Nanotechnology: Science, History and Applications

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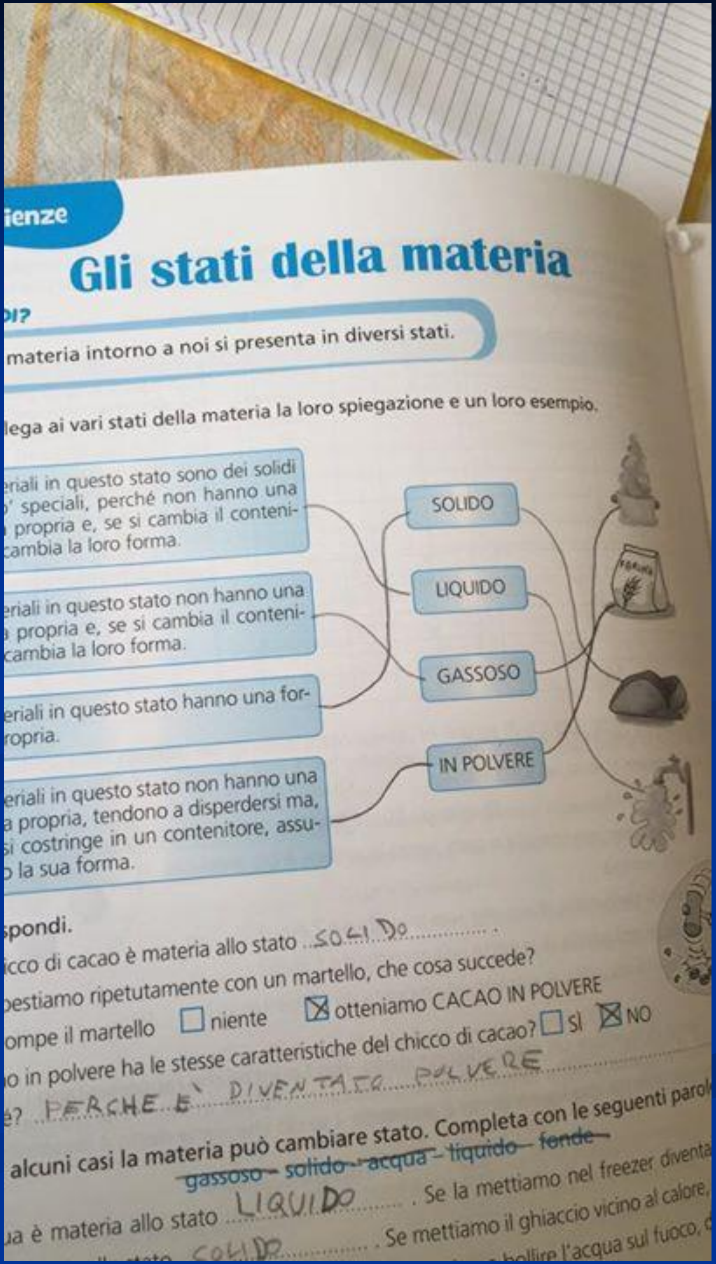
Strafalcioni o Visioni?



What is "Nano" (10^{-6} mm) ?

- NANOSCIENCE is exploring the novel effects in downsizing matter to the nanometer scale.

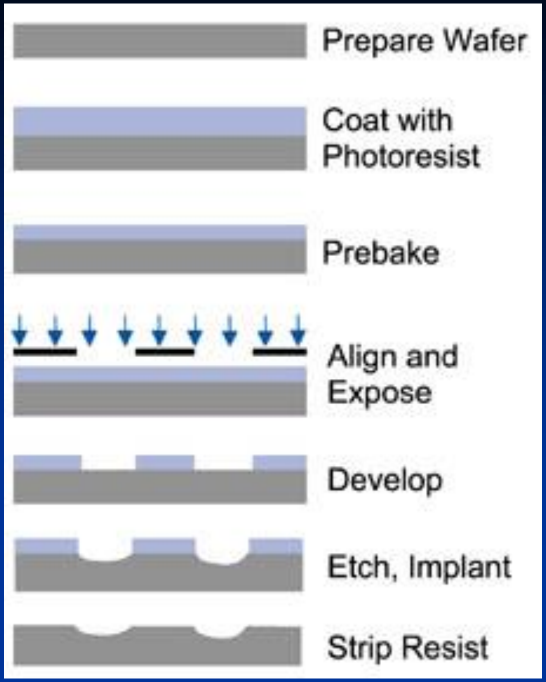
- NANOSTRUCTURES are the pieces of matter to that scale.

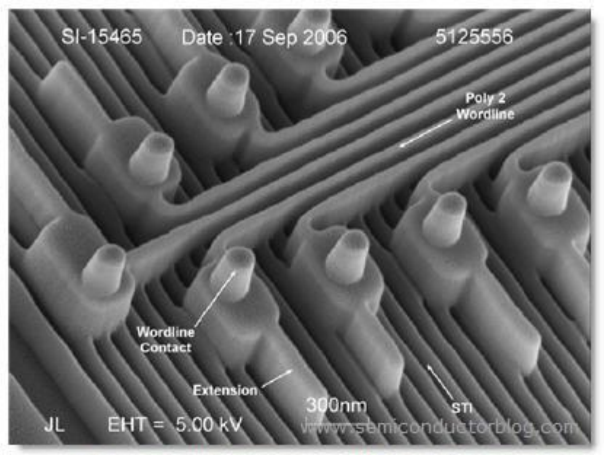
- NANOTECHNOLOGY is controlling the generation and the evolution of Nanostructures.

How to make them?

- **Top-down** is carving out /moving the Nanostructures from macroscopic scale.

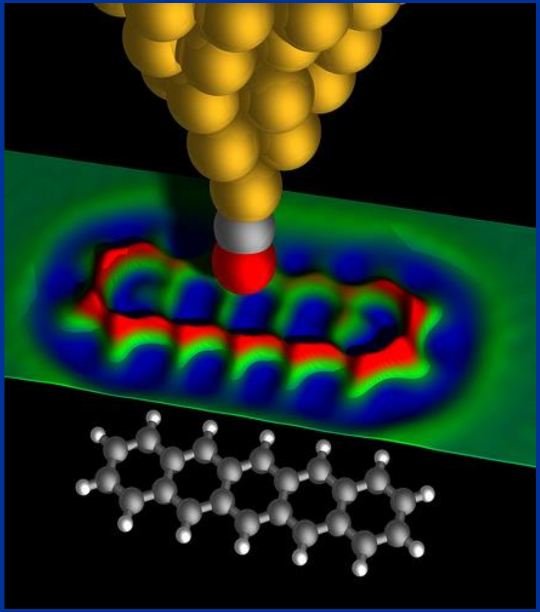
- **Bottom-up** is the spontaneous self-assembly of atoms/molecules: that's how we are built up!

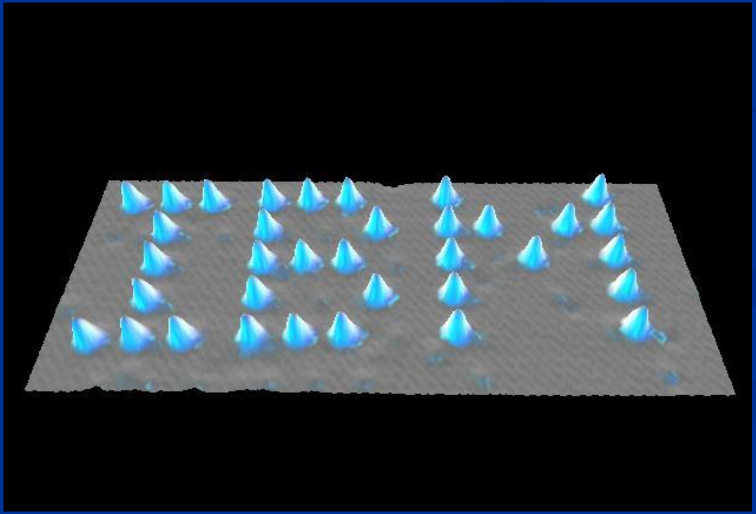




High magnification SEM image of IM Flash Technologies (IMFT) 4G 50nm NAND Flash (source: Semiconductor Insights)

Top-down carving by mask + etching

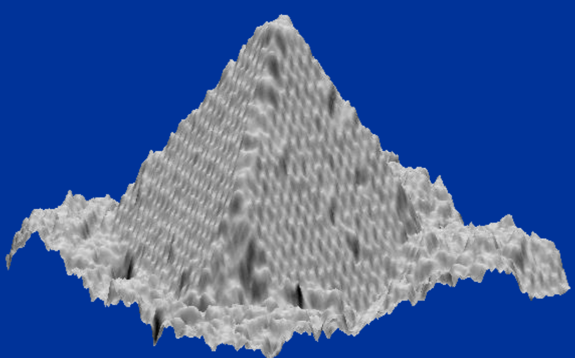




Top-down moving by a narrow tip

What is Selfassembly?

Spontaneous process, hierarchy in forces among building units: generate order



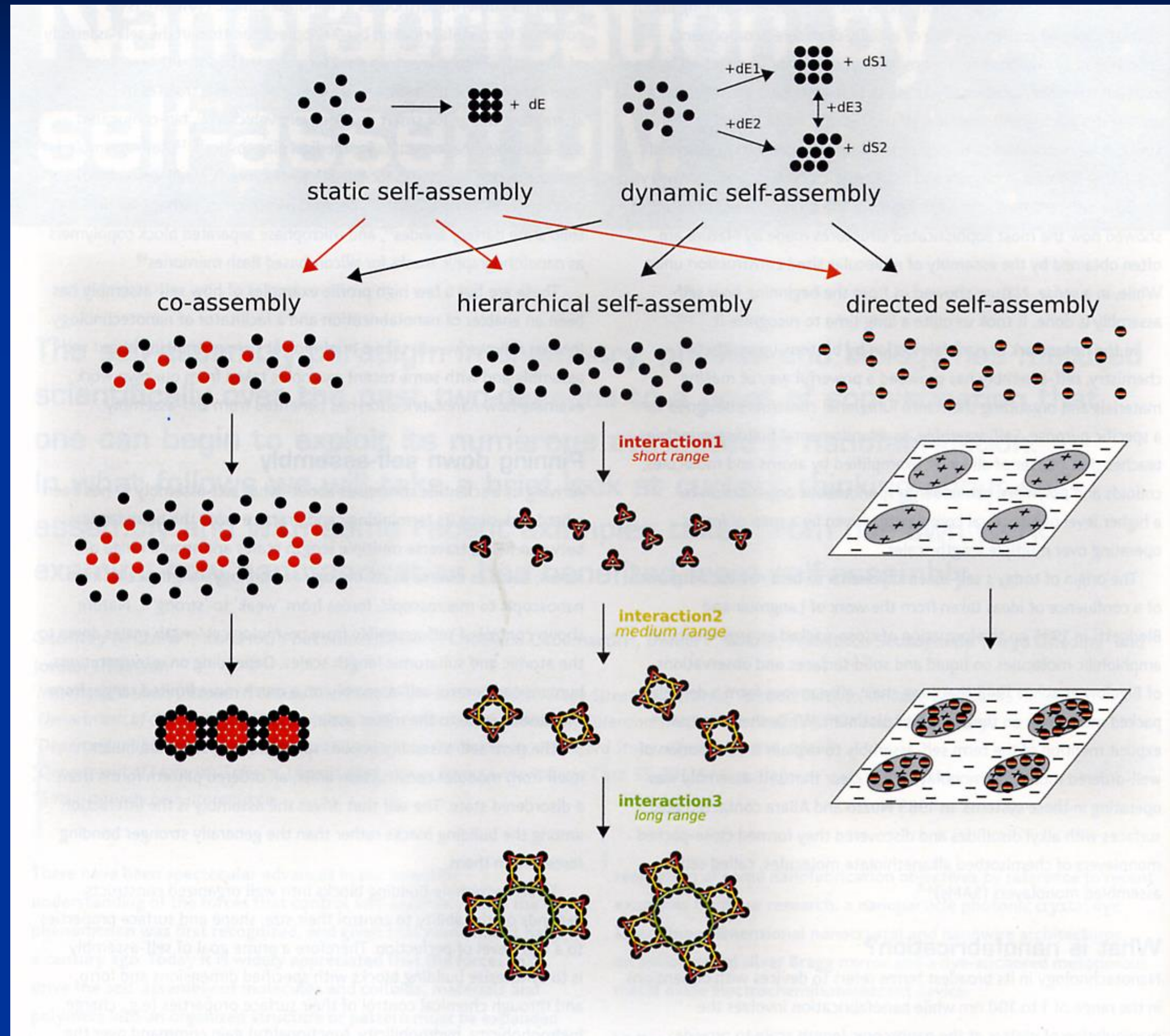


Fig. 1 Graphical rendition of static and dynamic self-assembly and how they relate to co-assembly, hierarchical assembly and directed assembly. This illustration is taken with permission from Concepts of Nanochemistry, L. Cademartiri and G.A.Ozin, VCH-Wiley, 2009[20].

A bit of taxonomy

- Nanostructures
- Nanomaterials
- Nanodevices
- Nanosystems

NANOTECHNOLOGY PRODUCTS

INORGANIC NANOSTRUCTURES

Zero-dimensional

- Fullerenes
- Semiconductor quantum dots & nanoprecipitates
- Clusters & nanoparticles

One-dimensional

- Metallic Nanowires (by planar assembly)
- Semiconductor nanowires (by vertical growth)
- Carbon Nanotubes (CNT e DW-CNT)

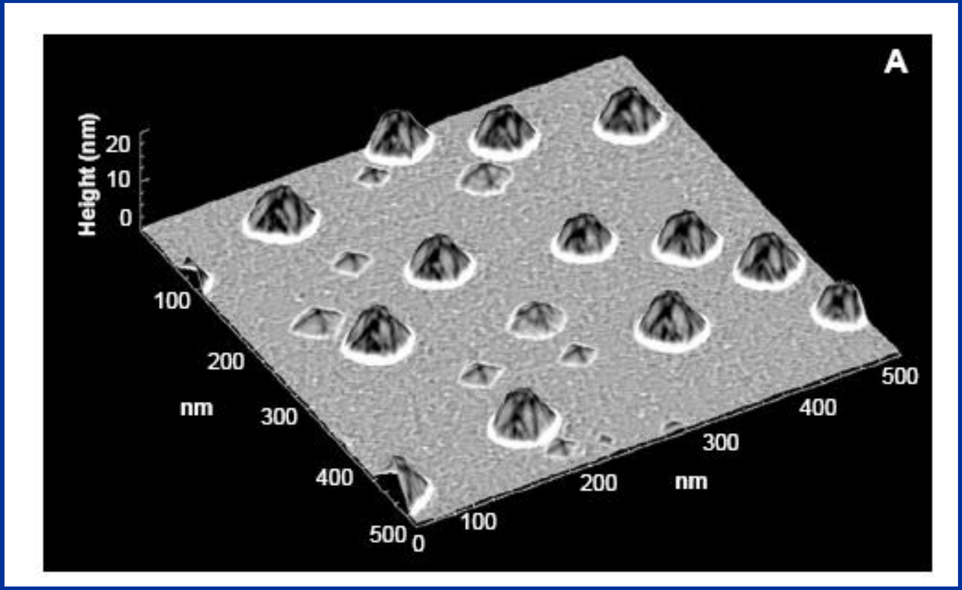
Two-dimensional

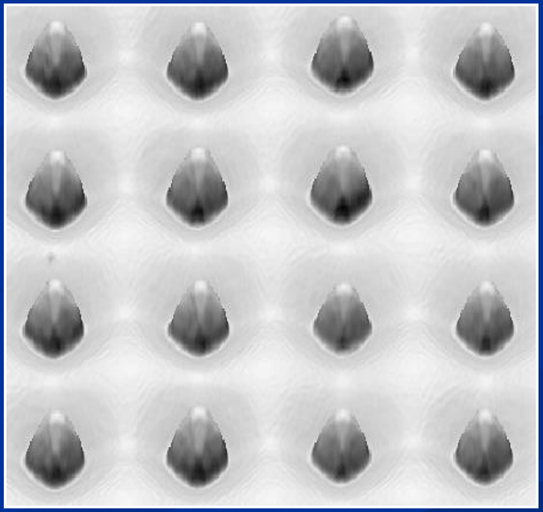
- Graphene and free-standing Si membranes
- Ultrathin films on substrates
- Semiconductor quantum wells

