutture

La conversione fotovoltaica dell'energia

Carlo Andrea Rozzi

**Centro Nazionale di Ricerca "S3" di CNR-INFM
Modena**

Sommario



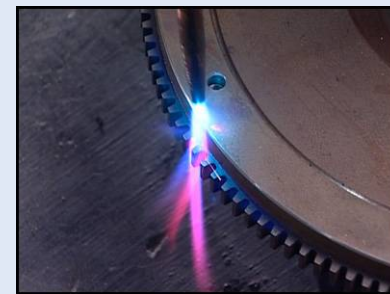
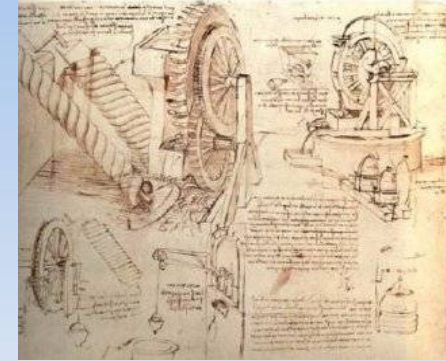
- L'energia
 - Energia dal sole
- La conversione fotovoltaica
 - Principio di funzionamento
 - Le generazioni classiche di celle solari
- Le nanoscienze e nanotecnologie
 - La nuova fisica
 - La nuova generazione di celle

Dov'è l'energia

- Acqua in caduta da 100 m: 0.001 MJ/kg
- Batteria NiMH: 0.4 MJ/kg
- Fiamma ossidrica (temp < 2800 C):
7 MJ/kg H₂O (142 MJ/kg H₂)
 - $2\text{H}_2 + \text{O}_2 \rightarrow 2\text{H}_2\text{O} + 3 \text{ eV}$
- Fiamma ossiacetilenica (temp > 3000 C):
17 MJ/kg C₂H₂
 - $\text{C}_2\text{H}_2 + \text{O}_2 \rightarrow 2\text{CO} + \text{H}_2 + 4.6 \text{ eV}$
- Biscotti: 20 MJ/kg

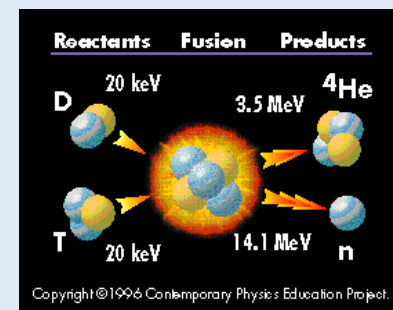
$$1 \text{ M} = 10^6 = 1 \text{ mln}$$

$$1 \text{ J} = 6.24 \cdot 10^{18} \text{ eV}$$



Fonti di energia

- Carbone: 20 MJ/kg
- Greggio: 46 MJ/kg
- Fissione nucleare: $24 \cdot 10^6 \div 88 \cdot 10^6$ MJ/kg
 - $^{235}\text{U} + n \rightarrow ^{141}\text{Ba} + ^{92}\text{Kr} + 3n + 200 \text{ MeV}$
- Fusione nucleare: $339 \cdot 10^6$ MJ/kg
 - $^2\text{H} + ^3\text{H} \rightarrow ^4\text{He} + n + 17.6 \text{ MeV}$
- Equivalenza massa-energia: $8.9 \cdot 10^{10}$ MJ/kg
 - $e^- + e^+ \rightarrow 1 \text{ MeV}$



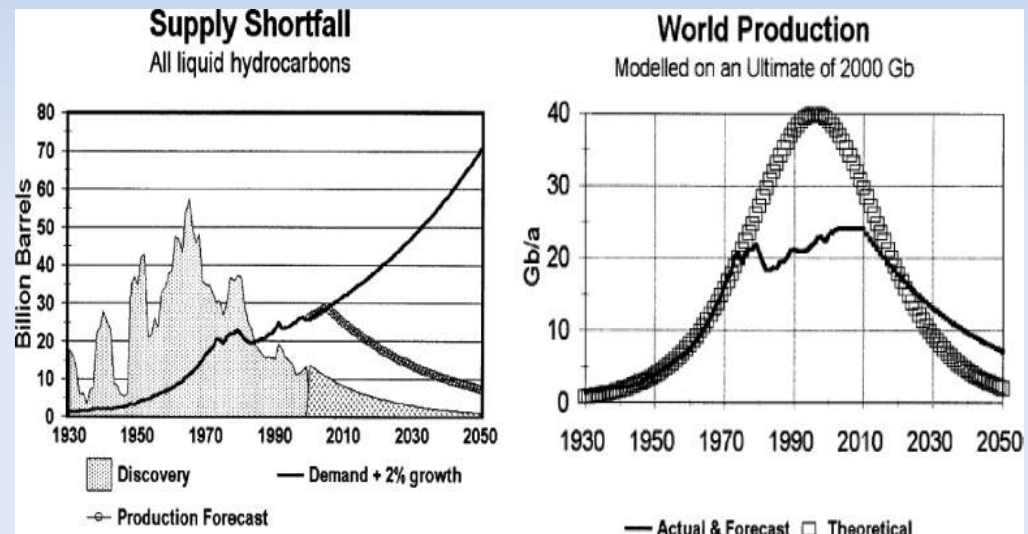
$$1 \text{ M} = 10^6 = 1 \text{ mln}$$
$$1 \text{ J} = 6.24 \cdot 10^{18} \text{ eV}$$

La bolletta del pianeta Terra

- **Popolazione:** 6.7 mld abitanti: 4 volte di più che nel 1900
- **Potenza consumata:** 13 TW (1940 W/persona): 16 volte di più che nel 1900

- **I combustibili fossili**

- totale: 2000 mld barili
- trovati: 1800 mld barili
- consumati: 875 mld barili



C.J. Campbell, *Popul. Environ.*, 24, 193 (2002)

- **stima:** per mantenere lo stile di vita attuale servono altri 10 TW da energia rinnovabile entro il 2050
- 1 nuova Caorso al giorno per oltre 30 anni, oppure 10 kg di antimateria al giorno

$$1 \text{ T} = 10^{12} = 1 \text{ mln di mln}$$

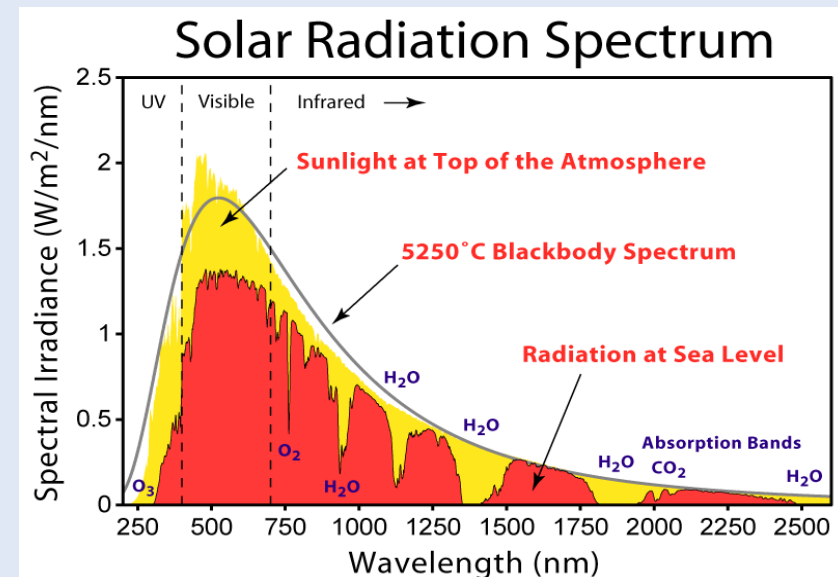
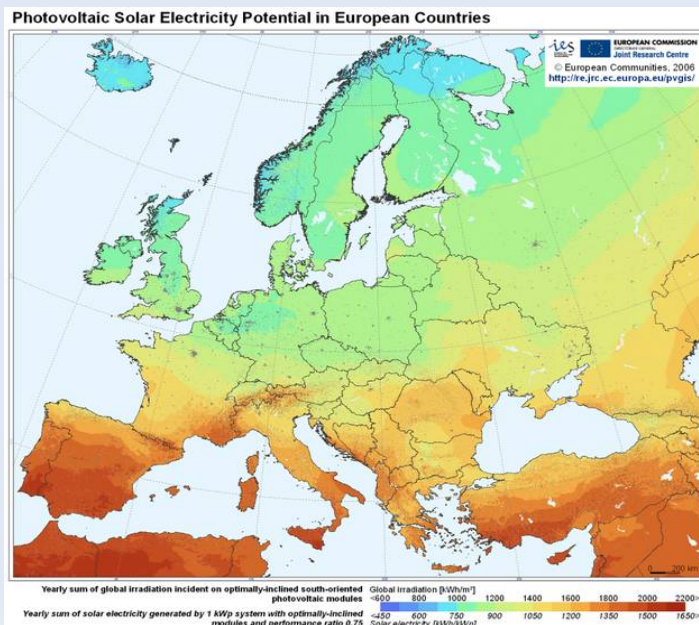
Fonti rinnovabili

