NANOTECNOLOGIE

esperienze, esperimenti, applicazioni

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Cose e loro dimensioni (arancio = cose fatte dall'uomo)

	Millimeters	Microns	Nanometers
Ball of a ball point pen	0.5		
Thickness of paper	0.1	100	
Human hair	0.02 - 0.2	20 – 200	
Talcum Powder		40	
Fiberglass fibers		10	
Carbon fiber		5	
Human red blood cell		4 – 6	
E-coli bacterium		1	1000
Visible Light Wavelength:		0.40 – 0.75 microns	400 – 750 nm
Size of a modern transistor		0.25	250
Transistor Gate			35
Size of Smallpox virus		0.2 – 0.3	200 – 300

Electron wavelength: Upper upper limit ~ 10 nm

	Nanometers
Diameter of Carbon Nanotube	3
Diameter of DNA spiral	2
Diameter of C60 Buckyball	0.7
Diameter of Benzene ring	0.7
Size of one Atom	0.1

Fisica quantistica

Scienza dei materiali

Dispositivi nanomeccanici

Nanotubi al carbonio

Nanoelettronica

Autoassemblaggi inorganici

Elettronica Organica

Nano-compositi

Nano-tribologia

Nanotecnologia per dispositivi

Nanomateriali, ricoprimenti e plastiche

Ricopromenti per attrezzi

Foto-voltaico

LED e laser tramite nanosemiconduttori

Trasporto

Dispositivi Magneto-resistivi

Electronica, informatica

Aerospazio

Sospensioni ed inchiostri

Processamento di dati bio-molecolari

Cosmetica

Miniaturizzazione

Tessile

Coloranti

Nanofabbricazione

Impianti micro-nano

Catalizzatori nanostrutturati

Farmaceutica

Sintesi di materiali

Distribuzione di medicinali

Alimenti e bevande

Chimica

Nano-filtrazione

Bio-sintesi di molecole funzionali

Sensori DNA

Ambiente

Energia

Nanotecnologie per la chimica e l'ambiente

Nanobiotecnologia

Batterie

Bio-sensori

Immagazzinamento dell'idrogeno

Biochip

Autoassemblaggio Biologico

Bio-catalisi

Auto-assemblaggio supra-molecolare

Chimica supramolecolare

Biologia molecolare

SCIENZA

complesso organico e sistematico delle conoscenze che si posseggono intorno a un determinato ordine di fenomeni

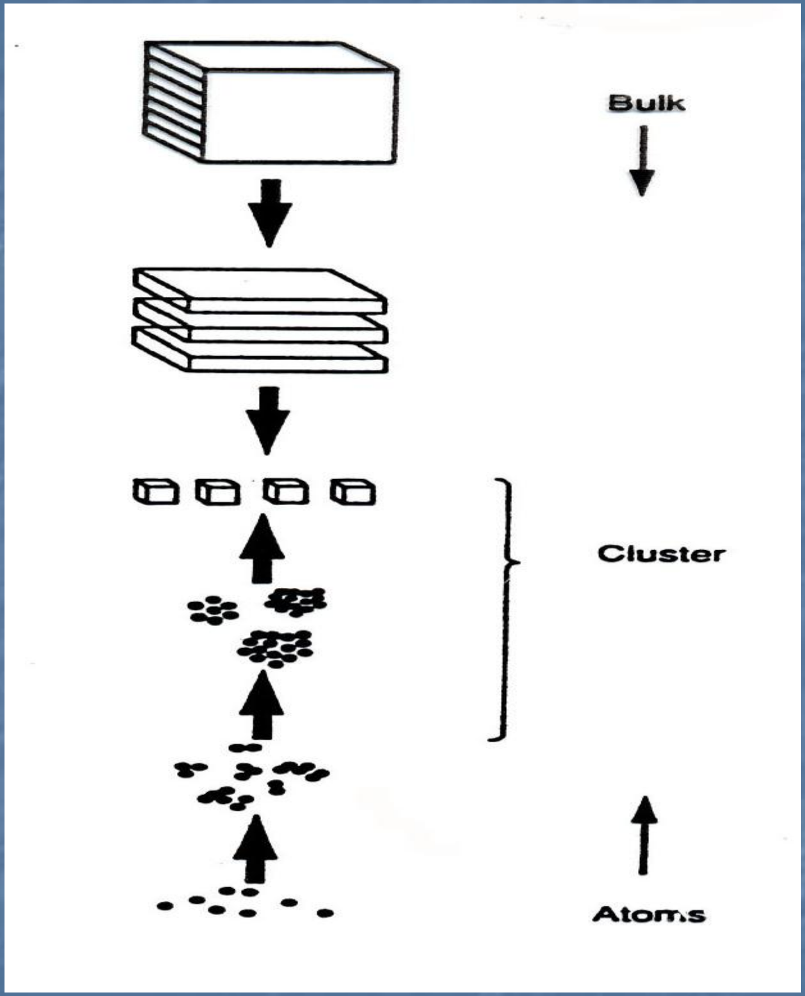
TECNOLOGIA

studio dei materiali, delle macchine e dei procedimenti tecnici da impiegarsi nella produzione di beni e servizi

DIGITA: Dizionario Interattivo Garzanti dalla lingua ITAliana

- La nanoscienza fornisce uno strumento concettuale estremamente potente ed innovativo, che apre orizzonti nuovi e vastissimi.
- Le nanotecnologie forniscono gli strumenti per lo sfruttamento pratico di questi nuovi concetti, consentendo la realizzazione di materiali nanostrutturati, di nanocompositi, di nanodispositivi.
- Al di là delle definizioni più o meno discusse su ciò che può essere considerato "nanotecnologia", le attività avviate sotto questa etichetta sono comunque una realtà importante, che avrà importanti conseguenze sul nostro mondo tecnologico.

Sintesi di nanostrutture



Top-down

Bottom-up

SCENARIO DI RIFERIMENTO - **nanofabbricazione**

Approccio Bottom-Up

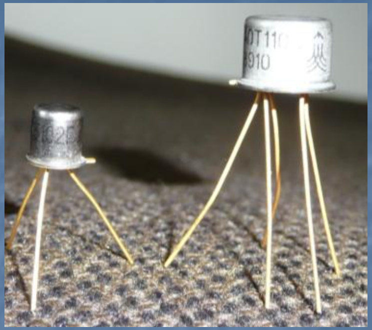
- ispirata alle forme spontanee con cui la biologia realizza architetture e funzioni complesse a partire da costituenti chimici, le molecole
- sintesi di origine fisica, chimica e biologica

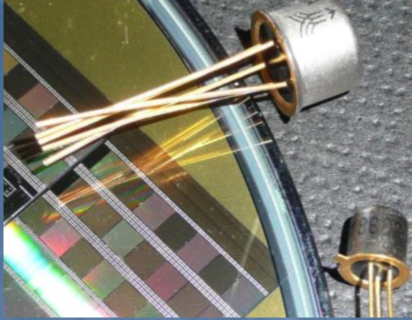
NANOFABBRICAZIONE

Approccio Top-Down

- riduzione sempre maggiore delle dimensioni degli oggetti provenendo da dimensioni relativamente grandi
- attuato con successo nel campo della microelettronica da fisici ed ingegneri

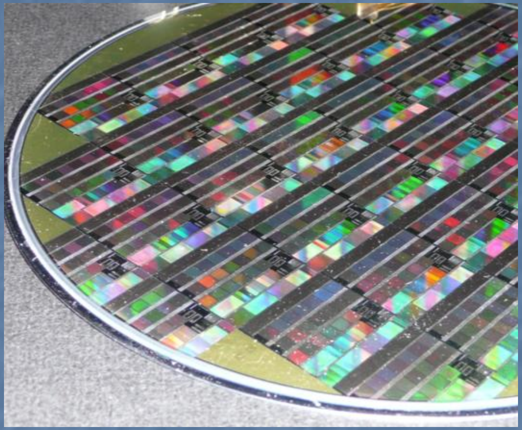
La nanofabbricazione è destinata a diventare un elemento costitutivo nella sequenza di sviluppo definita da ricerca, trasferimento tecnologico, industrializzazione e commercio





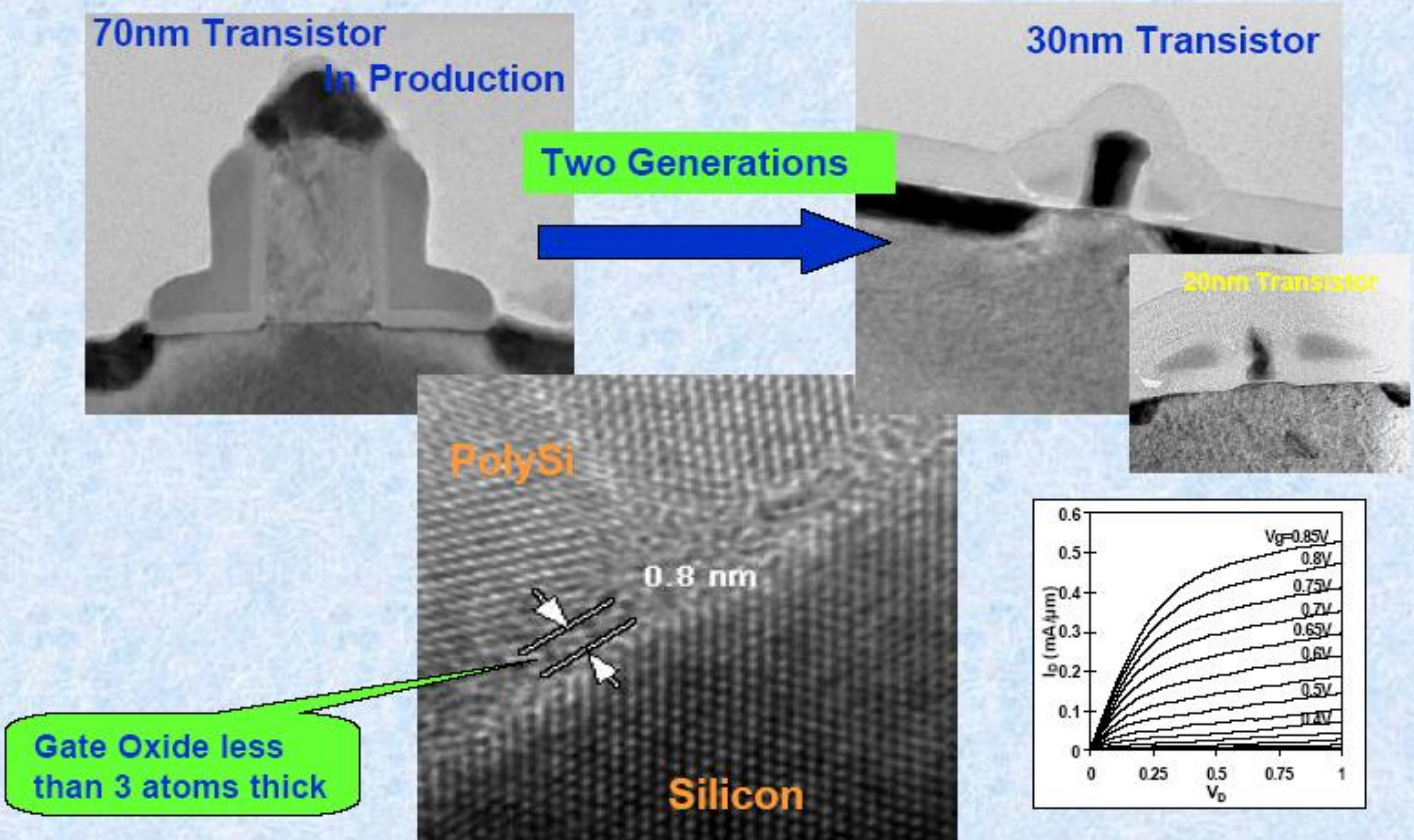
dal MACRO al MICRO
al

NANO



caso della MICROELETTRONICA

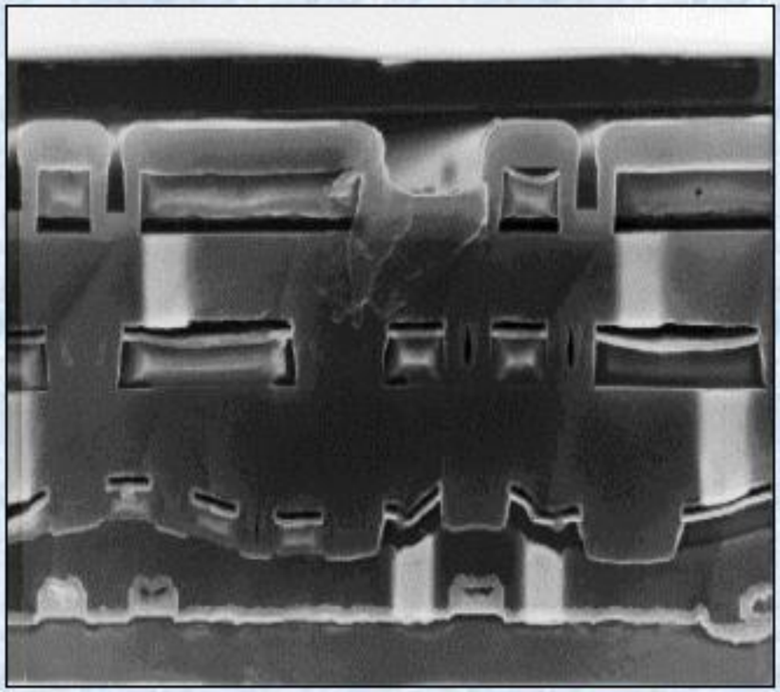
Functional Transistors at 30nm (and smaller)



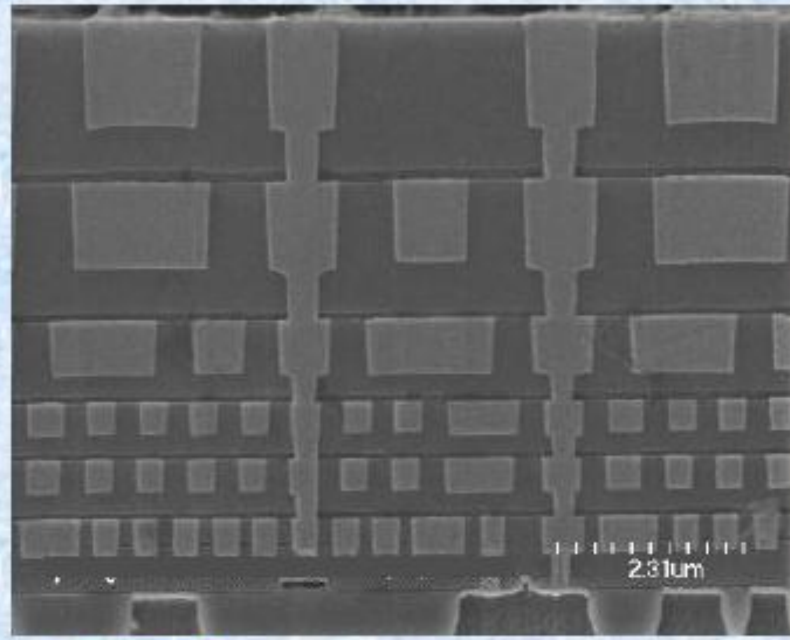
Continued Progress on Interconnects

8

500nm Interconnects

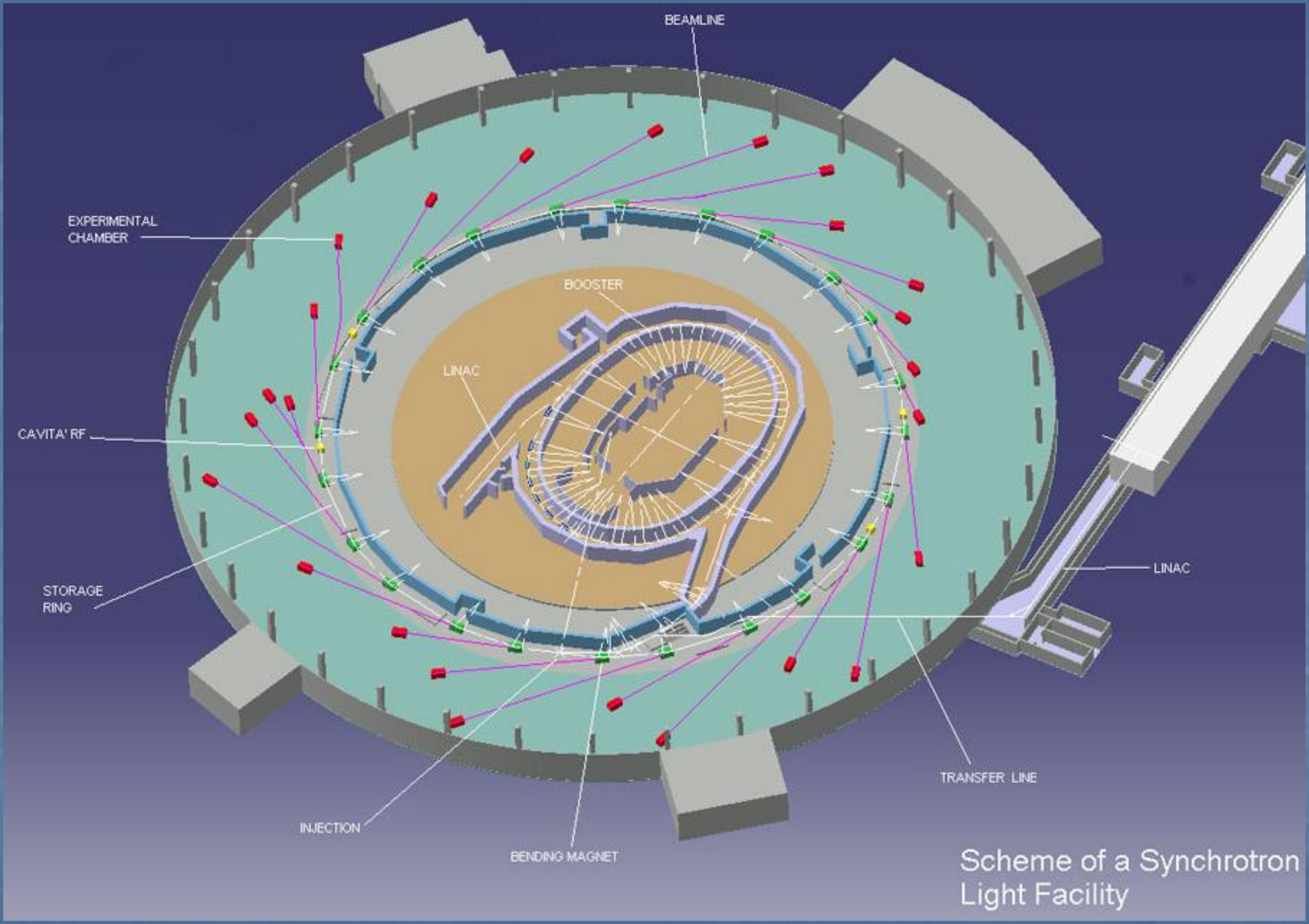


130nm Interconnects



Four Generations of Interconnect Progress

Determinazione delle proprietà elettroniche di superficie (primi piani atomici)

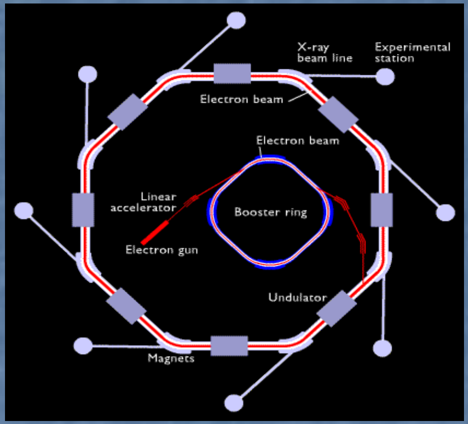


CALIFORNIA-Stanford WISCONSIN-Madison

La fabbrica europea di Luce (ESRF)

La luce dagli elettroni

- La luce è prodotto facendo circolare gli elettroni all'interno di un circuito di magneti.
- La radiazione emessa viene estratta dall'anello attraverso appositi canali (linee di luce)



Inoltre, con la microtecnologia si realizzano prodotti che ogni anno divemtano sempre più piccoli

MOORE'S LAW: *(INTEL-1965) ogni 18-24 mesi il numero di transistor in un dispositivo raddoppia*

IC's era stato inventato solo 7 anni prima!

(by Moore, his Fairchild/Intel colleagues, and Texas Instrument's Jack Kilby)

La sua legge ha predetto lo sviluppo per 40 anni:

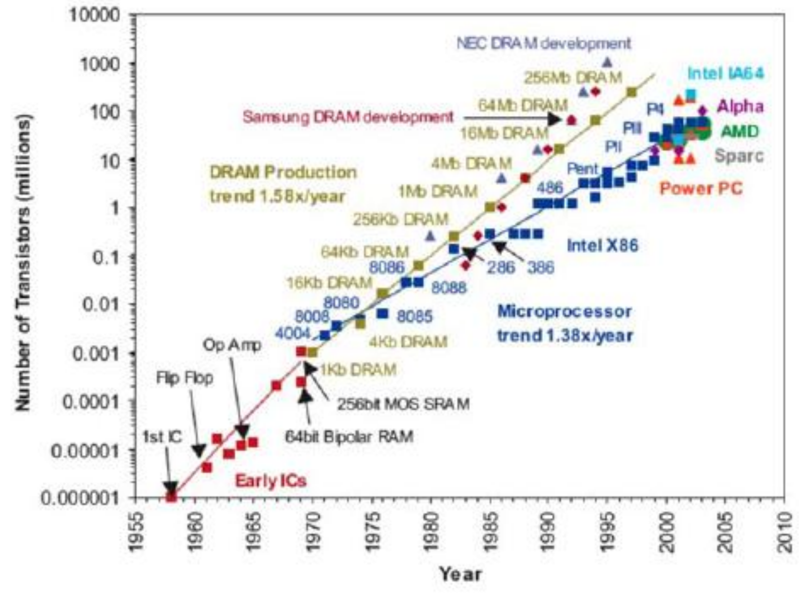
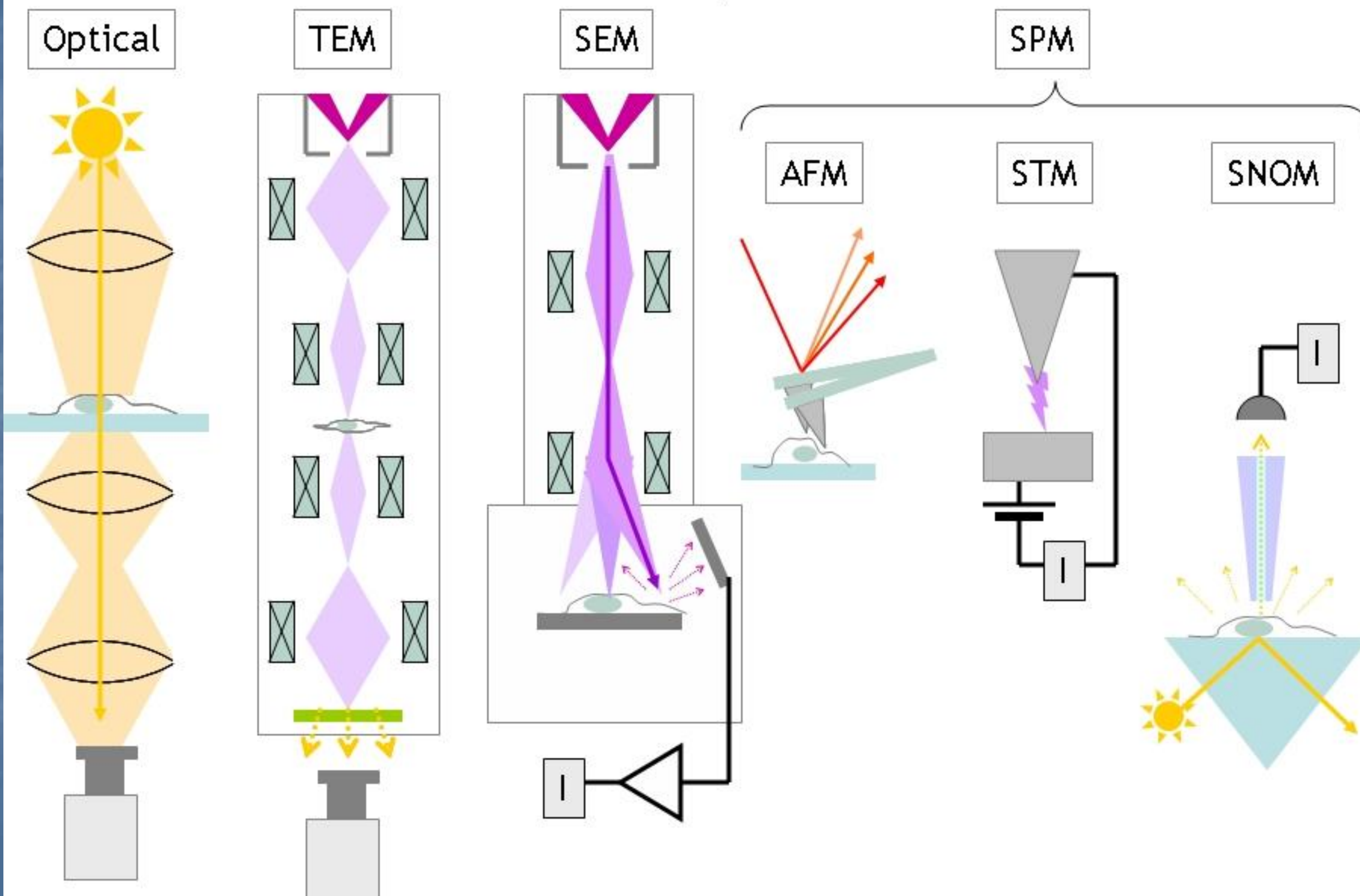


