The Symbiotic Relationship of Nanotechnology and Creativity

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Natural Sciences Economy

Kepler, Newton, Da Vinci Creation	1600–1700	⊄	Wealth
Bohr, Einstein, Heisenberg	1900	$M	
The "Boom" of NASDAQ	2000	$T	

The vast interdisciplinary nature of nanotechnology will…

- Improve characterization and imaging (visualization)
- Increase capabilities of chemical/biological analysis
- Facilitate manipulation of nanostructures
- Enhance theory and modeling
- Reveal the role of surfaces and interfaces
- Control size distribution, composition and self-assembly of nanostructures
- Solve concerns of thermal and structural stability
- Achieve reproducibility and scalability in synthesis and manufacturing
- Create a new type of researchers that can work across traditional disciplines and think out of the box
- Induce the congregation of all disciplines from Physics to Chemistry and Biology to essentially all other engineering disciplines
- Generate self–assembled organic (even life matter) material that can form a template of scaffolding for organic and inorganic additives

Nanosciences will replace natural sciences

CNT, DNA, Quantum dots	2000	Wealth
"Ultra boom" of NASDAQ	2050	Extreme Wealth

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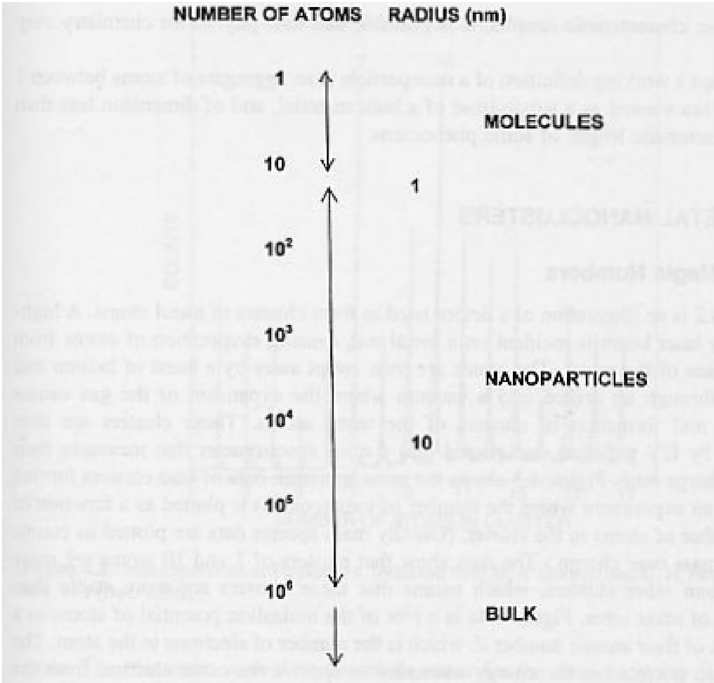
Nanotechnology definition

Nanotechnology is a new scientific field evolving from material–specific peculiarities of present elements when their sizes become nanometric (one nanometer corresponds to the millionth part of one millimeter).