- **Potenza** estraibile da fonti rinnovabili (in TW)
 - idroelettrica: 0.5
 - maree e correnti oceaniche: 2
 - eolica: 2-4
 - geotermica: 12
 - solare: 120000
- **Quota attuale di energia solare prodotta:**
0.01% della domanda globale

$$1 \text{ T} = 10^{12} = 1 \text{ mln di mln}$$

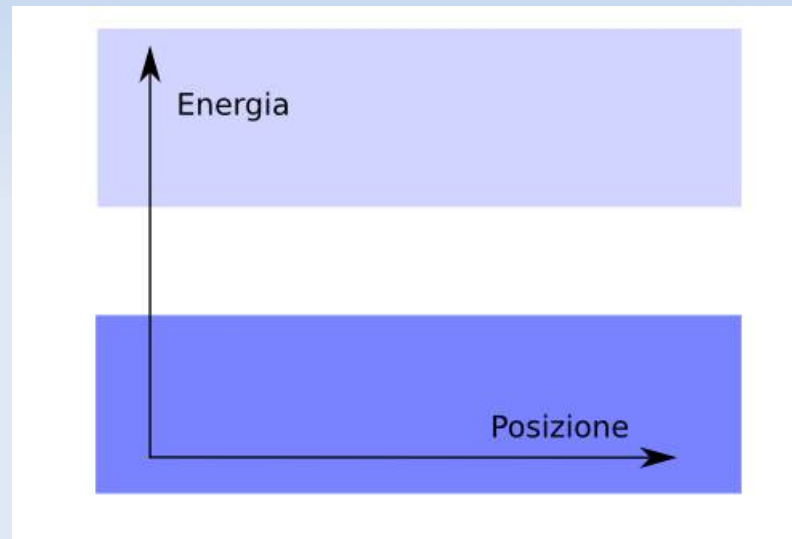
Energia dal sole

- Temperatura media alla superficie: 5500 C
- Luminosità: $384.6 \cdot 10^{24}$ W
- Costante solare terrestre in AM0: 1353 W/m^2
Mercurio 6272 W/m^2 ; Nettuno 1.47 W/m^2
- Spettro a terra: corpo nero a 5250 C con bande di assorbimento atmosferico