Epitaxial 3D island Ge/Si(001): bottom-up + top-down

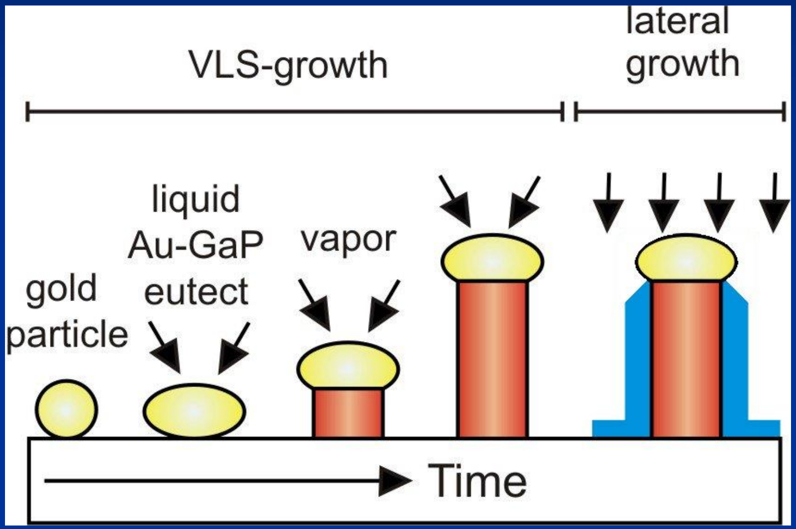
Unpatterned substrates

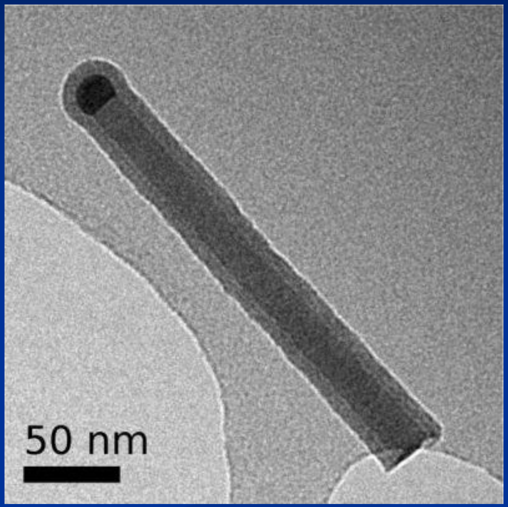
Patterned substrates

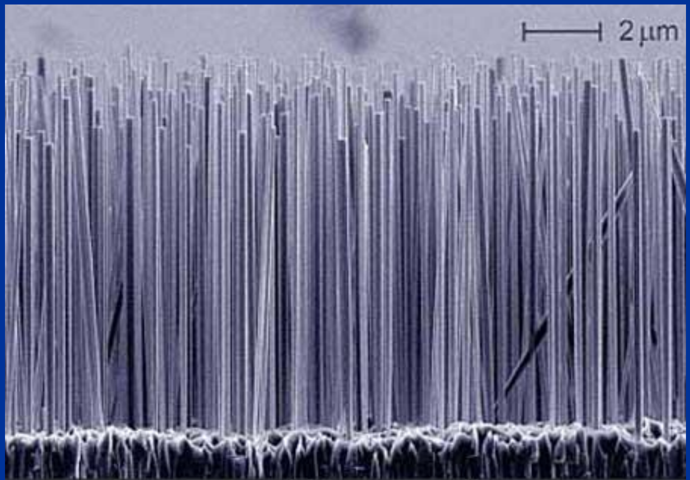




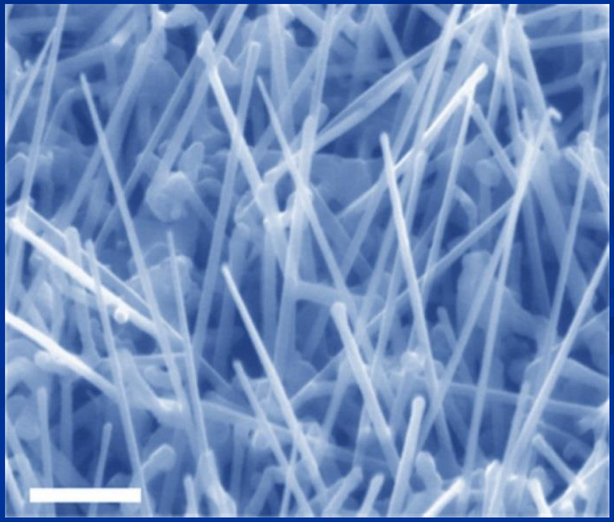
SEMICONDUCTOR NANOWIRES



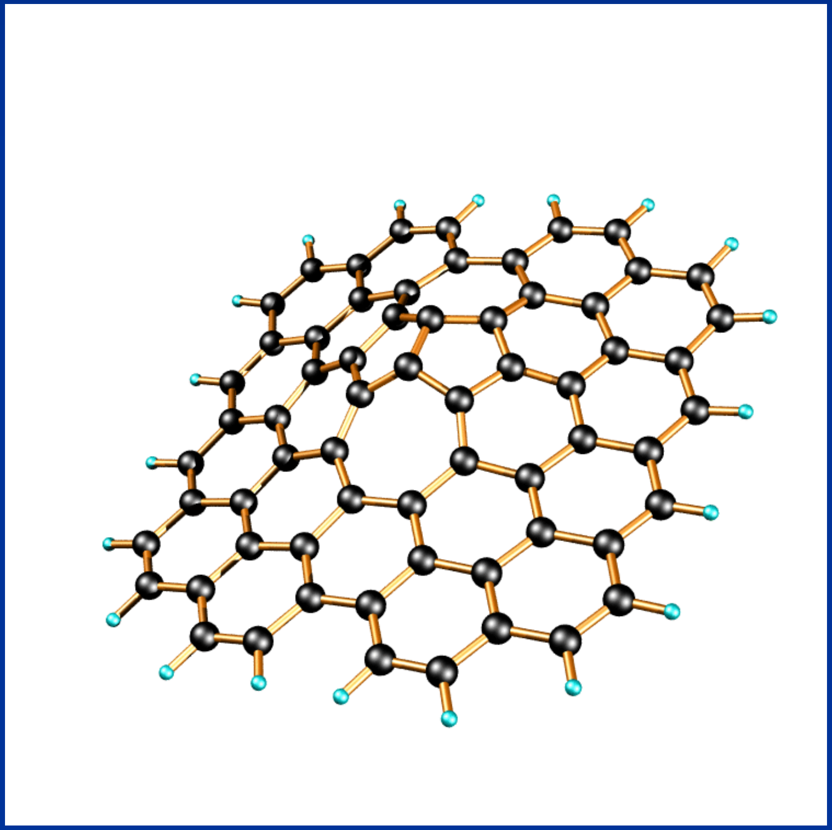


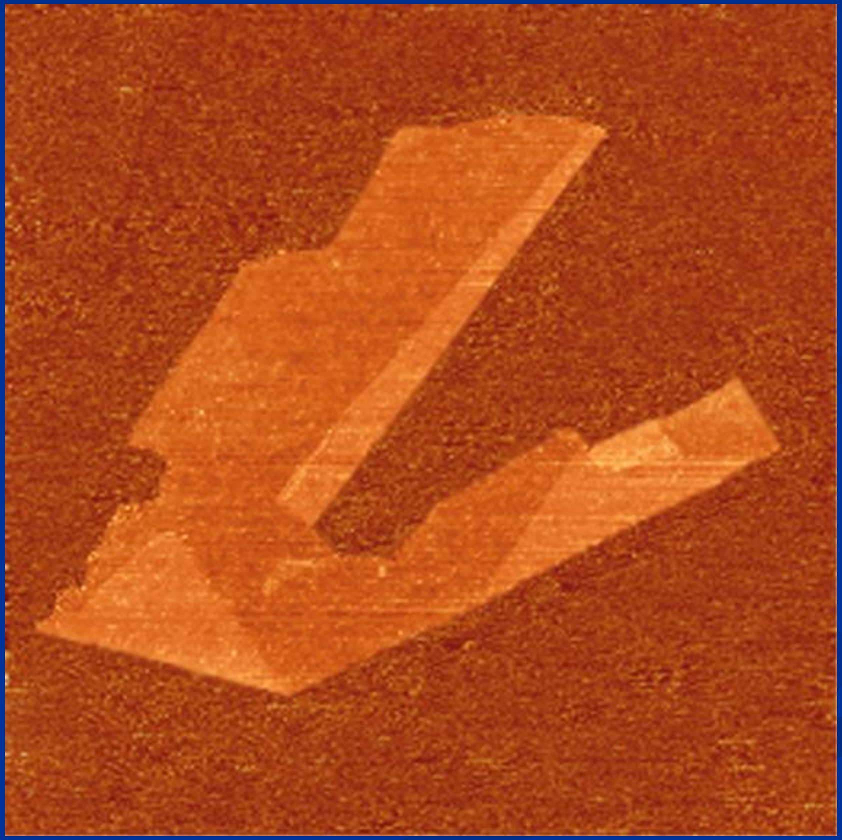


An array of silicon nanowires

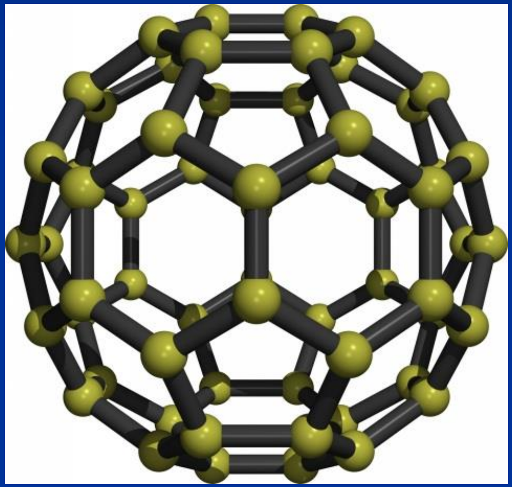


GRAPHENE (Nobel Prize 2010)

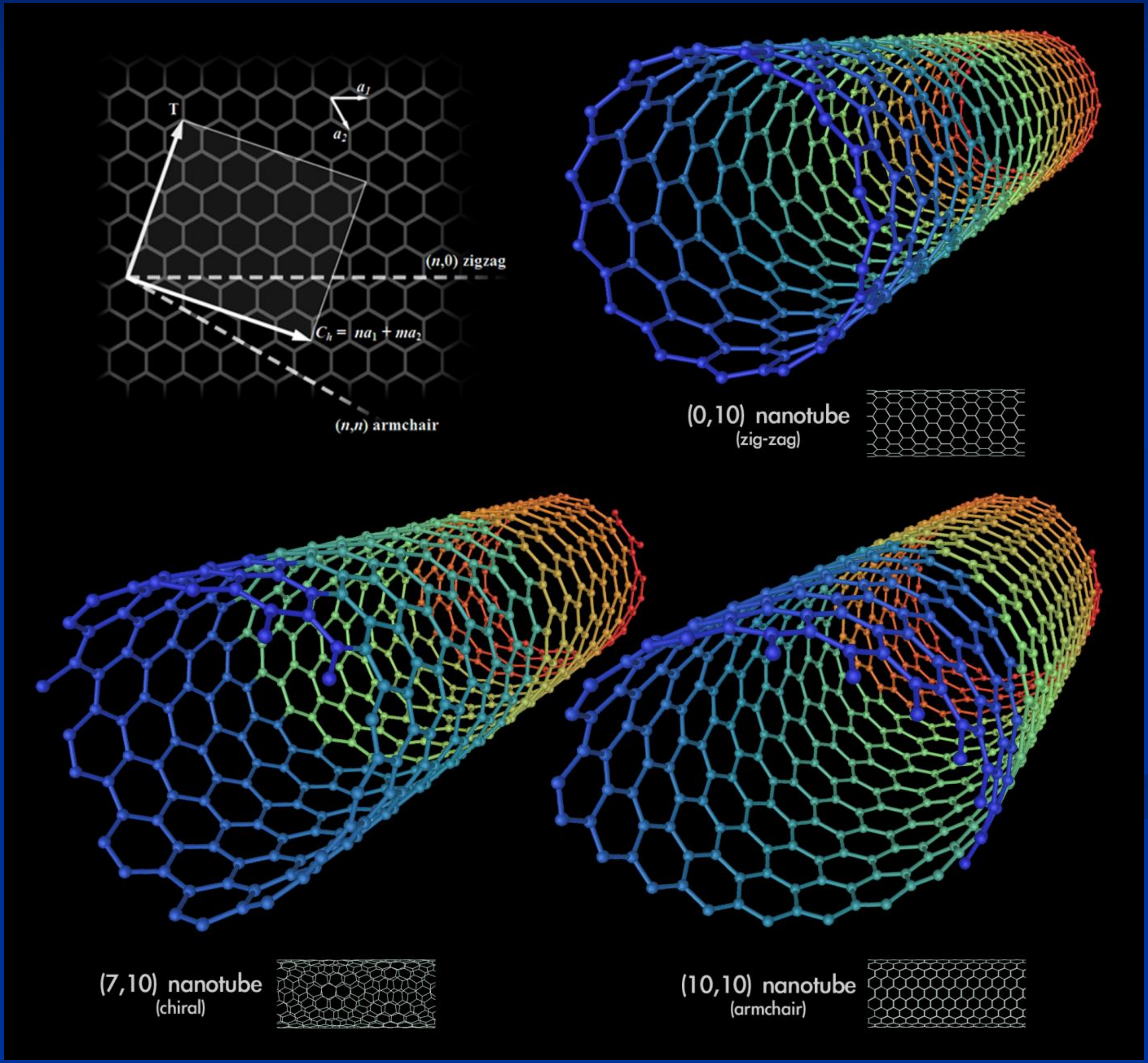




Rolling up graphene….