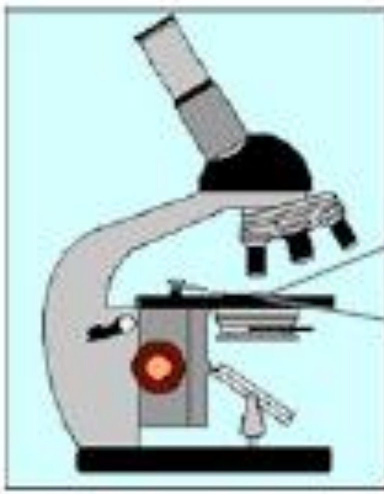
Figure 2.2: The first Moore law: time variation of the number of transistors in ICs (reproduced with permission from http://www.icknowledge.com)

Microscopes

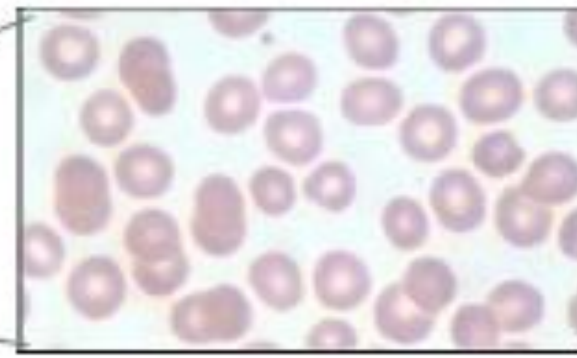


Using Light to See

- **The naked eye can see to about 20 microns**
  - A human hair is about 50-100 microns thick
- **Light microscopes let us see to about 1 micron**
  - Bounce **light** off of surfaces to create images



Light microscope
(magnification up to 1000x)

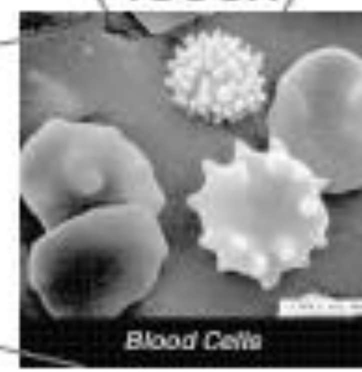


to see red blood cells
(400x)

Using Electrons to See

- **Scanning electron microscopes (SEMs), invented in the 1930s, let us see objects as small as 10 nanometers**
  - Bounce electrons off of surfaces to create images
  - Higher resolution due to small size of electrons

(4000x)



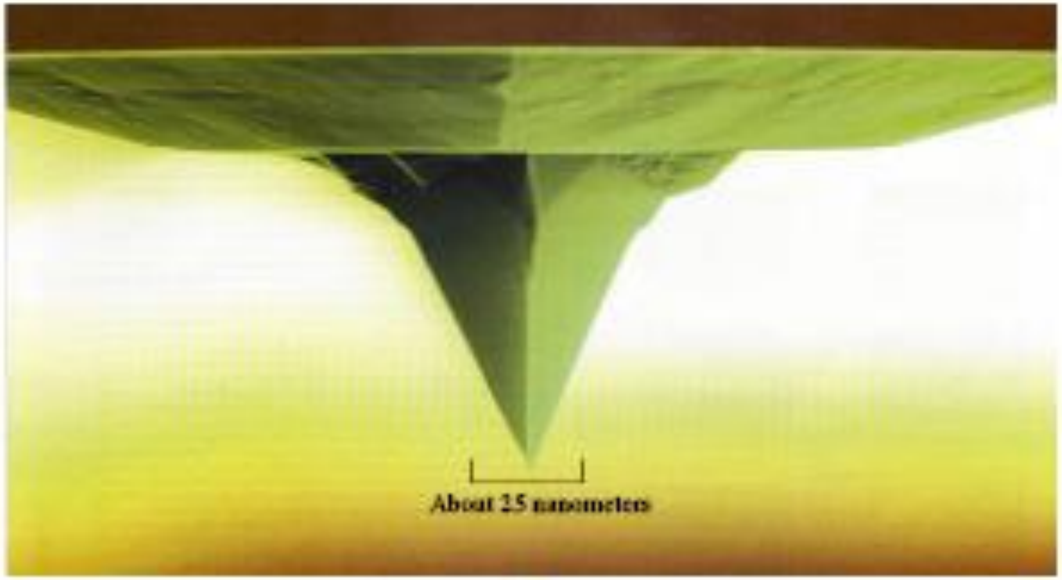
Greater resolution to see things like blood cells in greater detail

Scanning Probe Microscopes

- **Atomic Force Microscope (AFM)**
  - A tiny tip moves up and down in response to the **electromagnetic forces** between the atoms of the surface and the tip
  - The motion is recorded and used to create an image of the atomic surface
- **Scanning Tunneling Microscope (STM)**
  - A flow of **electrical current** occurs between the tip and the surface
  - The strength of this current is used to create an image of the atomic surface

Touching the Surface

- Scanning probe microscopes, developed in the 1980s, give us a new way to "see" at the nanoscale
- We can now see really small things, like atoms, and move them too!



This is about how big atoms are compared with the tip of the microscope

Sviluppo di tecniche di sintesi:

Espansione libera in fasci molecolari supersonici
Tecniche laser di vaporizzazione
Sputtering
Atomic Layer Deposition
Chemical vapor deposition (plasma assisted)

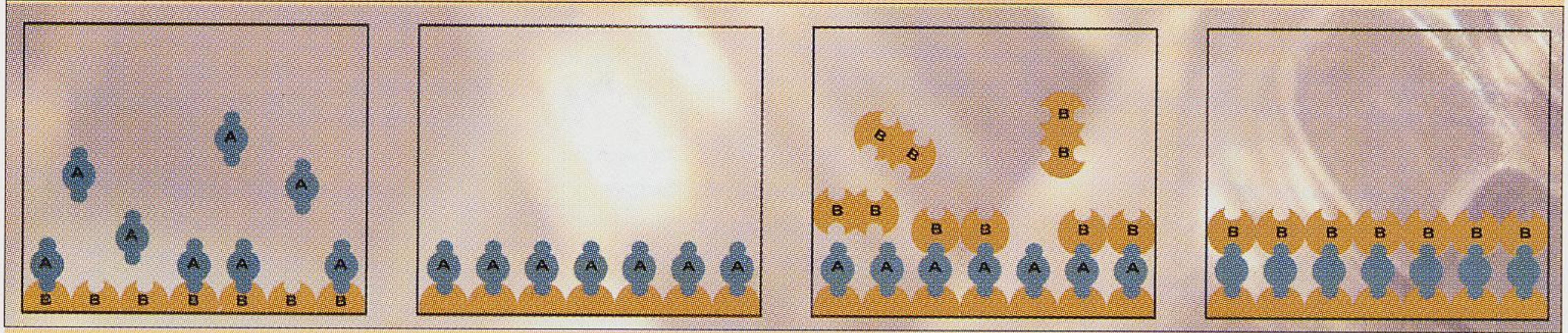
Impianto ionico
Sol-gel
Ball-milling

Litografia, reactive ion etching…

Atomic-Layer Chemical Vapour Deposition

Based on sequential saturated chemical reactions on the surface, this growth method has been called by various names: Atomic Layer Epitaxy (ALE), Atomic Layer Deposition (ALD), digital chemical vapour deposition (D-CVD) or atomic-layer chemical vapour deposition (ALCVD).

In Chemical Vapour Deposition (CVD) precursor chemicals are introduced simultaneously by a carrier gas into the reaction chamber where the precursors chemically react, depositing a thin film. However, in ALCVD, deposition is based on chemical reactions on the substrate surface. Also, in contrast to other CVD processes, ALCVD is divided into sequential saturated steps - growth takes place step-by-step, layer-by-layer - hence the name Atomic-Layer Chemical Vapour Deposition.



Vapour A chemisorbs on a surface covered by atoms B. The reaction proceeds until saturation, i.e. all bonding sites available to atoms A are filled.

After the saturation of the reaction, the surface is covered with atoms A, which makes the surface reactive to atoms B. Excess vapour is removed.

Vapour B chemisorbs on a surface covered by A. The reaction proceeds until all bonding sites available to atoms B are filled.

Reaction re-establishes the coverage with atoms B, which activates the surface to the next sequence of surface reaction with gas containing atoms A.

Breve storia dei nanomateriali

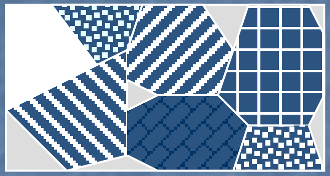
- 1861:   Thomas Graham conia il termine colloide per descrivere una soluzione contente particelle di diametro inferiore a 100 nm in sospensione; (Faraday, Ostwald,…)
- fine 1800 - inizio 1900: Rayleigh, Maxwell e Einstein studiano i colloidi (proprietà ottiche);
- 1908: Gustav Mie, calcolo elettrodinamico esatto della risposta ottica di nanocluster metallici
- 1930: metodo di Langmuir-Blodgett per deporre monostrati atomici;
- 1960: Uyeda studia con la microscopia e la diffrazione elettronica singoli nanocluster;
- 1970: nanocluster di lega metallica;
- 1985: Smalley & Kroto scoprono il C_{60} (fullerene)
- 1991: Iijima studia i nanotubi di C;
- 1993: Creato negli Usa il primo laboratorio di nanotecnologie (Rice University)
- 2000: manipolazione e posizionamento di singoli atomi (STM, AFM) nanotecnologia.
- 2002 L'Europa stanzia 700 milioni € in quattro anni.
- …la storia continua… ...Sistemi biologici…

Materiali Nanostrutturati
(dimensioni caratteristiche < 100 nm)

1.

Materiali
Massivi (3D)

2.

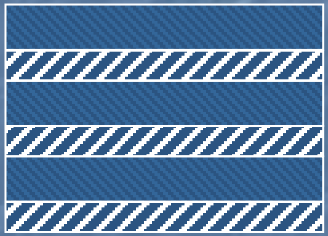


Materiali Nanofasici
(3D)

3.

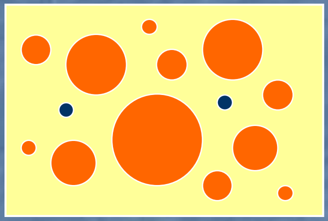
Film nanofasici
(1D-2D)

4.



Multi-strati
(1D-2D)

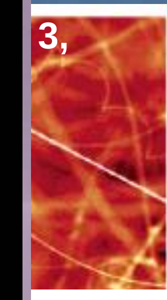
5.

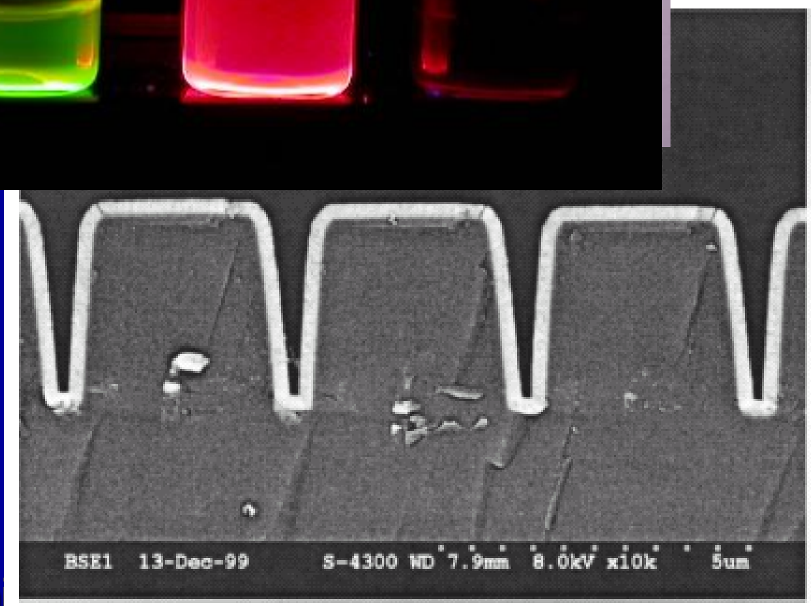


Nanoclusters (~ 0D)
(metalli,
semiconduttori,
nanotubi, fullereni…)

Cosa sono
(1 nn

- Nanoparticelle (0 D)
- Nanofili, nanofibre, nanc
- Film sottili (2 D)
- Nanomateriali massivi (3 D)
  - Materiali Mesoporosi
  - Ibridi organico-inorganici
  - Materiali Nanostrutturati (nanogran
  - Nanocompositi (nanoparticelle o nanofibre in





Attività di Ricerca & Sviluppo (R&D) sui nanomateriali

1) Ricerca sui nanomateriali:

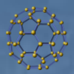
Nuove proprietà chimico-fisiche (diverse dal bulk)

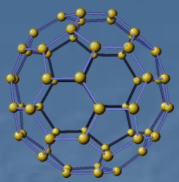
2) Sviluppo di tecniche di sintesi:

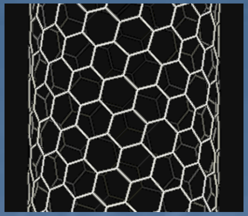
- **Espansione libera in fasci molecolari supersonici**
- **Tecniche laser di vaporizzazione**
- **Sputtering**
- **Impianto ionico**
- **Sol-gel**
- **Chemical vapor deposition**
- **Ball-milling**
- **Litografia, reactive ion etching…**

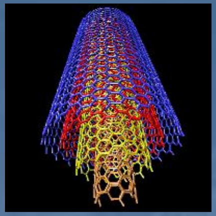
3 Nanomateriali a base di carbonio

3.1 Nanotubi di carbonio









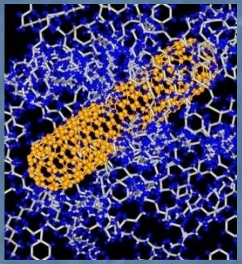
4 Nanomateriali a base polimerica

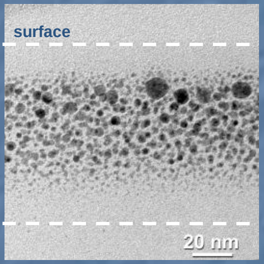
4.1 Compositi a matrice polimerica

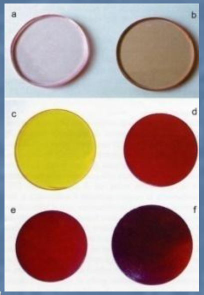
4.1.1 Sensoristica

4.1.2 Fotonica

4.1.3 Ricoprimenti





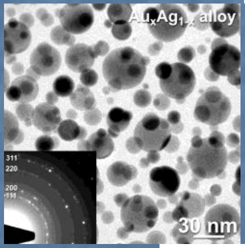


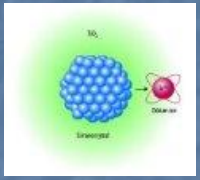
5 Nanomateriali a base vetrosa

5.1 Vetri e vetroceramici

5.1.1 Vetri tecnici

5.1.2 Vetroceramici

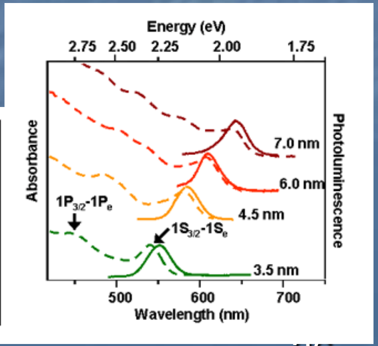




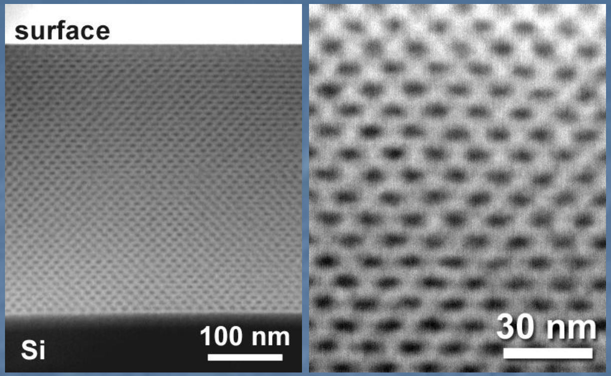
6 Nanomateriali e quantum dots

6.2 Nanofotonica

6.2.1 Ottica nonlineare



7 Nanomateriali per la sensoristica



7.1 Sensori chemio-resistivi

7.2 Sensori a lettura ottica (opto-chimici).

7.3 Sensori a film sottile mesoporoso

7.4 Sensori a matrice polimerica

8 Nanomateriali per la biotecnologia e l'ambiente

8.1 Diagnostica medica: il lab-on-chip

8.2 Nanoparticelle come biosensori

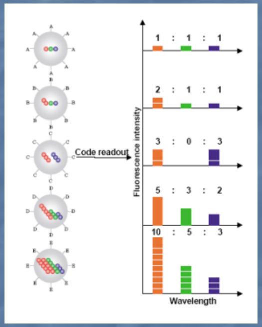
8.3 Ingegneria tissutale

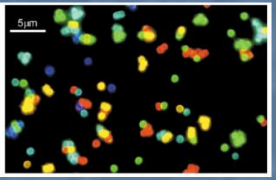
8.4 Biocapsule

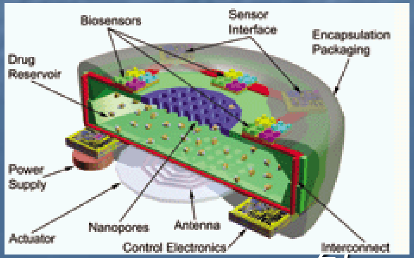
8.5 Le nanotecnologie per l'ambiente

8.6.1 Nanoparticelle di oro come catalizzatori

8.6.2 Nanoparticelle di oro funzionalizzate





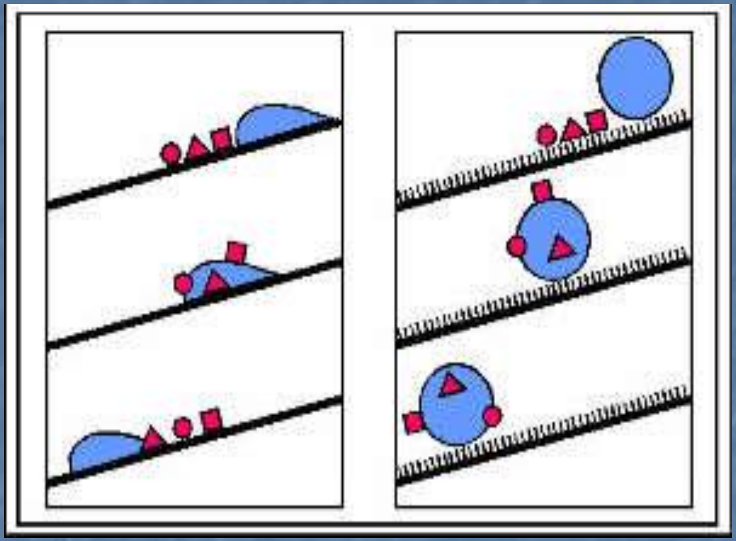


Un esempio dove l’uomo copia la natura:

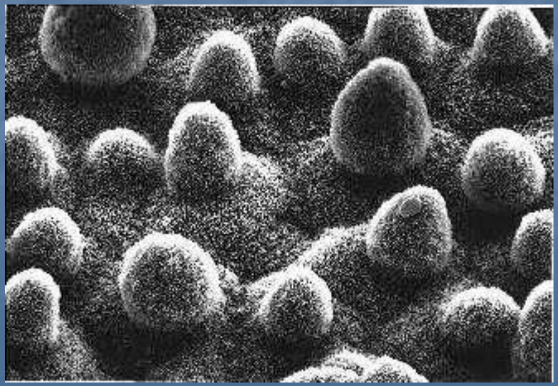
Il controllo chimico e morfologico consente di ottenere superfici super-idrofobiche con proprietà auto-pulenti sfruttando il cosiddetto “Effetto Loto”

Superfici auto-pulenti: Effetto Lotus

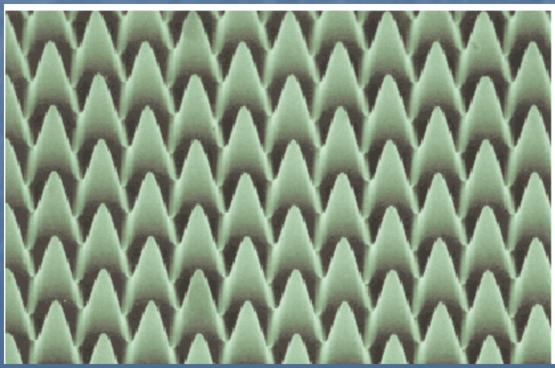
10 μm



W. Barthlott, Univ. di Amburgo



Cera cuticolare



REM recording of a holographically produced self-cleaning surface.
© Fraunhofer ISE

Tensione Superficiale   Forze di Adesione

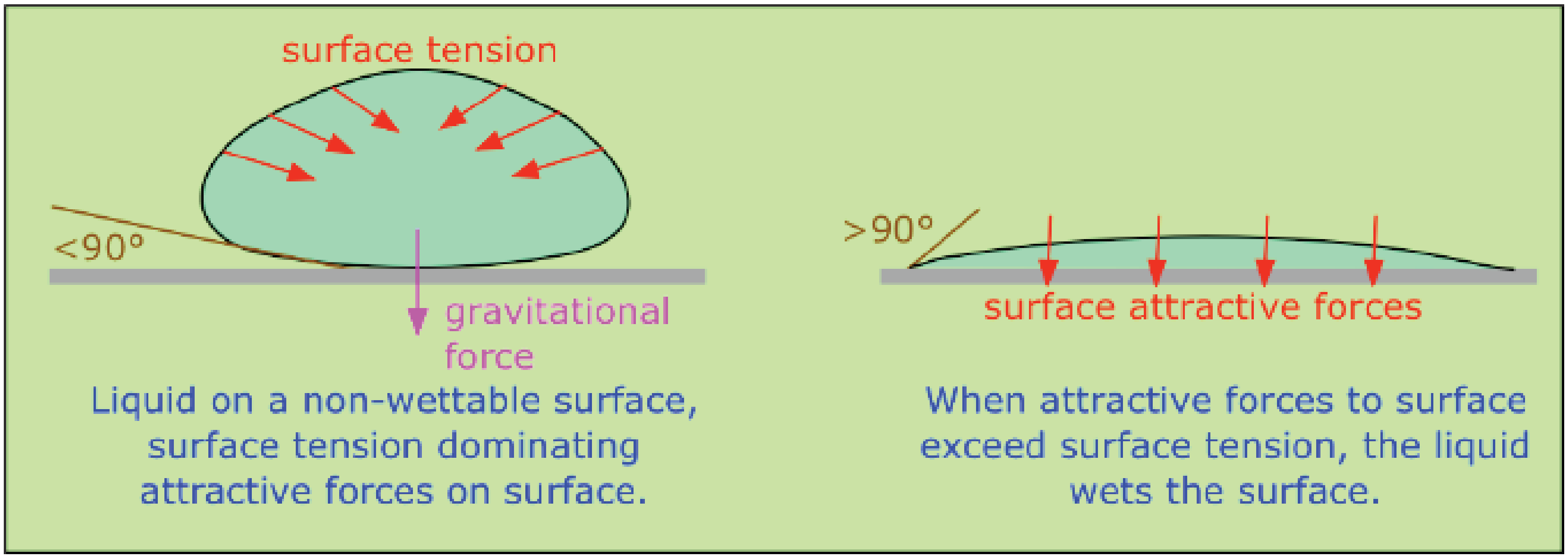
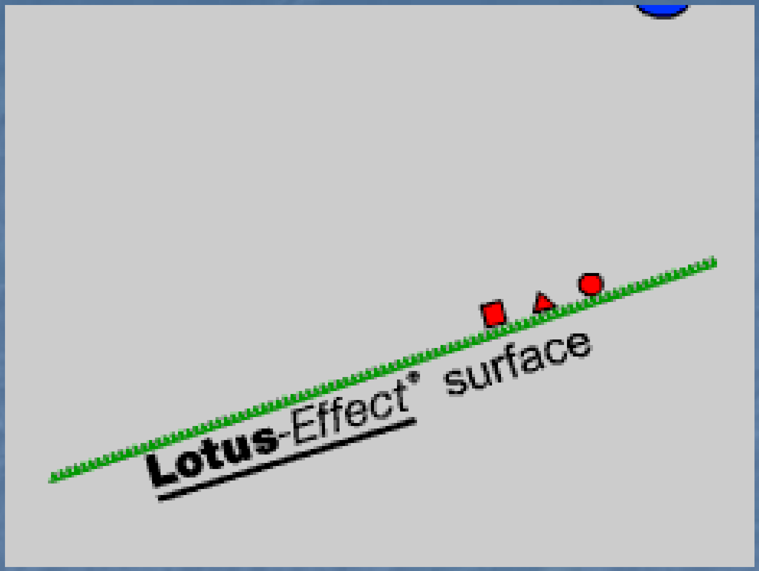
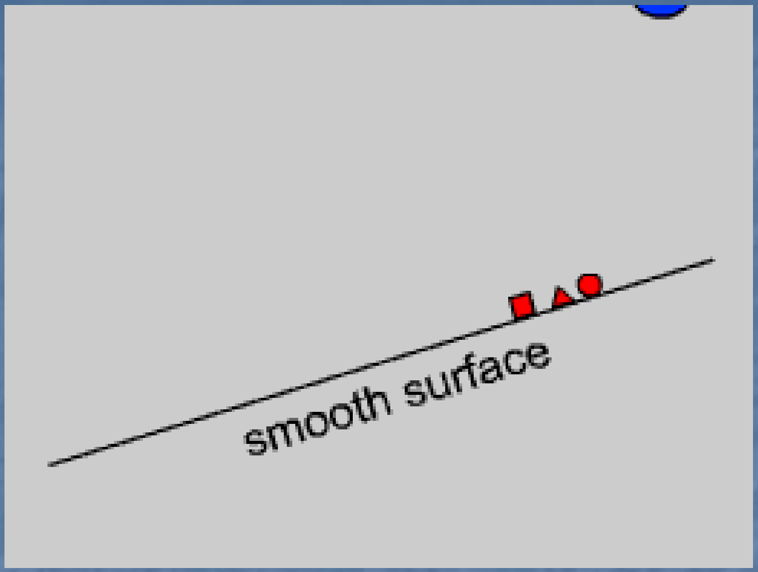
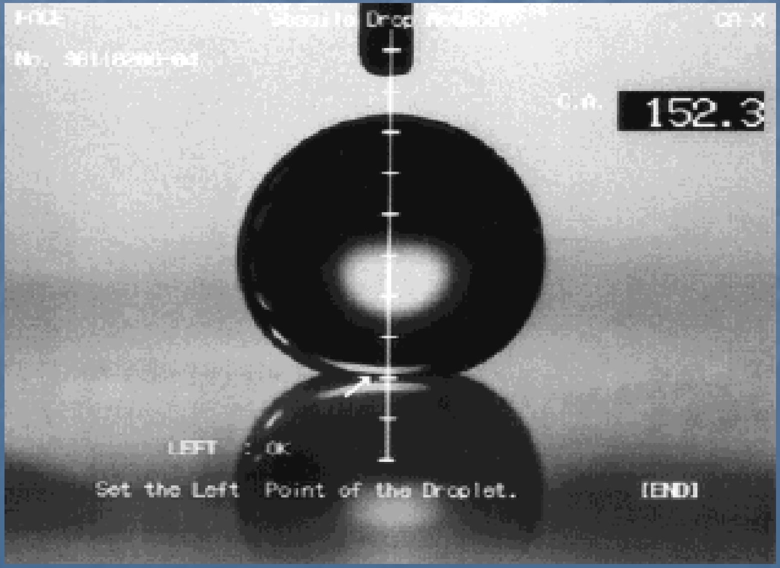


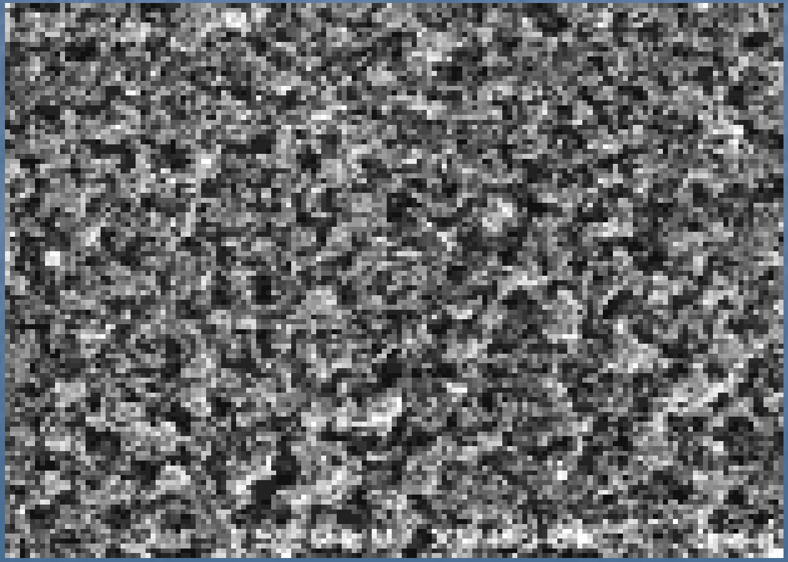
Figure 1. Surface tension and surface attractive forces for a drop of water on a non-wettable surface like glass (left), or a more attractive surface (right) [1].