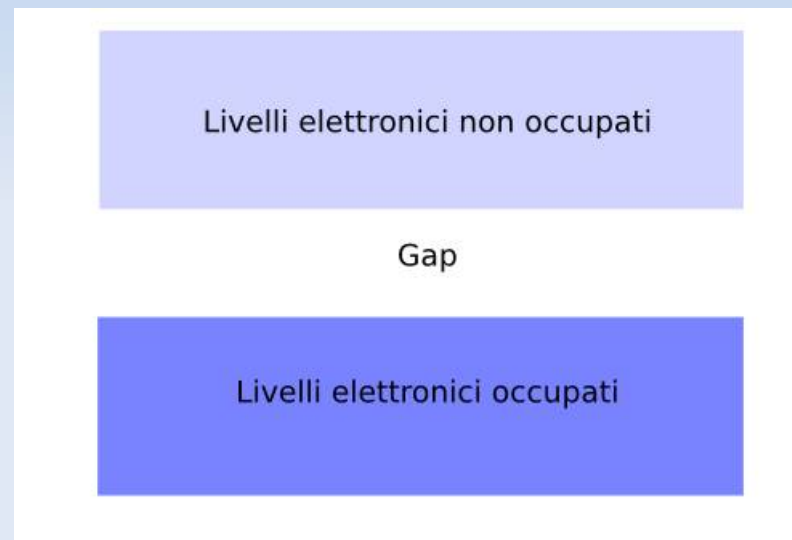


Fonte: American Society for Testing and Materials

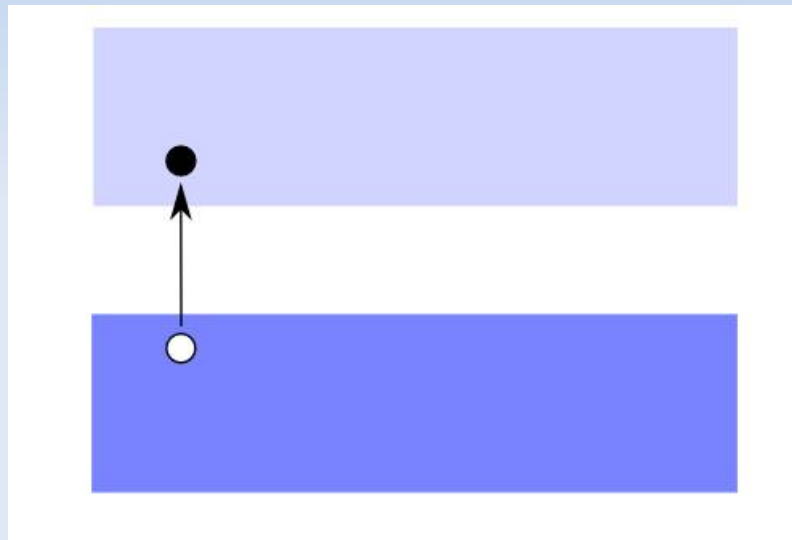
Rappresentazione di un semiconduttore



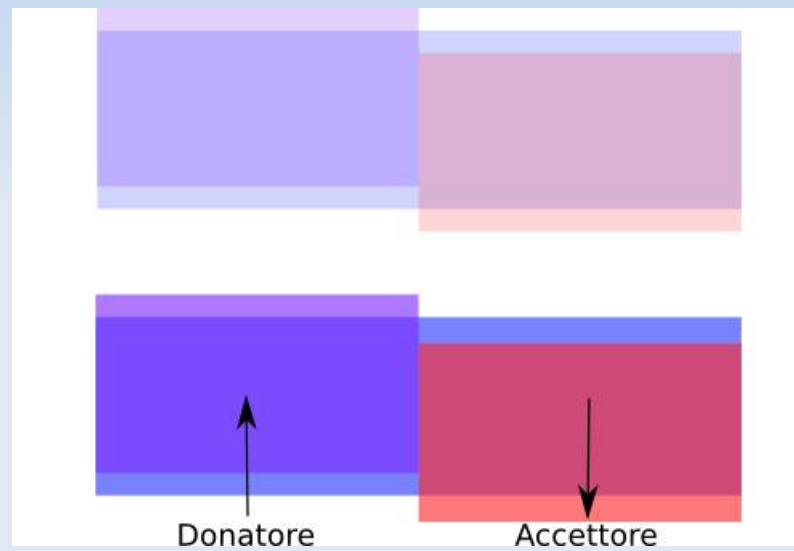
Rappresentazione di un semiconduttore



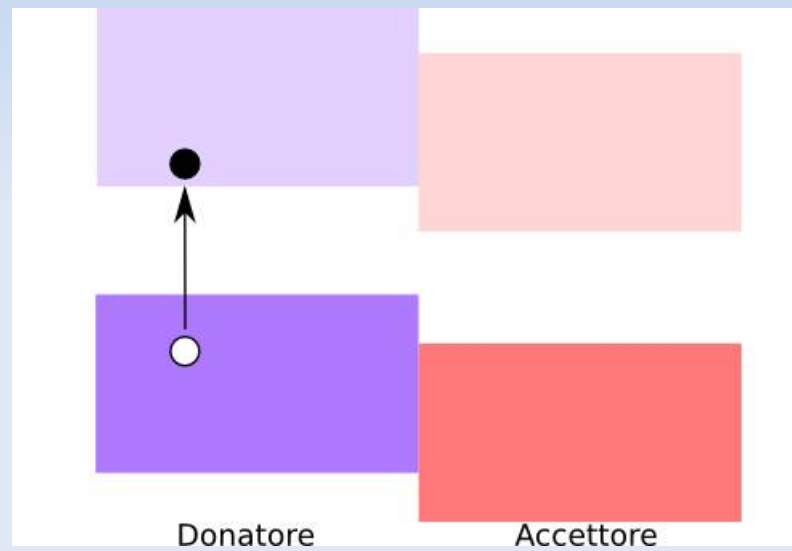
Fotoeccitazione



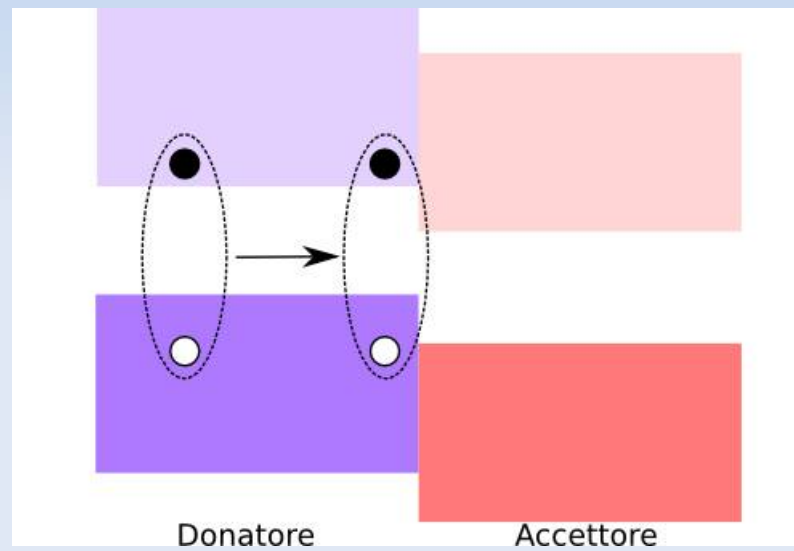
Drogaggio



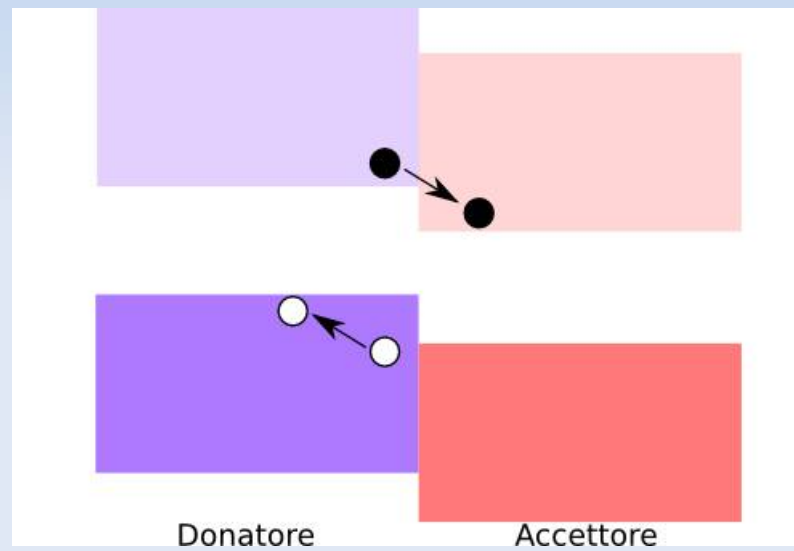
Giunzione pn



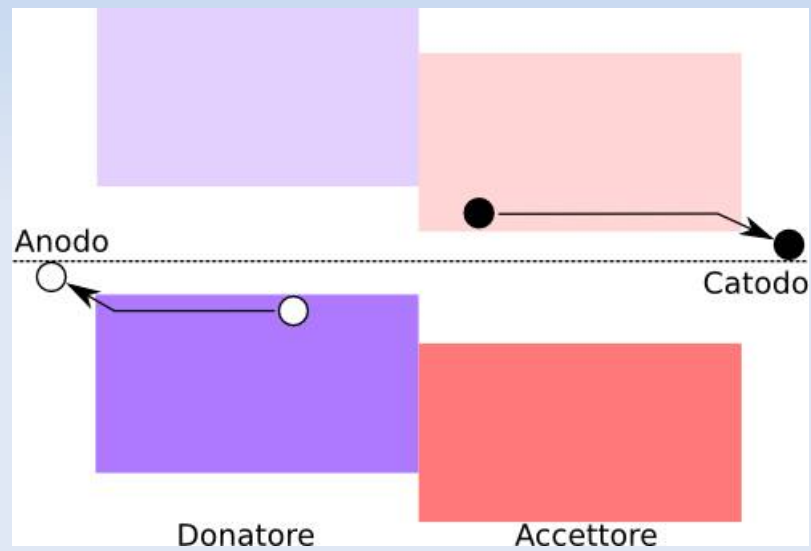
Diffusione



Separazione di carica

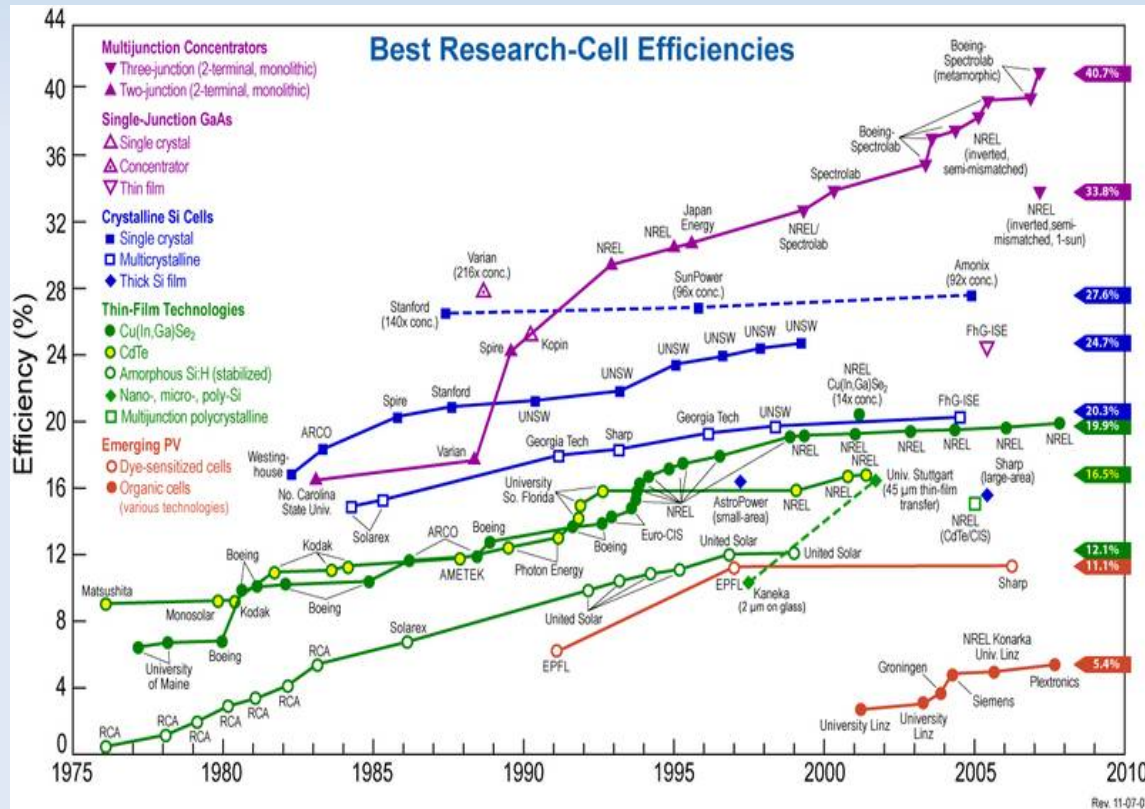


Raccolta

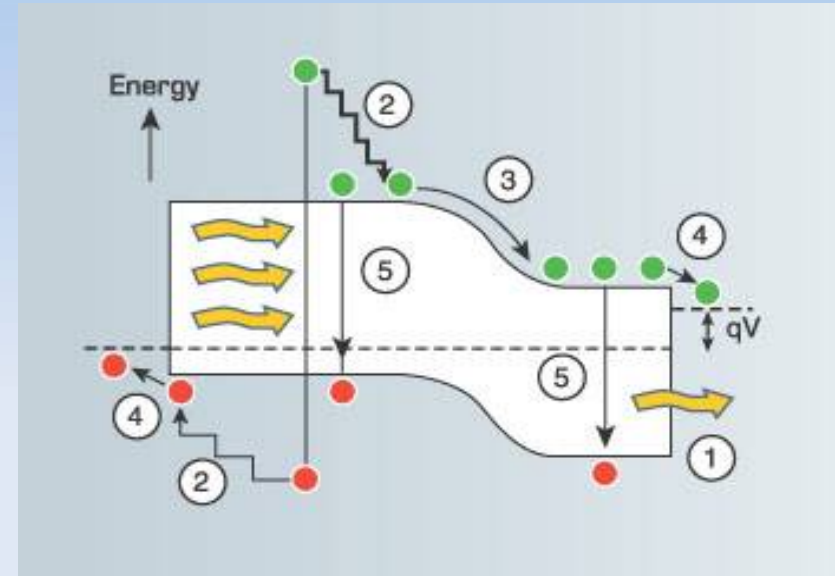


Il problema dell'efficienza

Limite termodinamico all'efficienza: 93%
Banda IR-UV: 0.5 ÷ 2.9 eV



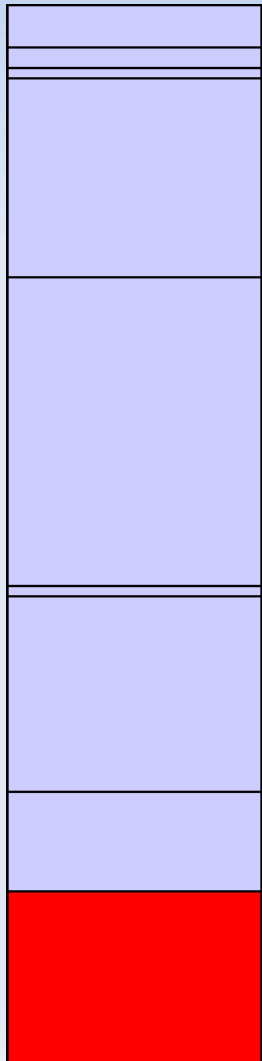
Fonte: National Renewable Energy Laboratory