Buckminster Fullerene



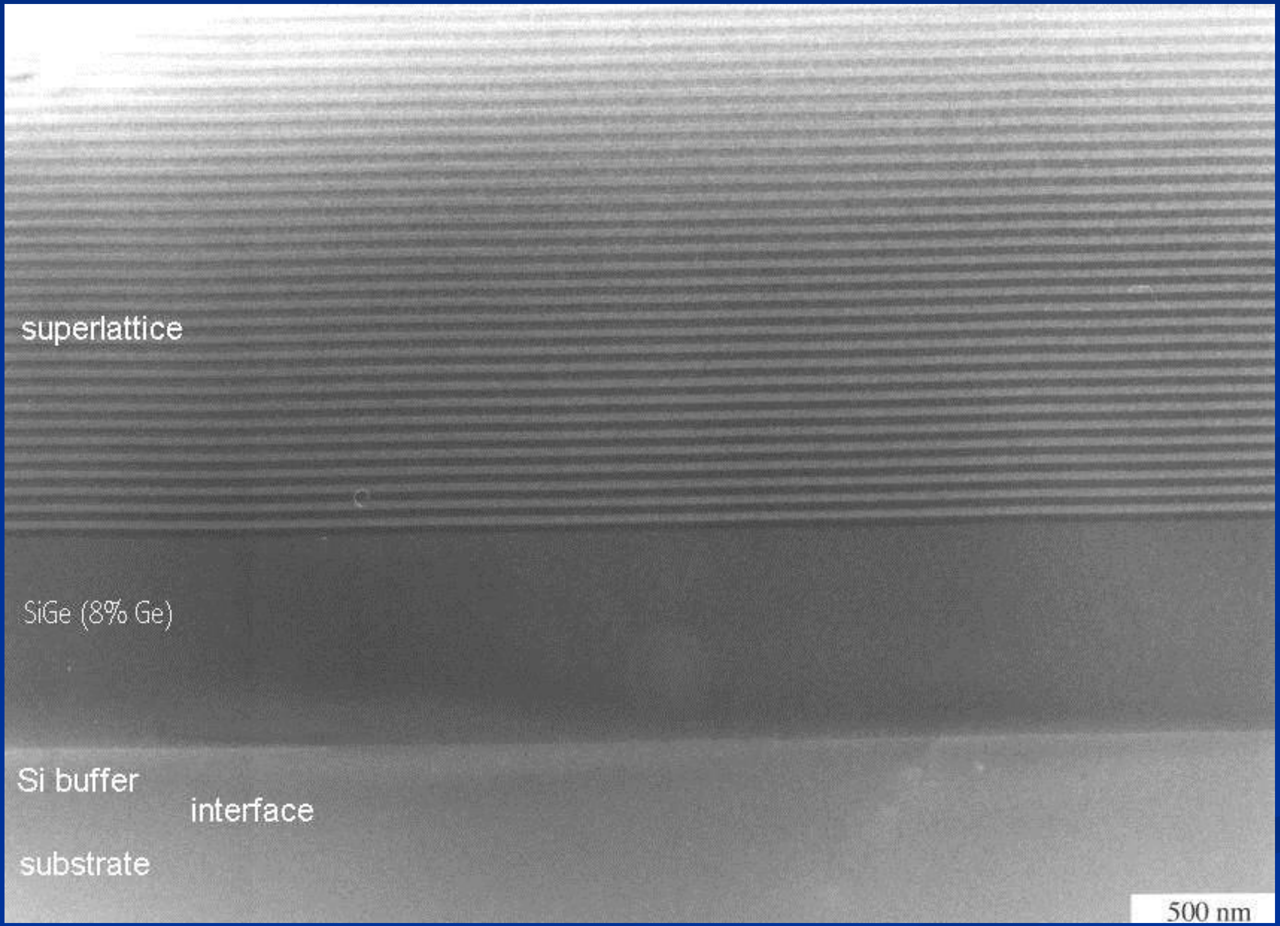
Carbon NanoTubes

NANOTECHNOLOGY PRODUCTS

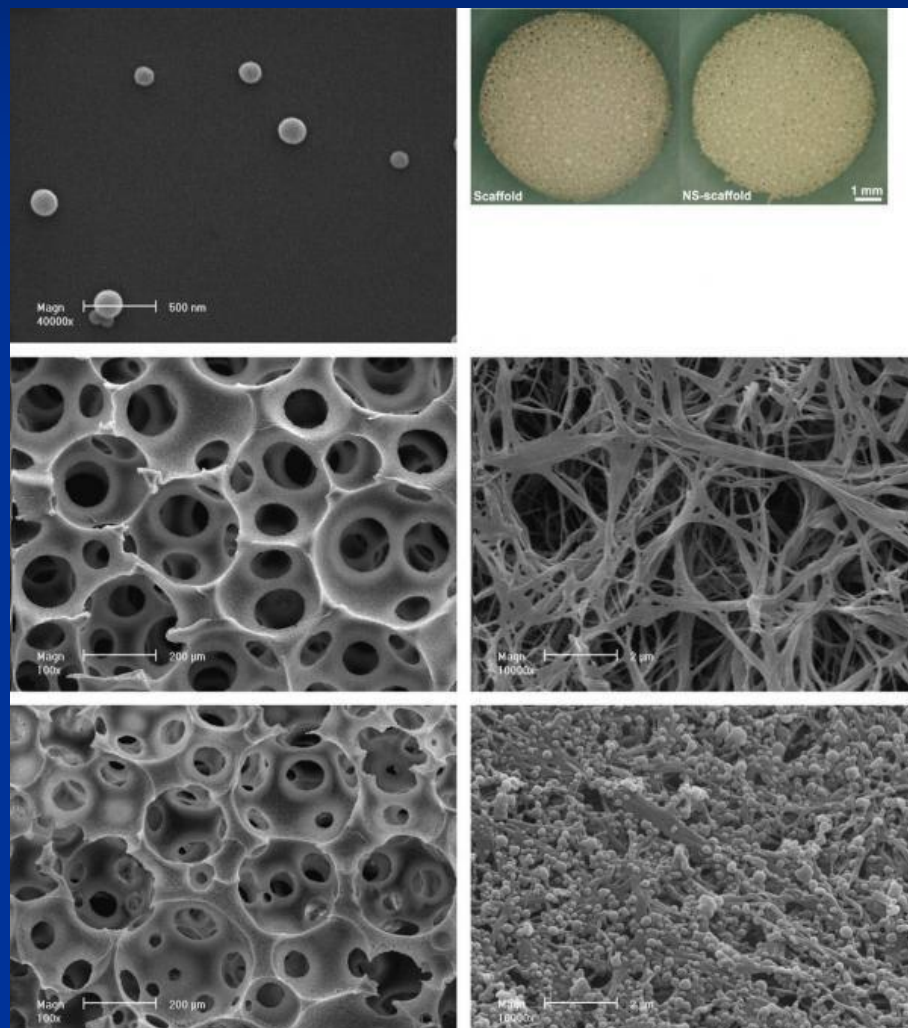
NANOMATERIALS

- Meso- (Nano-) porous silica, porous silicon
- Nanocomposites (e.g. inorganic nanoparticles in polymeric matrix, precipitates, alloys)
- Nanostructured materials (nanocrystalline silicon, block co-polymers)
- Metallic or semiconductor superlattices
- Biologic scaffolds

Heteroepitaxial superlattices



Nanoscaffolds for tissue growth



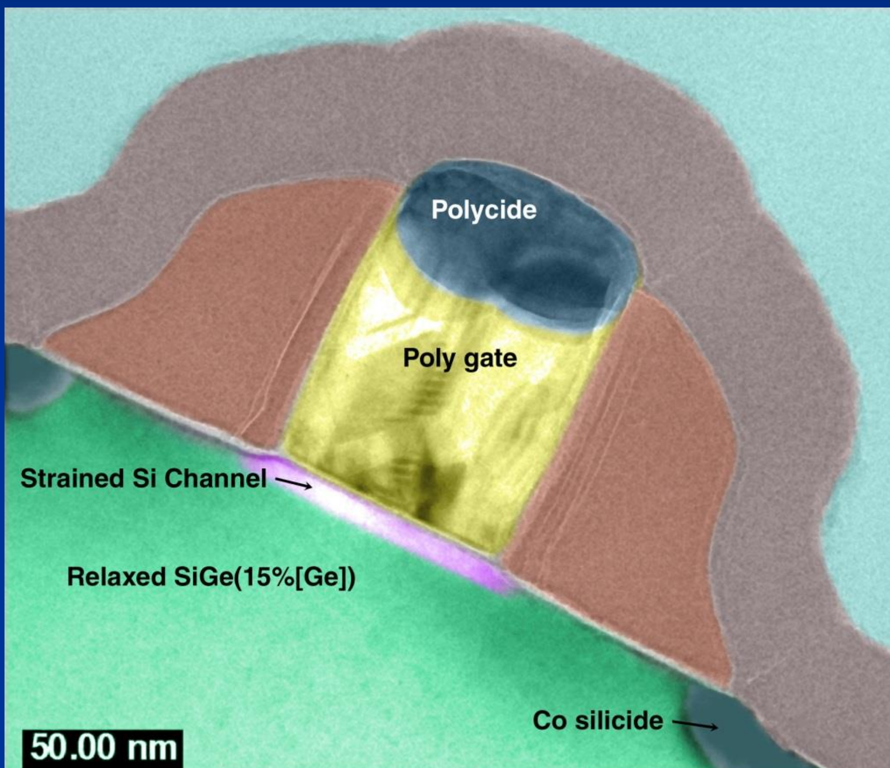
NANOTECHNOLOGY PRODUCTS

NANODEVICES

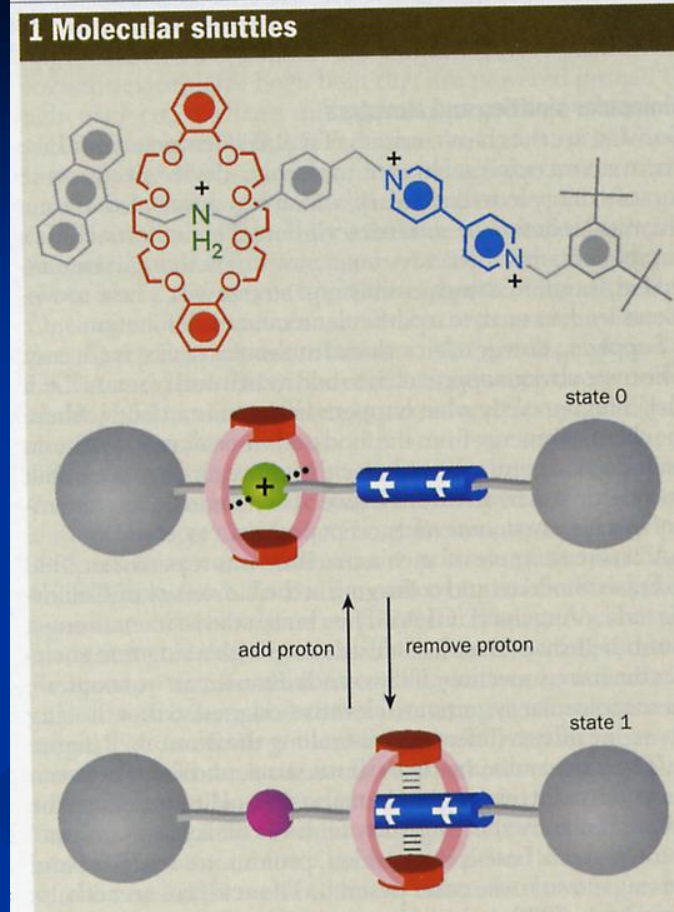
(all components contribute to one function)

- Field-Effect –Transistor
- Molecular switcher
- Molecular transistor
- Fluidic nanochannels
- Nano-cantilever

Molecular swhitcher



Strained-Si IBM Transistor



This "molecular shuttle" was built in 1998 by Fraser Stoddart from the University of California at Los Angeles. Based on a supramolecular species called a "rotaxane", it consists of a ring and a dumb-bell-shaped component that contains a dialkylammonium unit (green) and a 4,4′-bipyridinium unit (blue). The ring normally surrounds the dialkylammonium unit because the hydrogen bond between them is much stronger than the "donor–acceptor" interaction between the ring and the bipyridinium unit. Adding a base, however, removes a proton (H^+) from the dialkylammonium centre, which weakens the hydrogen bond. The ring therefore moves to the bipyridinium unit, where it is stabilized by a donor–acceptor interaction. The addition of acid restores the ammonium centre and makes the ring to shuttle back to its original position. The fact that the ring can be in two possible positions could enable this molecular machine to process information, with the different positions representing "0" and "1".

NANOTECHNOLOGY PRODUCTS

NANOSYSTEMS

(different components perfom different functions)

- Nano (Micro-) Electro-mechanical Systems (MEMS o NEMS)
- Lab-on-chip
- Sensors
- Integrated Photonic-Electronic Platforms