Lotus Effect

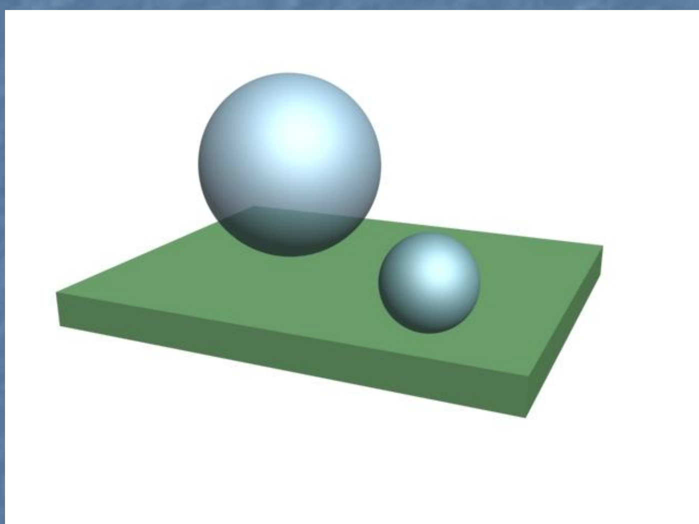








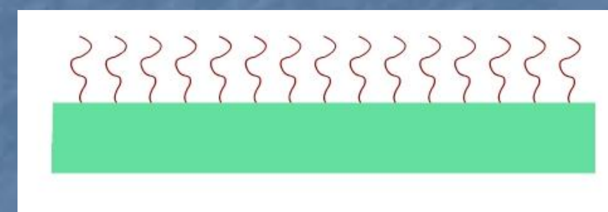
Film autopulente superidrofobico



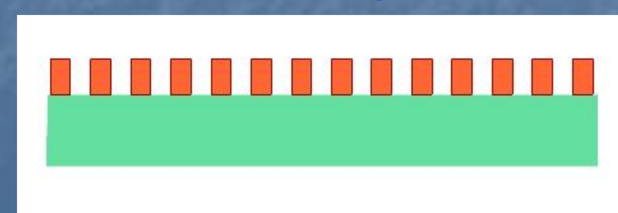
Contributo chimico

Innesto di alchilfluorosilani

Molecole idrofobiche



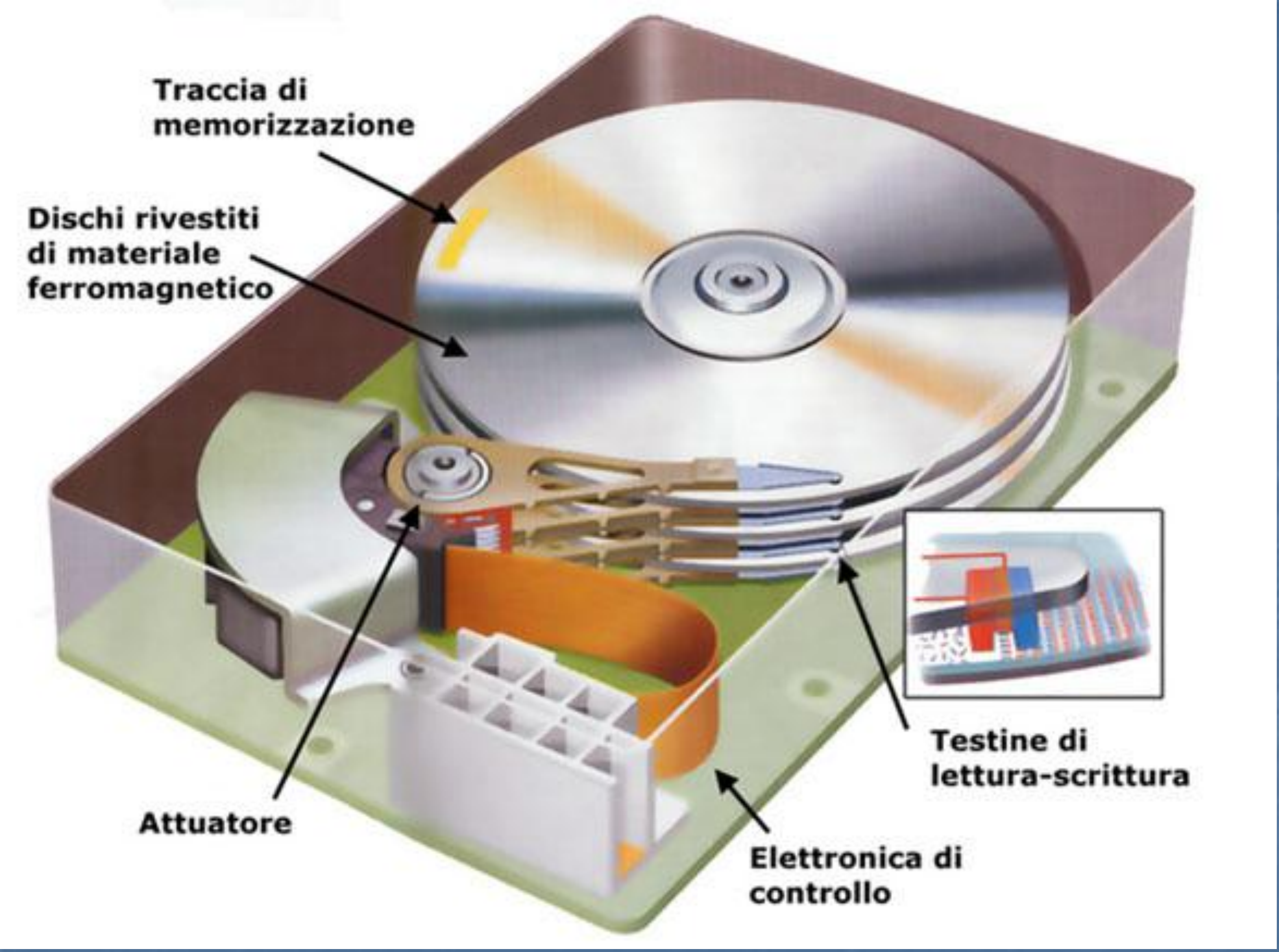
Morfologia

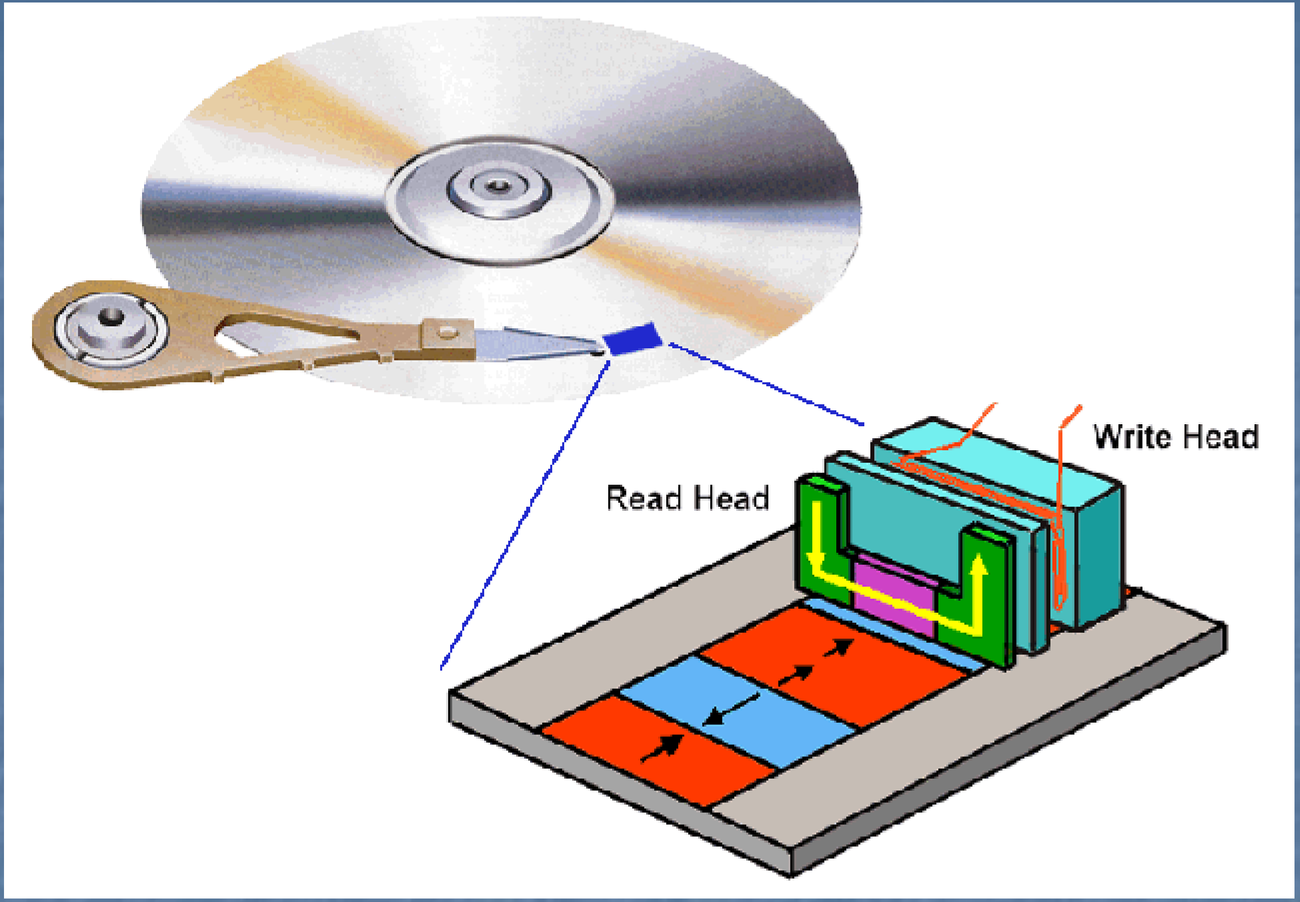


Contributo geometrico


Disco Rigido
HITACHI DK23EA-60
da 60 GB su 2 piatti,
4200 giri/minuto.
Peso 95 grammi. Proveniente da
PC portatile, circa anno 2005.


Disco rigido IBM 0667 da 70 MB con elettronica di controllo ESDI formato da 4 piatti con 8 testine magnetiche di lettura – scrittura. Anno 1985.
(Materiale gentilmente messo a disposizione dal CICAIA – Università di Modena e Reggio Emilia)


Traccia di memorizzazione
Dischi rivestiti di materiale ferromagnetico
Attuatore
Testine di lettura-scrittura
Elettronica di controllo


Write Head
Read Head

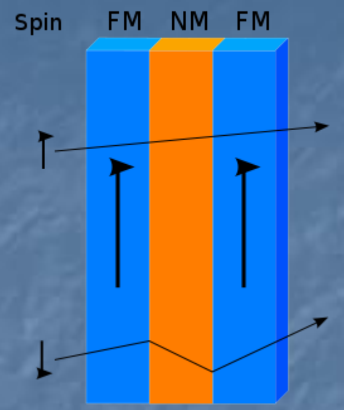
Giant magnetoresistance (GMR) (1988) is a quantum mechanical magnetoresistance effect observed in thin film structures composed of alternating ferromagnetic and nonmagnetic layers.

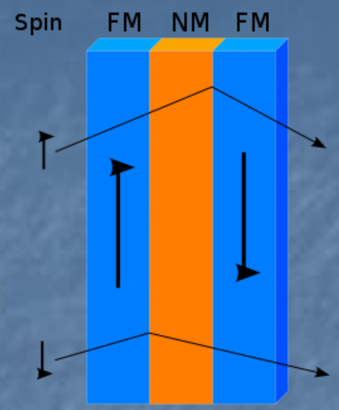
The effect manifests itself as a significant decrease (typically 10–80%) in electrical resistance in the presence of a magnetic field. In the absence of an external magnetic field, the direction of magnetization of adjacent ferromagnetic layers is antiparallel due to a weak anti-ferromagnetic coupling between layers. The result is high-resistance magnetic scattering as a result of electron sp

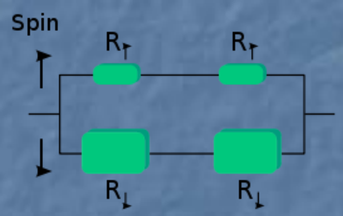
When an external magnetic field is applied, the magnetization of the adjacent ferromagnetic layers is parallel. The result is lower magnetic scattering, and lower resistance.[1]

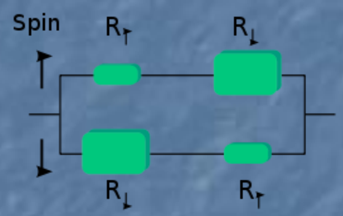
The effect is exploited commercially by manufacturers of hard disk drives.

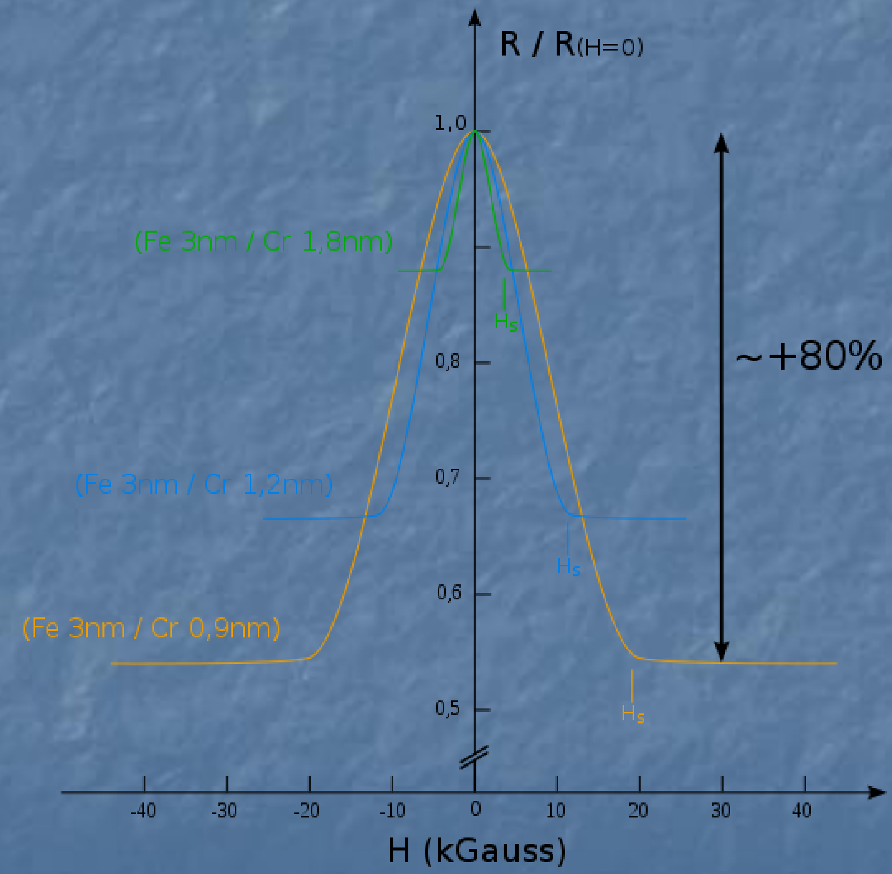
The 2007 Nobel Prize in physics was awarded to Albert Fert and Peter Grünberg for the discovery of GMR.