- 1), 5) ricombinazione
- 2) termalizzazione
- 3) diffusione
- 4) perdite ai contatti

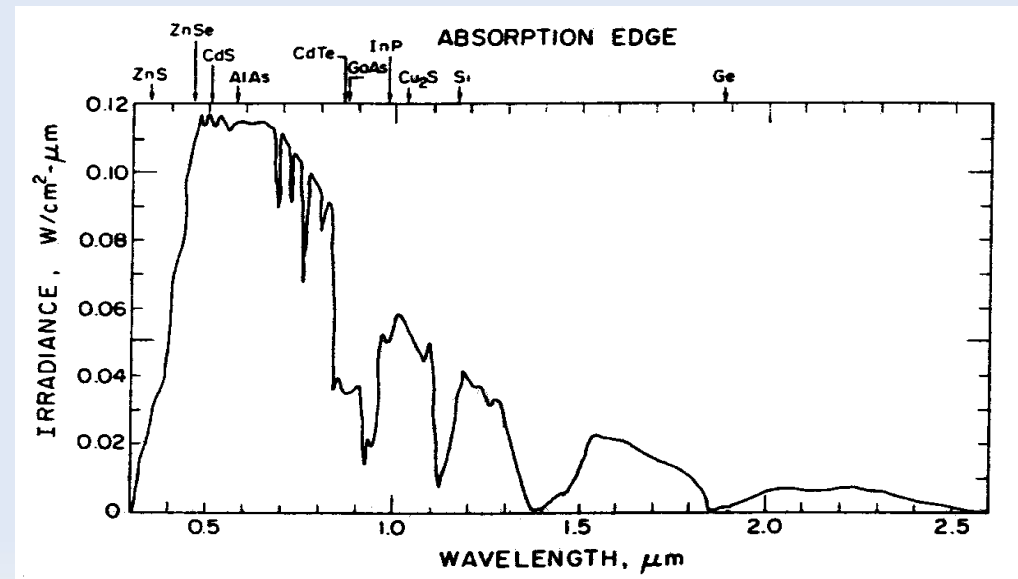
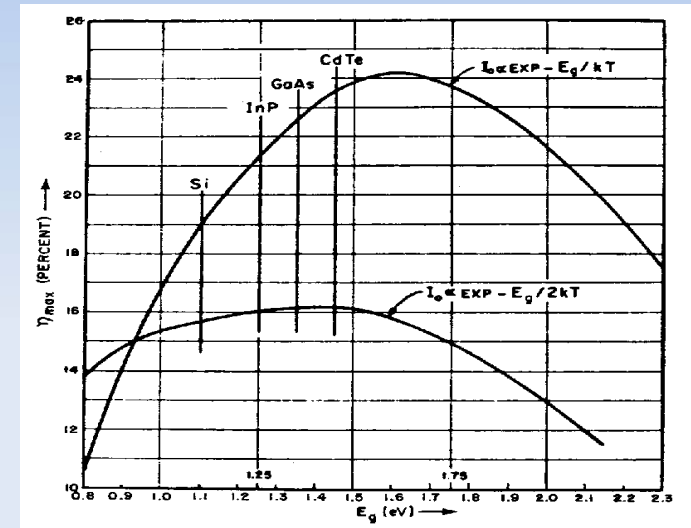
Il problema dell'efficienza

η/η_{th} in una cella reale a giunzione
singola = circa 16.6%

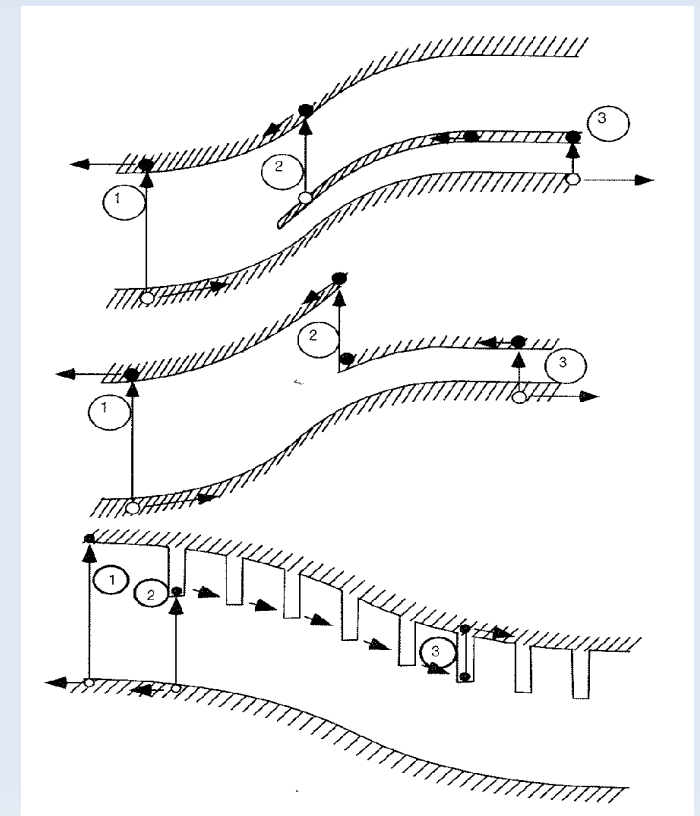
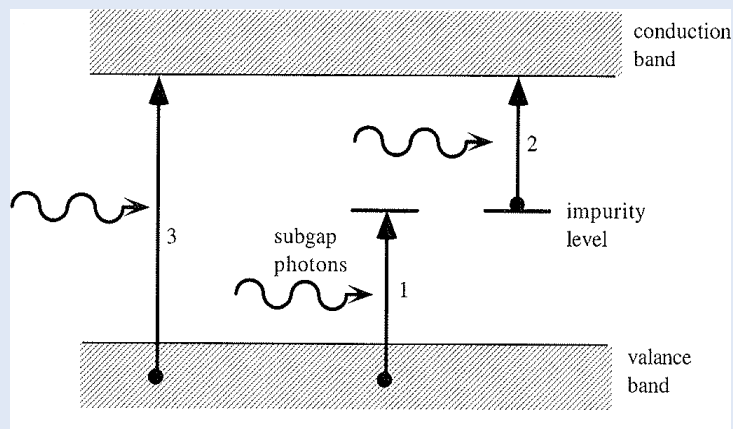
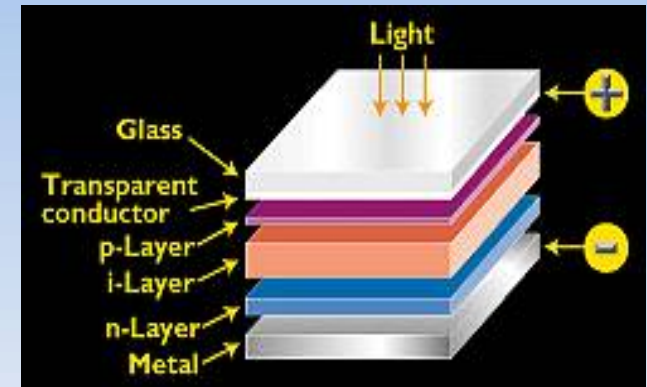
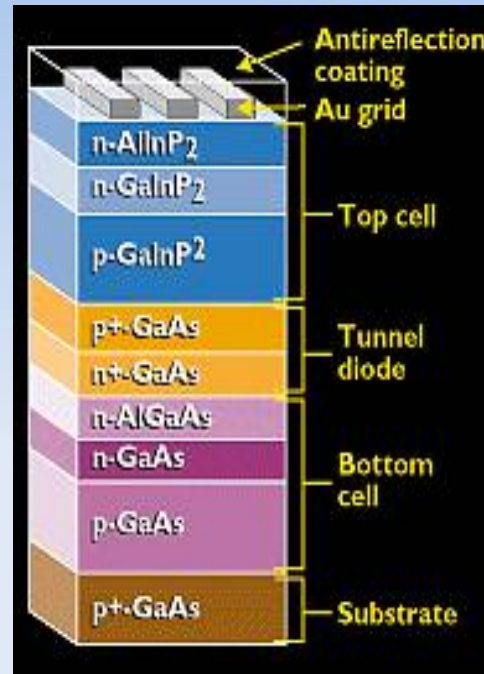
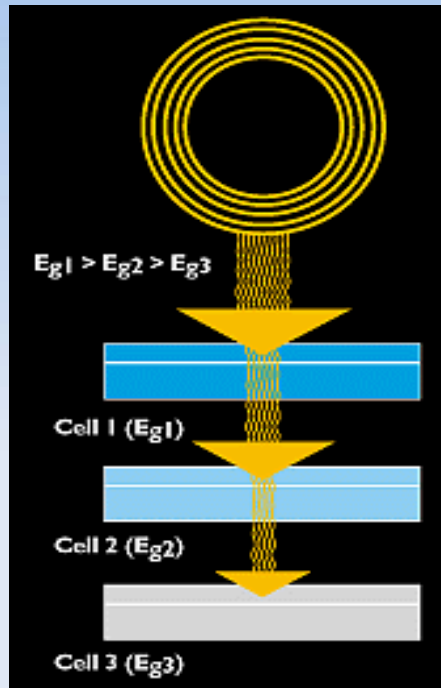