Distinction between molecules, nanoparticles and bulk

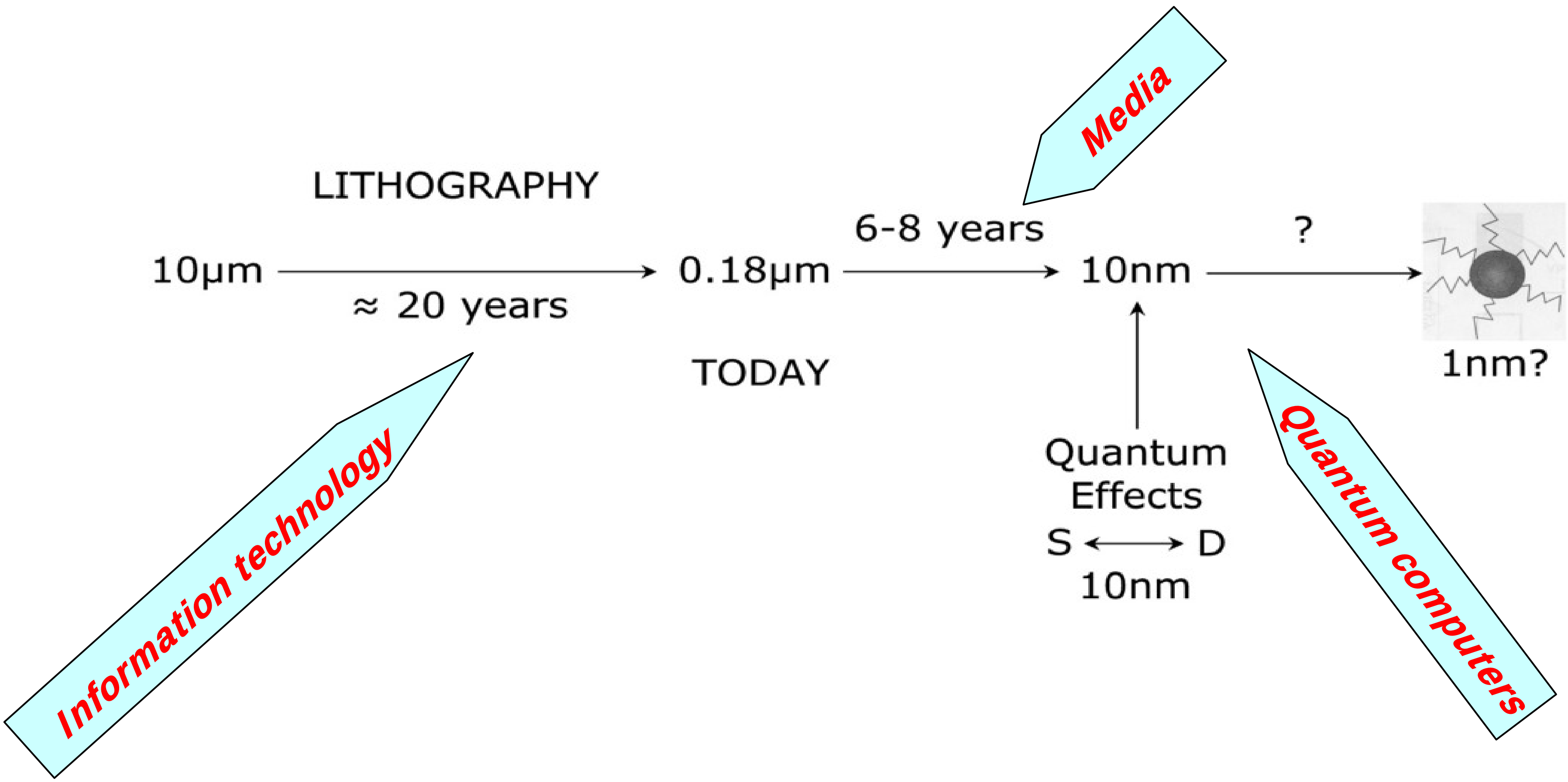


Distinction between molecules, nanoparticles and bulk according to the number of atoms in the cluster.