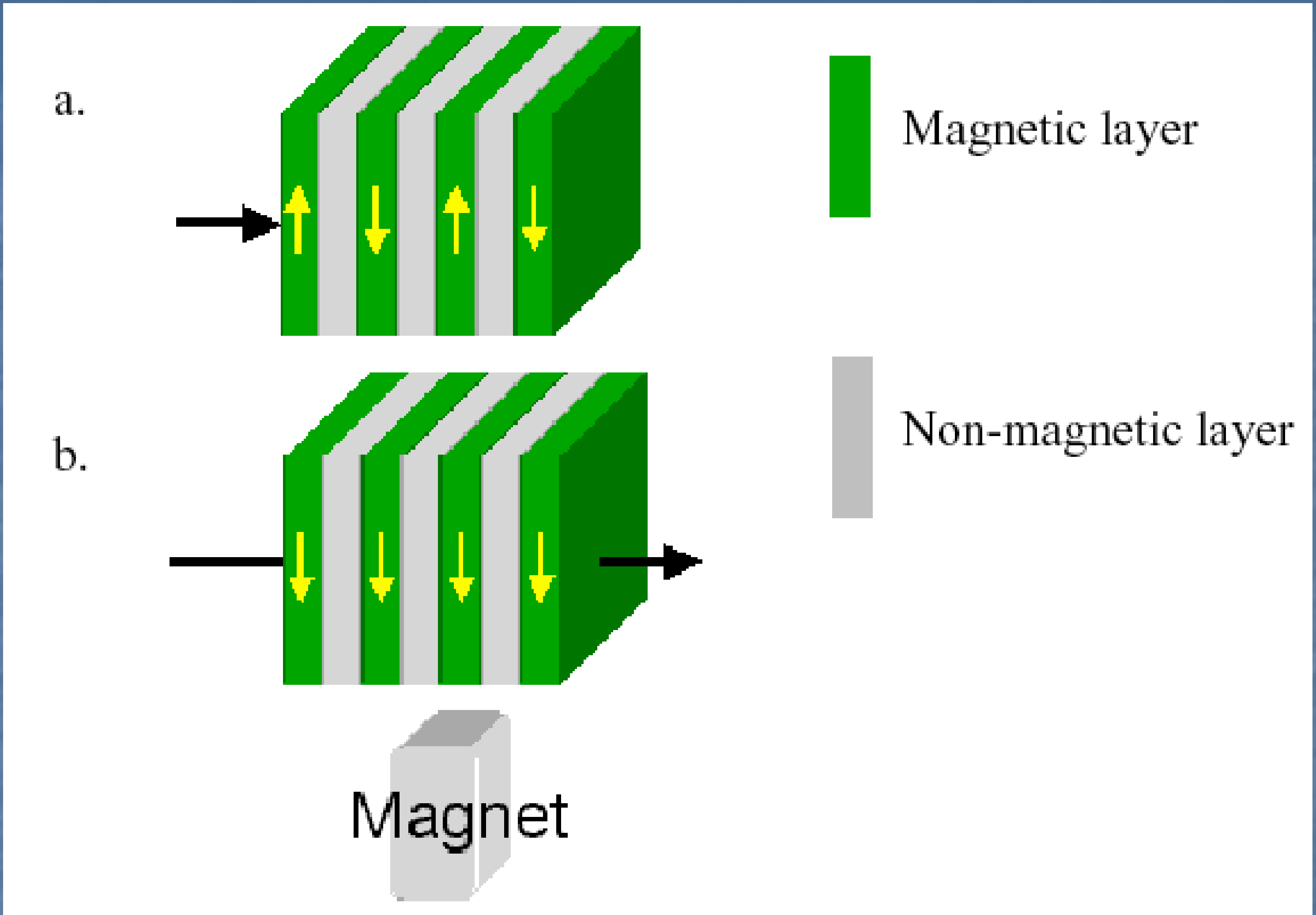

Spin
FM
NM
FM

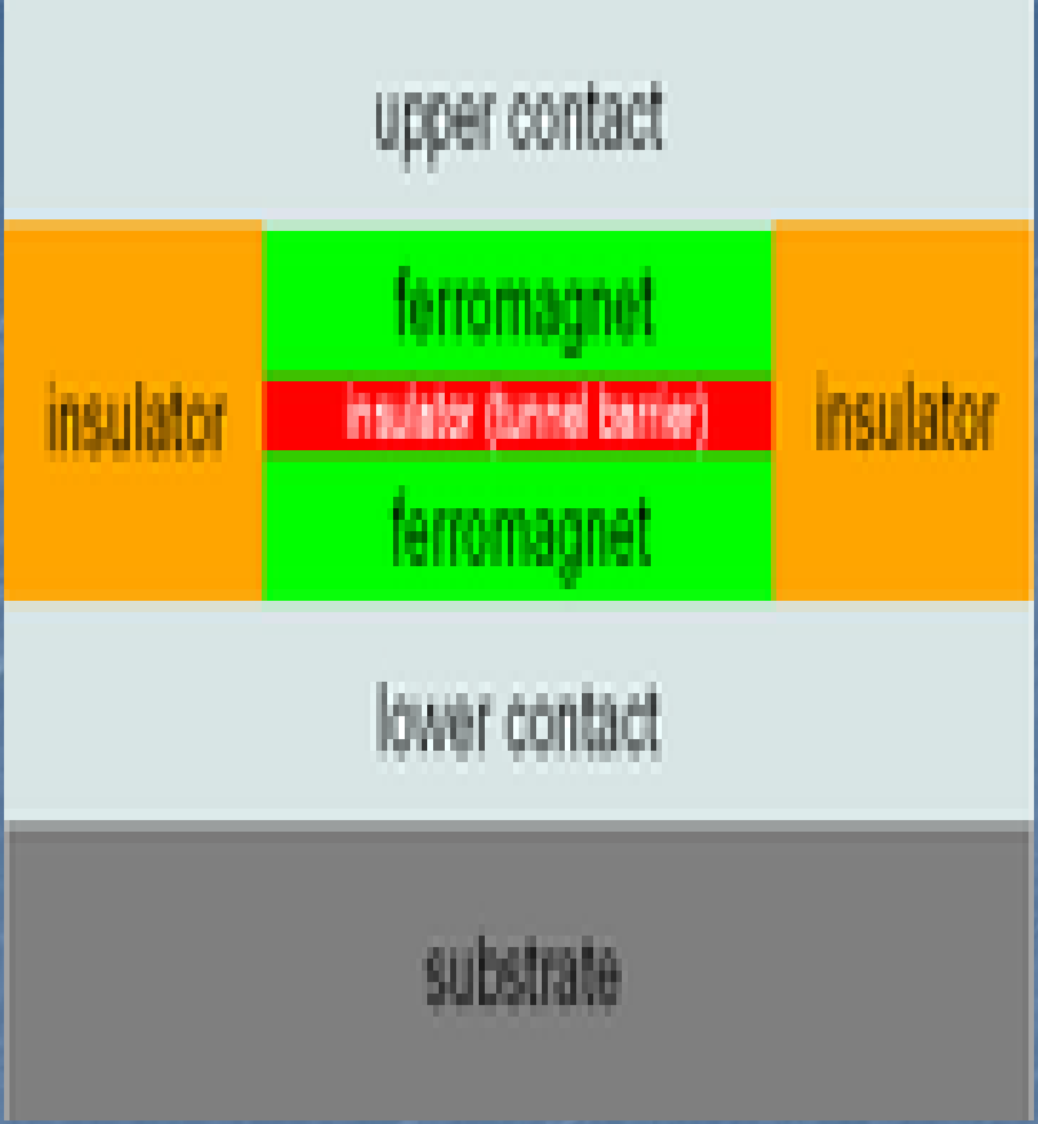

Spin
FM
NM
FM


Spin
R↑
R↑
R↓
R↓


Spin
R↑
R↓
R↓
R↑

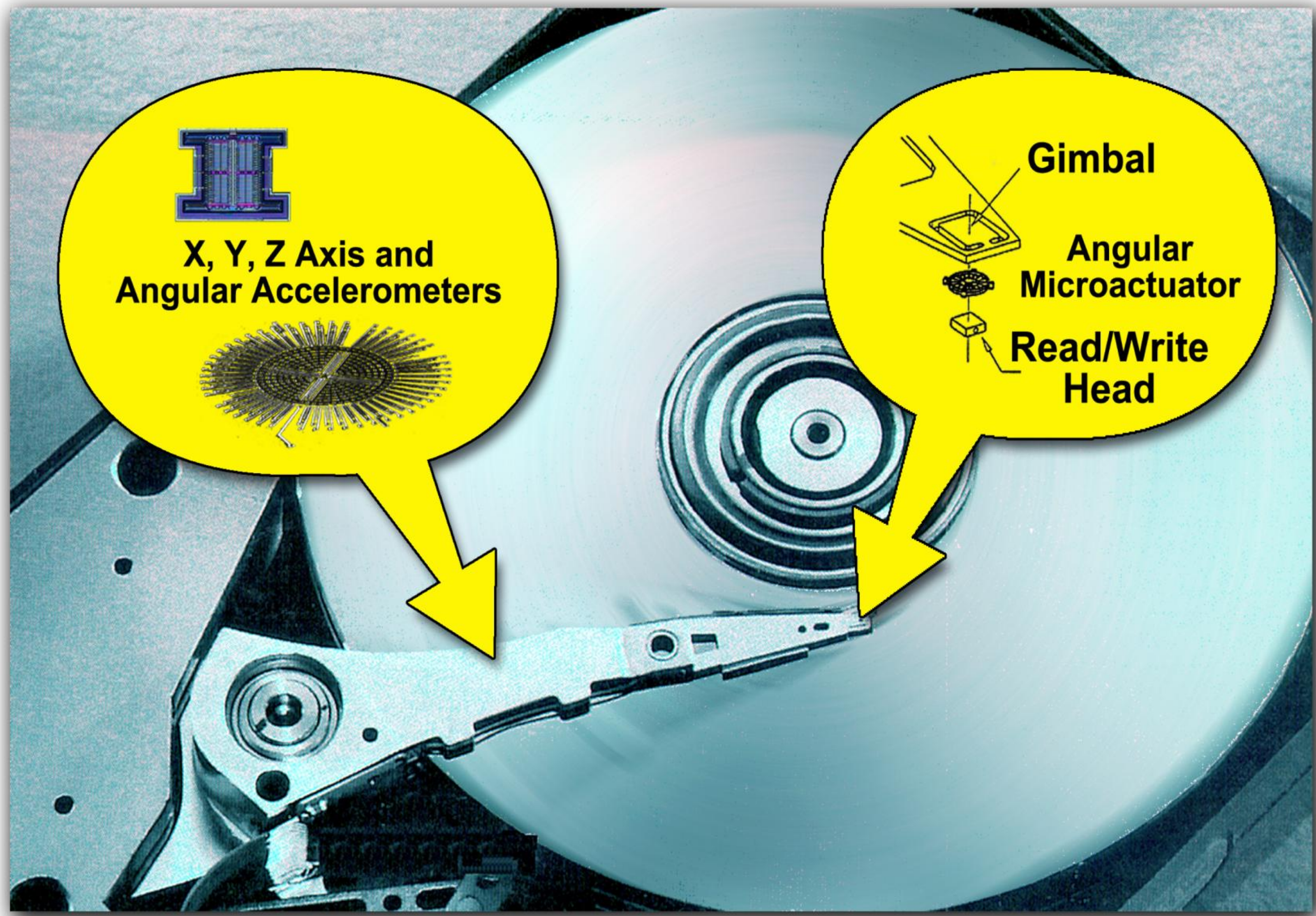

R / R(H=0)
1,0
0,8
0,7
0,6
0,5
(Fe 3nm / Cr 1,8nm)
(Fe 3nm / Cr 1,2nm)
(Fe 3nm / Cr 0,9nm)
Hs
Hs
Hs
~+80%
-40
-30
-20
-10
0
10
20
30
40
H (kGauss)


a.
b.
Magnetic layer
Non-magnetic layer
Magnet

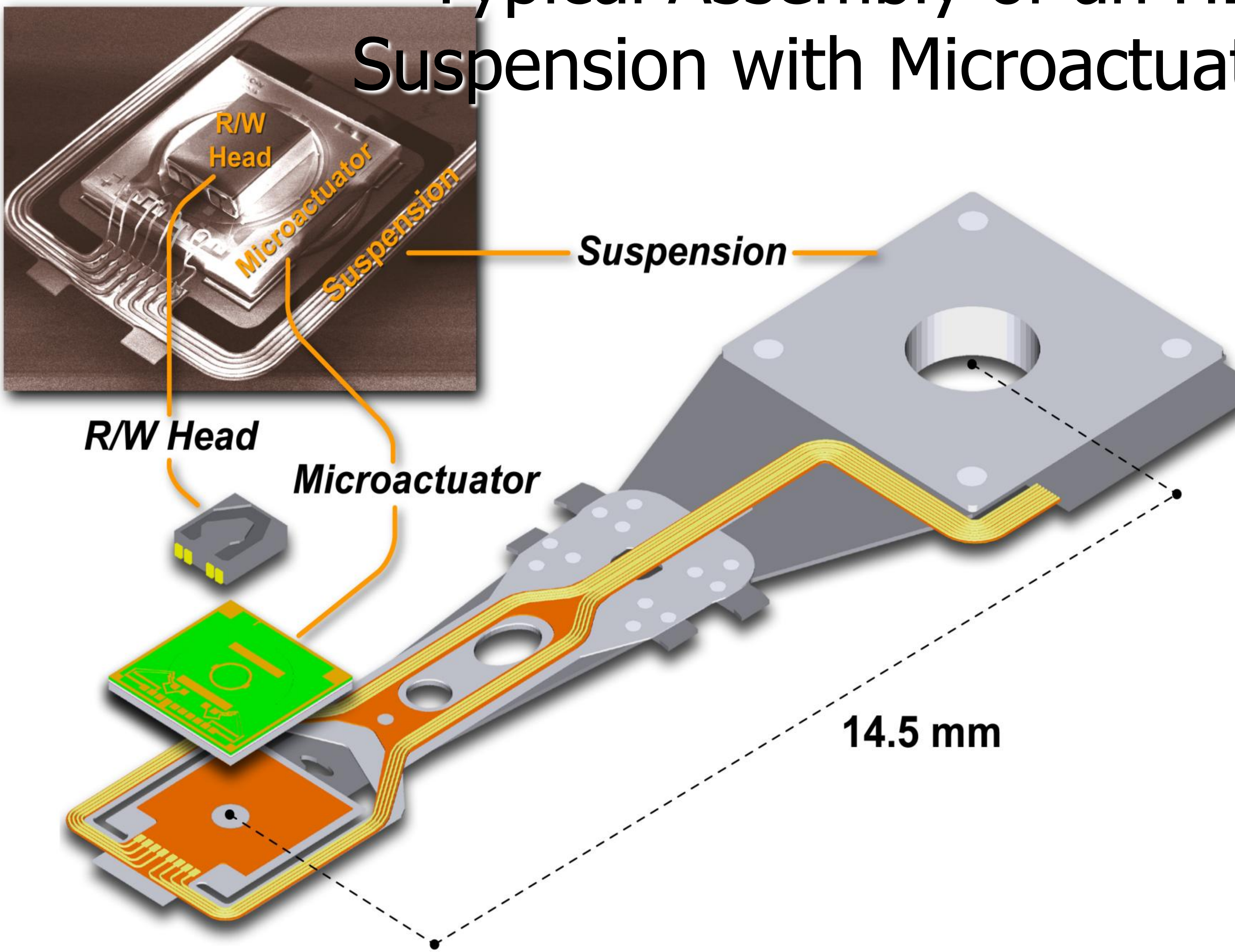


Tunnel magnetoresistance (TMR)

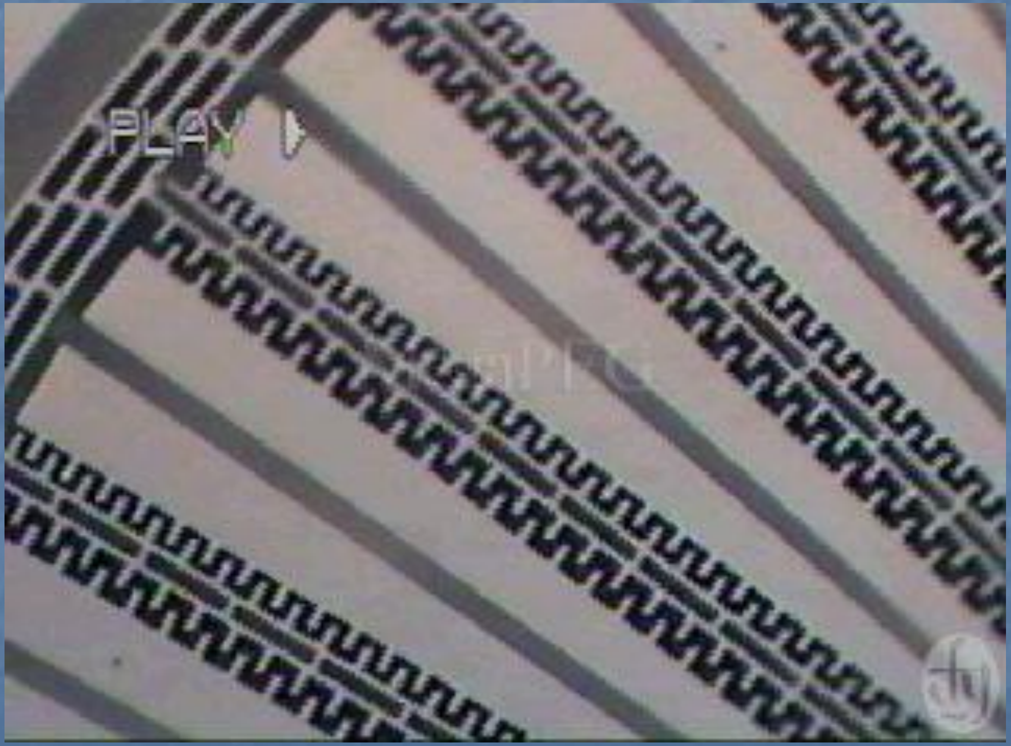
Silicon Microstructures in Future HDD



Typical Assembly of an HDD Suspension with Microactuator

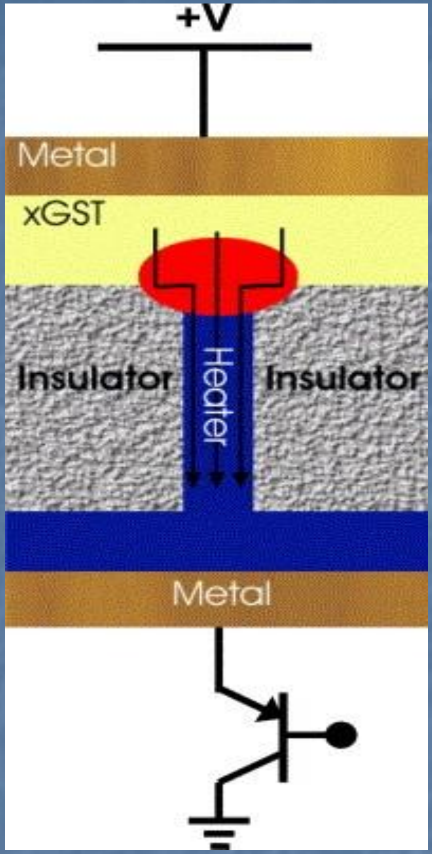


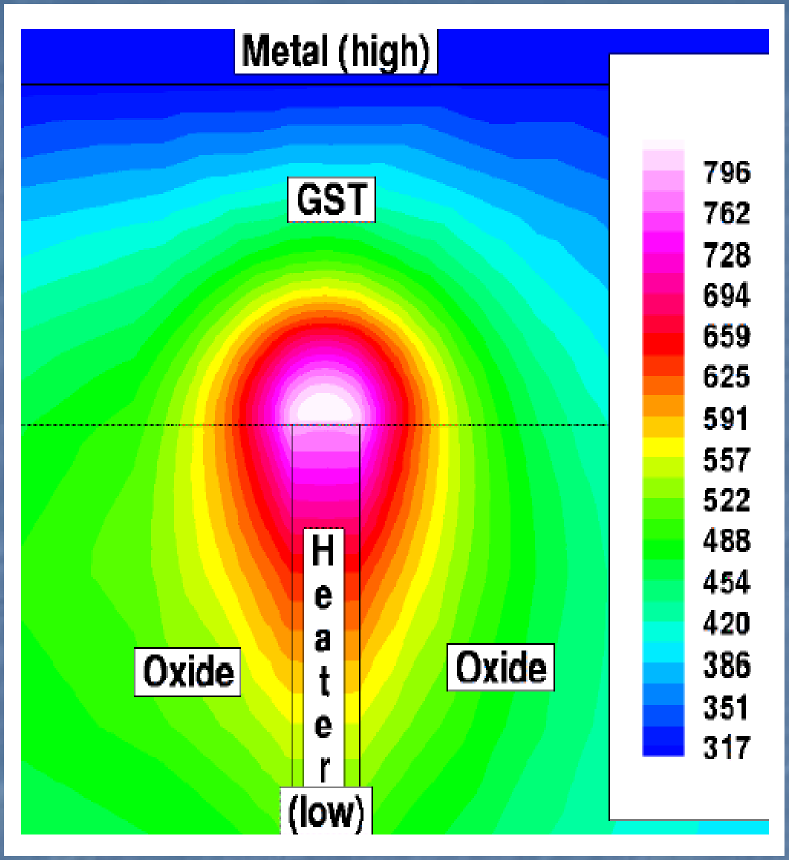
Microactuator without Cap Movie



MEMORIE ELETTRONICHE DI NUOVA GENERAZIONE A CAMBIAMENTO DI FASE REVERSIBILE

PCM = Phase Change Memories



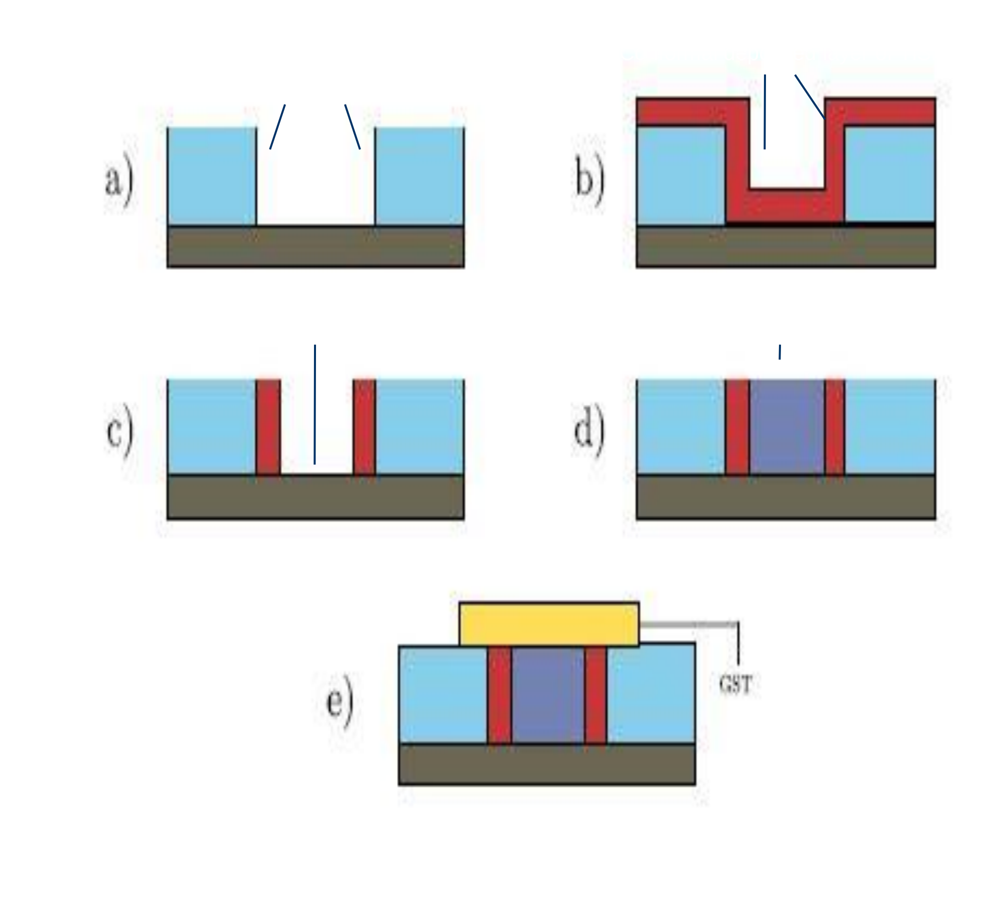


-Maximum temperature at the GST/Heater interface: ~800 °C

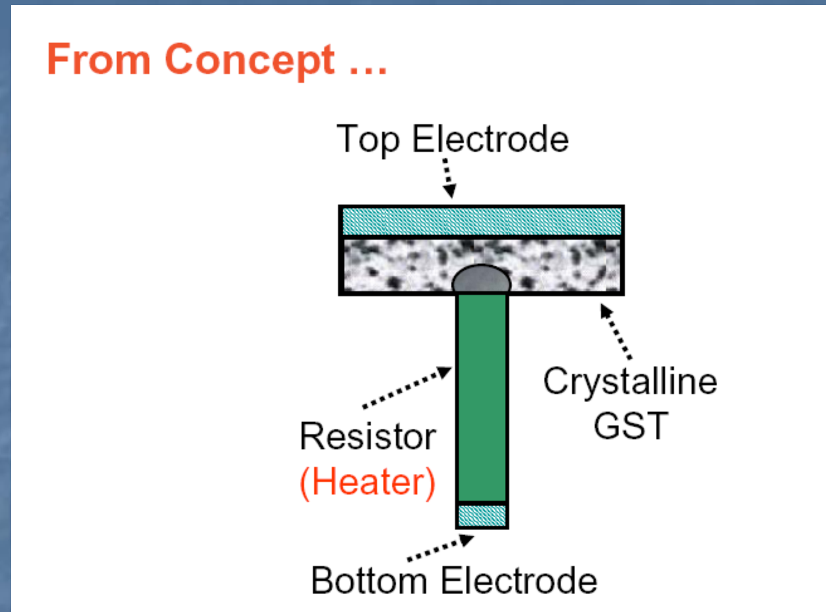
-Maximum temperature at Metal/GST interface: 300 ÷ 400 °C

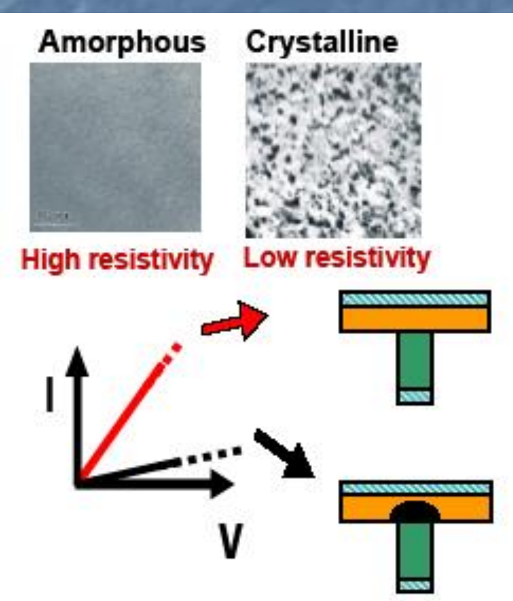
Sample Deposition Process

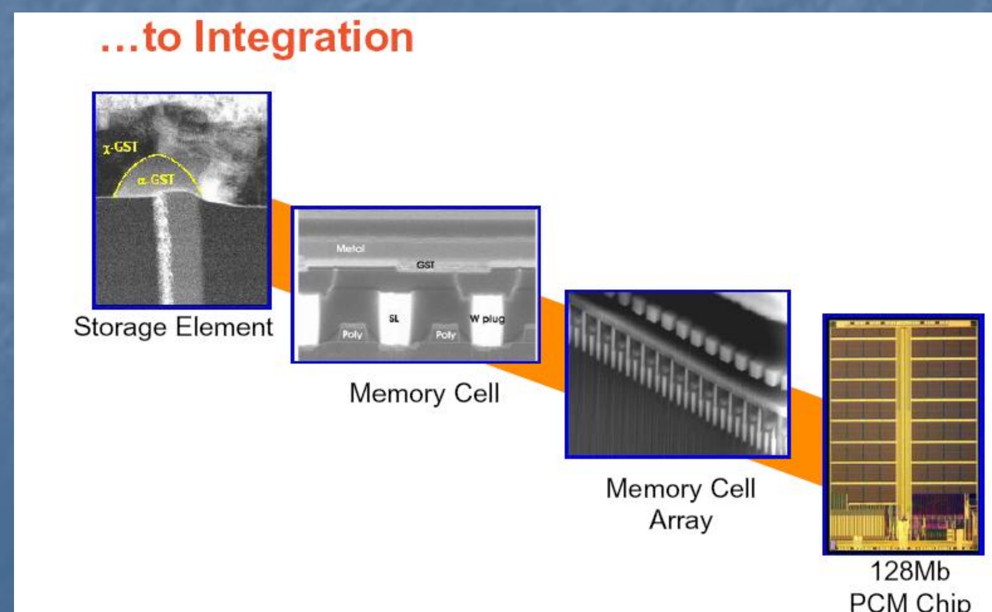
No Lithographic process



Cella di Memoria Elettronica non-volatile con materiale con cambiamento di fase reversibile