- -4% copertura della superficie
- -2% riflesso dalla superficie
- -1% assorbito dalla superficie
- -18.8% $h\nu < E_g$
- -29.2% $h\nu > E_g$
- -4.5% $\eta_Q = 0.9$
- -19.2% $E_g > qV_{oc}$
- -4.7% $ff = 0.78$

Efficienze a ricombinazione zero per celle a semiconduttore a singola giunzione



Migliorie classiche



Le prime generazioni

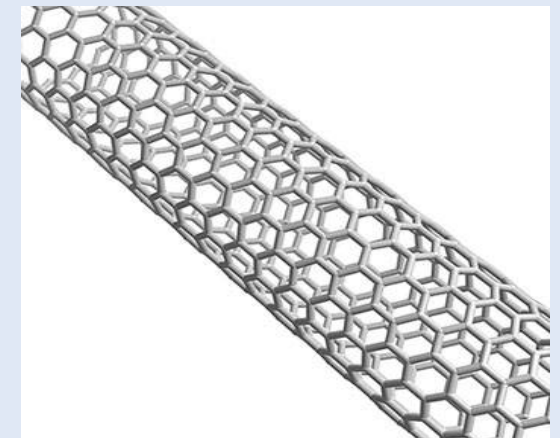
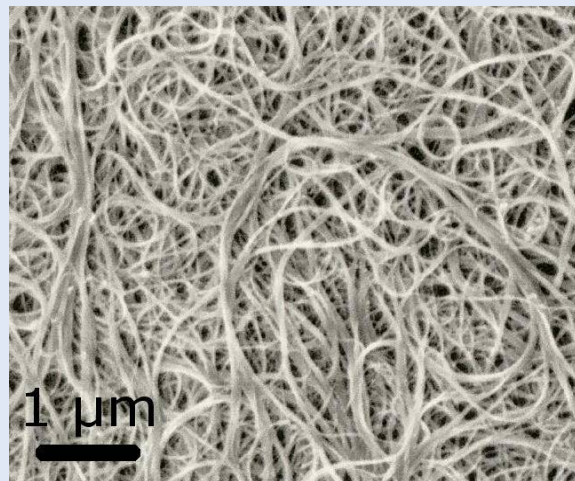
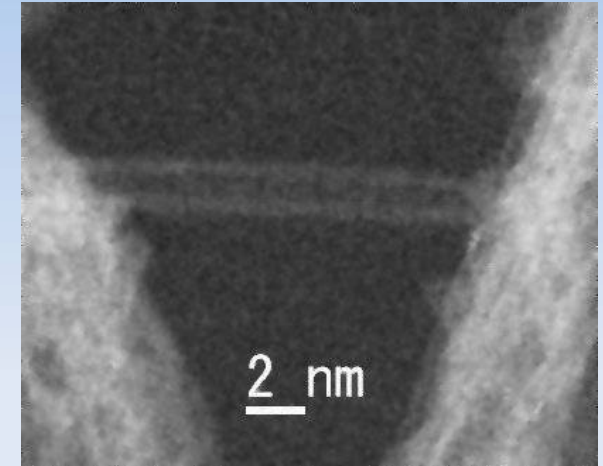
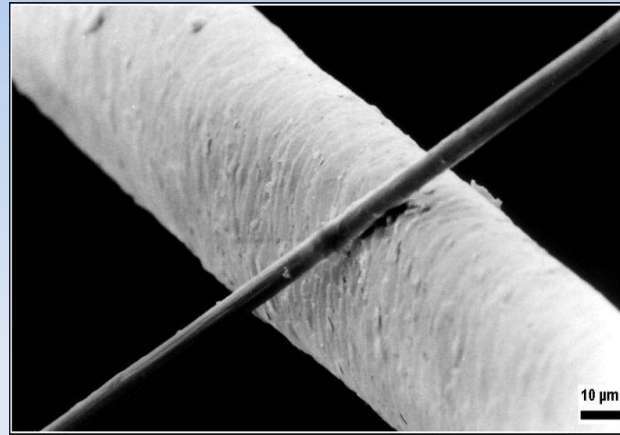


- Prima generazione:
 - vacuum deposition
 - celle a giunzione singola, Si monocristallino
 - elevati costi di produzione buone efficienze
- Seconda generazione:
 - vapour deposition
 - celle a film sottile, CdTe, $\text{CuIn}_x\text{Ga}_{1-x}\text{Se}_2$, Si amorfo
 - Bassi costi di produzione, efficienze mediocri

Cos'è "nano"



$1 \text{ nm} = 10^{-9} \text{ m} =$
1 milionesimo di mm



"Nano" in natura

Fiore di Loto



Nymphaea Caerulea



Fonte: Nees-Institut für
Biodiversität der Pflanzen,
Bonn



Fonte: BASF

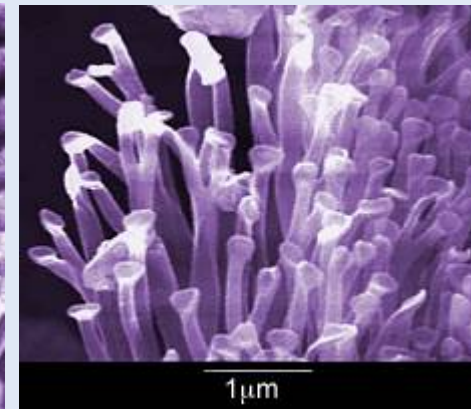
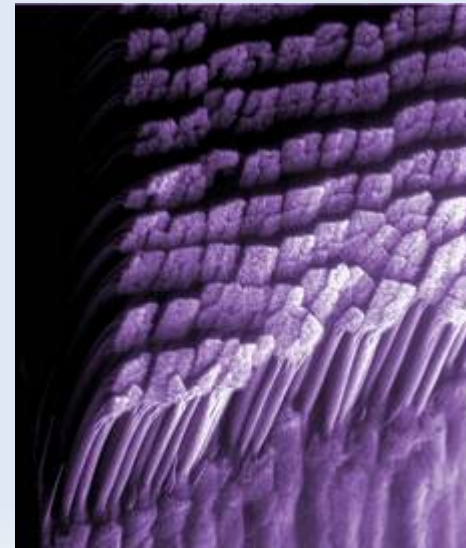