STMicroelectronics lab-on-chip

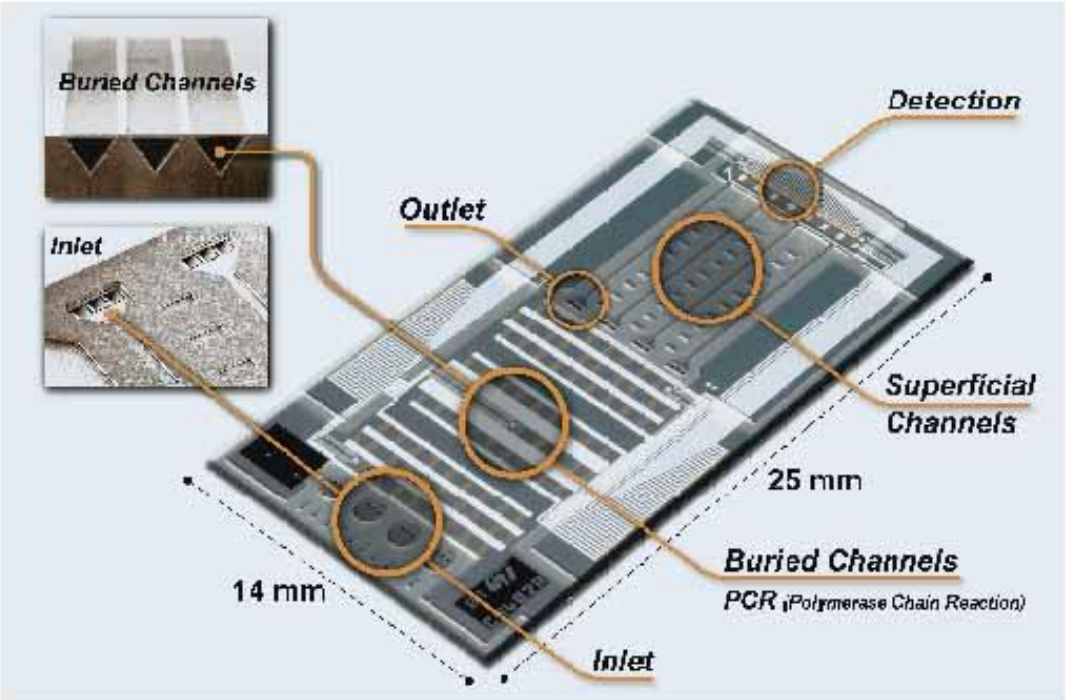
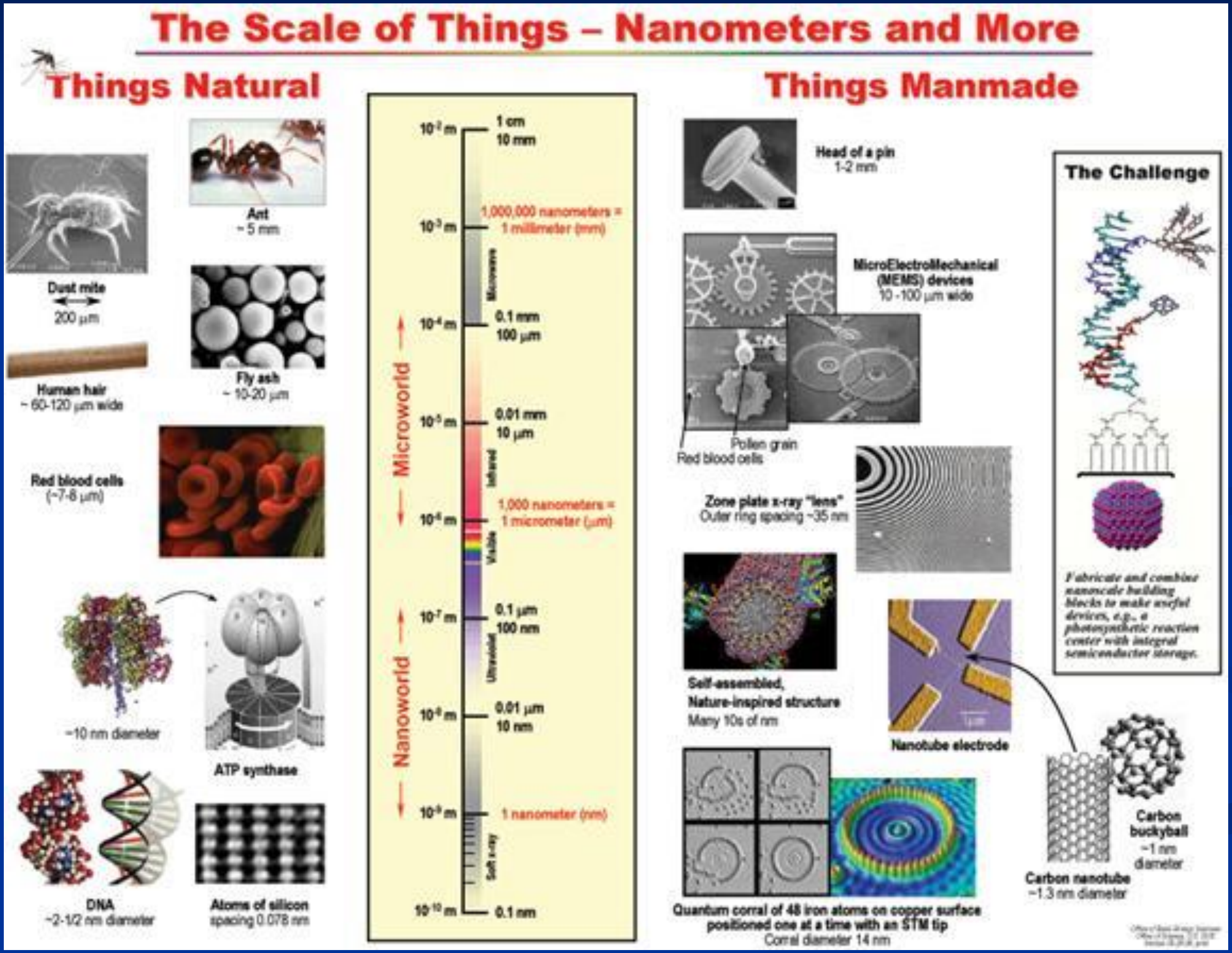


Fig 1 ST's Lab-on-a-Chip

Texas Instrument MEMS

Scaling of Natural and Artificial Structures



Effects of size reduction

- "Physiologic" scaling-laws of classical physics
- Surface to volume ratio
- Just Size Effects
- "Pathologic" quanto-mechanical effects

The Elephant and the flea:

force scales as muscle section (L^2) and wheight scales as volume (L^3)

would collapse under its own weight if it were the size of an elephant. Nonetheless, the scaling law explains quite a bit.

If a flea falls from a second-story window, it lands undisturbed but lost—not the elephant! Again, the explanation lies in characteristic dimension. The elephant's characteristic dimension (meters) is 1000 times that of the flea (millimeters). The elephant is about 1000^3 (one billion) times heavier than his companion. Based on the strength-to-weight ratio determined above, if a flea can support something 100 times its body weight, then an elephant can only support something 1/10 its body weight.

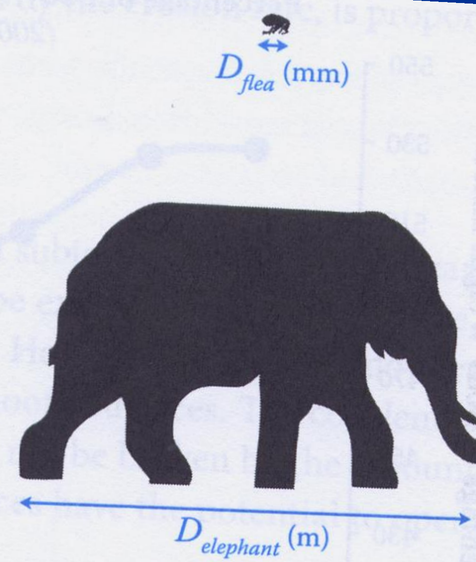


FIGURE 2.3 The flea and the elephant. The flea's characteristic dimension is best measured in millimeters, the elephant's in meters. This difference gives rise to very different strength-to-weight ratios for these very different creatures.

Scaling laws of classical physics

e.g. resistance:

$R = \rho\, l / A = L^{-1}$

K E Drexler

Table 1. Classical continuum scaling laws, with characteristic magnitudes for $L = 10^{-8}$ m. These relationships break down at smaller scales, where atomic structure and (in some instances) quantum effects become important, and volumes become too small to hold all the components of a productive nanosystem. Note that mechanical power densities can be reduced to values that are more reasonable by reducing forces and speeds.

Quantity	Scaling	Magnitude	
Magnetic force	L^4	10^{-19}	N
Volume	L^3	10^{-24}	m^3
Mass	L^3	10^{-21}	kg
Electrostatic energy	L^3	10^{-19}	J
Torque	L^3	10^{-15}	m N
Gravitational force (weight)	L^3	10^{-20}	N
Area	L^2	10^{-16}	m^2
Force (at working stress)	L^2	10^{-7}	N
Mechanical power	L^2	10^{-7}	W
Electrostatic force (constant field)	L^2	10^{-11}	N
Electric current	L^2	10^{-6}	A
Length	L^1	10^{-8}	m
Deformation (constant stress)	L^1	10^{-11}	m
Motion time	L^1	10^{-8}	s
Stiffness	L^1	10^{4}	$N\,m^{-1}$
Voltage (constant field)	L^1	10^{0}	V
Gravitational stress	L^1	10^{-5}	$N\,m^{-2}$
Mechanical working stress	L^0	10^{9}	$N\,m^{-2}$
Modulus of elasticity	L^0	10^{12}	$N\,m^{-2}$
Electrostatic stress (constant field)	L^0	10^{5}	$N\,m^{-2}$
Adhesive strength (dispersion forces)	L^0	10^{9}	$N\,m^{-2}$
Strain	L^0	10^{-3}	—
Density	L^0	10^{3}	$kg\,m^{-3}$
Speed	L^0	10^{0}	$m\,s^{-1}$
Current density	L^0	10^{10}	$A\,m^{-2}$
Electric field	L^0	10^{8}	$V\,m^{-1}$
Amplitude of thermal vibrations	$L^{-1/2}$	10^{-12}	m
Acceleration	L^{-1}	10^{8}	$m\,s^{-2}$
Spring stiffness	L^{-1}	10^{4}	$N\,m^{-1}$
Deformation (constant force)	L^{-1}	10^{-11}	m
Mechanical power density	L^{-1}	10^{17}	$W\,m^{-3}$
Electrical resistance	L^{-1}	10^{0}	Ω
Motion frequency	L^{-1}	10^{8}	s^{-1}
Relative productivity (scaled parts)	L^{-1}	10^{5}	s^{-1}
Relative productivity (atomic parts)	L^{-4}	10^{3}	s^{-1}

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Exposed surface = chemical activity

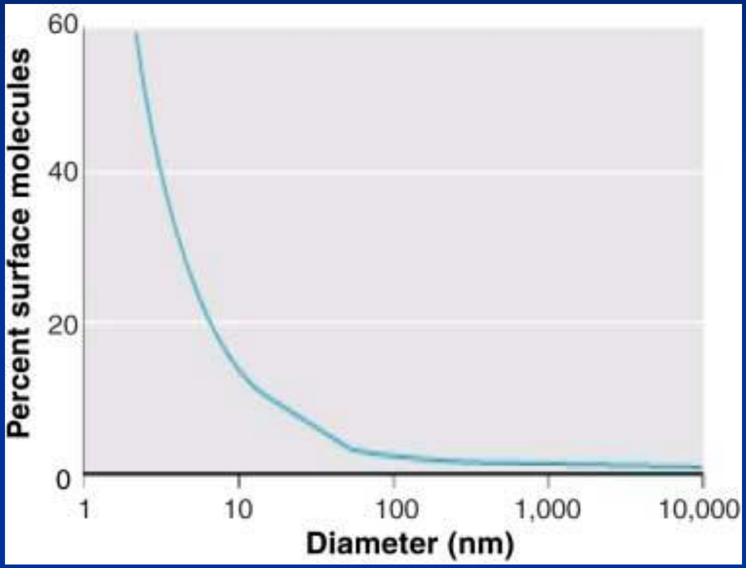

Fig. 1. Inverse relationship between particle size and number of surface expressed molecules. In the size range G 100 nm, the number of surface molecules (expressed as a % of the molecules in the particle) is inversely related to particle size. For instance, in a particle of 30 nm size, about 10% of its molecules are expressed on the surface, whereas at 10 and 3 nm size the ratios increase to 20% and 50%, respectively. Because the number of atoms or molecules on the surface of the particle may determine the material reactivity, this is key to defining the chemical and biological properties of nanoparticles. [Adapted from (4)]

Table 1. Particle number and particle surface area for 10 µg/m^3 airborne particles (5).

Particle diameter (µm)	Particles/ml of air	Particle surface area (µm^2/ml of air)
2	2	30
0.5	153	120
0.02	2,390,000	3000

Mechanisms for reactive oxygen species

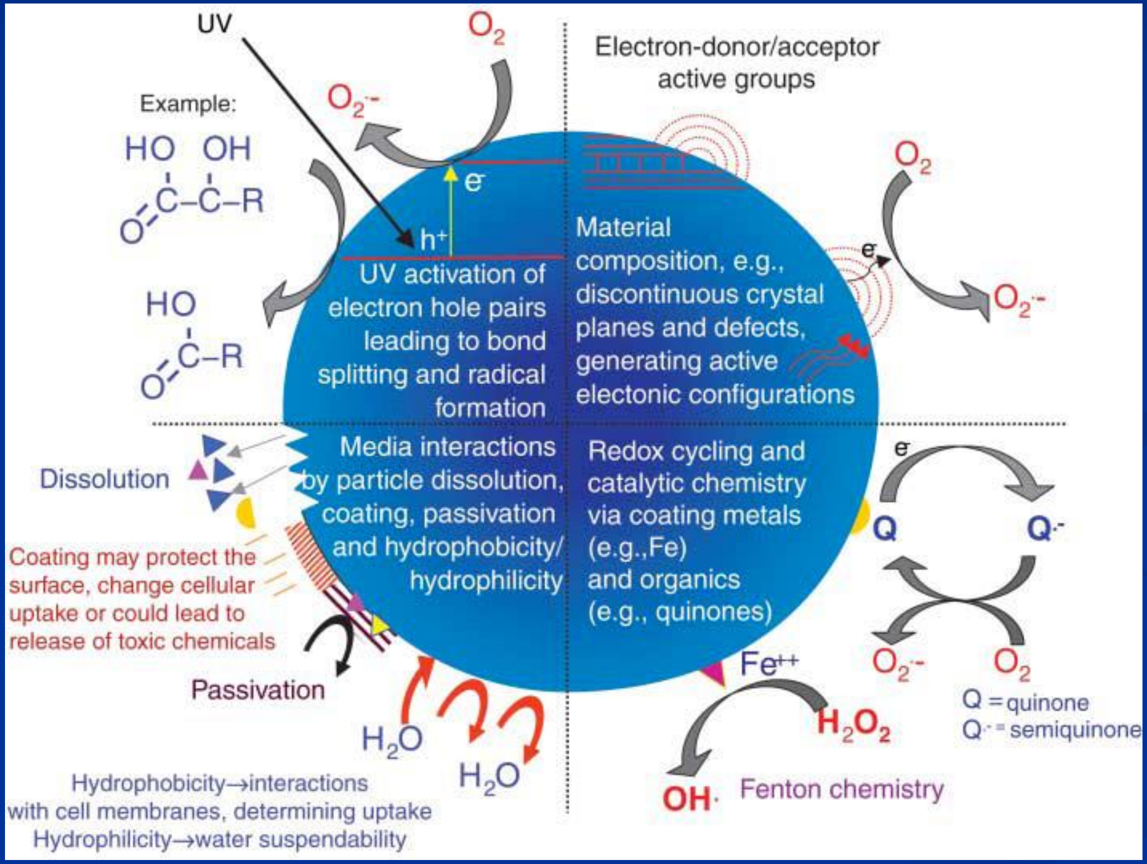

Fig. 2. Possible mechanisms by which nanomaterials interact with biological tissue. Examples illustrate the importance of material composition, electronic structure, bonded surface species (e.g., metal-containing), surface coatings (active or passive), and solubility, including the contribution of surface species and coatings and interactions with other environmental factors (e.g., UV activation).