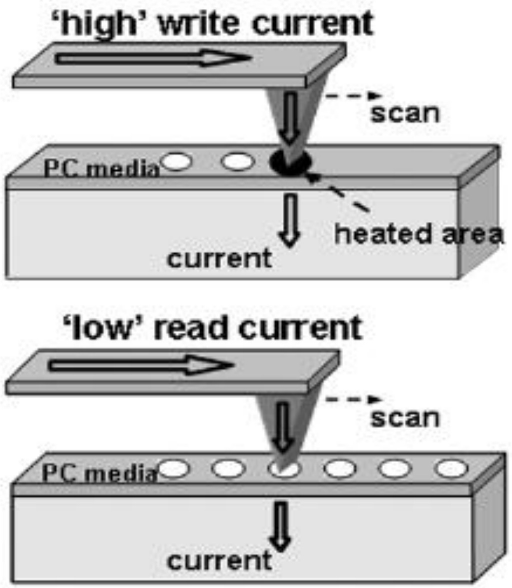


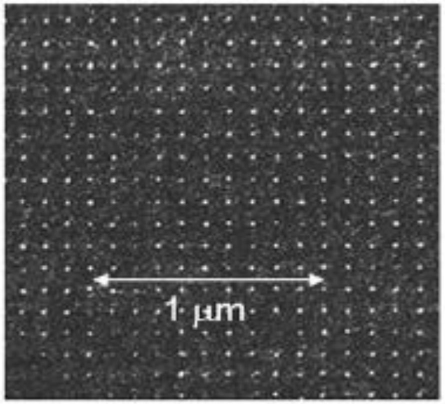


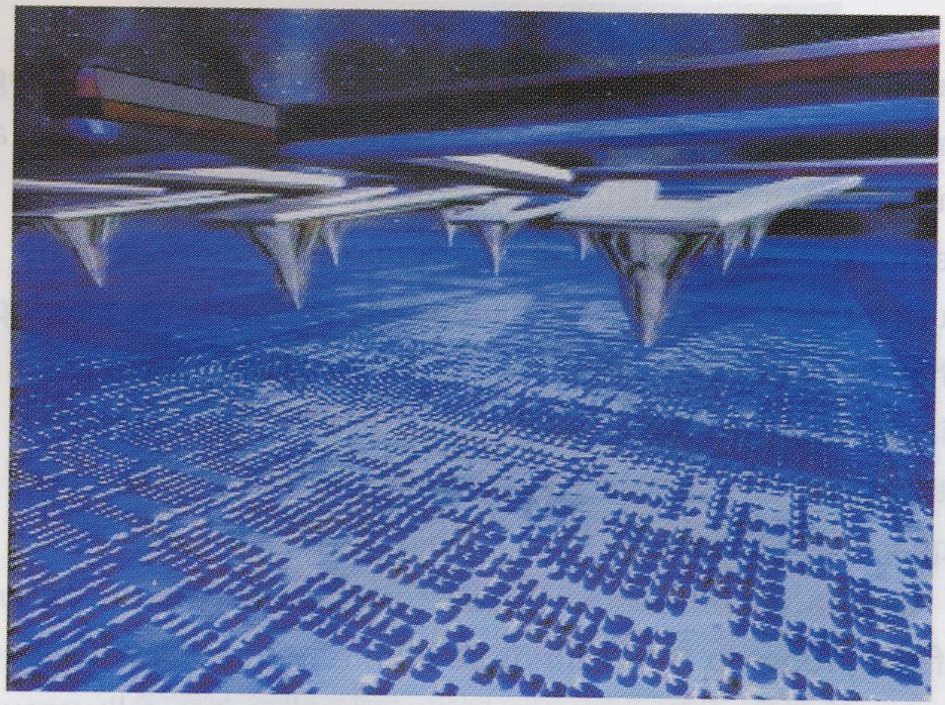


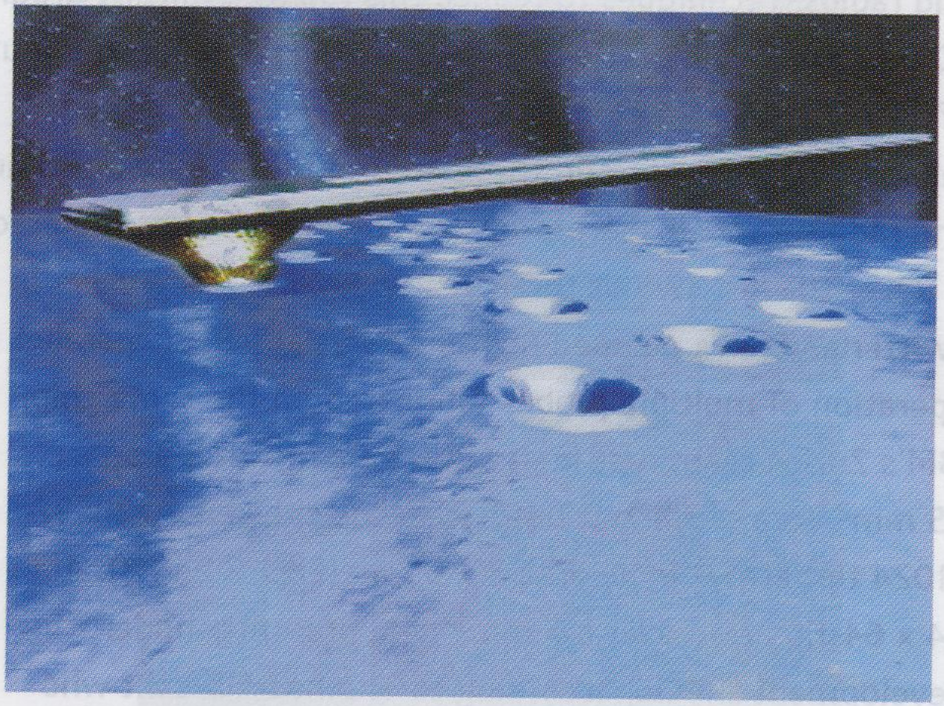
NUOVI TIPI DI MEMORIE

BASATI SU AFM e MATERIALI A VARIAZIONE DI FORMA REVERSIBILE



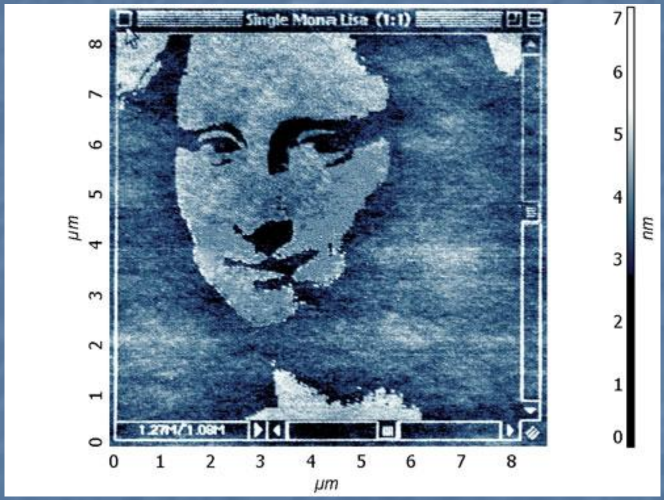




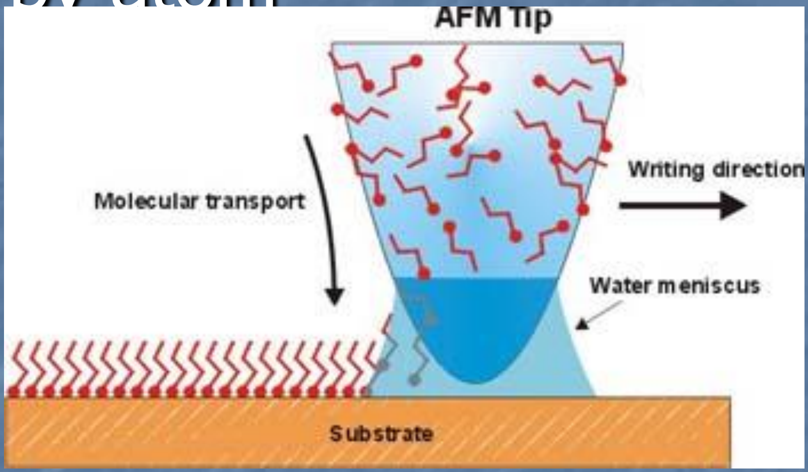


Technology: Building Smaller Devices and Chips

- Nanolithography to create tiny patterns
  - Lay down "ink" atom by atom



Mona Lisa, 8 microns tall, created by AFM nanolithography



Transporting molecules to a surface by dip-pen nanolithography

Sources: http://www.ntmdt.ru/SPM-Techniques/Principles/Lithographies/AFM_Oxidation_Lithography_mode37.html
http://www.chem.northwestern.edu/~mkngrp/dpn.htm

EFFETTO SEEBECK

(THOMSON)

*L'**effetto Seebeck** è un effetto termoelettrico per cui, in un circuito costituito da conduttori metallici o semiconduttori, una differenza di temperatura genera elettricità*

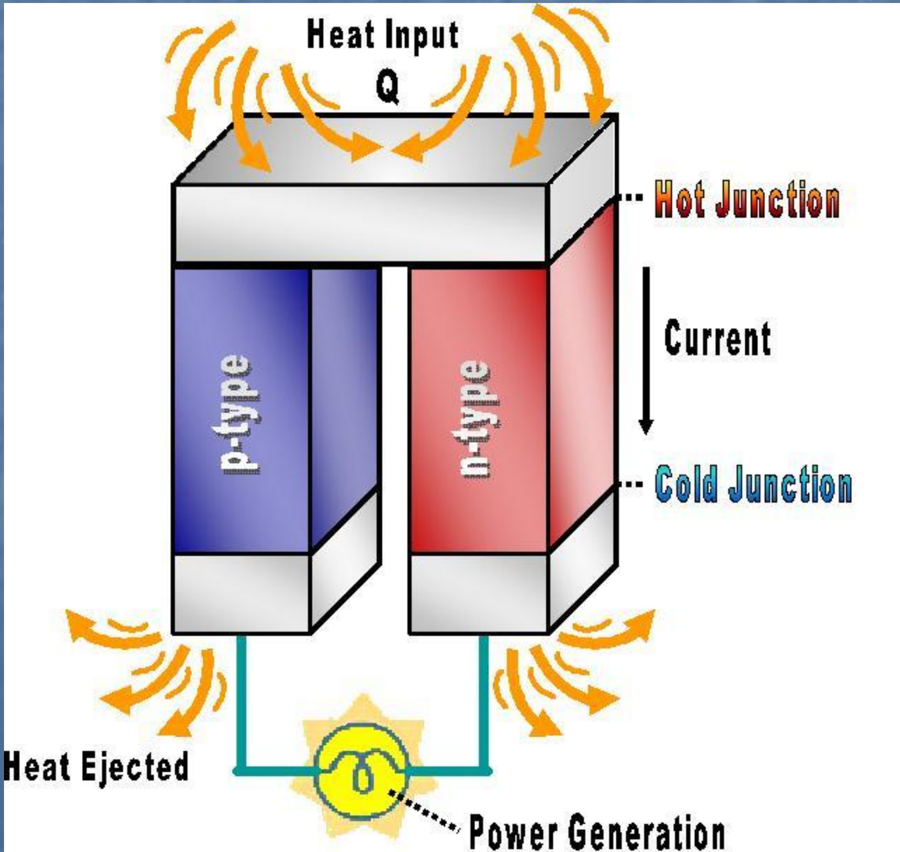


Figura di merito Seebeck

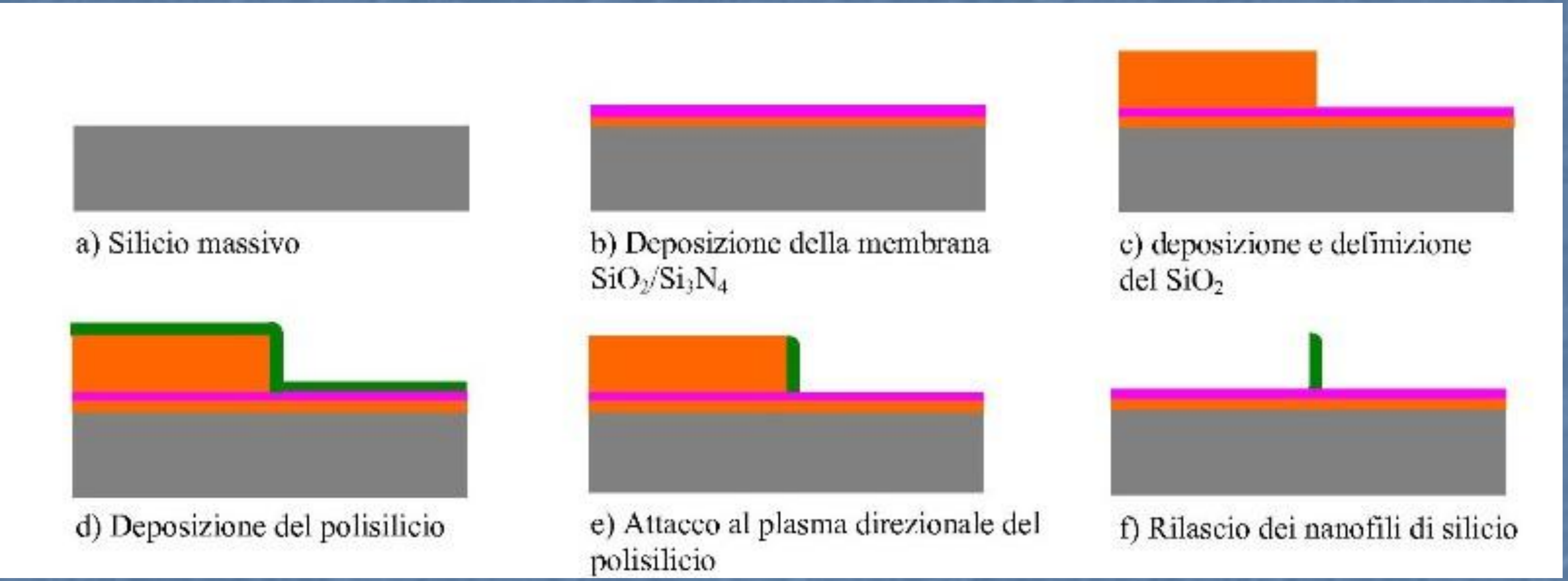
Rapporto tra:
Conducibiltà elettrica e Conducibiltà termica

Dipende dal materiale attraverso il coefficiente Seebeck

Valori Figura di Merito:
Bi_2Te_3 circa 1 (materiale generalmente usato)
Metalli circa 10^{-4} -10^{-5}
Silicio poly circa $3x10^{-2}$

In fili nanocristallini di silicio la conducibilita termica diminuisce di un fattore 100 dovuto allo scattering dei fononi sulle superfici

Effetto Seebeck nanofili di silicio



Effetto Seebeck nanosuperfici di silicio

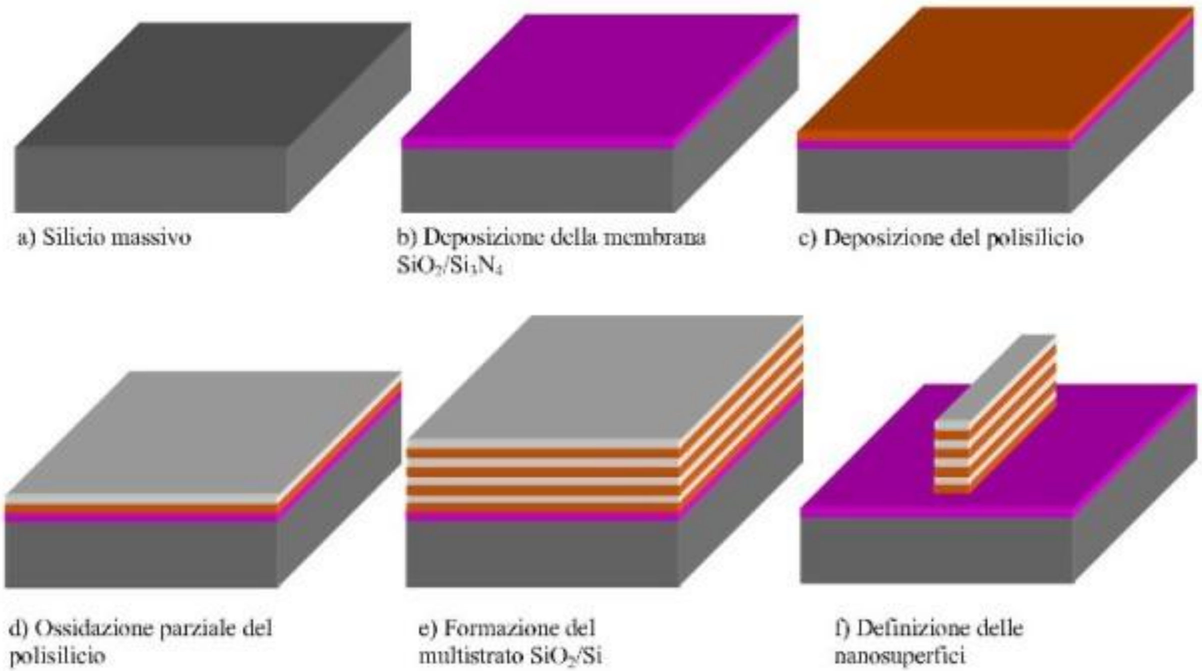
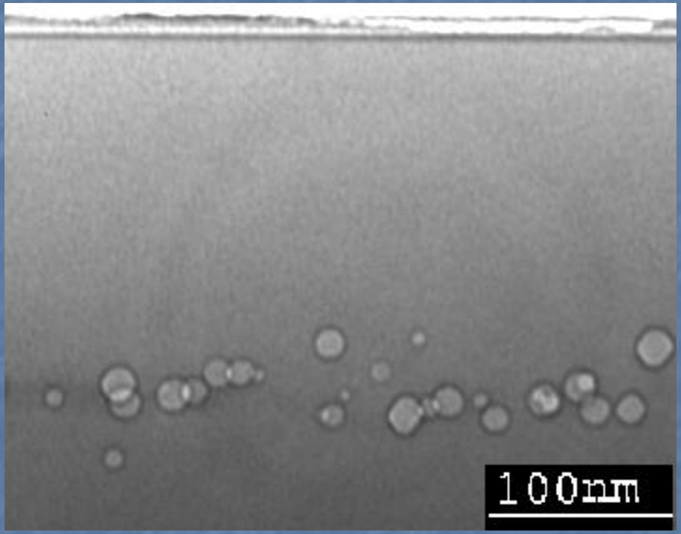


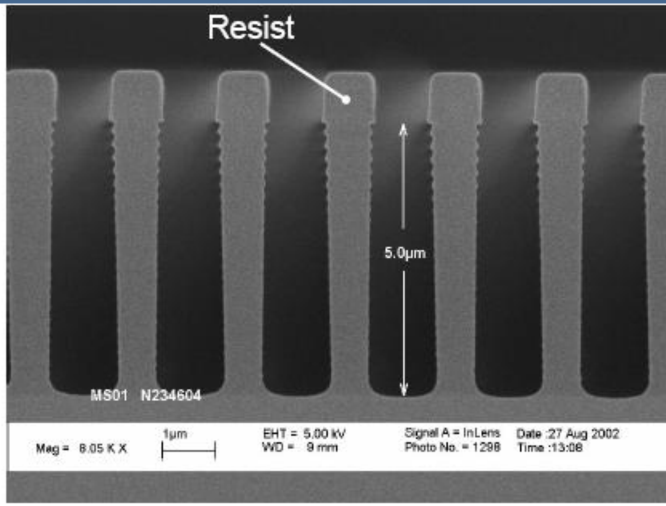
Fig. 3: Flusso di processo per la realizzazione di nanosuperfici di silicio

Helium Implanted Silicon

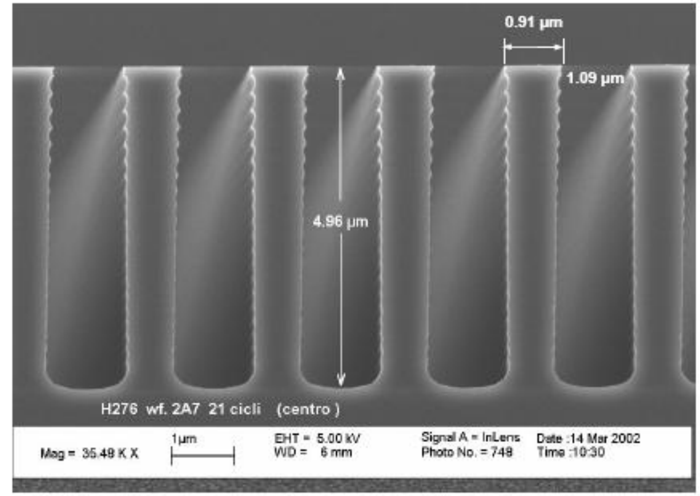


800 C 2 hours

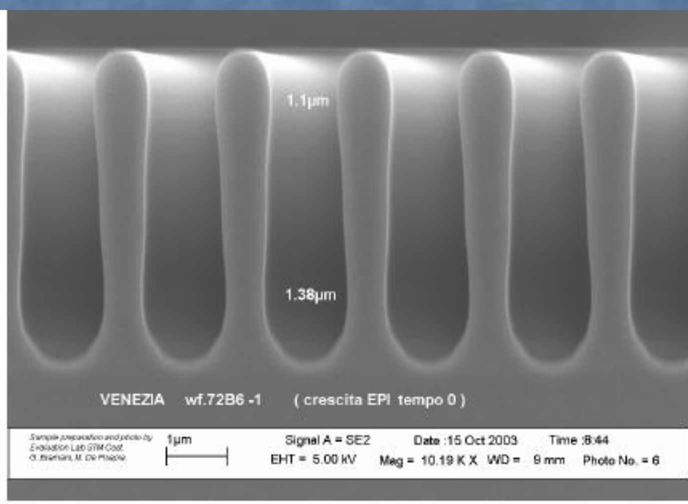
500 C 2 hours



After trench etch

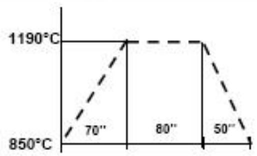


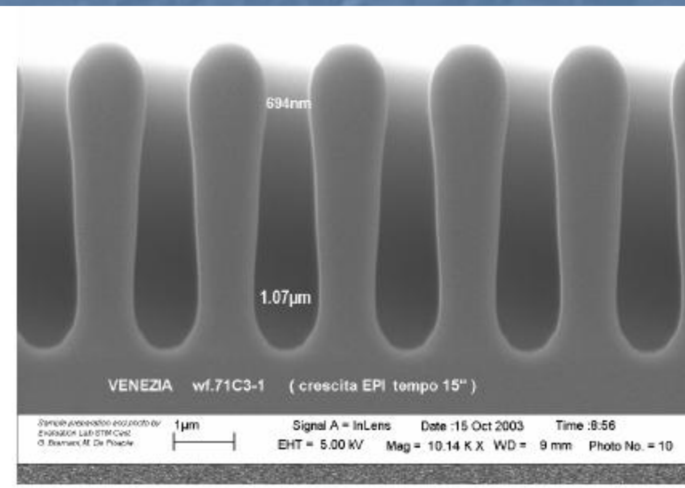
After resist strip



Atmospheric pressure

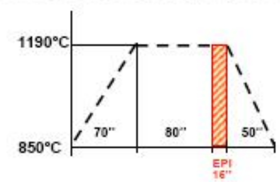
H_2 flow: 70 l/m

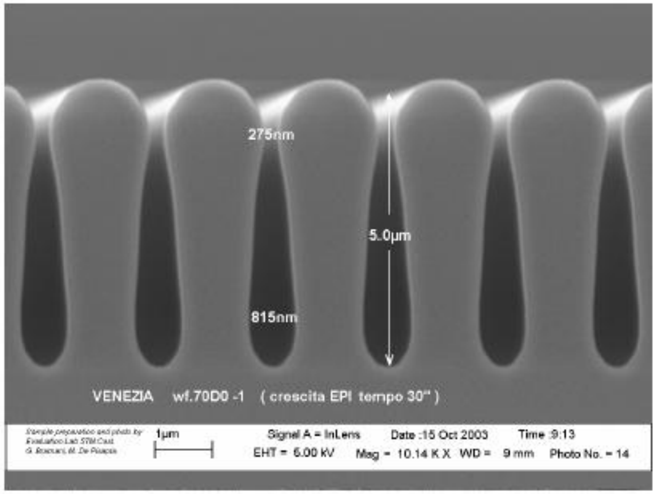




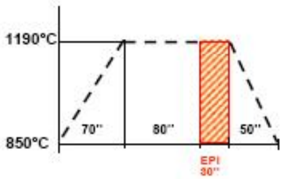
Atmospheric pressure
H_2 flow: 70 l/m

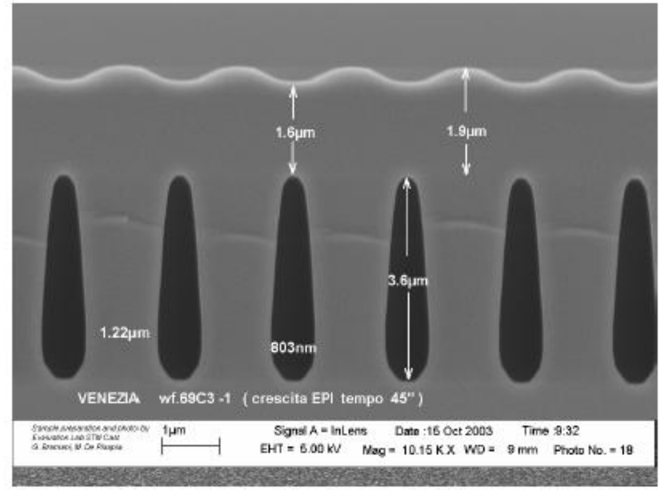
$SiHCl_3$ flow: 9.7 g/m
Dep rate: 54.7 nm/s



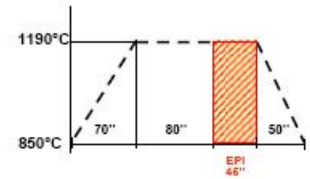


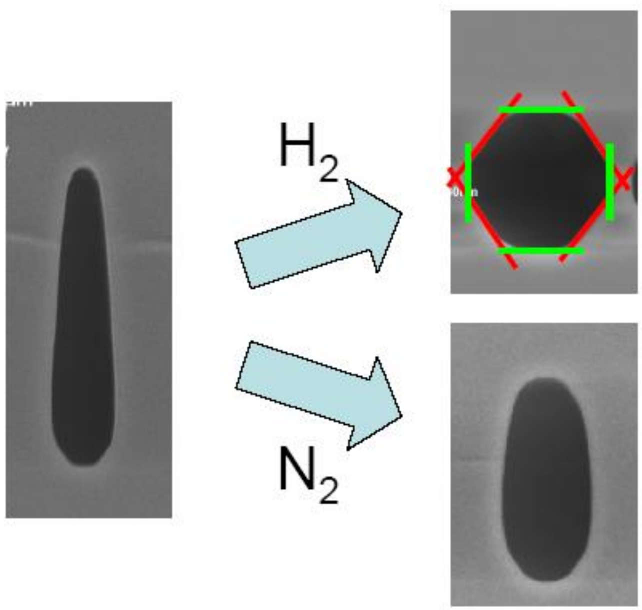
Atmospheric pressure
H_2 flow: 70 l/m
$SiHCl_3$ flow: 9.7 g/m
Dep rate: 54.7 nm/s

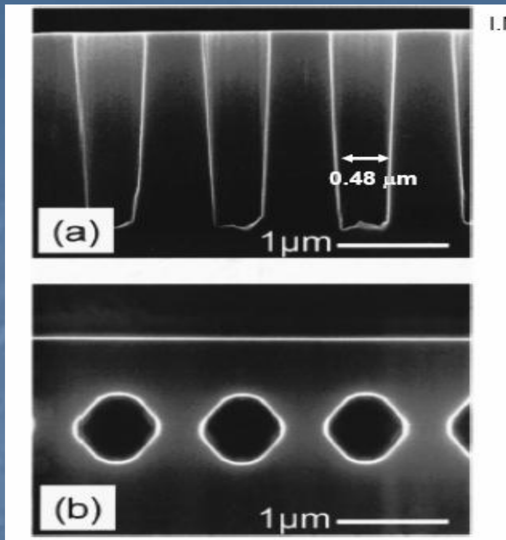


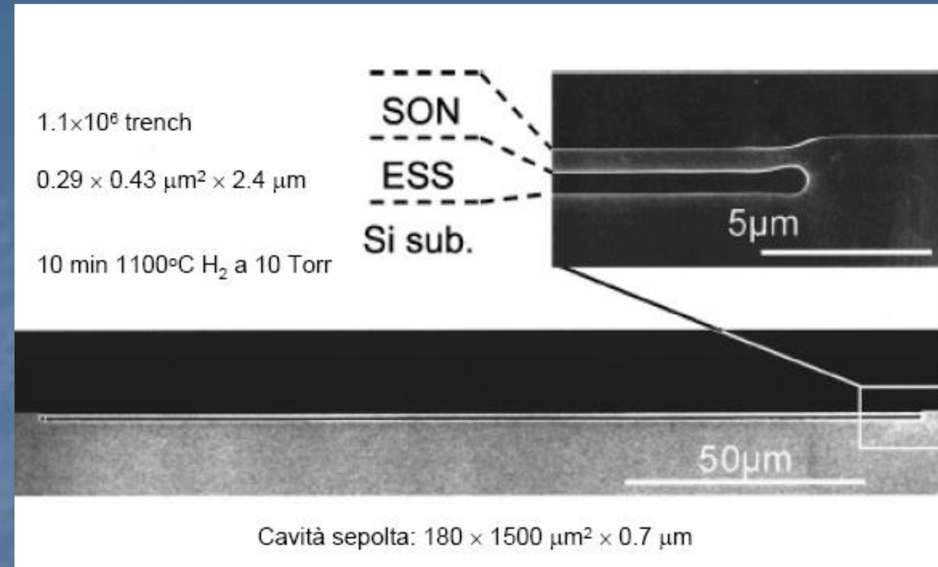


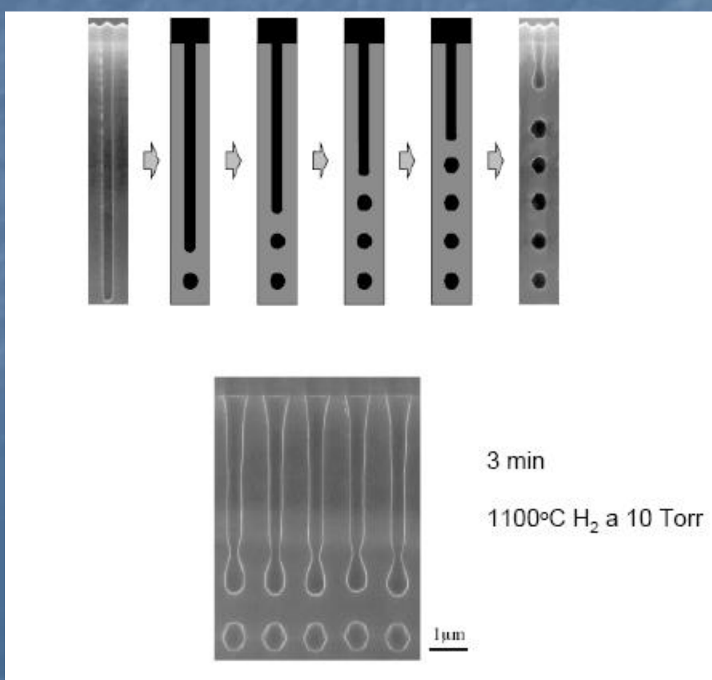
Atmospheric pressure
H_2 flow: 70 l/m
$SiHCl_3$ flow: 9.7 g/m
Dep rate: 54.7 nm/s