Geco

Fonte: Lewis & Clark College, Portland, Oregon

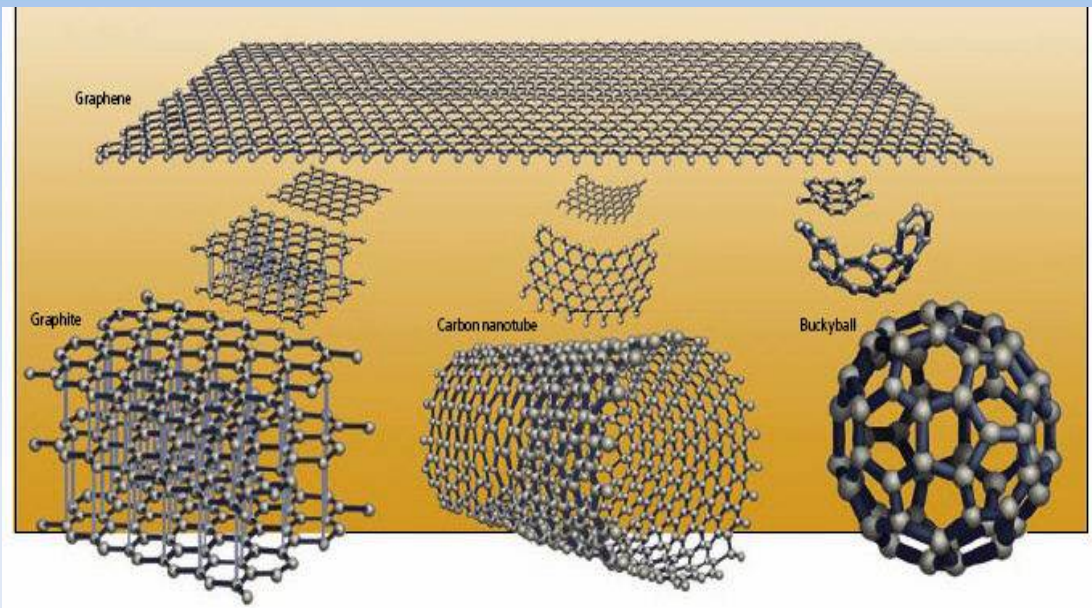


14000 setae/mm² diam. 5 μ m

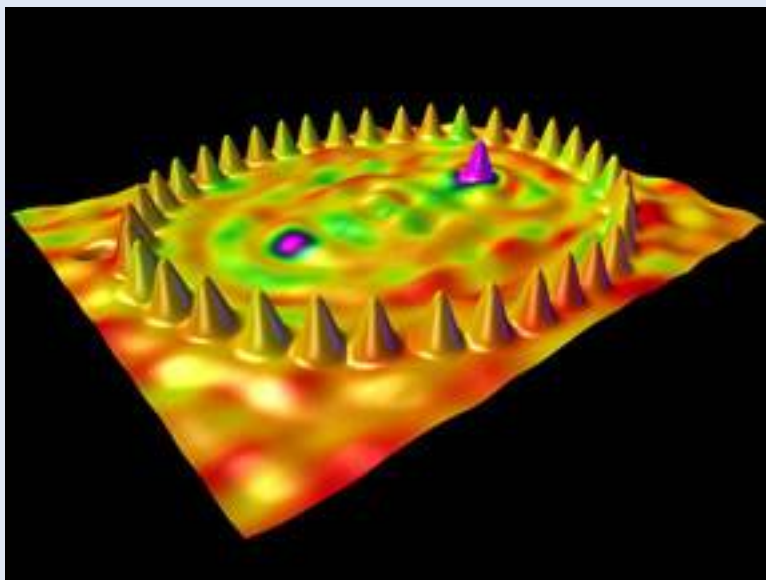


100 ÷ 1000 spatulae/seta

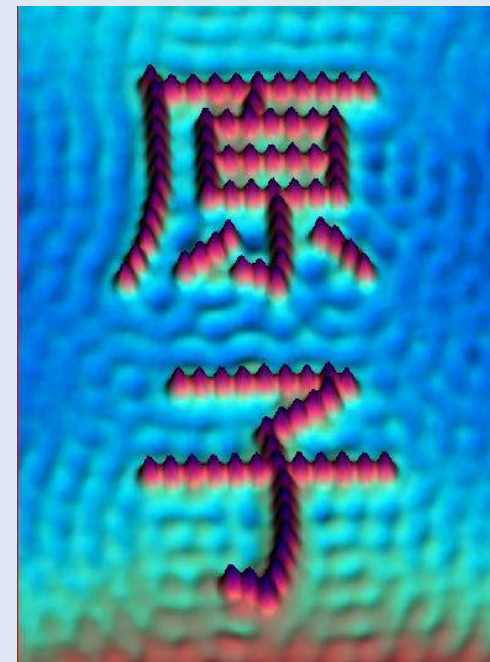
Nuova fisica



Nanocristalli di CdSe,
J. Phys. Chem C, 11, 2974 (2007)

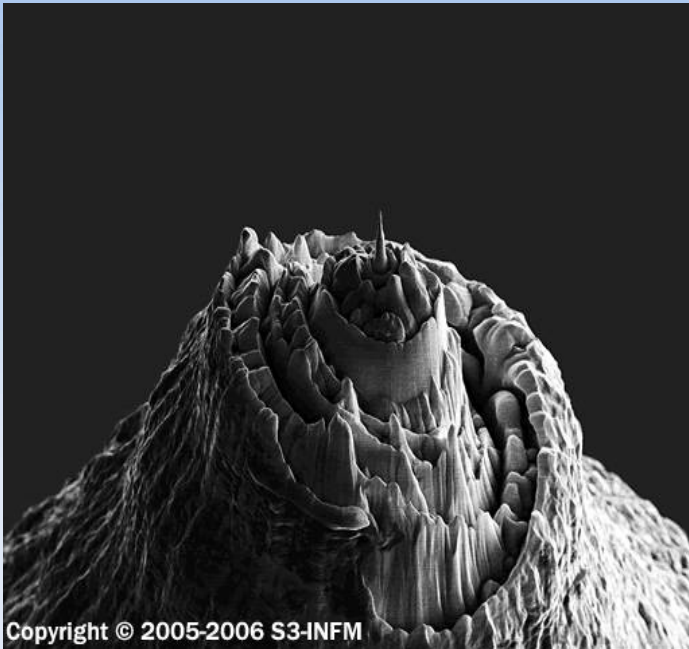


Nanoring, Co/Cu, Nature 403, 512 (2000)

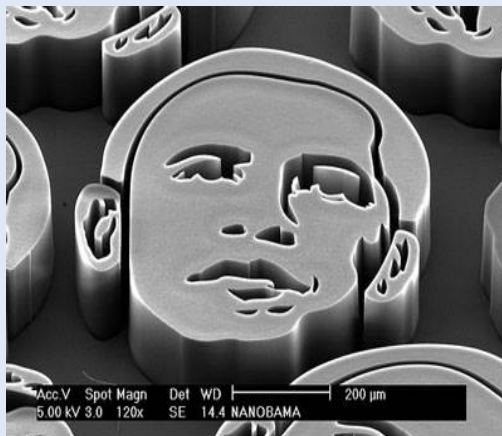


Nanokanji, Fe/Cu(111), Science 262, 218 (1993)

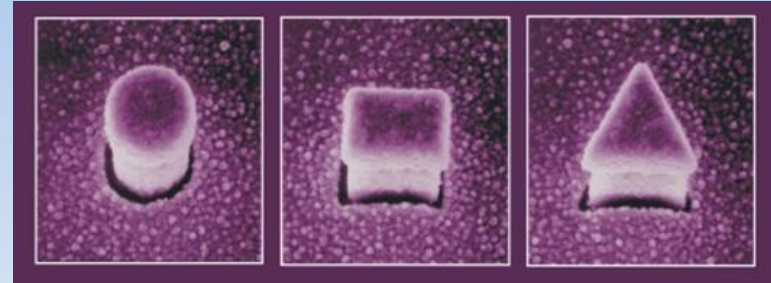
Nuove tecnologie



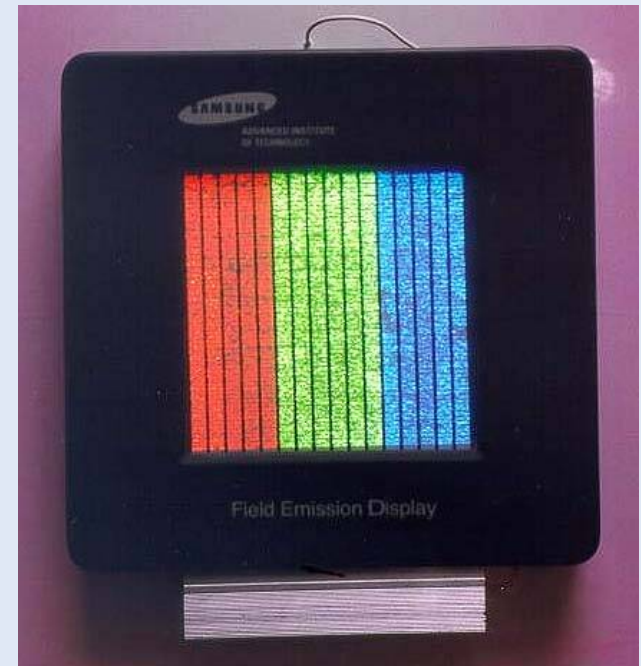
Punta per microscopio a scansione:
<http://www.s3.infm.it/blowup>