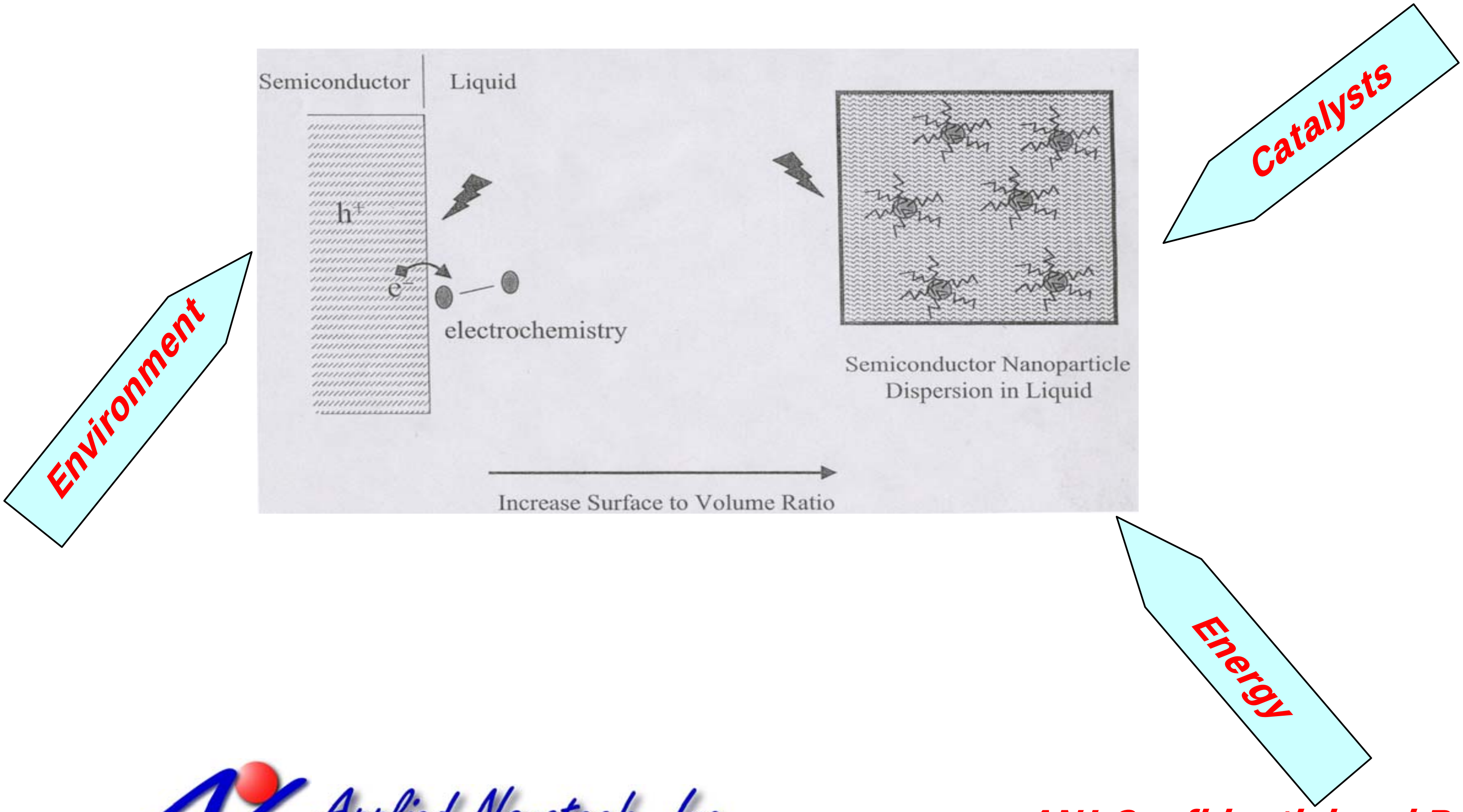
Alternative nanotechnology definition (1)

Nanotechnology describes the creation and utilization of functional materials, devices and systems with novel functions and properties that are based either on geometrical or on material specific peculiarities of nanostructure.