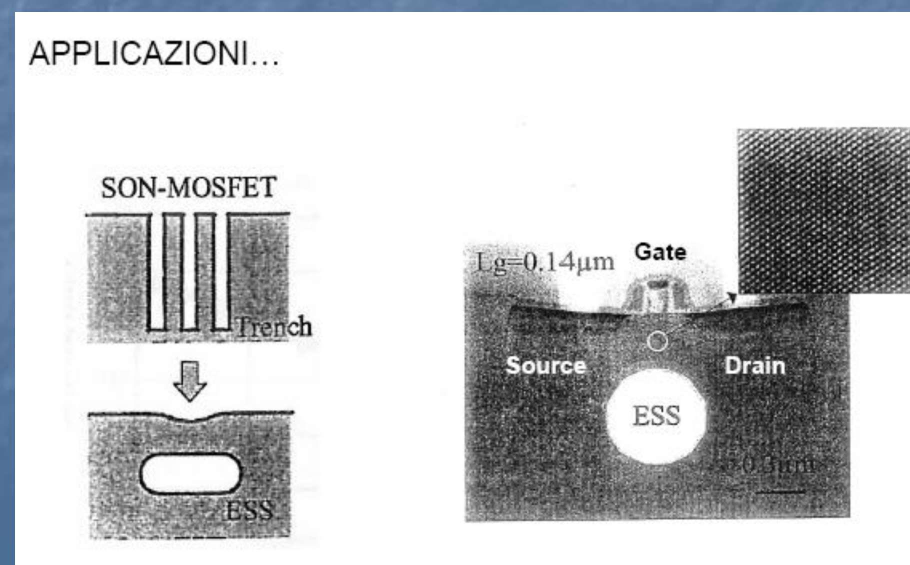




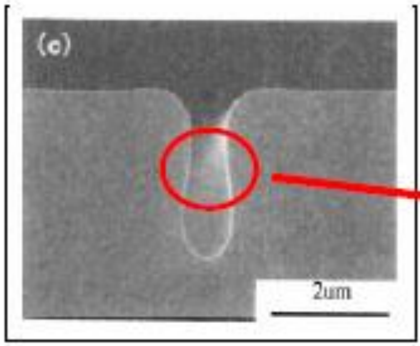

0.48 µm
(a)
1µm
(b)
1µm


1.1×10⁶ trench
0.29 × 0.43 µm² × 2.4 µm
10 min 1100°C H_2 a 10 Torr
SON
ESS
Si sub.
5µm
50µm
Cavità sepolta: 180 × 1500 µm² × 0.7 µm

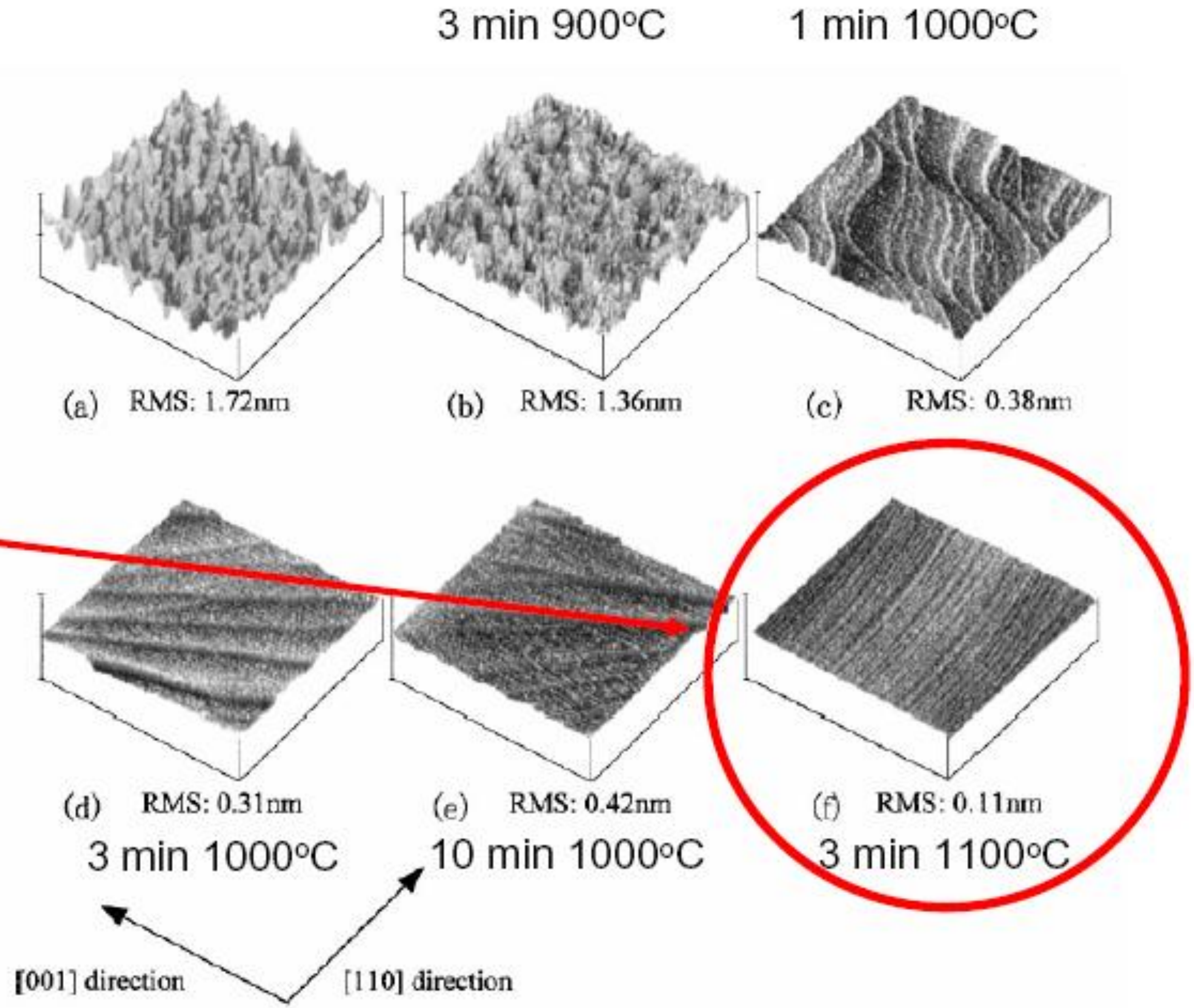

3 min
1100°C H_2 a 10 Torr
1µm


APPLICAZIONI…
SON-MOSFET
Trench
ESS
Lg=0.14µm
Gate
Source
Drain
ESS

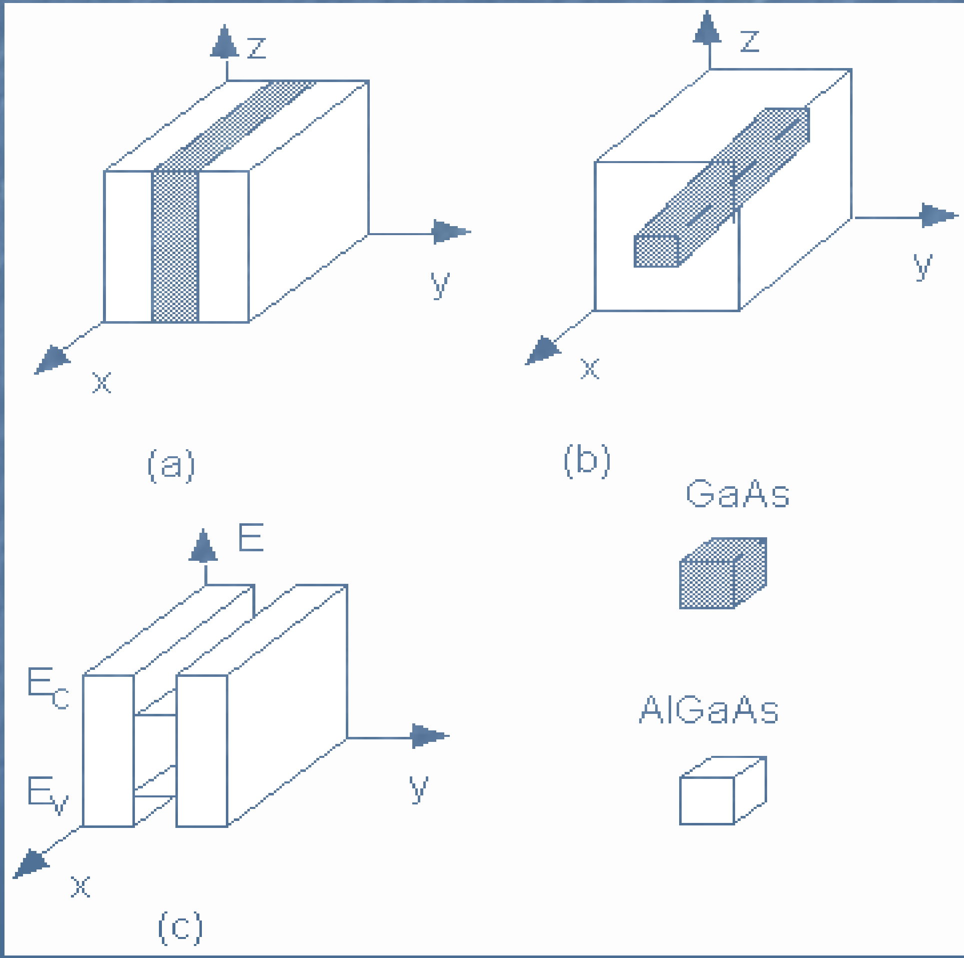
Parete laterale interna del trench circa a metà profondità



P_{H2} = 40 Torr

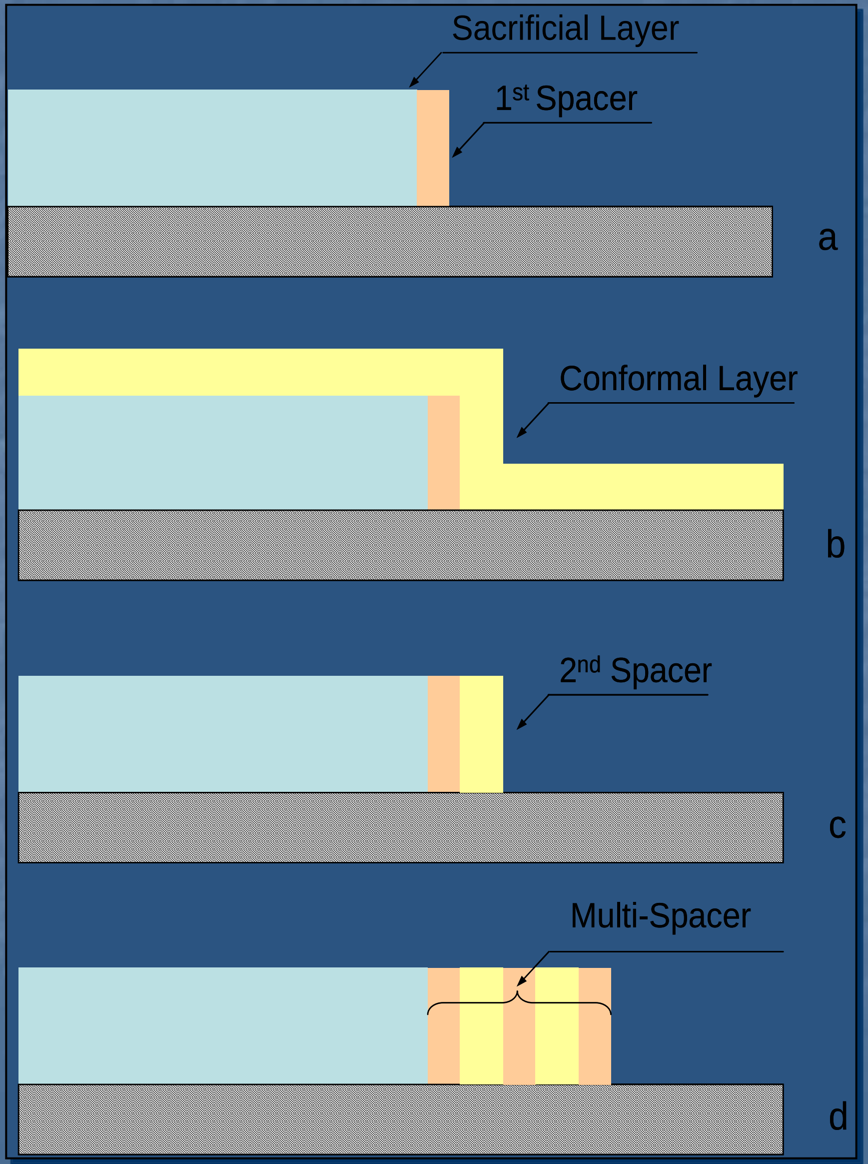


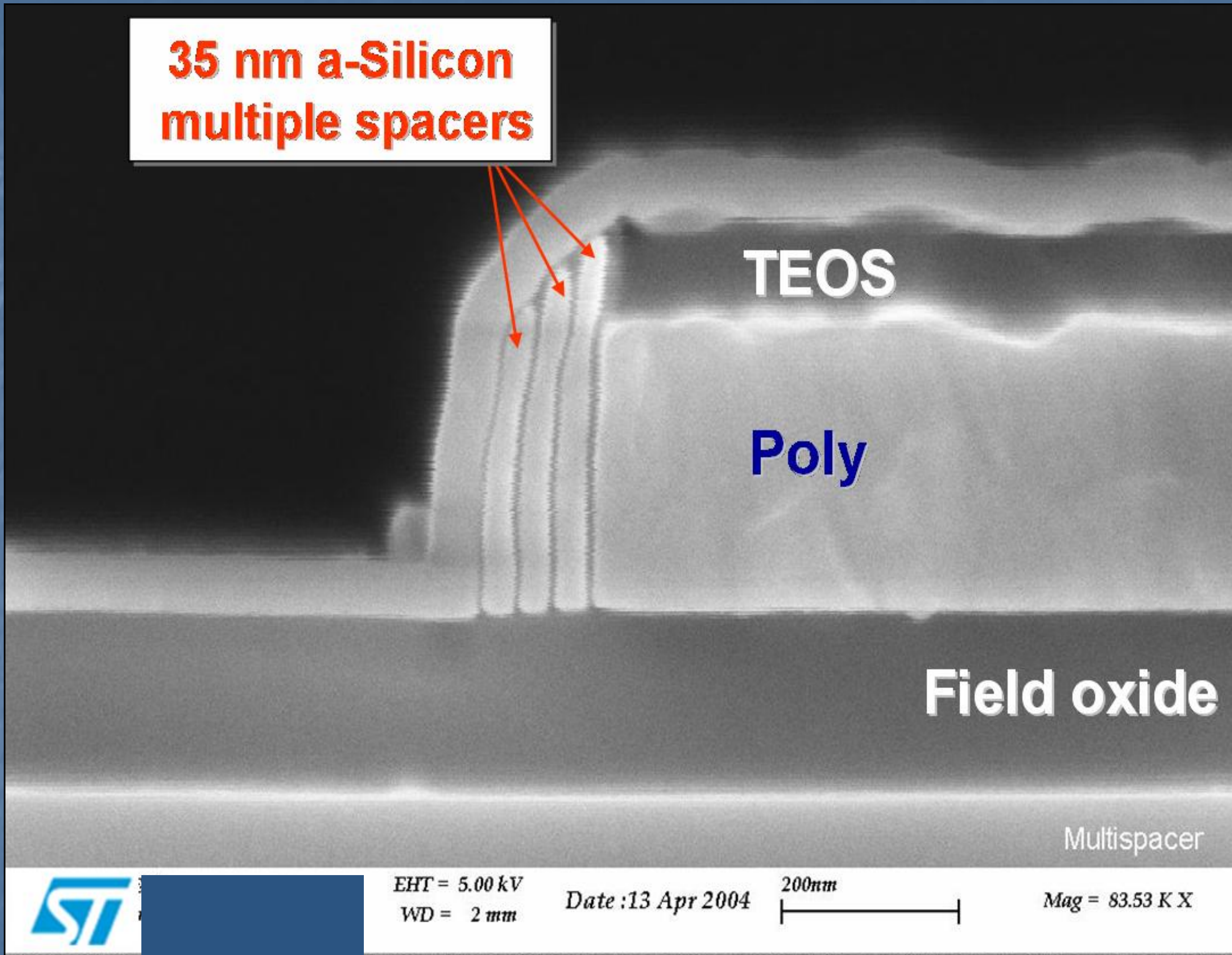
il confinamento quantico



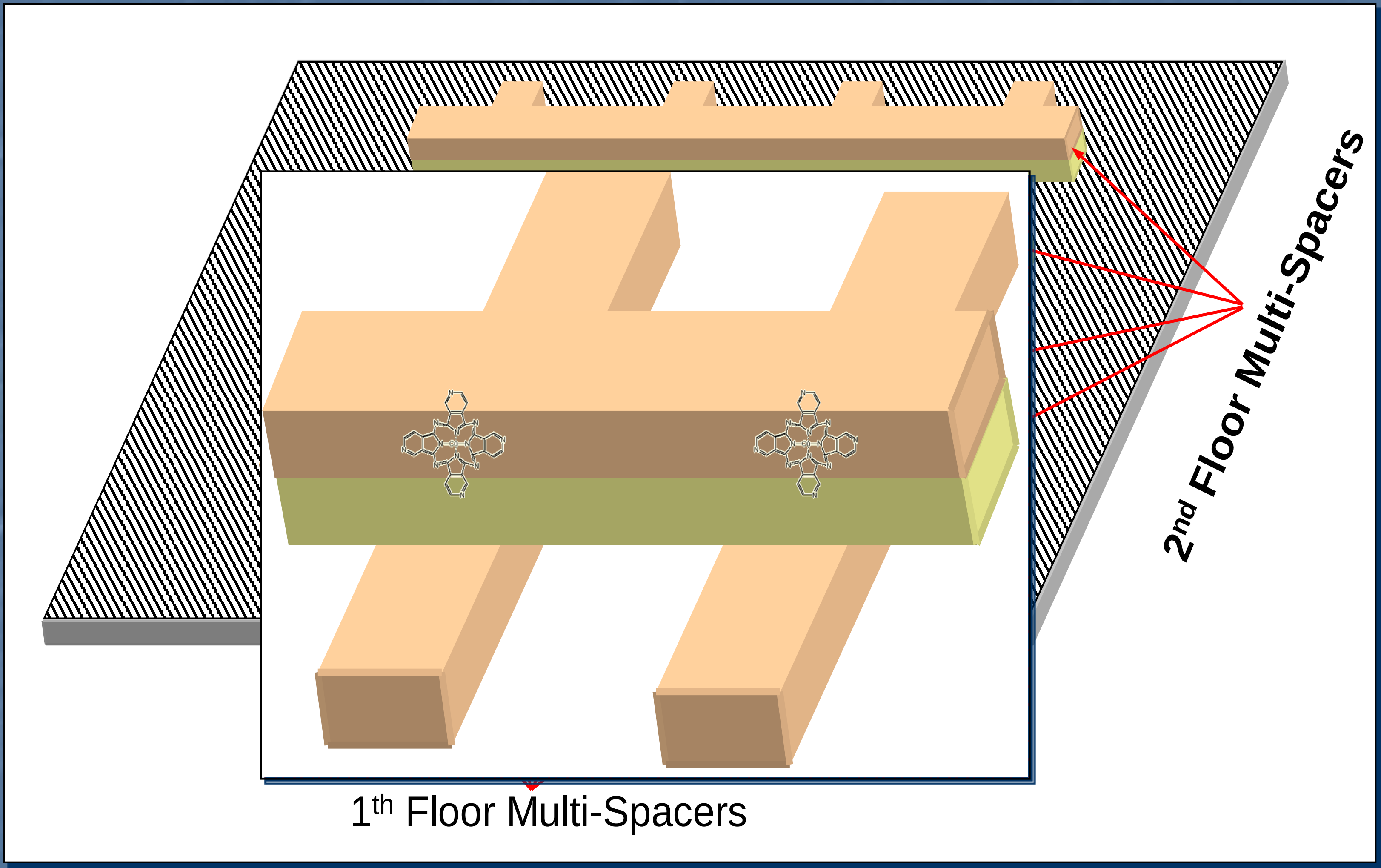
ELETTRONICA MOLECOLARE UNA POSSIBILITA'

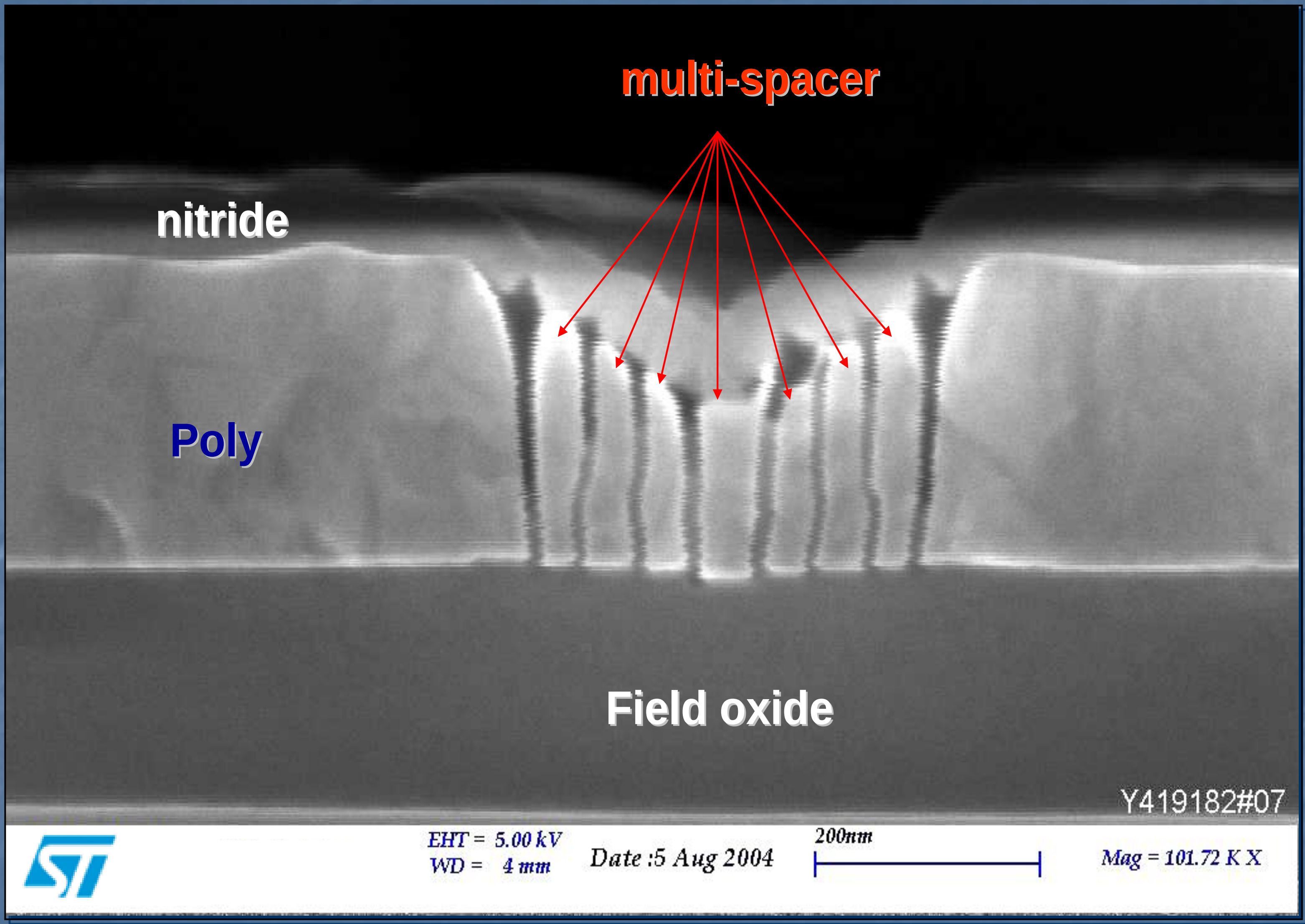
The Multi Spacer Technology



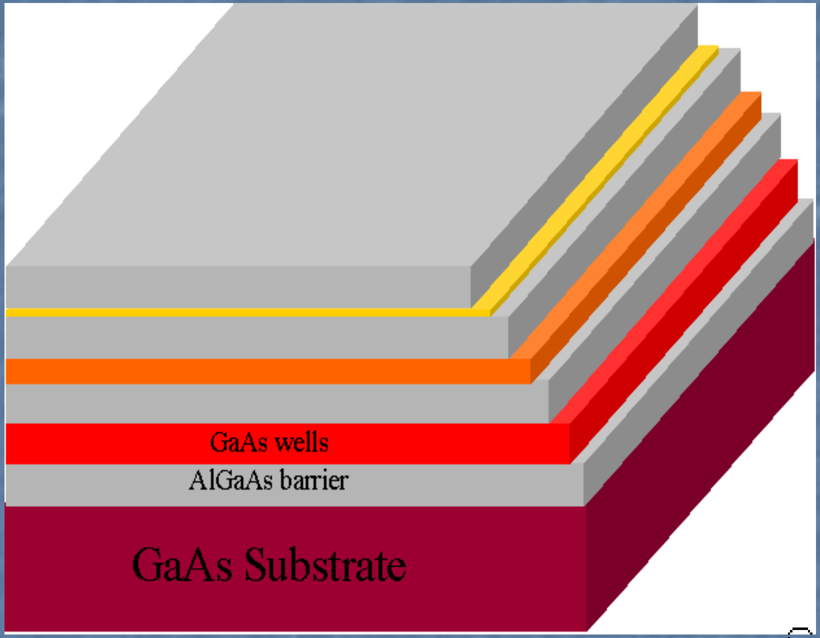

35 nm a-Silicon multiple spacers
TEOS
Poly
Field oxide
Multispacer
[redacted]
EHT = 5.00 kV
WD = 2 mm
Date :13 Apr 2004
200nm
Mag = 83.53 K X