Nanobama, University of Michigan

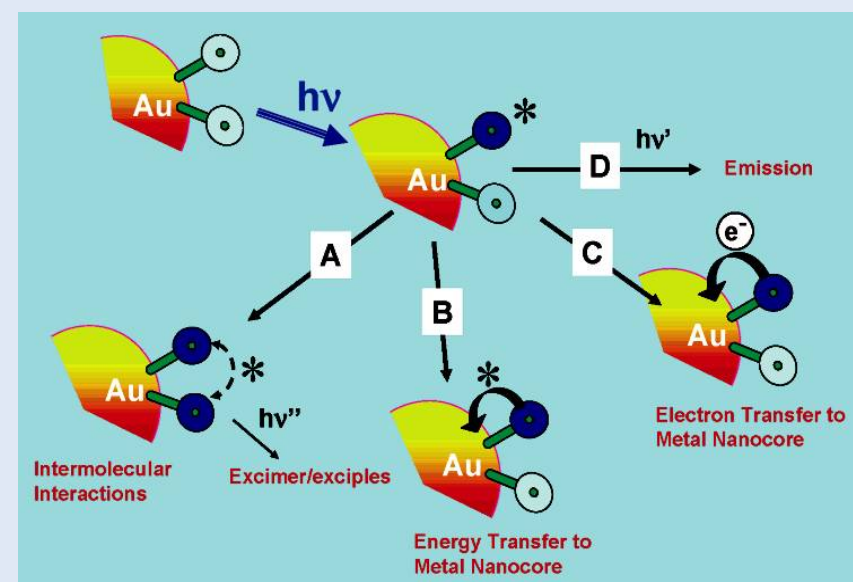
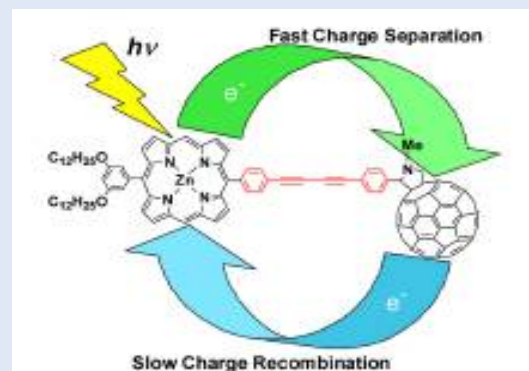
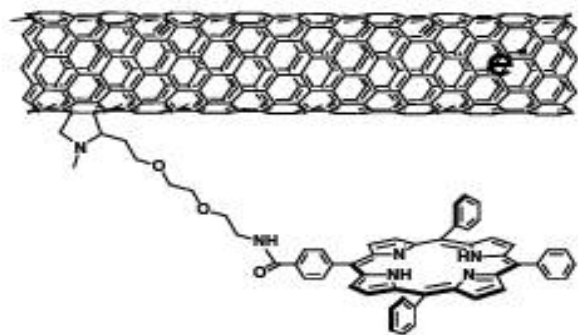
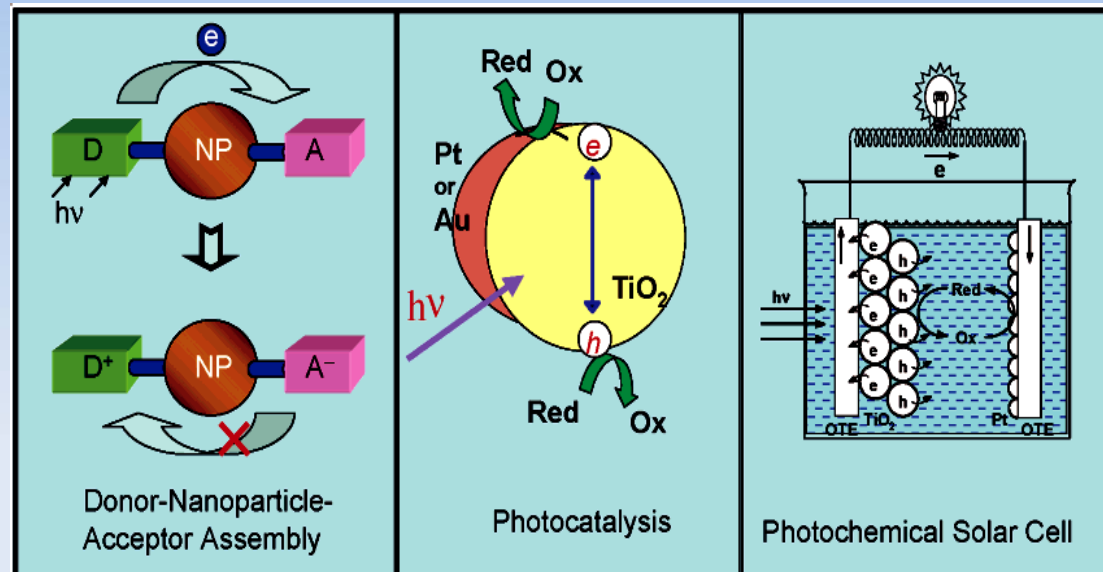
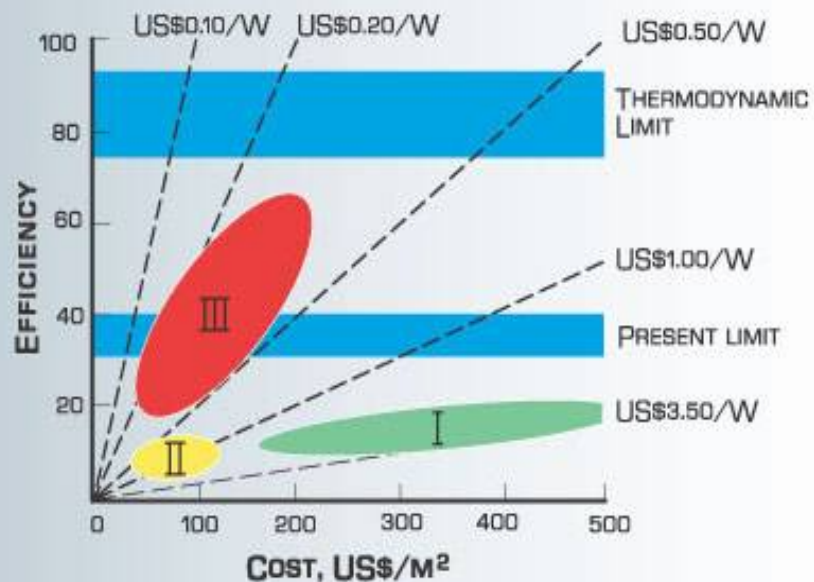


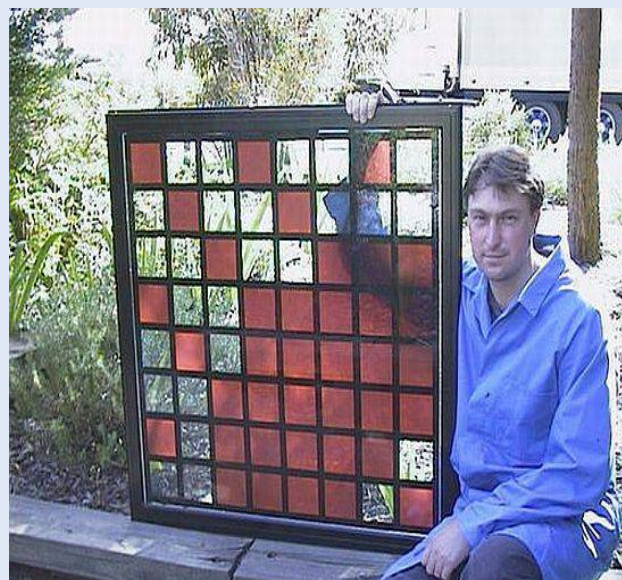
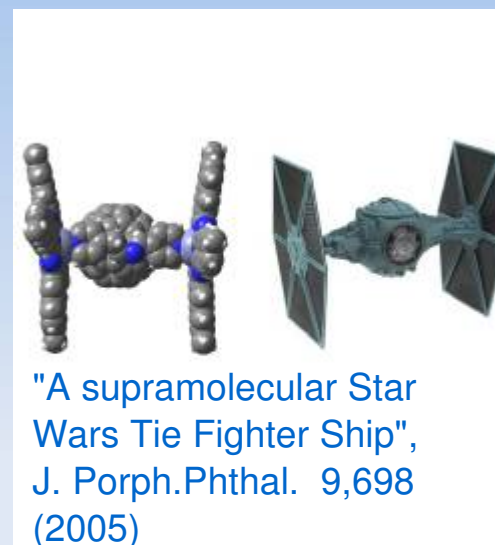
Few-electron Quantum Dots
Rep. Prog. Phys, 64, 701 (2001)