Motivation: the physicists Moore's Law limit



Motivation: the chemists

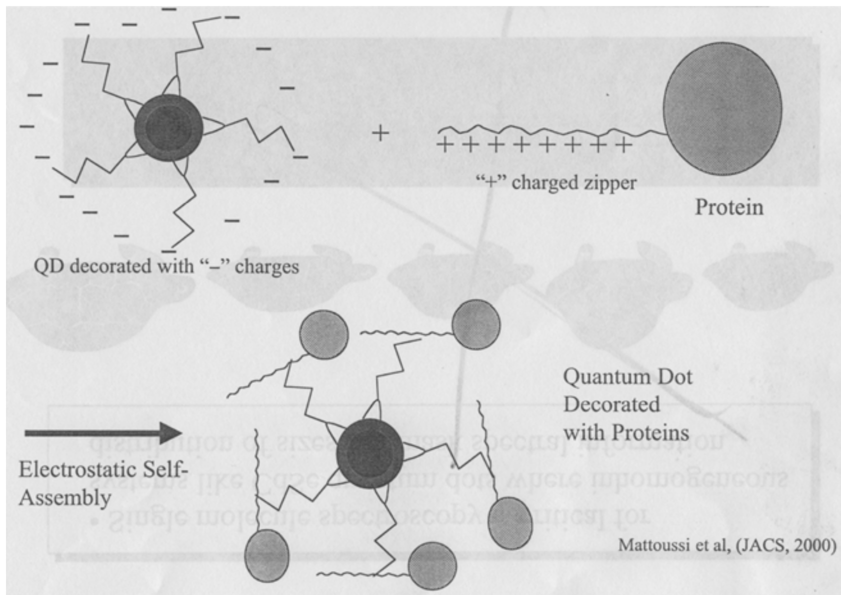


Motivation: the biologists
Quantum dot bioconjugates

Health

Ageing

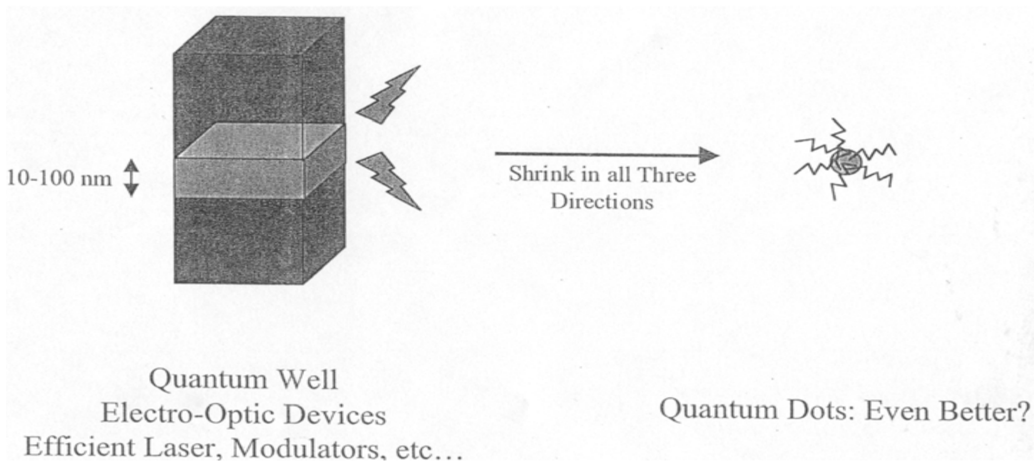
Sensors



Motivation: the optical engineers

Electrooptics

Communications

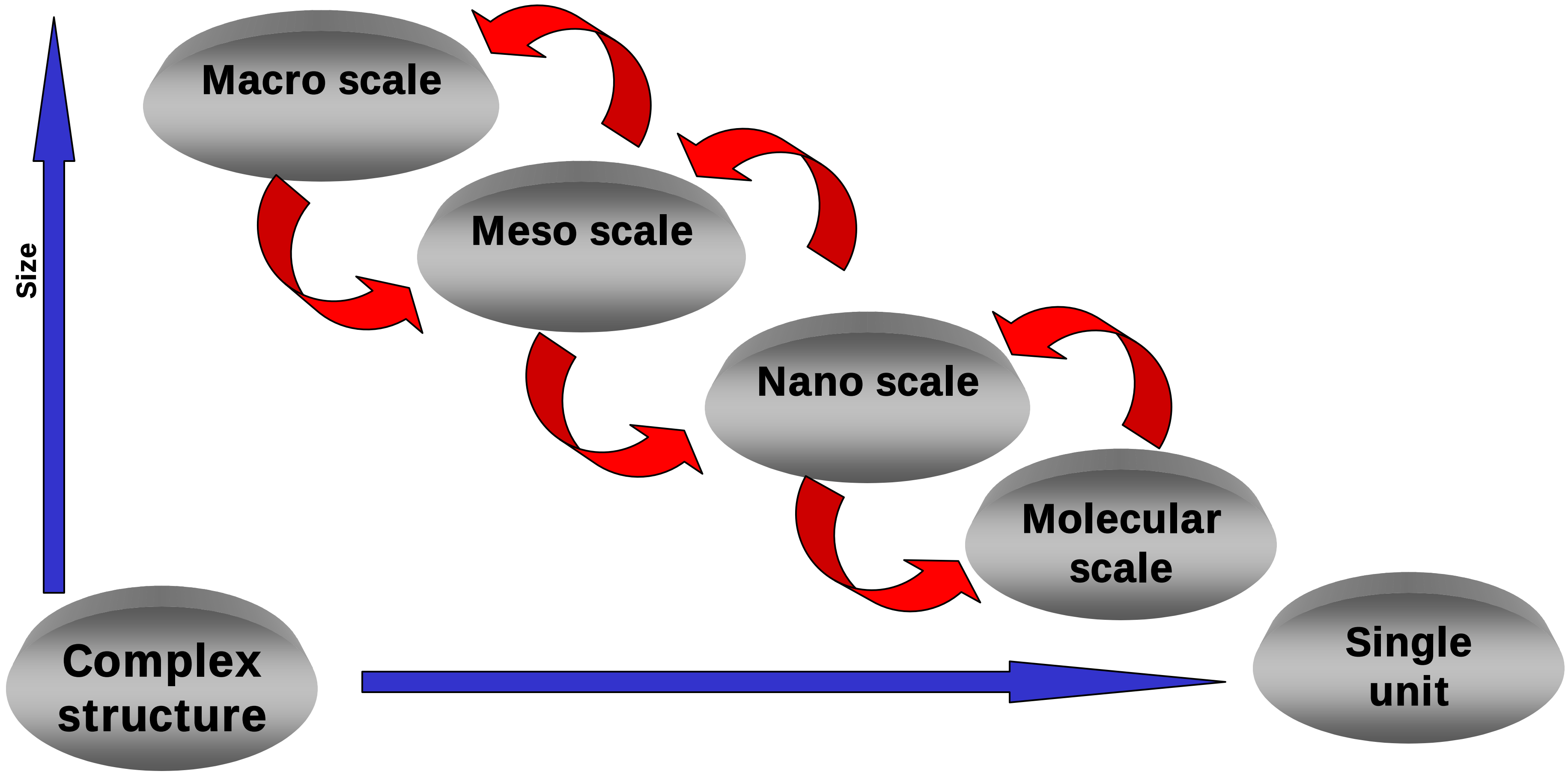


Nanophotonics

Alternative nanotechnology definition (2)

Nanotechnology is the scientific field encompassing the mastery of understanding and manipulating atomic and molecular matter and interactions as prerequisite for the optimization of existing products and the creation of new ones.

Hierarchical structure of nanoparticle systems



Importance of nanotech

- Provide the “Genome” for artificial materials.
- Will impact nearly EVERY industry (Chemical, Computing, Storage, Power, Energy, Biotech, Pharmaceuticals, Manufacturing, Transportation).
  - Create artificial materials per order: stronger, lighter, with predefined optical and electronics properties, etc.
  - Create matter with emergent properties not yet known.

What is needed to succeed?.. Creativity!

- New techniques must be discovered to organize, characterize and manipulate these nanoscale individual elements.
- Insights into self−organization principles of these nanoelements are necessary.
- Implementation of nanoscale architectures with new microscopic and macroscopic functions.
- Nanotechnology will catalyze the unification of processes from the living to the non-living worlds.
- Nanotechnology is revolutionizing materials' understanding and offers the capability to create new artificial materials (stronger, lighter, with pre-defined optical and electronic properties, etc.).

The building blocks of nanotechnology

- Ultra–thin layers
- Top down nanostructures
- Bottom up structures
- Ultra–precise surface preparation
- Analytical instrumentation for nanostructures
- Integration of nanomaterials and molecular structures
- Nanotechnology and biotechnology convergence