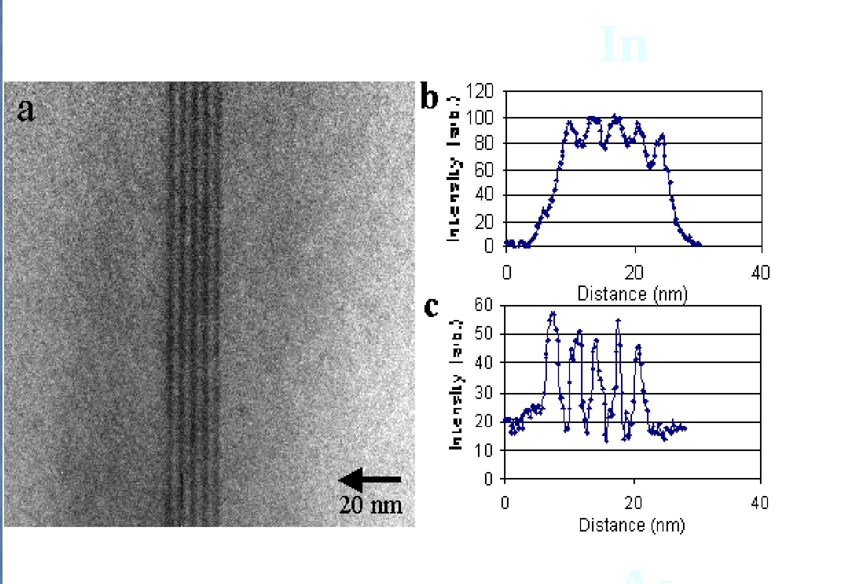
Silicon Host – Molecular Guest

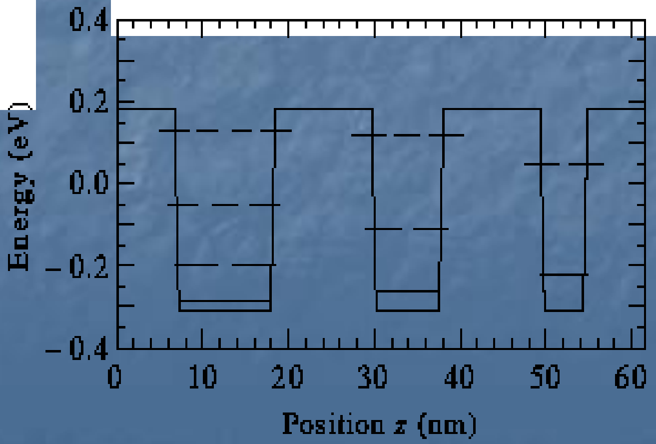



multi-spacer
nitride
Poly
Field oxide
Y419182#07
EHT = 5.00 kV
WD = 4 mm
Date :5 Aug 2004
200nm
Mag = 101.72 K X

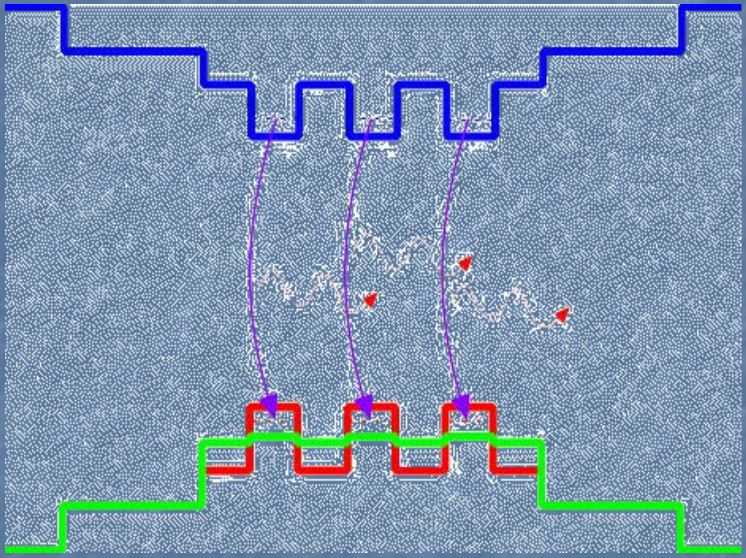
Buche quantiche





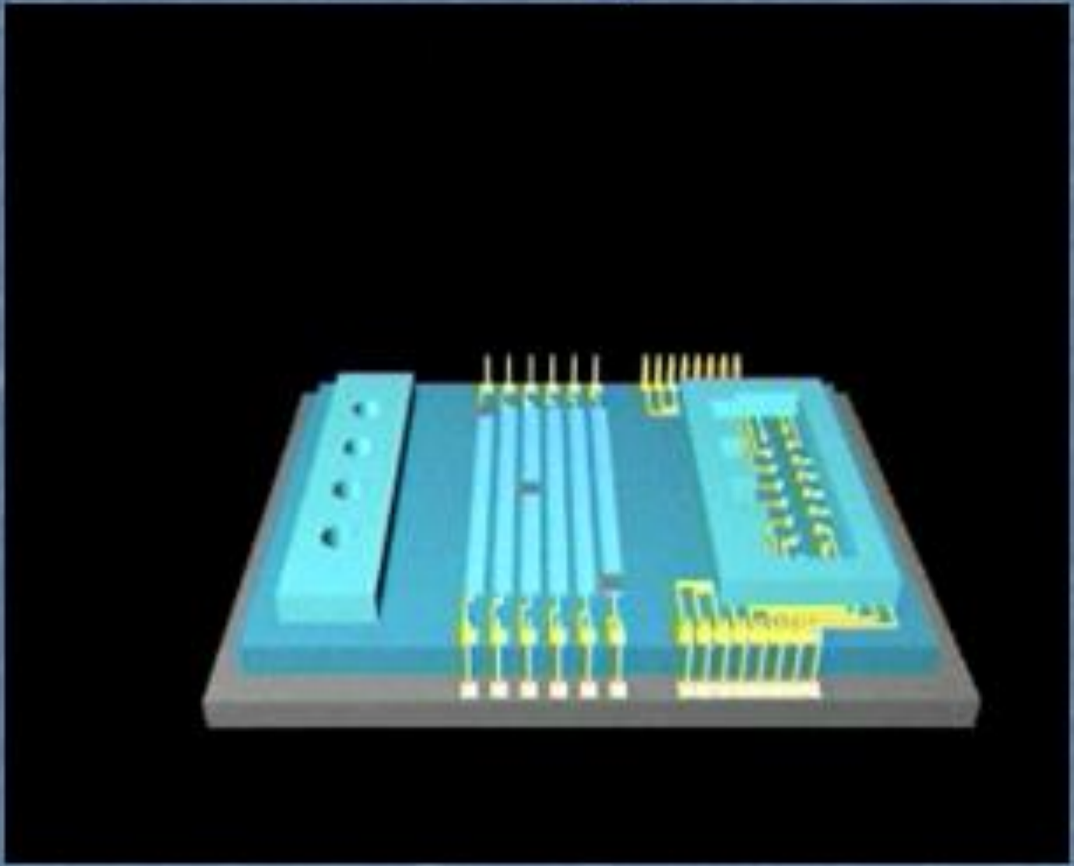


Buche quantiche

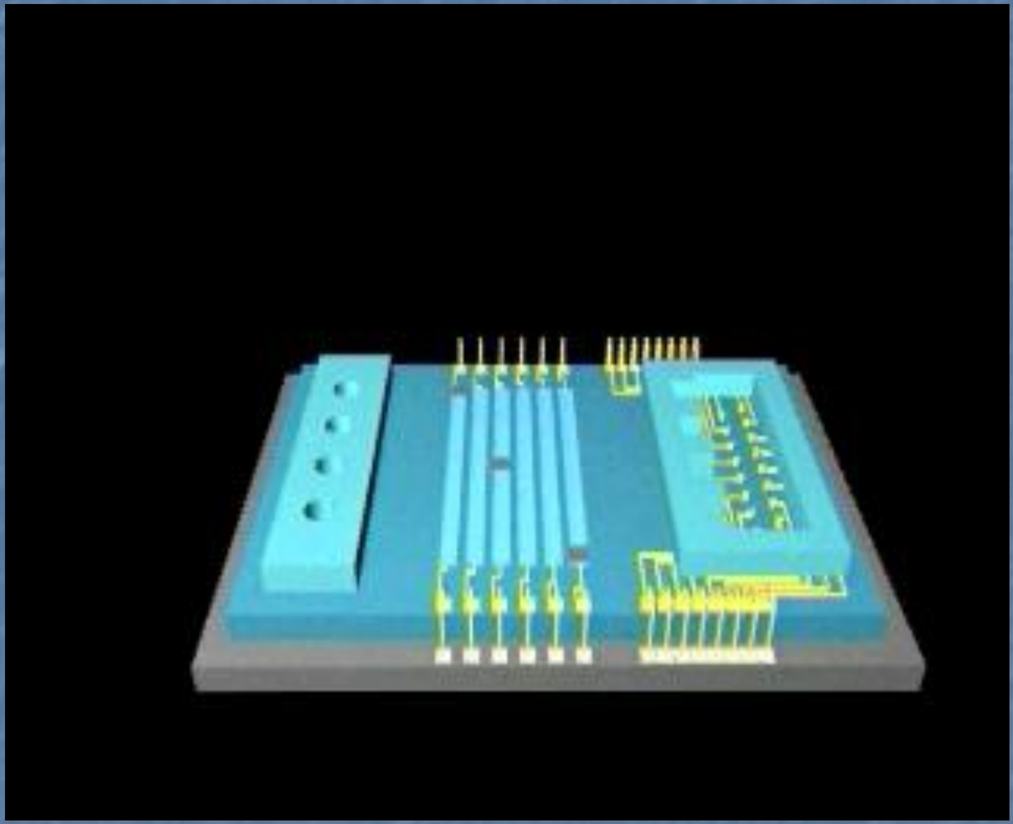


Esempio di
realizzazione di un LED

LAB on CHIP

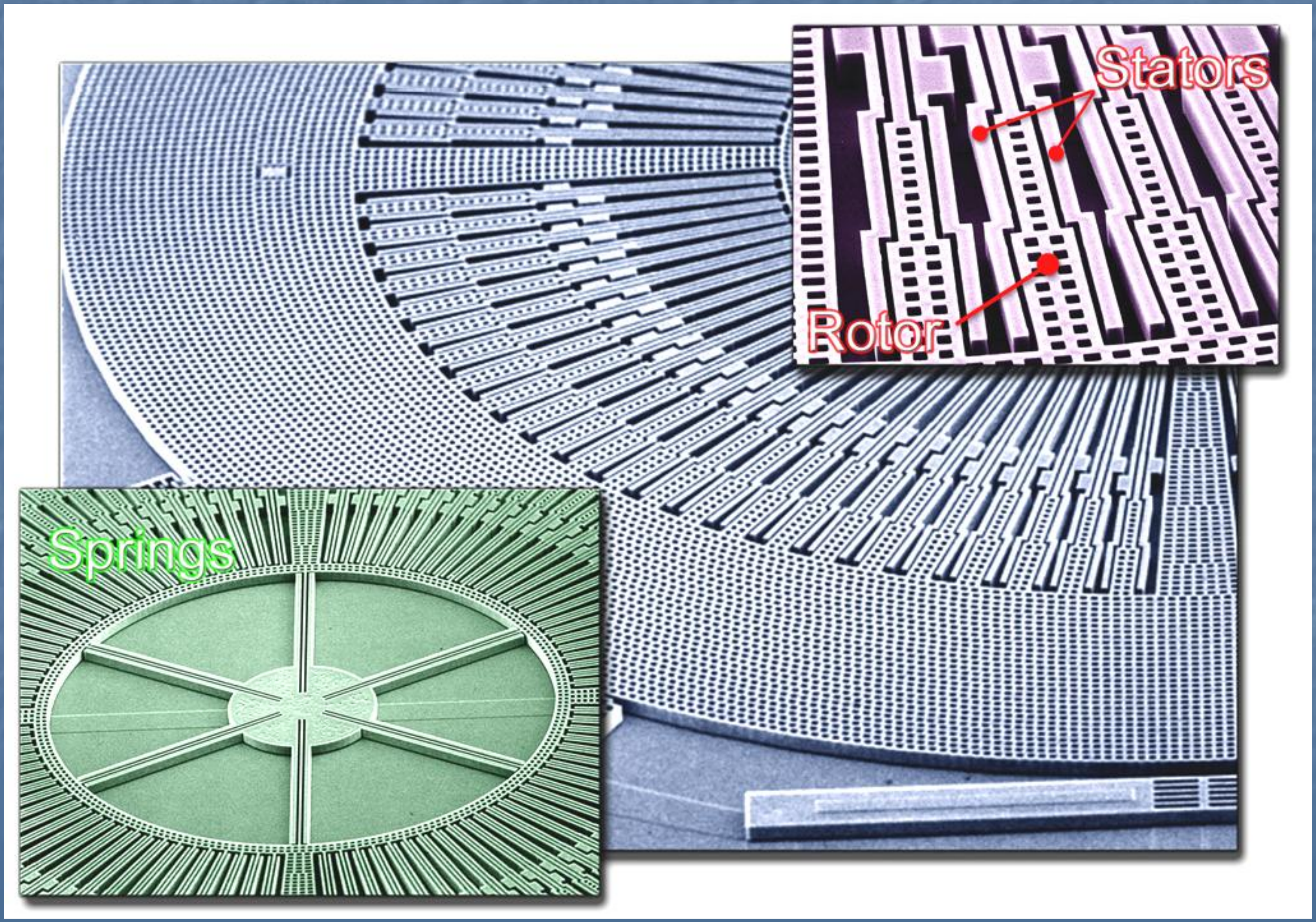


Lab on Chip Movie

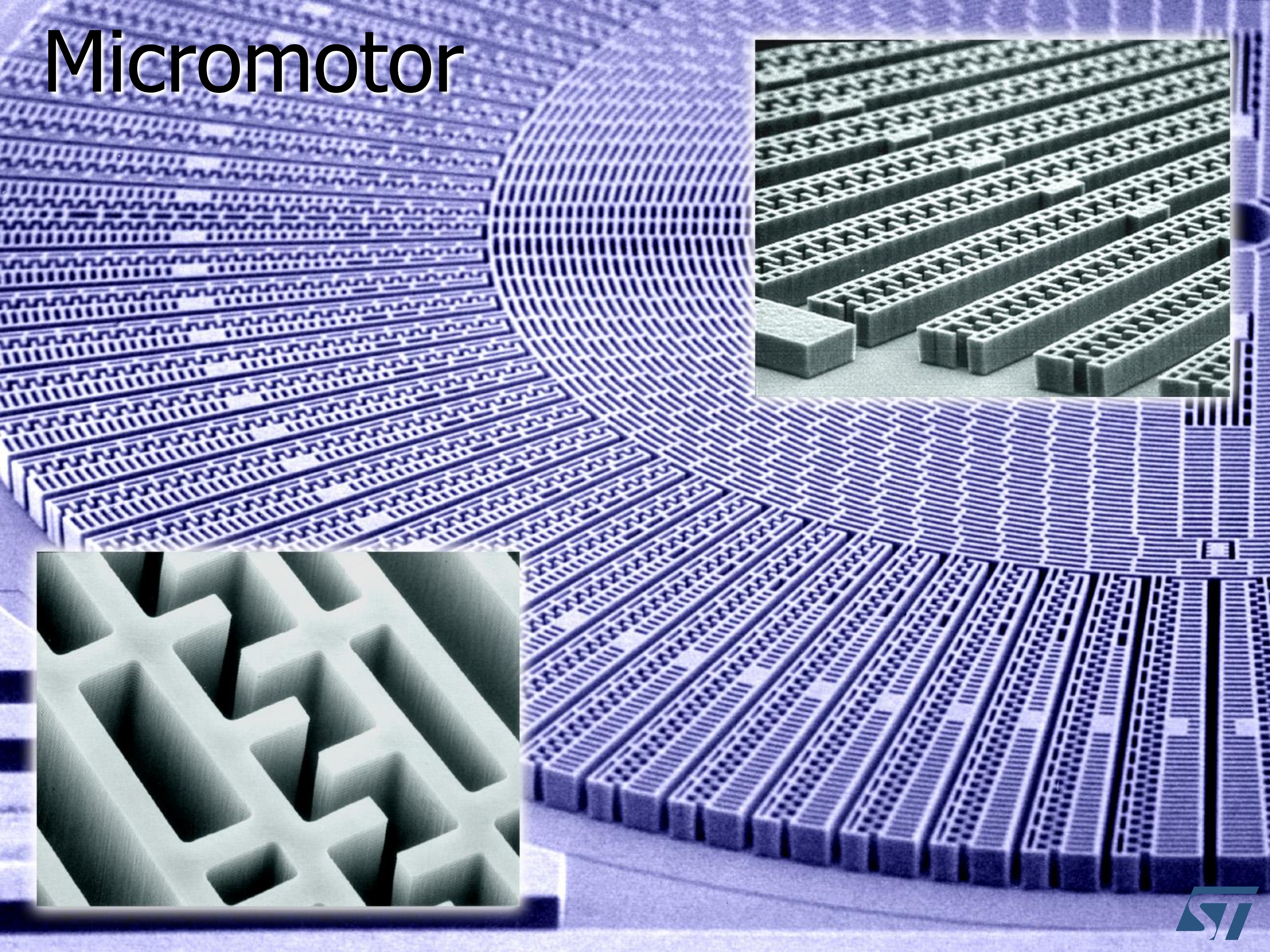


Sensing Element

- MEMS (Micro Electro Mechanical System) Structure
- Angular acceleration is converted into a differential capacitive change