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Thermodynamics of small systems

- Breakdown of thermodynamic limit $N \to \infty$
- Increase of fluctuations, especially @ critical points
- Mean values (intensive quantities) are ill-defined
- Additivity of extensive quantities (e.g. S) breaks down

Gold microclusters (1-10nm) on SiO2/Si by e-microscope @ 120 KeV

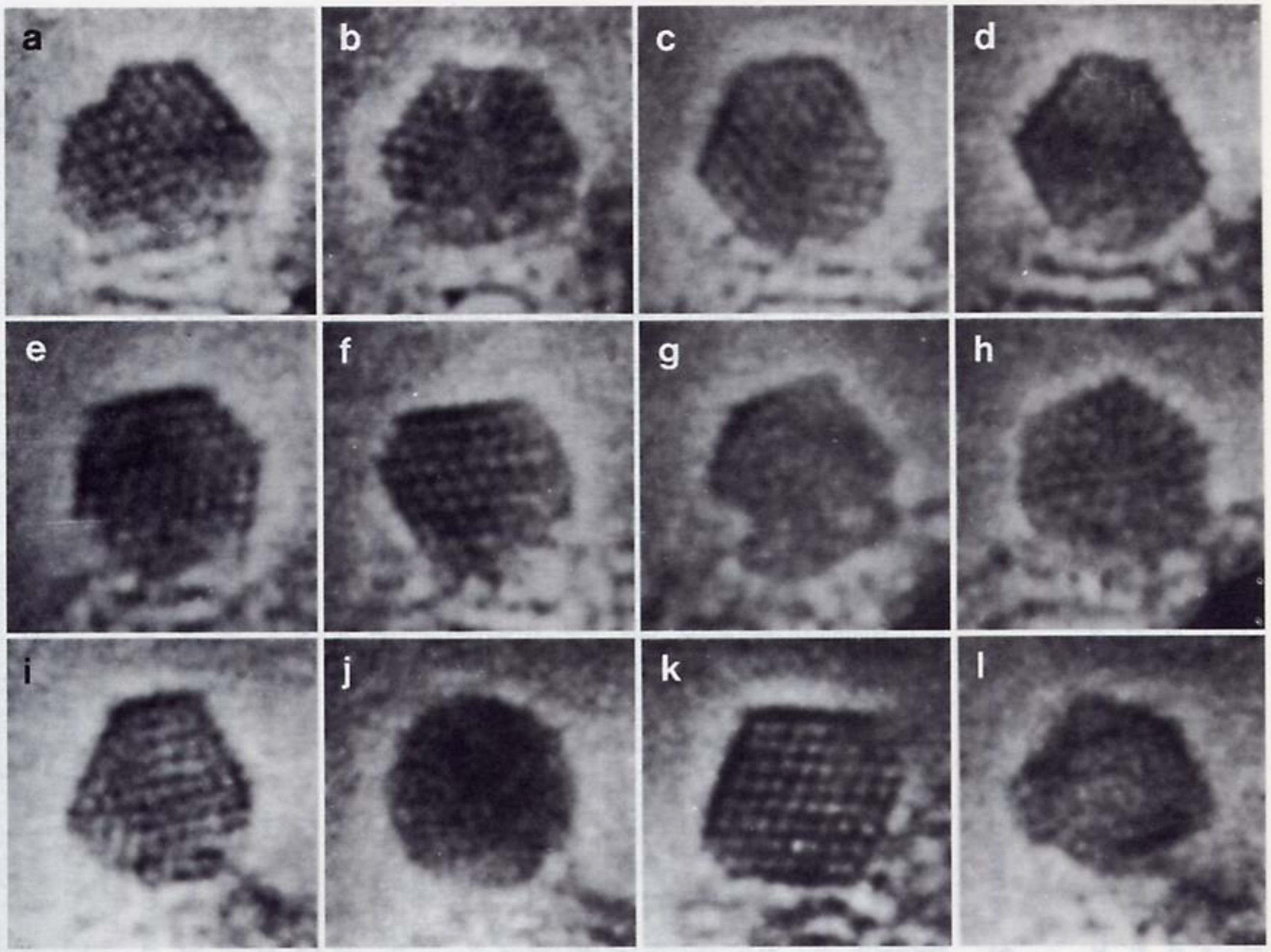

Fig. 2.1. A series of the electron micrographs showing the structural changes of a gold cluster that consists of about 460 atoms. For the details, see the text [2.3]

Optical effects: colour depends on size of gold nanoparticles

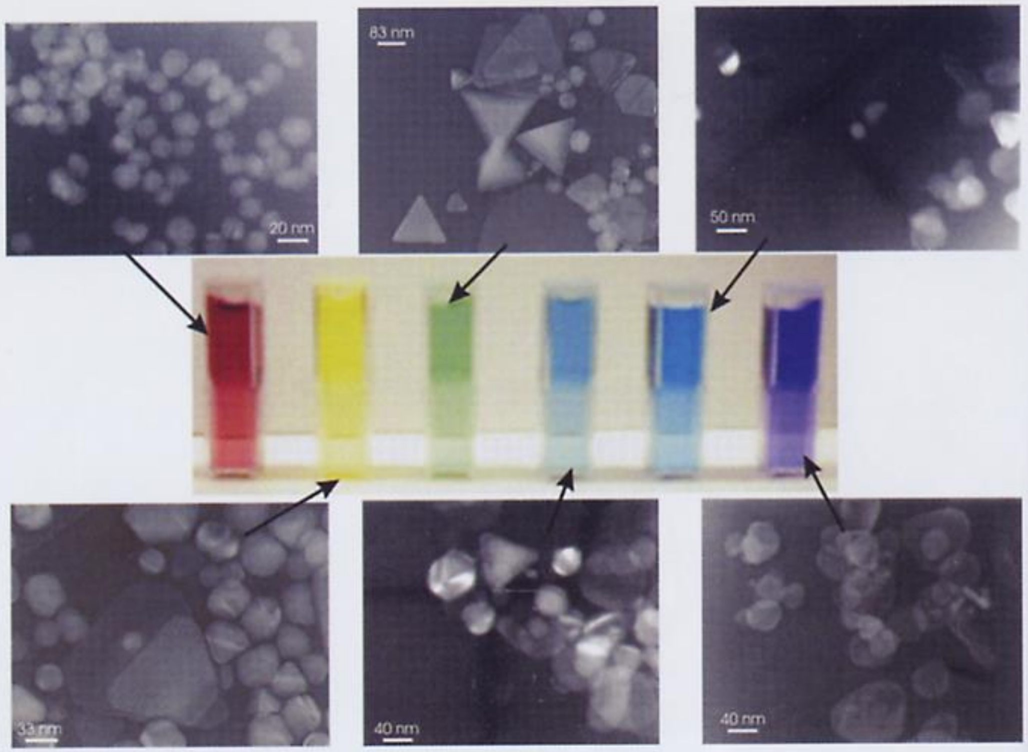

Figure 2.3
Nanocrystals in suspension. Each jar contains either silver or gold, and the color difference is caused by particle sizes and shapes, as shown in the structures above and below.
From Richard Van Duyne Laboratory, Northwestern University.

Effects of size reduction

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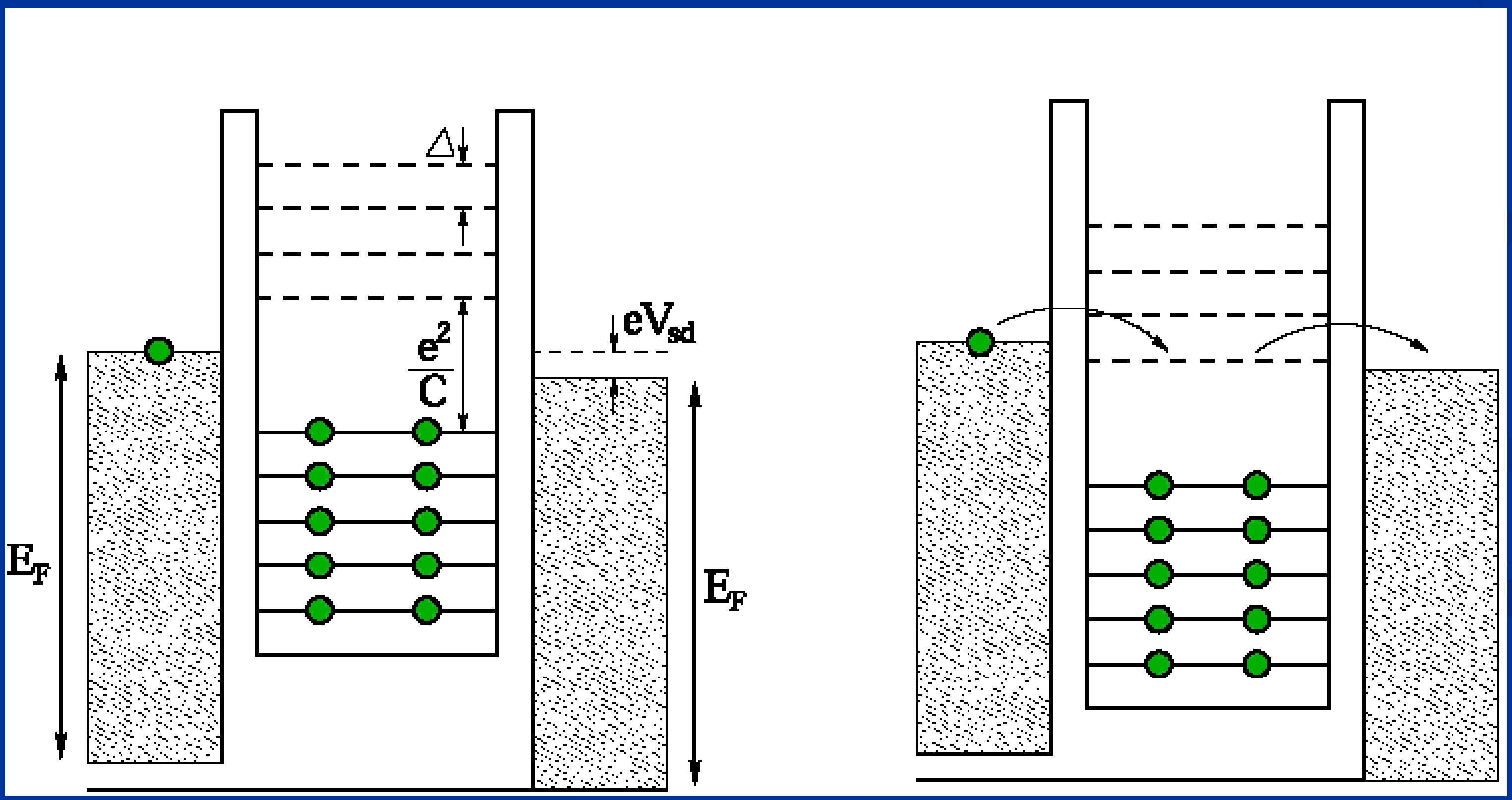
Coulomb blockade

Classical effect of a reduced capacity: the potential increases dramatically even for one single electron addition. Second is forbidden

Quantum effect of resonant tunelling: if the gate is biased the electronic levels are shifted down to Fermi levels and transition occurs



Quanto-mechanical effects

- Quantum confinement: energy levels and their spacings scale as $1/L^2$. Optical shift with size.
- Tunnelling: current scales as exp $(-2d/\Lambda)$, where d is the thickness of the barrier.
- Mesoscopic charge transport: relaxation-time approximation breaks down if $D < \lambda = v(E_F)\,\Delta t$. Resistivity is ill-defined

A short History of Nanotechnology

- The Science of Miniaturization (R. P. Feynman)
- Nanomachines and Nano-devices (K. E. Drexler)
- Nanomaterials with taylored properties (R. E. Smalley)

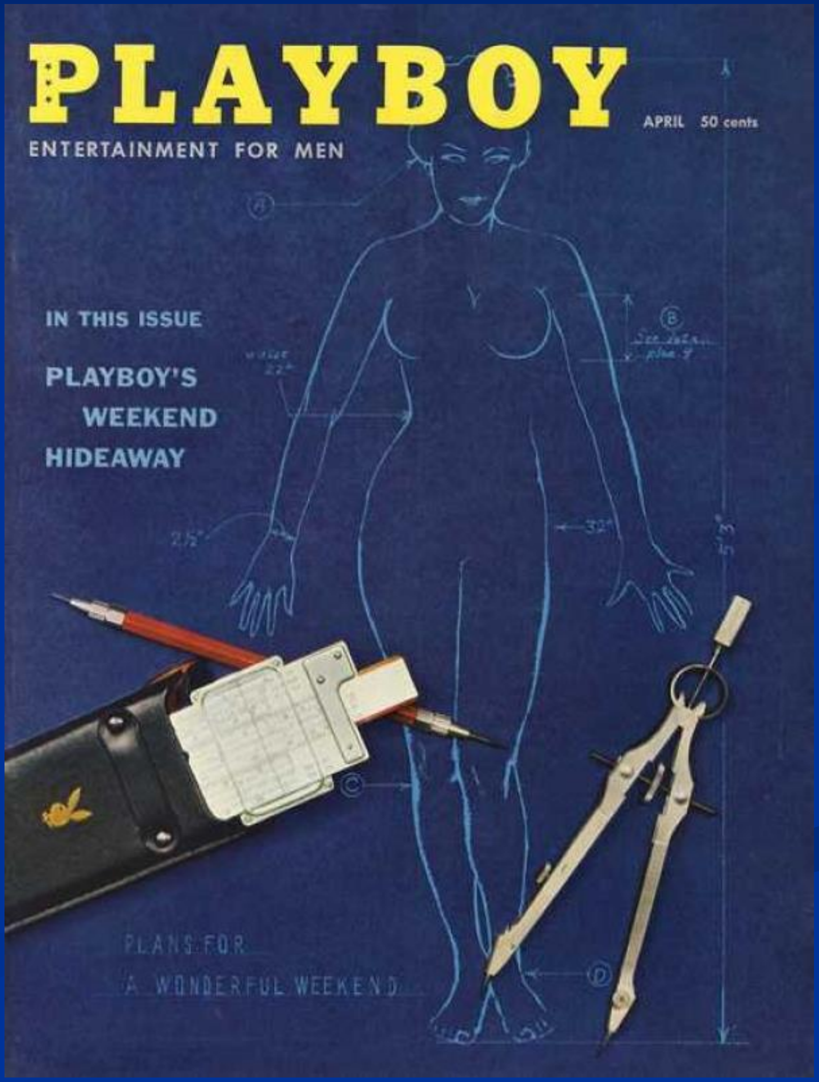
Richard P. Feynman (1918-1988)

THERE'S PLENTY OF ROOM AT THE BOTTOM:
December 29th 1959 at the annual meeting of the American Physical Society at Caltech

- Vision and physical factibility of :

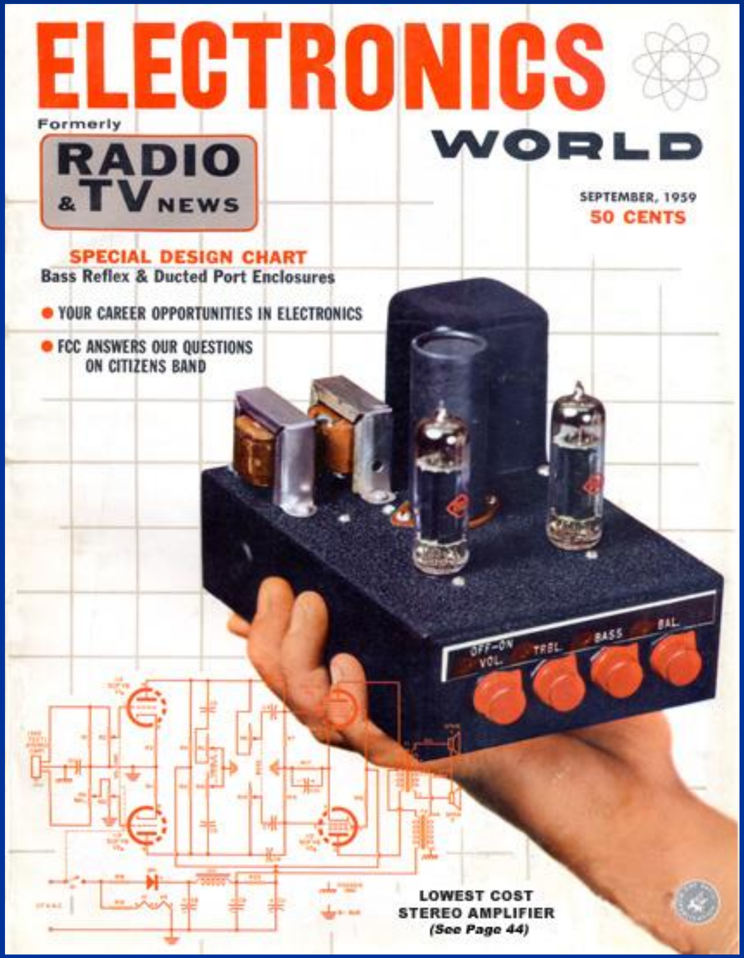
1. microelectronic integration techniques & data storage
2. nanomachines & nanodevices
3. electron microscopy and single atom manipulation
4. surgical laparoscopy
5. friction at the nanoscale
6. nanofluidics

Technology in 1959…..