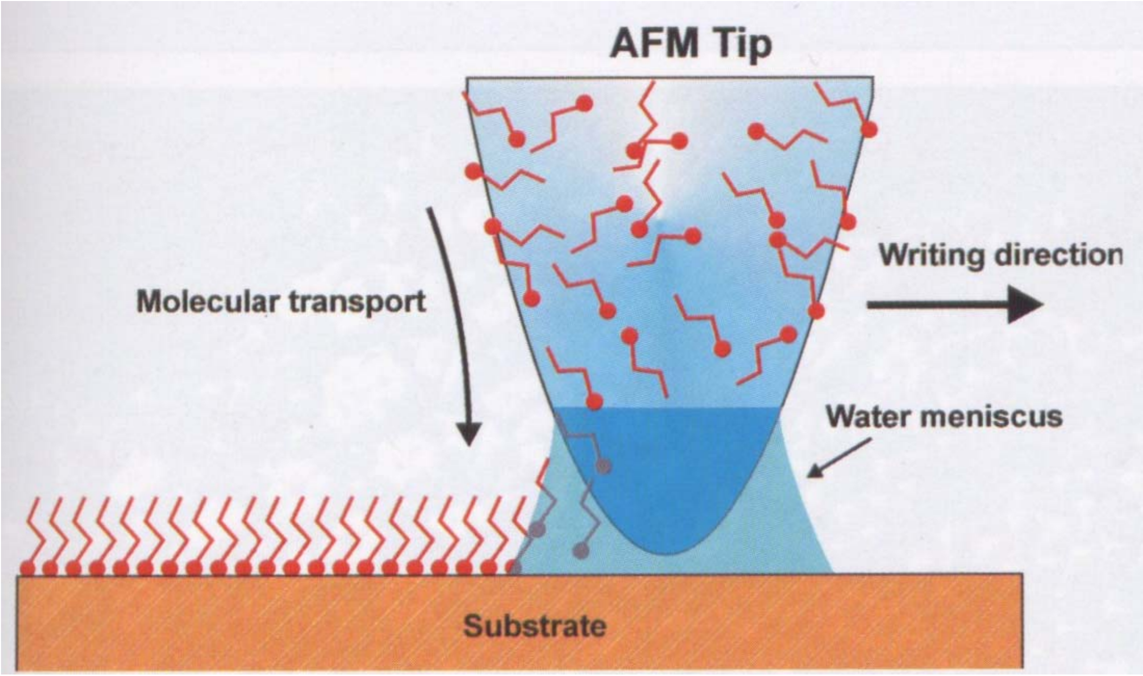
Ultra-thin layers

Functional ultra−thin layers will enable the development of new products. Combinations of mechanical, optical, electrical and chemical properties can be created three−dimensionally, with a predesigned function and characteristic and with high integration density. All types of materials such as inorganic, organic and biological can be used to achieve switches, sensors, processors, actuators, membranes, catalysts and inhibitors for a multitude of new and exciting applications.

Top down nanostructures

The top down strategy is based on decreasing structural dimensions as occurs in microelectronics. In order to extend Moore's Law to the nanometric world, we need to transit from microelectronics to nanoelectronics. The transition requires, in addition to the extension of the lithographic limits, a new understanding of the laws of physics as we move from the continuum to quantum. New techniques will be employed to create sub−100−nanometer scale structures (i.e. writing with light, particle beams and ink).

“Printing-like” lithography



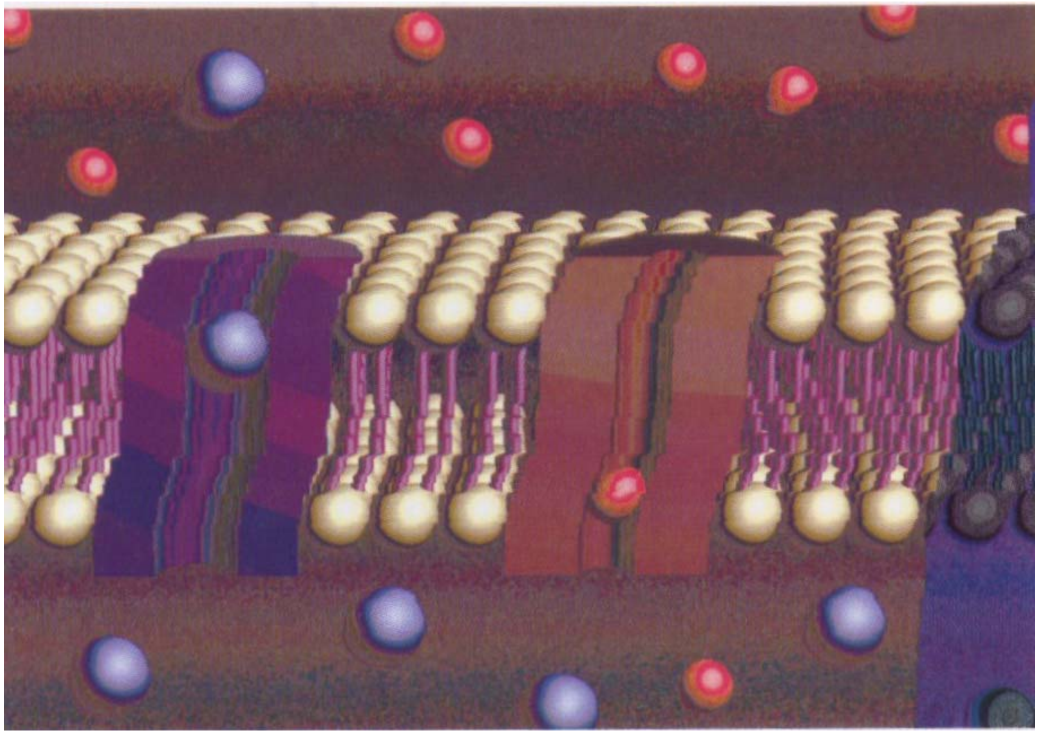
Schematic of the dip pen lithography process – the wiggly lines are molecular “ink.”