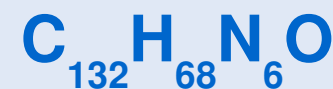
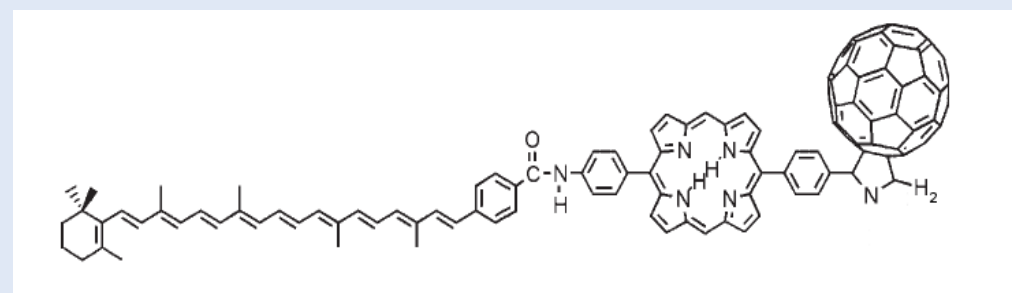
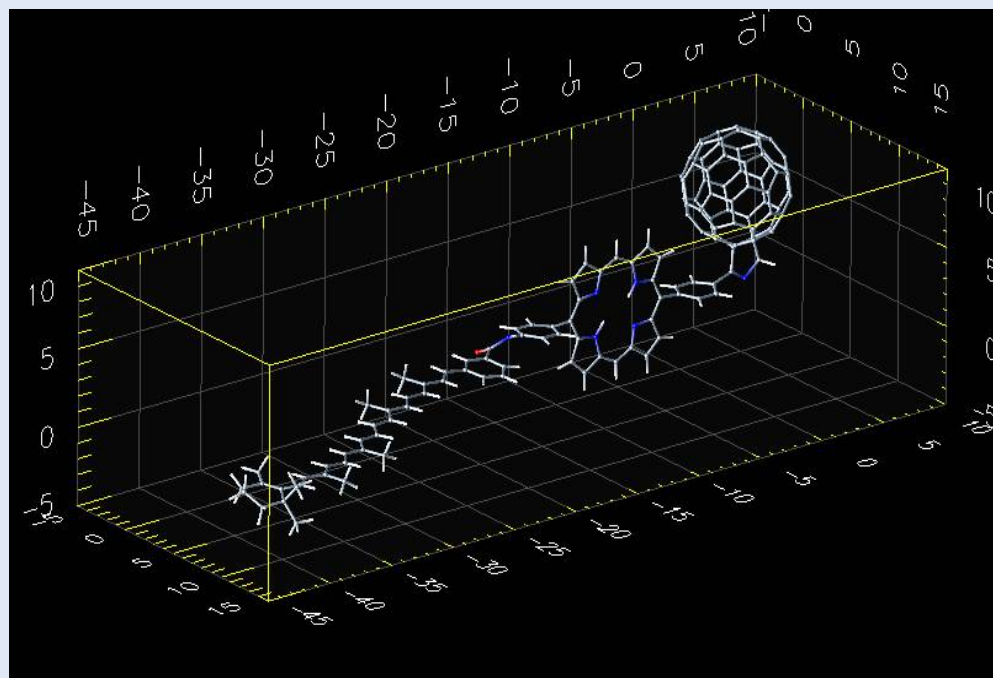
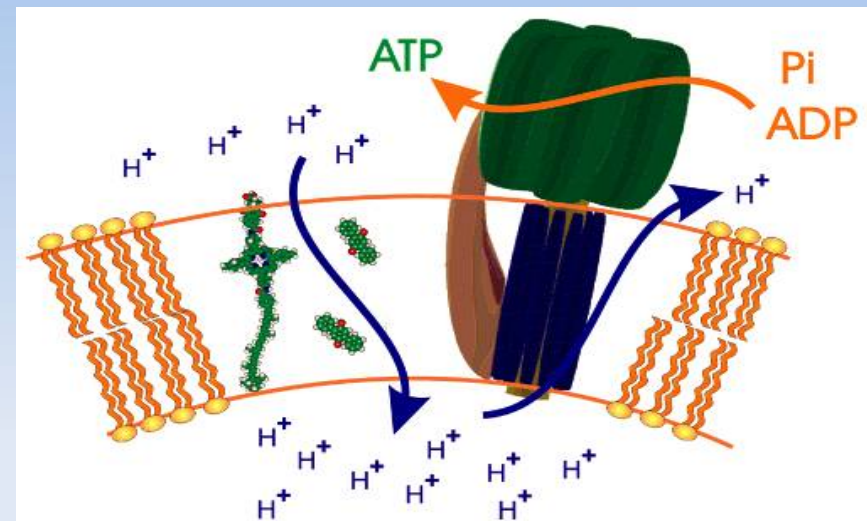
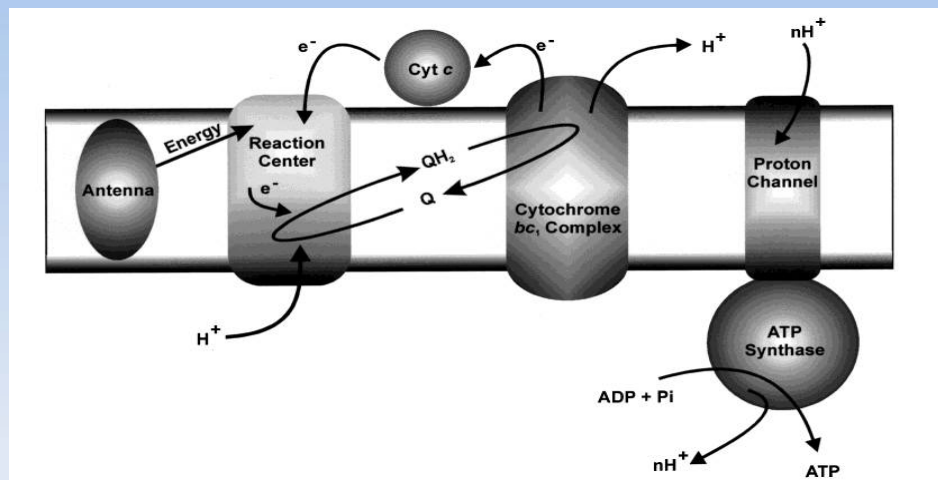
Samsung CNT display
Appl. Phys. Lett. 75, 3129 (1999)

Nuove generazioni

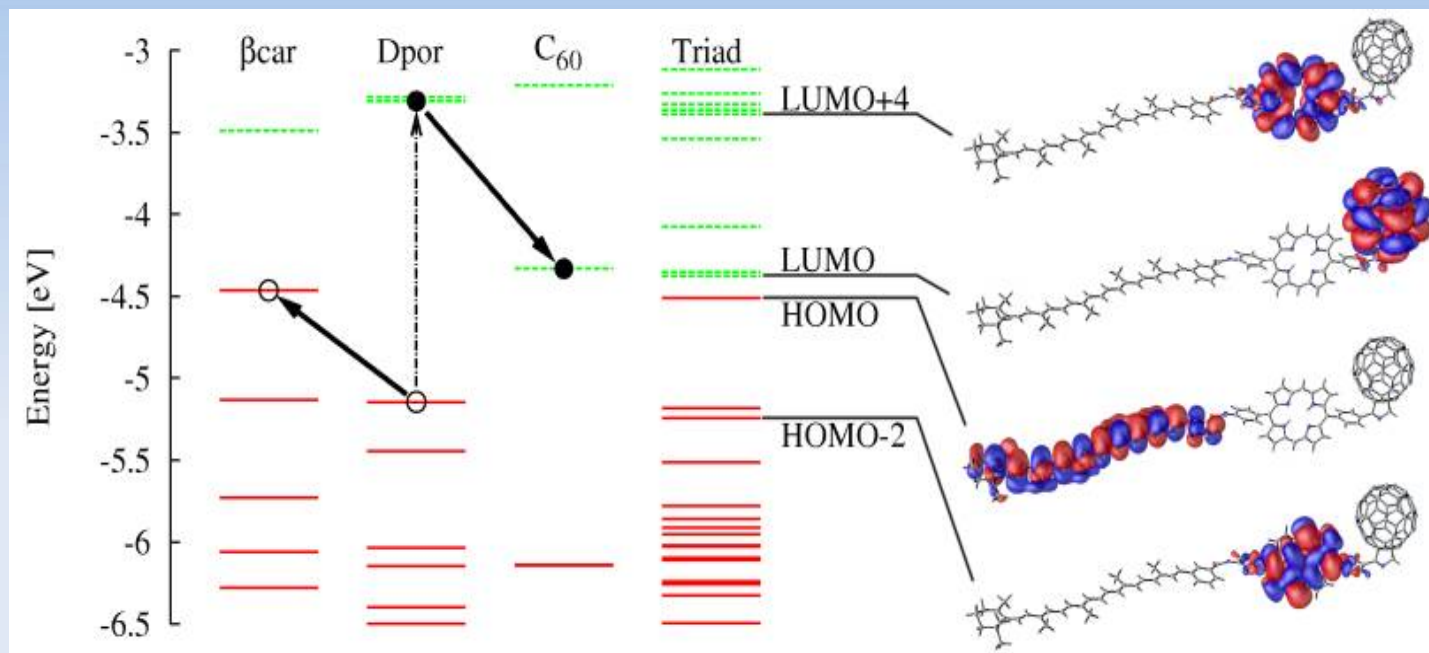




Imitare la fotosintesi



Livelli ed eccitazioni



N. Spallanzani, C.A. Rozzi, *et al.*, J. Phys. Chem. B 113, 5345 (2009)

Simulazioni numeriche

- Griglia di 1.287.768 punti spazati di 0.02 nm
- 632 elettroni di valenza
- $\Delta t = 1.7 \text{ as}$ (10^{-18} s)
- 700 iterazioni = 1.2 fs (10^{-15} s) in circa 24 ore su 64 processori IBM Power6 4.7 Ghz
- Gira su IBM pSeries 575, CINECA (Bologna), 5376 processori, 101 Tflop/s peak performance, 46 al mondo



Grazie



NASA Dryden Flight Research Center Photo Collection

<http://www.dfrc.nasa.gov/gallery/photo/index.html>

NASA Photo: ED01-0230-1 Date: August 13, 2001 Photo by: Nick Galante

NASA's Helios Prototype aircraft taking off from the Pacific Missile Range Facility, Kauai, Hawaii, for the record flight.