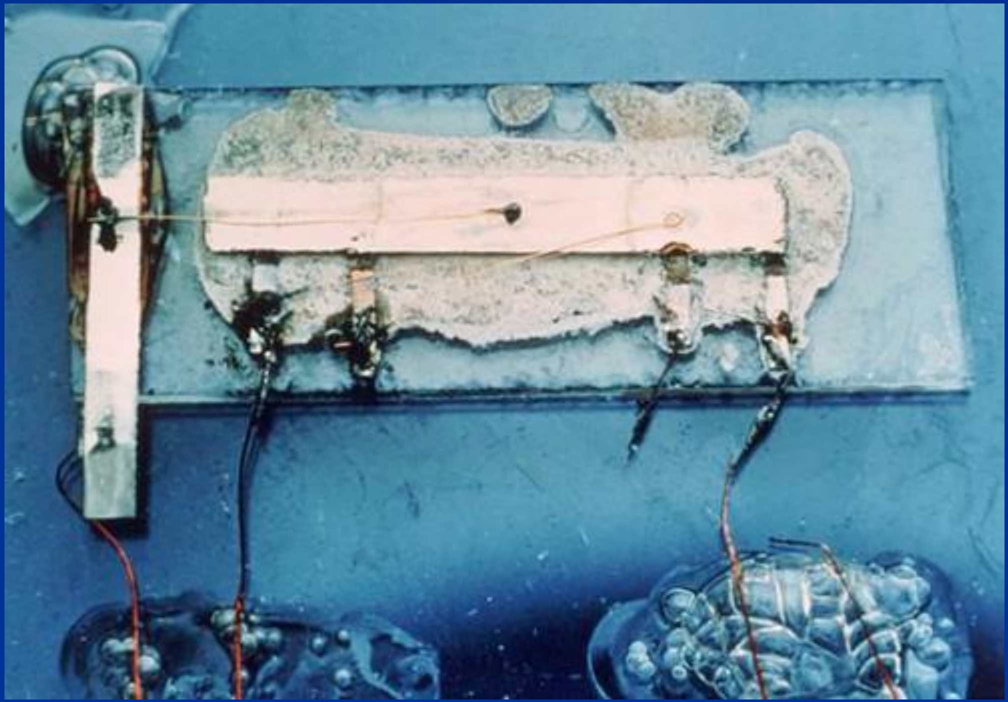


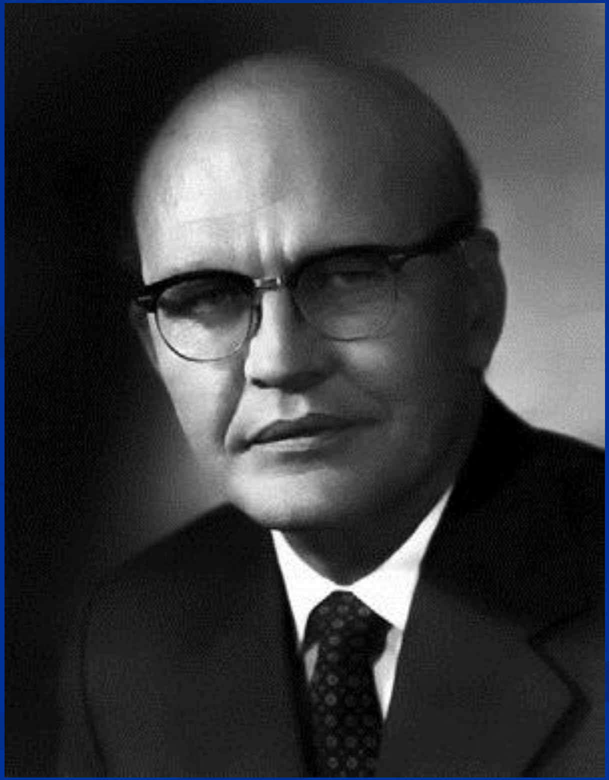
Cars & coaches

Valve electronics… But..

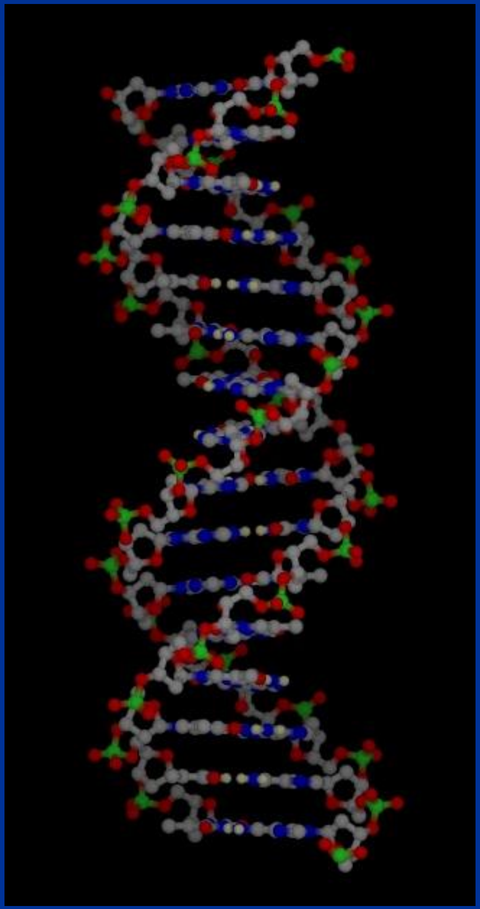


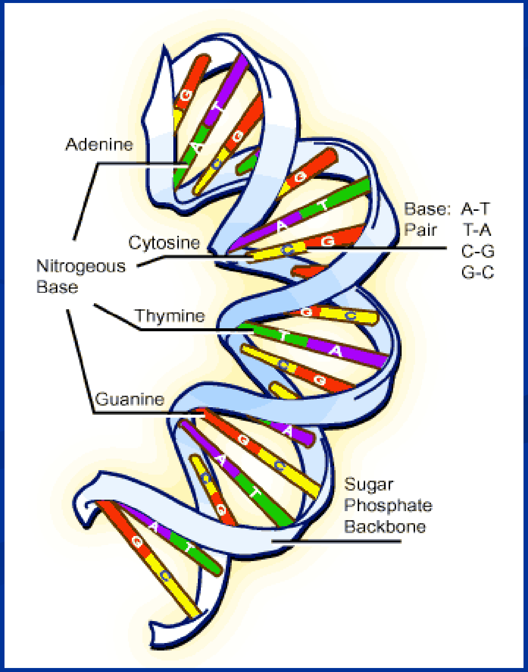
Integrated circuit: July 1958 @ TI by Jack Kilby (1923-2005)





James Watson and Francis Crick, crackers of the DNA code in 1953

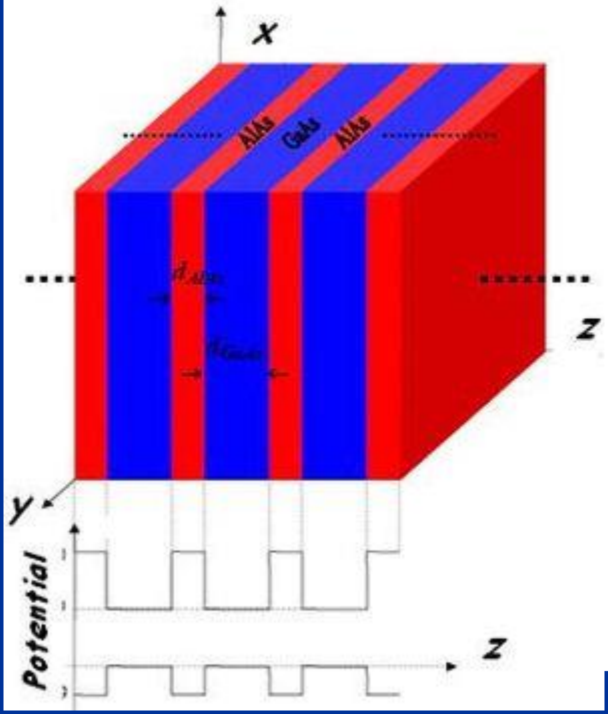




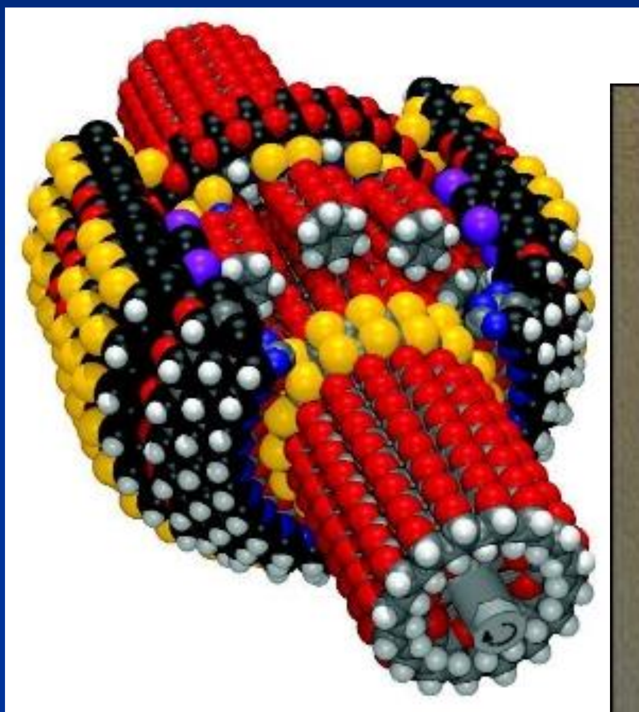
The sentence "This structure has novel features which are of considerable biological interest" may be one of science's most famous understatements.

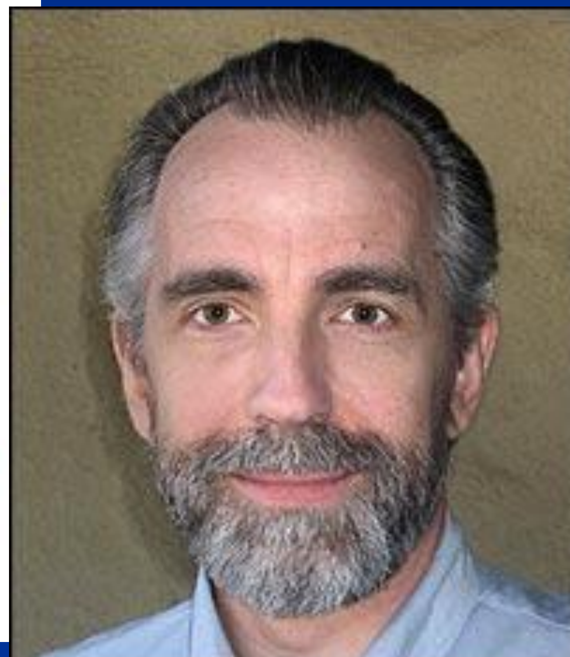
Leo Esaki (1925-). Nobel 1973

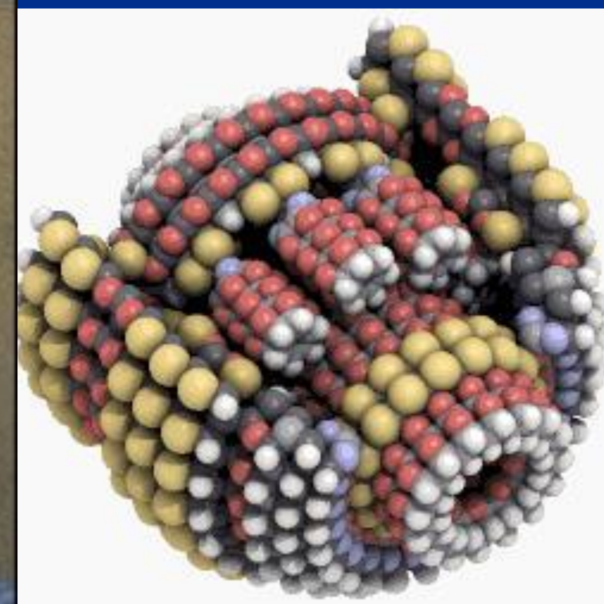
Semiconductor superlattice: a 2D nanostructure and nanodevice



From miniaturization to nanomachines: 20 years later the vision of Eric Drexler





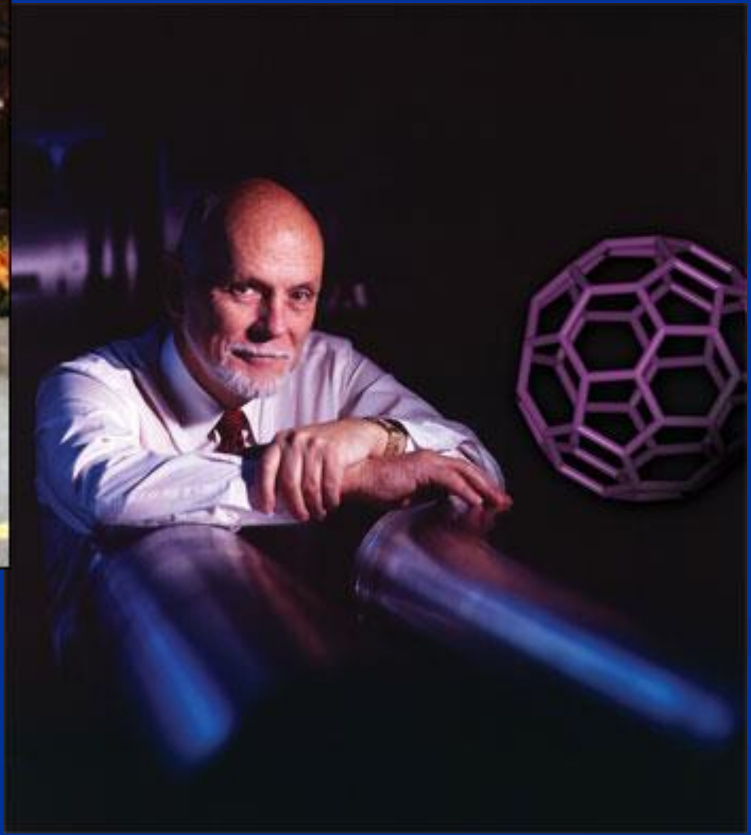


In 1977, while an undergrad at MIT, Drexler came up with a mind-boggling idea. He imagined a sea of minuscule robots that could move molecules so quickly and position them so precisely that they could produce almost any substance out of ordinary ingredients in a matter of hours. Start with a black box of so-called molecular assemblers, pour in a supply of cheap chemicals, and out would flow a profusion of gasoline, diamonds, rocket ships, whatever, all built without significant expenditure of capital or labor. In the bloodstream, tiny machines could cure diseases. In the air, they could remove pollutants.