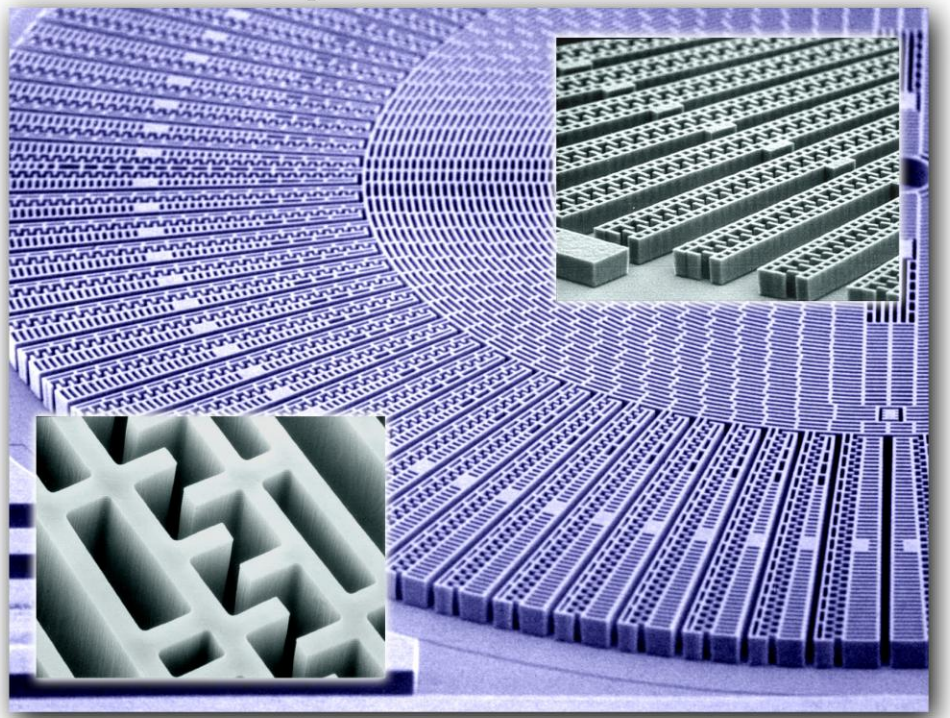


Micromotor

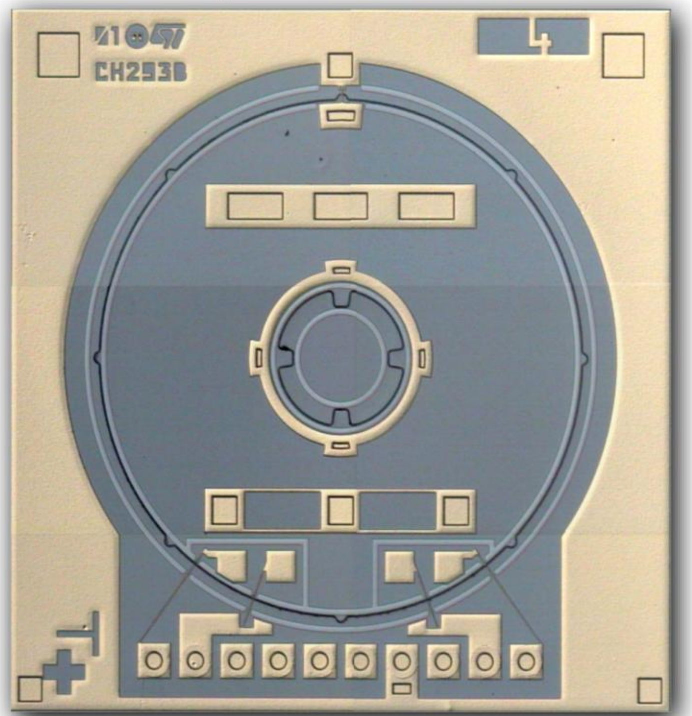


Microactuator Chip

without Cap



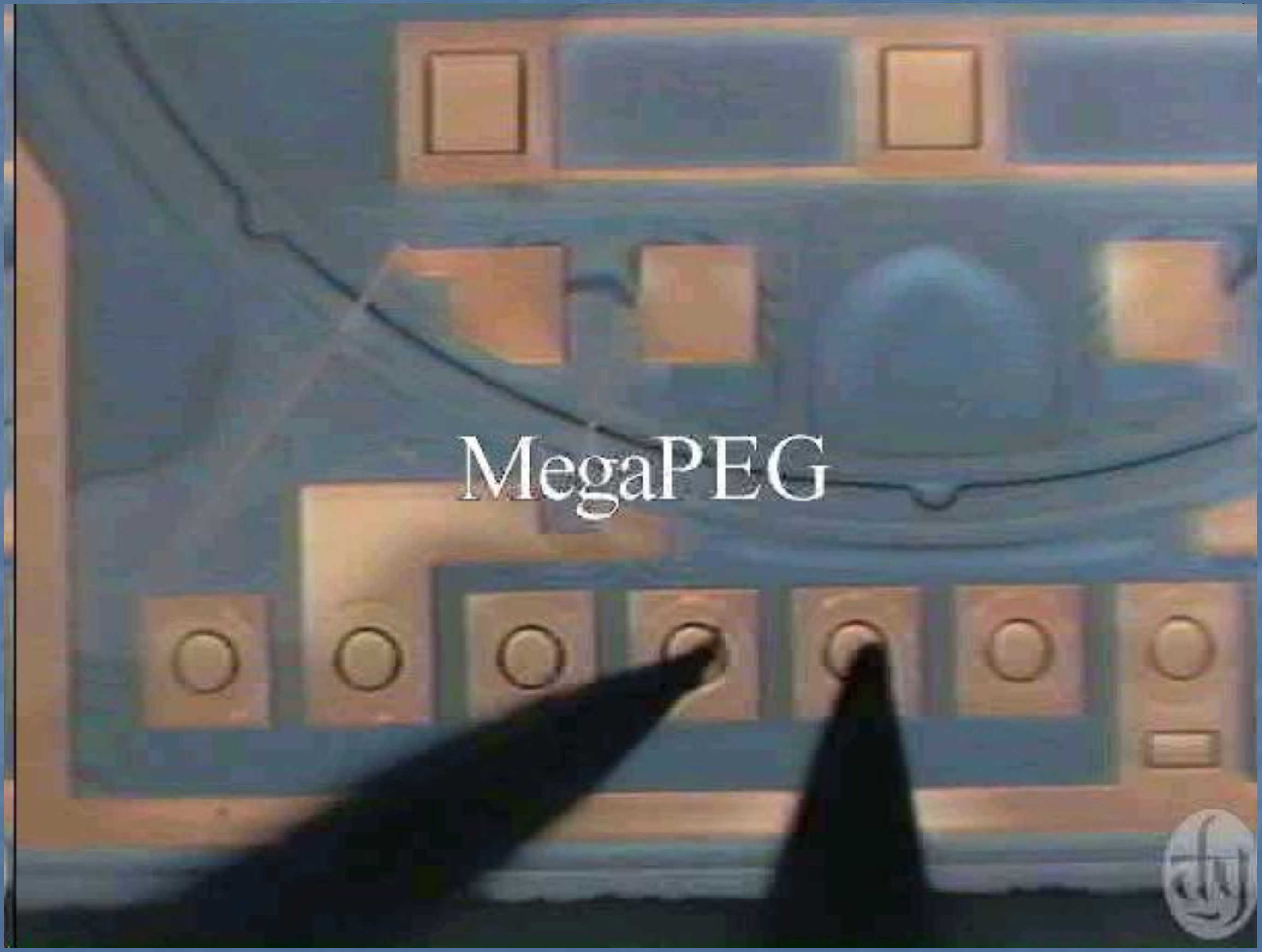
with Cap



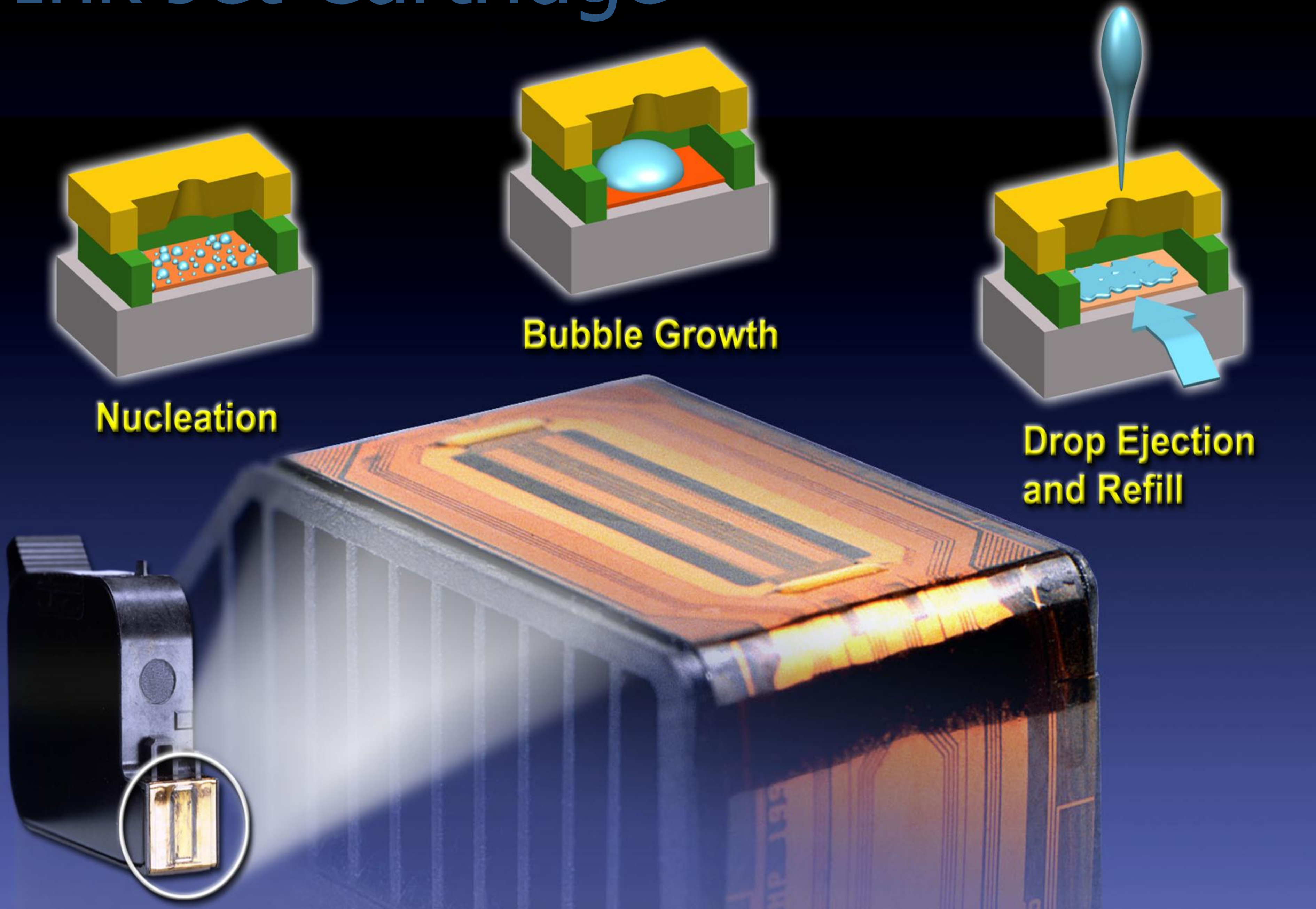
Die Size = 2.5 x 2.5 mm

Epipoly Thickness = 35 µm

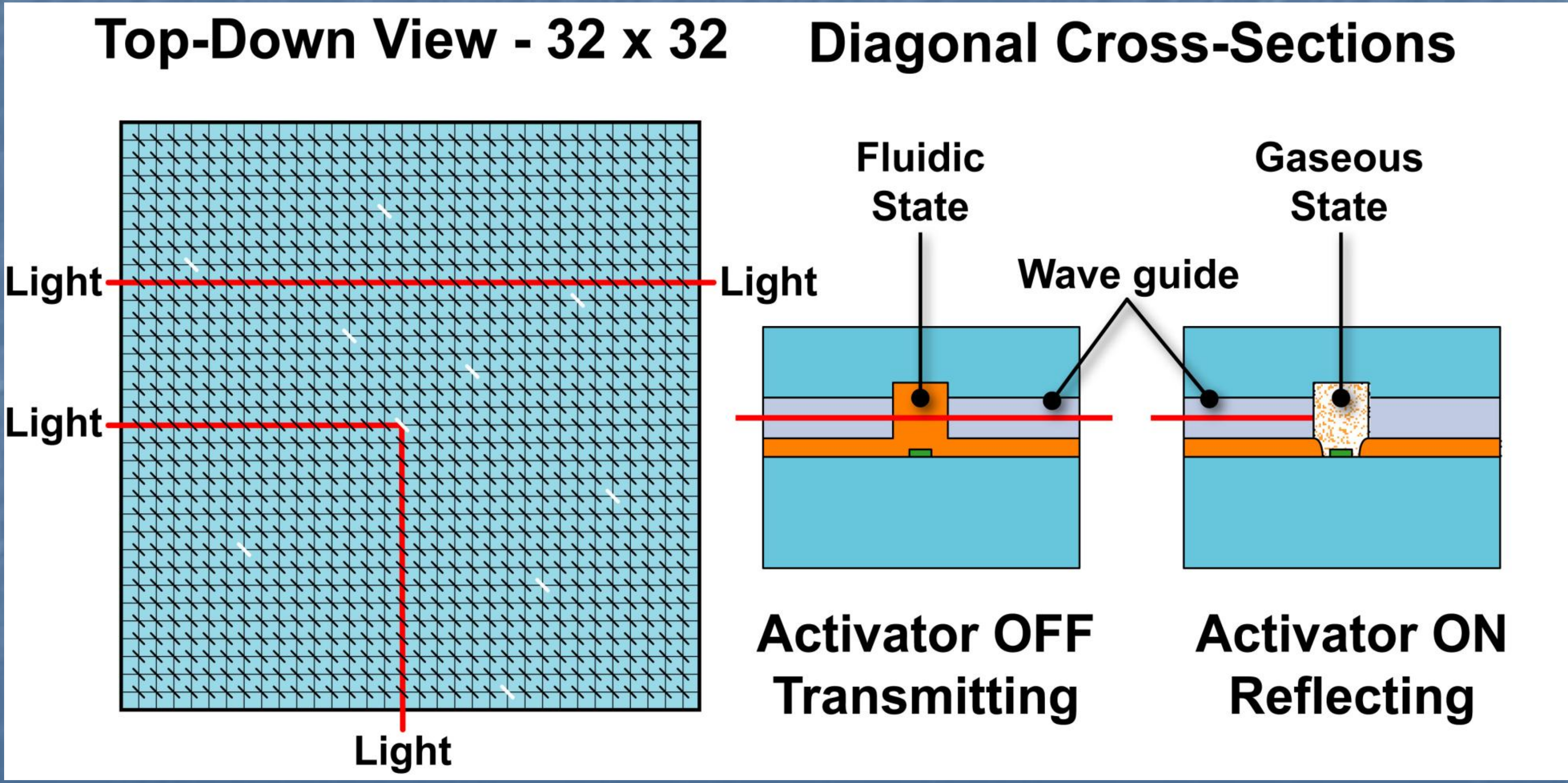
Electrostatic Micromotor



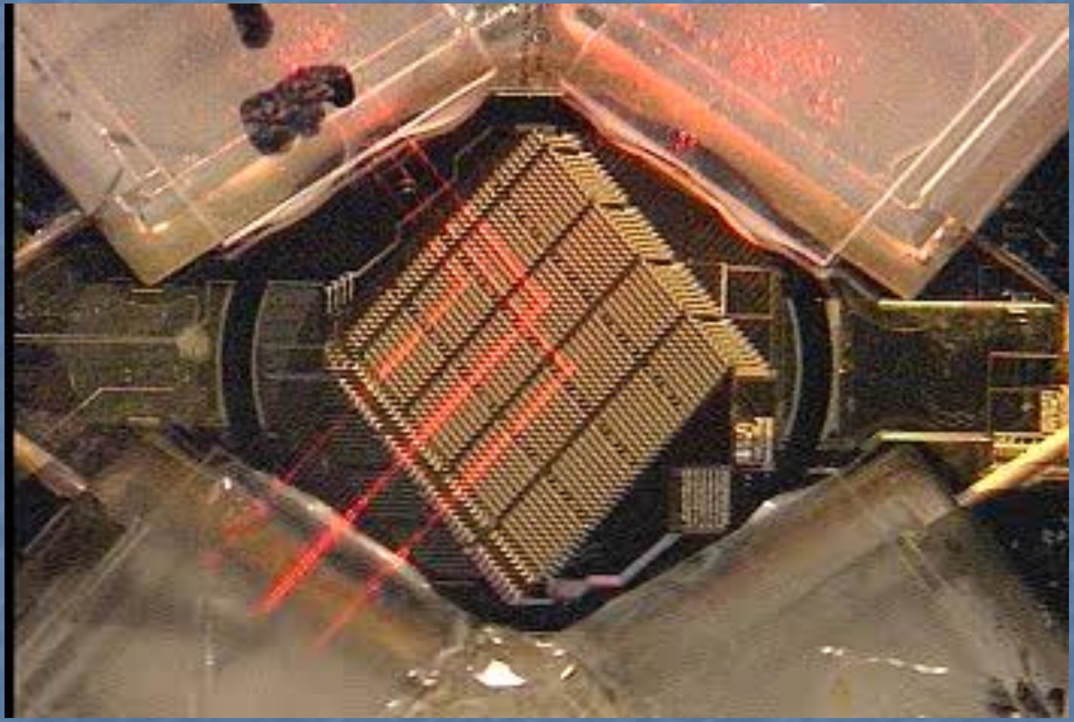
Ink Jet Cartridge



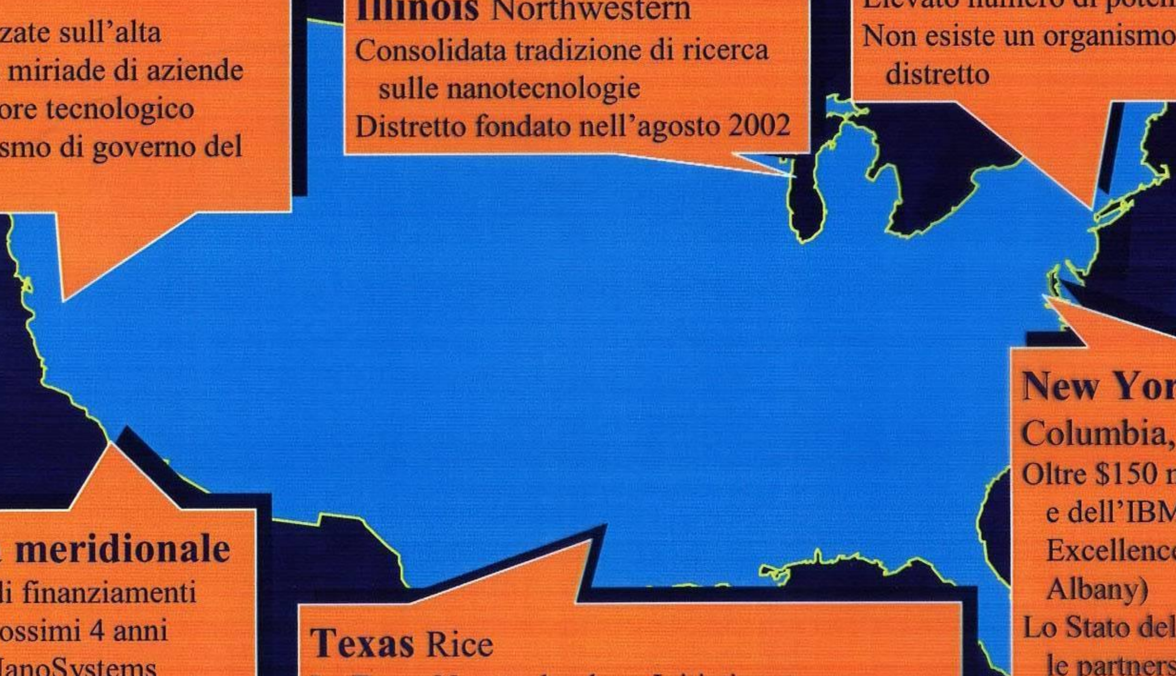
Photonic Switching Concept



ST/AGILENT Bubble Switch Movie



NEGLI STATI UNITI ESISTONO ESEMPI DI DISTRETTI IN VIA DI SVILUPPO SPECIALIZZATI SULLE NANOTECONOLOGIE



Silicon Valley
- $100 milioni di finanziamenti statali nei prossimi 4 anni
- Infrastrutture focalizzate sull'alta tecnologia con una miriade di aziende preminenti nel settore tecnologico
- Non esiste un organismo di governo del distretto

Illinois Northwestern
- Consolidata tradizione di ricerca sulle nanotecnologie
- Distretto fondato nell'agosto 2002

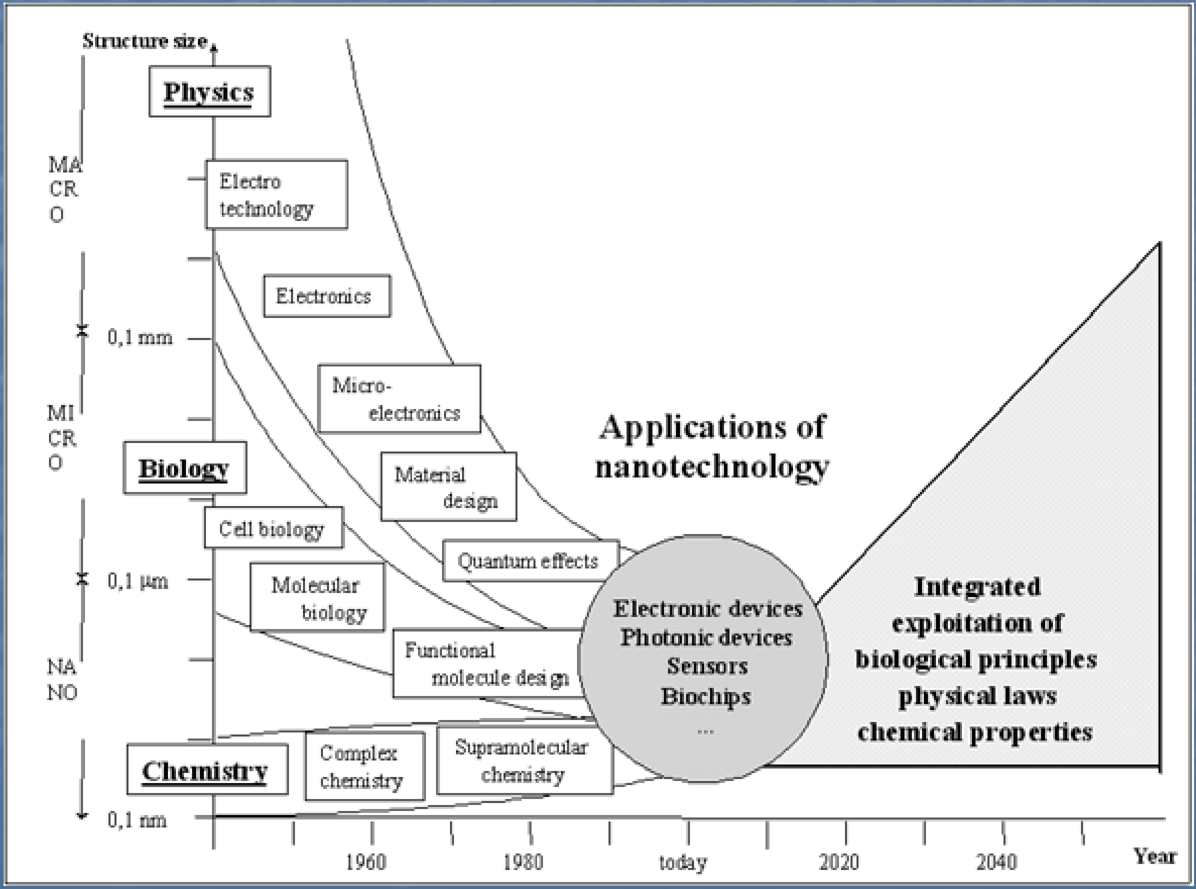
Massachusetts Harvard
- Consolidata reputazione nel creare imprese in nuovi settori industriali
- Elevato numero di potenziali imprenditori
- Non esiste un organismo di governo del distretto

New York/New Jersey
Columbia, Cornell
- Oltre $150 milioni da fondi statali e dell'IBM per il Center for Excellence in Nano (SUNY at Albany)
- Lo Stato del New Jersey incentiva le partnership tra università e imprese
- Distretto fondato nell'ottobre 2001

California meridionale
- $100 milioni di finanziamenti statali nei prossimi 4 anni
- Il California NanoSystems Institute sta incoraggiando le collaborazioni tra università e imprese
- Distretto fondato nel giugno 2001

Texas Rice
- La Texas Nanotechnology Initiative sta promuovendo le collaborazioni tra università, imprese e amministrazioni locali
- Il tessuto locale ha dimostrato elevata capacità di attrarre imprese con contenuti tecnologici
- Distretto fondato nell'ottobre 2000

Un mondo di applicazioni



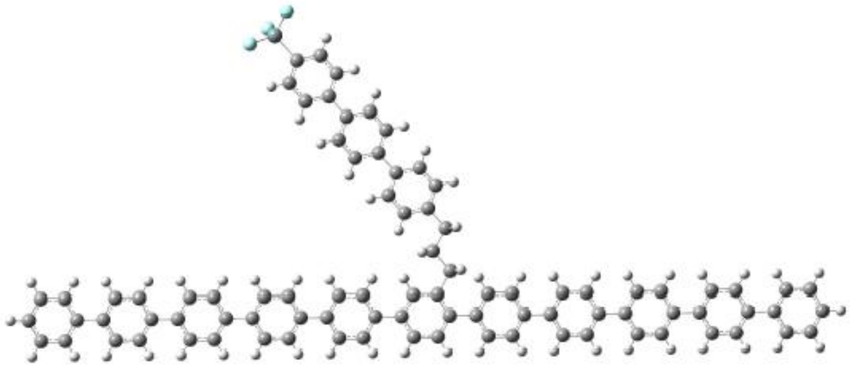
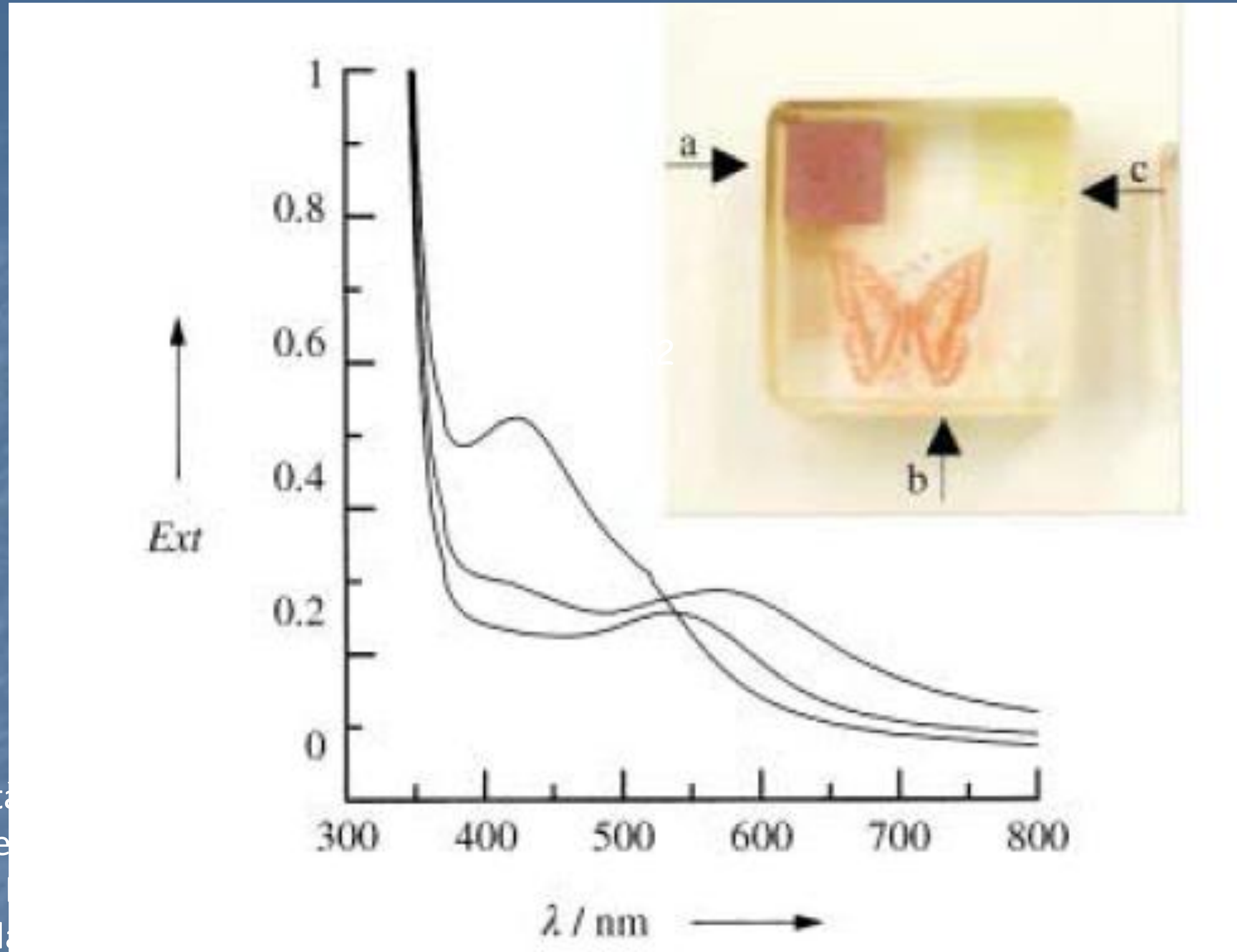


FIG. 1: A molecule characterized by a wire whose conduction state may be controlled by a side redox state

Irraggiamento a diverse intensità,
a) 6.5×10^{13} W/cm^2,
b) b) 2.3×10^{14} W/cm^2,
c) 5×10^{16}W/cm^2, e in diverse zone.
Trattamento termico 550C ,1 ora



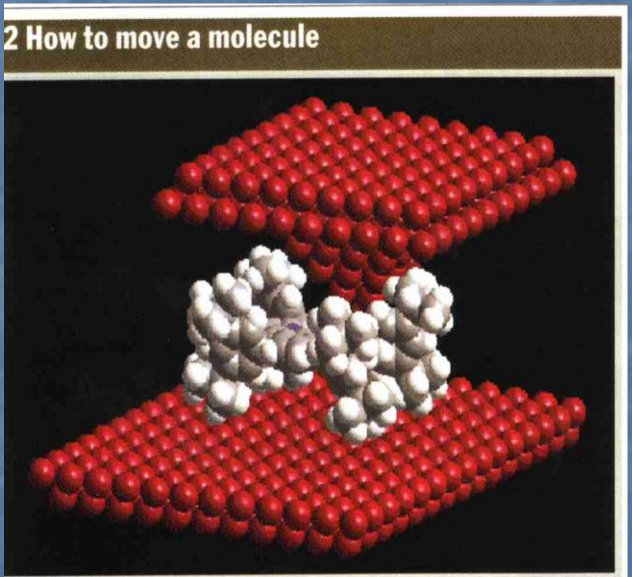
All'aumentare dell'intensità
colore delle aree irraggiate
violetto al rosso , al giallo.
d'assorbimento si sposta d
(risonanze delle particelle d'oro, lo shift da 568 a 534 nm legato alla variazione di dimensione delle particelle d'oro) a 422 nm (Au_{11} ?).
All'aumentare dell'intensità si riducono le dimensioni delle particelle.

Tecniche di analisi di superfici e interfacce

Microscopia

a scansione di sonda

Risoluzione atomica



Computer simulation by Christian Joachim (CEMES-CNRS) showing how an STM tip can push a molecule. The point of the tip (top) is lowered between the bulky legs of the molecule, which are repelled as the tip approaches. A rounded molecule would be more difficult to move, because it could slide away from the tip.