Richard E. Smalley (1943-2005)

Nobel Prize in 1996
for Buckminsterfullerene

Founder of the nanomaterials perspective of Nanotechnology

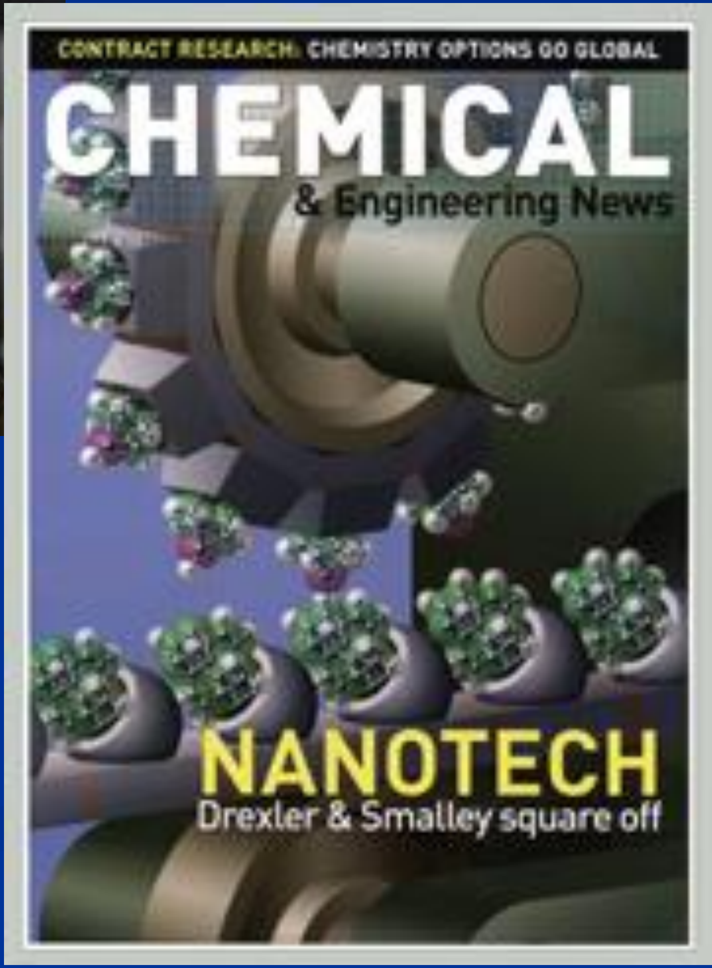


Smalley recalls a meeting he arranged with Drexler at Stanford in 1994 . "I wanted to talk about the tip," he says, referring to the business end of Drexler's machines. "I love the idea of the assembler. So I tried to drag him into a conversation about the tip, and he stonewalled. It was as if the tip was a job for later."

Drexler remembers the same meeting with no less frustration. "I found it very hard to explain things to him," he says. "He was asking for an irrelevant and impossible control of the motion of every atom. The question isn't, Are there some things that won't work? The question is, Are there enough things that will?"

A bitter quarrel with R. Smalley

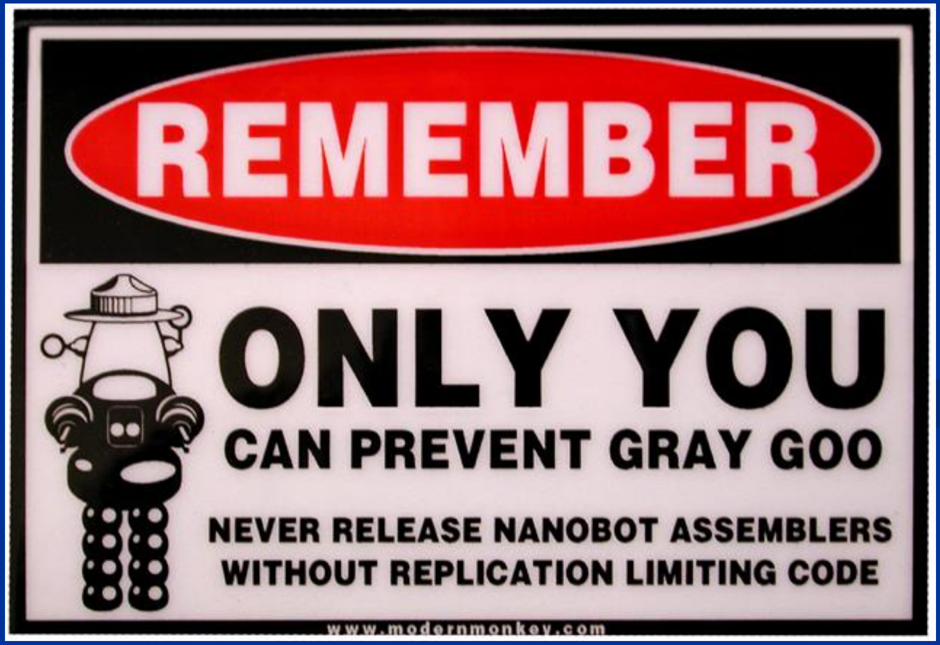
Drexler's first book, *Engines of Creation*, published in 1986, introduced the term nanotechnology to the world at large.



On December 1, 2003 the technical journal *Chemical and Engineering News* published a series of letters between Drexler and Smalley in which the Nobelist made his position clear: Molecular assembly is impossible. "Chemistry of the complexity, richness, and precision needed to come anywhere close to making a molecular assembler - let alone a self-replicating assembler - cannot be done simply by mushing two molecular objects together," Smalley wrote.

The first environmental issue, taken from blast propagation

Smalley accused Drexler of terrorizing the world with the prospect that self-reproducing assemblers might escape the lab and devour everything in their path, turning the Earth into an inert, undifferentiated blob of gray goo.



Reply:
"Safe Exponential Manufacturing"
Phoenix, C, and K.E. Drexler
Nanotechnology **15,** 869-872 (2004).

But others are the closest risk concerns…

Nature 444, 267-269 (16 November 2006)

Safe handling of nanotechnology

Andrew D. Maynard1, Robert J. Aitken, Tilman Butz, Vicki Colvin, Ken Donaldson, Günter Oberdörster, Martin A. Philbert, John Ryan, Anthony Seaton, Vicki Stone, Sally S. Tinkle, Lang Tran, Nigel J. Walker & David B. Warheit

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Researchers & Producers

Consumers and traders

Environmental and Health Risks

- Risks in manufacturing/transport
- Risks in use/mis-use
- Risks in disposal/recycling

- Primary vehiculations of nanoparticles in the body: inhalation, skin penetration, swallowing.
- Main issues: penetration/intracellular mobility, accumulation, toxicity

Toxicity: still no dosimeters

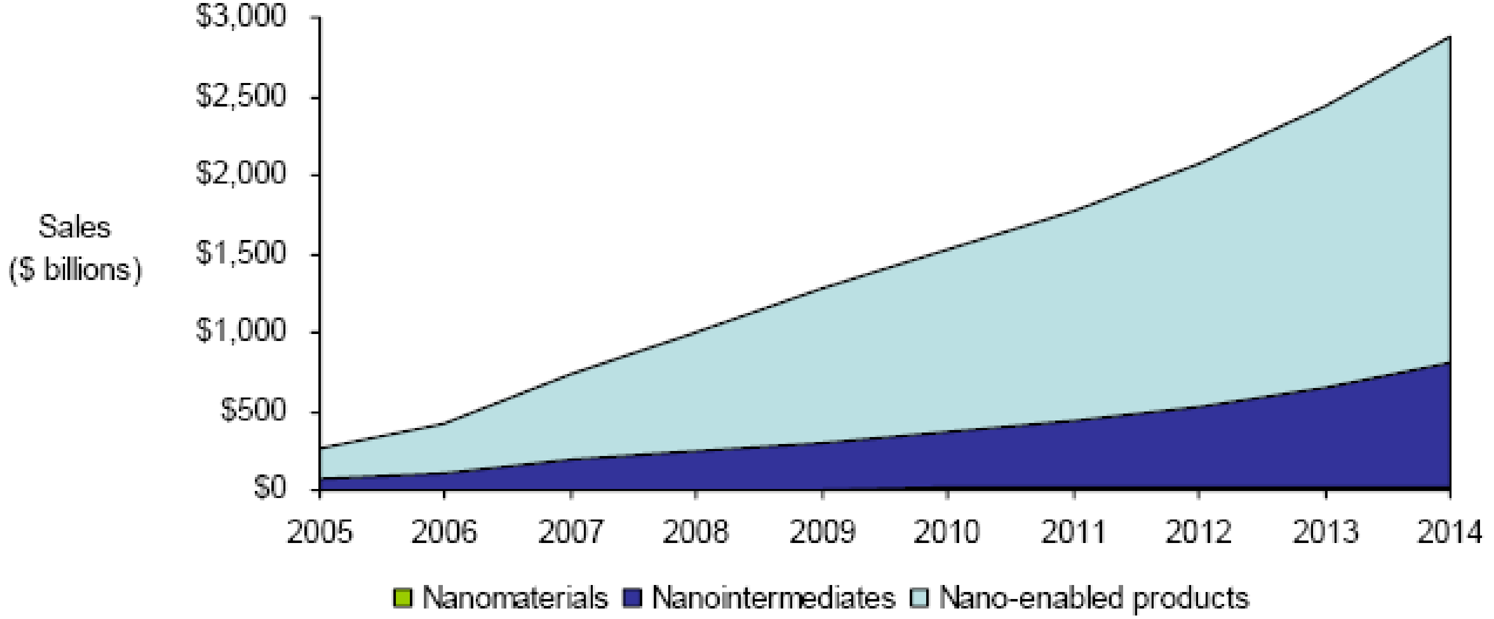
Fears over the possible dangers of some nanotechnologies may be exaggerated, but they are not necessarily unfounded. **Recent studies examining the toxicity of engineered nanomaterials in cell cultures and animals have shown that size, surface area, surface chemistry, solubility and possibly shape all play a role in determining the potential for engineered nanomaterials to cause harm.** This is not surprising: we have known for many years that inhaled dusts cause disease, and that their harmfulness depends on both what they are made of and their physical nature. For instance, small particles of inhaled quartz lead to lung damage and the potential development of progressive lung disease, yet the **same particles with a thin coating of clay are less harmful**. Asbestos presents a far more dramatic example: thin, long fibres of the material can lead to lung disease if inhaled, but grind the fibres down to **shorter particles with the same chemical make-up and the harmfulness is significantly reduced.**

Financial & Economic Issues with Applications

Nanotech business: a 1000-billions USD world-wide affair

Nanotechnology will impact $2.9 trillion worth of products across the value chain by 2014

Sales of products incorporating nanotechnology, 2005 to 2014

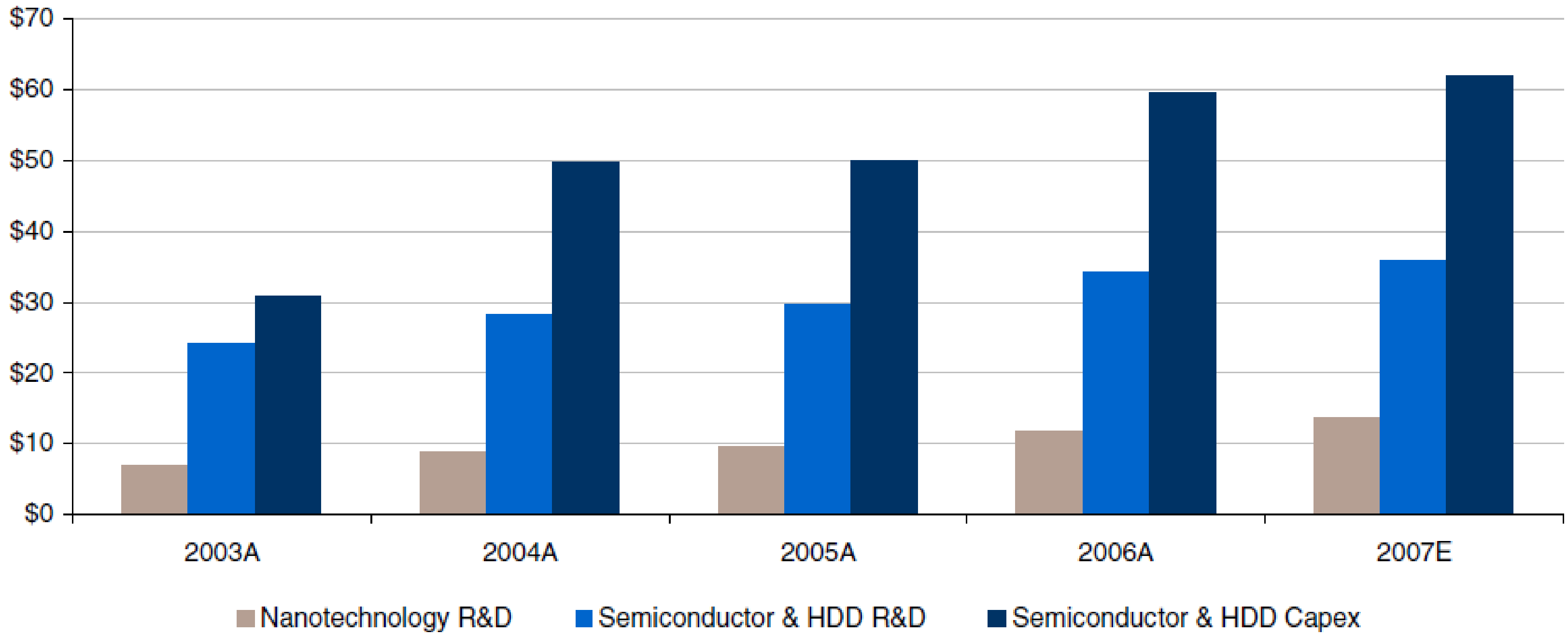


Forecast based on Lux Research's value chain ontology, secondary research, and more than 100 interviews with executives, thought leaders, and academics. Projections were triangulated from bottom-up, top-down, analogical, and third-party market estimates, as well as advanced evolutionary models.

Source: Lux Research Report "Sizing Nanotechnology's Value Chain"

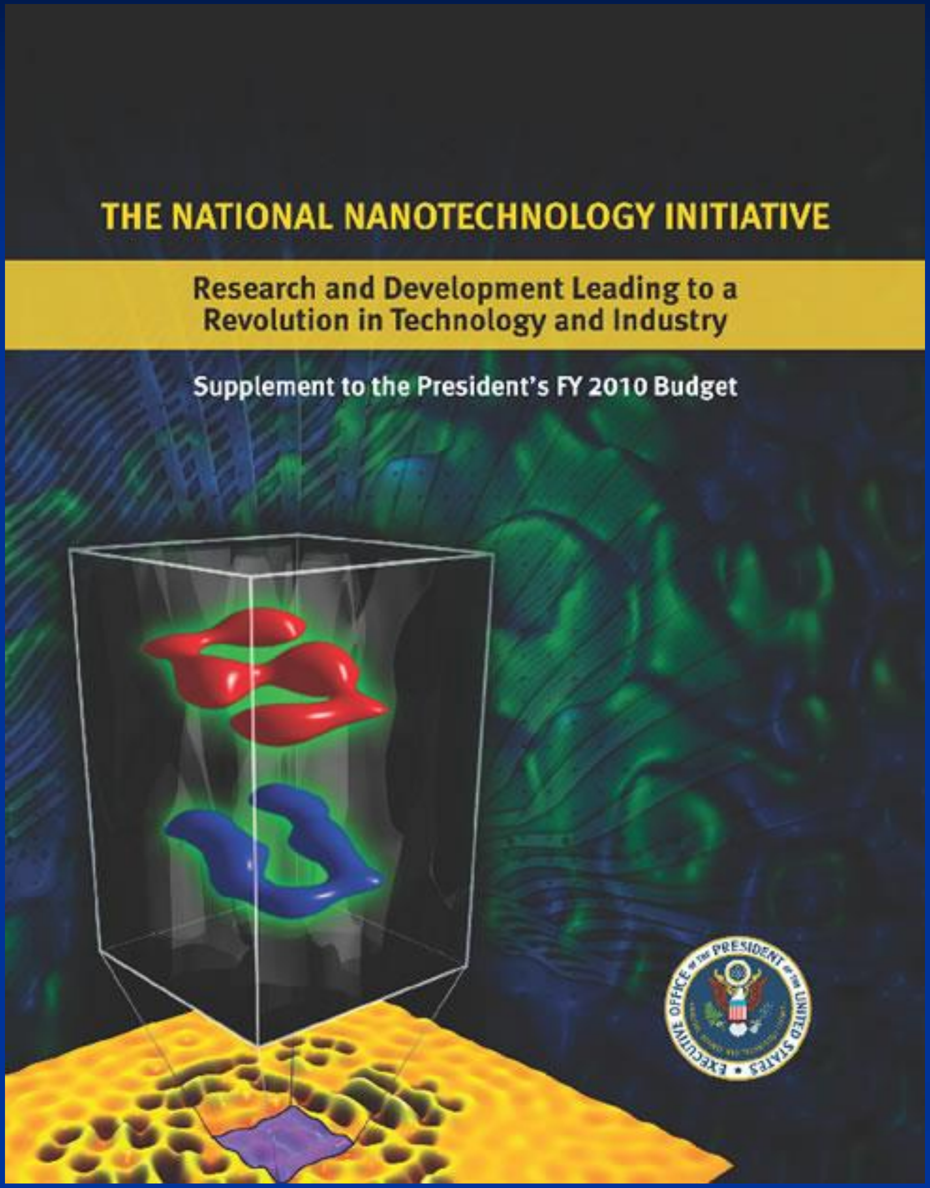
R&D spending in Nanotech

Exhibit 1: Comparison of R&D and Capital Spending ($ billions)



Source: Lux Research, Credit Suisse estimates.

In 2001 president Bill Clinton launches the….



2010 budget of 1.6 billion USD

THE BASICS OF INNOVATION

TECHNOLOGY

PUSH

MARKET

PULL

INNOVATION

Offer of new materials, processes, devices

Demand of new products, cheaper/cleaner processes, new services

Technology push..

Exhibit 7: **Selected Nanomaterials**

Material	Description	Market Size ($m) 2006	Market Size ($m) 2011	2006-11 CAGR
Carbon Nanotubes	Tubular structures of hexagonally-oriented carbon atoms	$49	$460	56%
Nanowires	Wire-like structures that are less than 100nm in diameter	1	38	107%
Fullerenes	Spherical cages of carbon atoms arranged in hexagons or pentagons	8	66	53%
Quantum Dots	Nanocrystals with size-dependent optical and electrical properties	11	62	41%
Ceramic Nanoparticles	Nanoscale particles of ceramics, predominantly metal oxides	240	1,100	36%
Dendrimers	Repeatedly branched molecules in shape of a snowflake	7	54	50%
Metal Nanoparticles	Nanoscale particles of metals, typically gold, silver, aluminum	90	500	41%
Nanoporous Materials	Usually made from silica, carbon or polymers. Include aerogels	65	690	60%
Nanoscale Encapsulators	Nanoscale vehicles to contain other materials such as drugs	17	260	73%
Nanostructured Metals	Metals with nanoscale grain sizes that make them stronger	35	380	61%
Total		**$523**	**$3,610**	**47%**

Source: Lux Research.

Carbon NanoTubes (CNT) … and graphene!

- *Structual.* CNTs can be found in a wide range of products and materials. Below is a brief list of products where CNTs are utilized and the benefits they add:
  - *Clothes*. Waterproof tear-resistant cloth fibers
  - *Combat jackets*. Ultrastrong fibers that can monitor the condition of the wearer
  - *Concrete*. Increased tensile strength and ability to halt crack propagation
  - *Polyethylene*. 30% increase in polymer's elastic modulus
  - *Sports equipment*: Stronger and lighter tennis rackets, bike parts, golf balls, clubs, etc.

Exhibit 9: **The Bike That Won Tour de France 2006 (CNTs Alloyed in Carbon Fiber)**

Carbon NanoTubes (CNT)

- *Electrical circuits.* CNTs can be ideal components for electrical circuits because of their unique dimensions, unusual current conduction mechanism and thermal stability. In addition, their size enables creation of nano-sized circuitry, which can extend the process technology roadmap for integrated circuits:

  Source: Wikipedia.

  - *Carbon nanotube interconnects.* Properties of metallic CNTs such as high thermal stability, high thermal conductivity and large current carrying capacity have led to research into replacement of copper interconnect in integrated circuits with CNTs. An isolated CNT can carry current densities in excess of 1,000 MA/sq-cm without any signs of damage even at an elevated temperature of 250 degrees Celsius, thereby eliminating electromigration reliability concerns that plague copper interconnects. CNTs can be used in bundles to form interconnect or in conjunction with copper. Such hybrid CNT/copper solutions employ CNT vias in tandem with copper interconnects. Both solutions have been shown to offer thermal and reliability advantages over traditional copper interconnect.
  - *Carbon nanotube transistors.* Semiconducting CNTs have been used to fabricate field effect transistors (CNTFETs), which show promise due to their superior electrical characteristics over silicon based MOSFETs. CNTFETs can exhibit near-ballistic transport characteristics, resulting in high speed devices. CNT devices have the potential to be operational in the frequency range of hundreds of GHz. IBM, among others, has been active in exploring applications in assembling advanced circuitry from individual nanotubes.

Carbon NanoTubes (CNT)

- *Electromagnetic*. A wide range of applications from mundane to highly futuristic:
  - *Field emission displays (FEDs)*. By launching electrons at a phosphorescent screen from a field emission source rather than a cathode ray tube, it is possible to create bright, thin and more efficient flat panel displays.
  - *Electric motor brushes*. CNTs replace traditional carbon black, which consists mostly of impure spherical carbon fullerenes. The nanotubes improve electrical and thermal conductivity because they stretch through the plastic matrix of the brush.
  - *Lithium-ion batteries*. CNTs grown on the surface of small silicon particles using CVD allow the resulting composite to be used for the battery anode and extend battery life.
  - *Light bulb filament*. Alternative to tungsten filaments in incandescent lamps.
  - *Artificial muscles*. Methanol-powered artificial muscles have been created by researchers aiming to create battery-free robotic limbs and prosthetics.
  - *Transparent conductors*. LCDs and touchscreen displays use layers of indium tin oxide (ITO), a transparent conductive material that provides the electrodes to turn the pixels on or off. Companies like Eikos and Unidym are developing CNTs as a new electrode material for displays.
  - *Sensors*. CNTS enable construction of sensors with very high sensitivity utilizing the property of CNTs whereby its conductivity changes when molecules attach to its surface.

Carbon NanoTubes (CNT)

- *Mechanical:*
  - *Oscillators*. Fastest known oscillators (> 50 GHz).
  - *Nanotube membrane*. Liquid flows up to five orders of magnitude faster than predicted by classical fluid dynamics. Can be used for water and air filtration.
  - *Slick surface*. Slicker than Teflon and waterproof.
- *Chemical:*
  - *Biotech containers*. Nanotubes can be opened and filled with materials such as biological molecules, raising the possibility of applications in biotechnology.
  - *Hydrogen storage*. Research is currently being undertaken into the potential use of carbon nanotubes for hydrogen storage.

THE BASICS OF INNOVATION

TECHNOLOGY PUSH

MARKET PULL

INNOVATION

Offer of new materials, processes, devices..

Demand of new products, cheaper/cleaner processes, new services

The market side: players

Exhibit 3: **Categories for Organizing Nanotechnology Companies**

Category	**Enablers**	**Producers**	**Product Innovators**	**Roadmap Extenders**
Description	Companies who enable development and production of nanotechnology-based products. Consists primarily of nanotool vendors.	Vendors whose core business is manufacturing of nanomaterials. Companies increasingly expand downstream, often with focus on specific verticals.	Includes companies with end market expertise who leverage nanotechnology to launch new products and enter new segments. Some overlap with material producers who have application expertise.	Companies whose primary interest in nanotechnology is for the purpose of extending their technology roadmap. Limited interest in exploring new end markets.
Examples	FEI Veeco Molecular Imprints	Nanophase Technologies Nanosys Selah Technologies	Valence Technology Nanosolar Nanospectra Biosciences	Intel, Samsung, Hynix, Seagate, Hitachi GST

Source: Credit Suisse estimates.

End Markets

- ICT & related
- Energy
- Medicine & Pharma
- Agricolture & Food
- Chemical industry
- Fabrics & personal
- Mechanical & Metallurgy

ICT: micro/nano-electronics

- Transistors (intrinsically nano) : quantum dot stressors, spintronics, molecular electronics

  ⇕ semiconductor nanowires, graphene

- Interconnects: CNTs, metallic inks and pastes

Exhibit 5: NRAM Structure

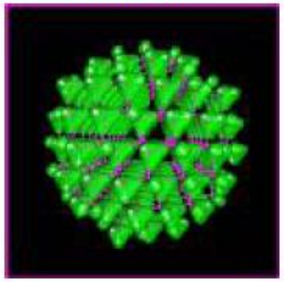
Source: Nantero.

- Non volatile memories: phase-change chalcogenides, ferroelectric RAM
- Hard-disk drives: GMR, tunnel magnetoresistive, perpendicular recording, nanoimprint lithography

ICT: opto-electronics, photonics

- LASER, LED/OLED, lighting: semiconductor quantum well, quantum dot (simple, core-shell)

Exhibit 17: **Quantum Dots**



Computer model of a quantum dot

"Quantum dot rainbow" from blue to red

Source: PhysOrg.com.

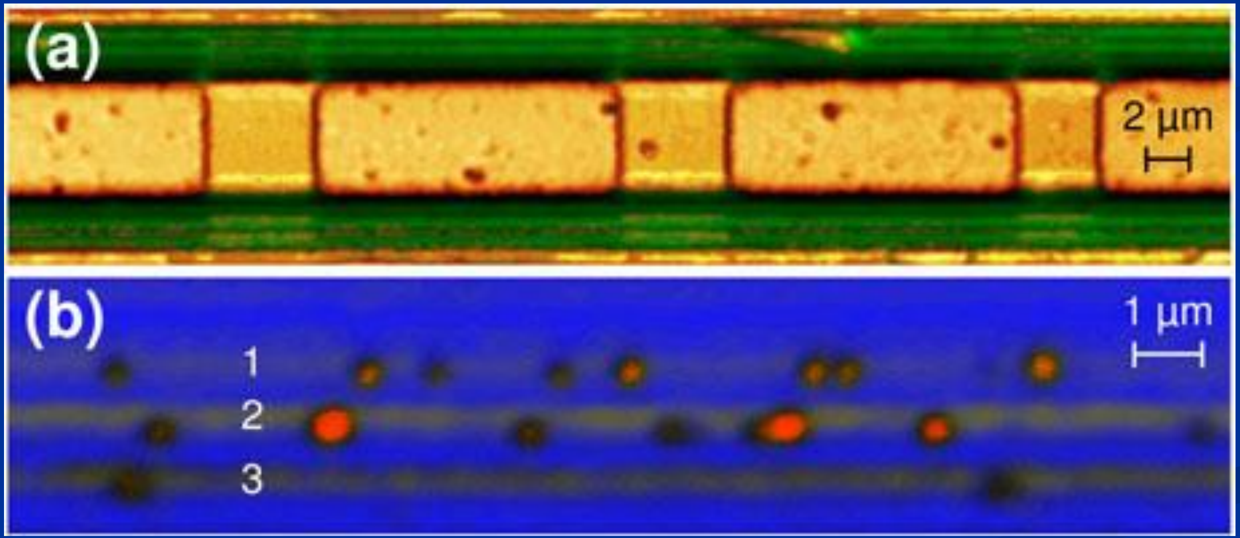
- Passive elements: nanocomposite fibers & filters, integrated optical interconnects, photonic crystals
- Optical modulators, amplifiers: InP superlattices
- Detectors: multi - quantum well, - quantum dot

ICT: micro/nano electro-mechanical systems, sensors

- Actuators, mechanical sensors
- Micropumps, micro/nano fluidic systems
- Magnetic sensors: spintronic devices
- Chemical sensors: molecular recognition

How nanochannels of different width can select proteins of different size

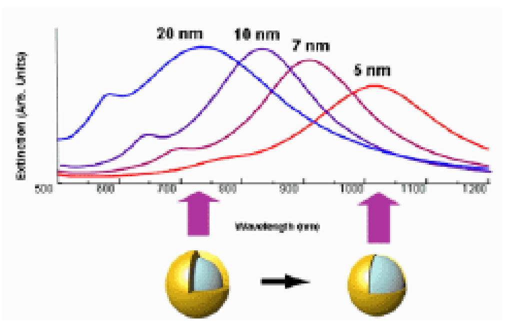
A nanofilter (L-NESS in Como and MPI-FKF Stuttgart). Capillarity motion is critical: selection of the suitable solvent!



Medicine & Pharma

- Diagnostic tools: lab-on-chip, nanoarrays for proteomics
- Anti-cancer targetted therapy: chemical, thermal and mechanical apoptosis of cancer cells (e.g. magnetic nanoparticles covered by gold)
- Regenerative Medicine: nano-scaffolds, hemostatics; nanomaterials for prosthesis and friction-reduced stents

Exhibit 6: AuroShell Structure

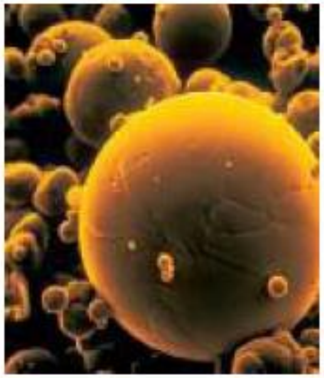


Source: Nanospectra.

Medicine & Pharma

- Transdermal drug delivery systems: MEMS, ..
- Topical drug delivery systems: functionalized encapsulators
- Injectable drug delivery systems: nanosolubility
- Toxin removal by functionalized microemulsions
- Cosmetics: sunscreens, skin creams …..

Nanoparticles

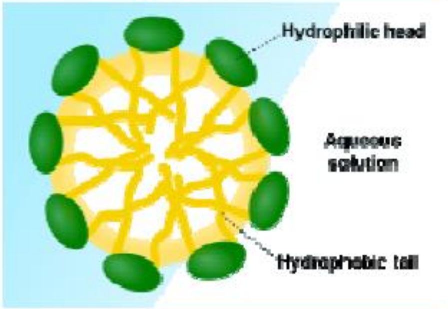


Agricolture & Food

- GPS-based remote croop sensors for ripening and diseases
- Smart delivery systems for pesticides: nanoencapsulators, nanoemulsions
- Water filtration and purification:

  Al-oxide nanofibers, lanthanum nanoparticles (phosphates)
- Contaminated soil purification: iron (C-tethracloride, dioxins..) and iron-oxide nanoparticles with graphene (arsenic..)

Exhibit 28: Micelle



Source: Wikipedia.

Agricolture & Food

- Smart packaging I : sensors for food spoiling, temperature history
- Smart packaging II : gas/water permeation barriers, oxigen getters (silica, clays), thermal and mech. reliability, antimicrobial effects (nano Ag,..)
- Food processing I : encapsulators for additives, interactive food (release on command)
- Food processing II : fat management

Fabrics & personal

- Surface treatement of consumer fabrics: spill resistance (NanoTex), …
- Special-purpose fabrics: bullet-resistant and fire-resistant for military and fire-service uses
- Intelligent clothing: sensors included or temperature/light – sensitive fibers
- Electro-sensitive glasses, CNT sport equipments

What is Nano?
Science, Technology & Business.