Courtesy of the Mirkin Group. Northwestern University

Bottom up structures

The bottom up strategy is based on achieving larger systems from very small units through self-organization. The principles of self–organization are based on the specific properties of organic/inorganic boundary surfaces and the selective chemical and physical couplings of molecular systems to properly prepared surfaces. These structures are required for full convergence of nanotechnology and biotechnology that eventually will combine the advantages of top down structures and bottom up structures.

Self-assembly



A computer-generated model of a portion of cell membrane. The gold balloons are hydrophilic, and the purple thin strands are hydrophobic. The red and blue cylinder structures are channels for moving ions through the membrane.

General Chemistry, 8/e, by Petrucci/Howard; Pearson Education, Inc.

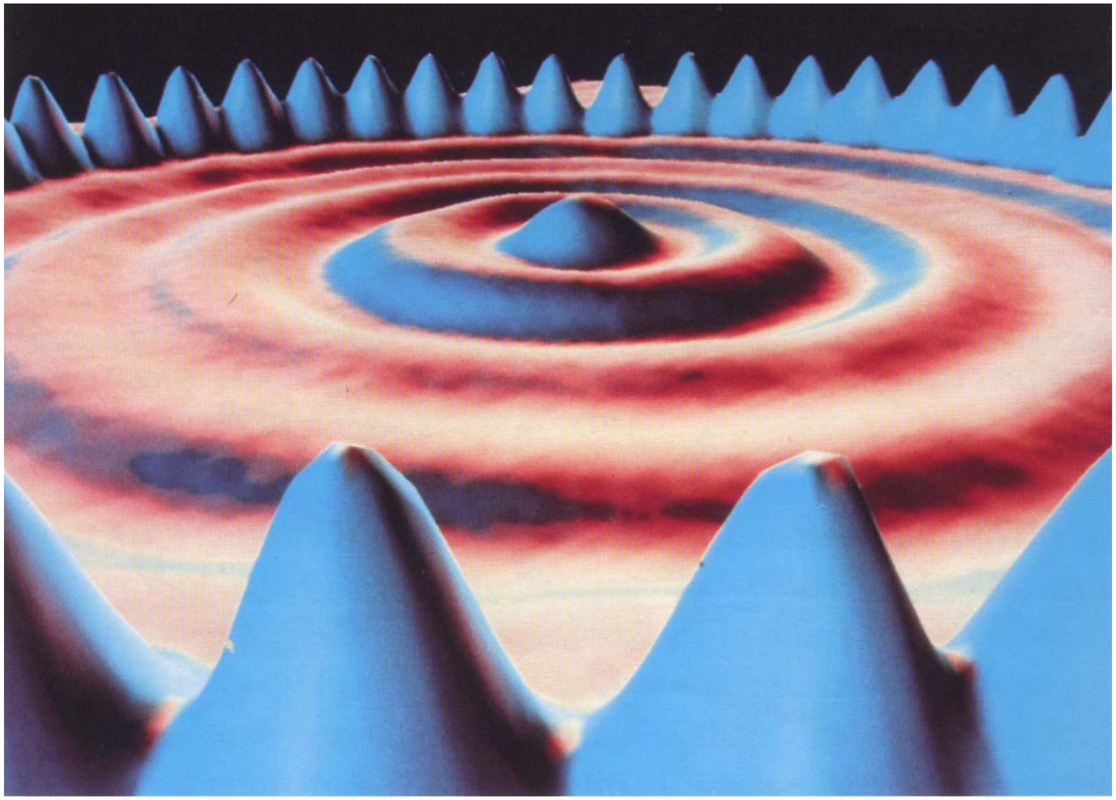
Ultra-precise surface preparation

Optical characteristics of optical elements depend on the quality of surfaces. New optical elements are required for the visible, infrared, UV and x–ray ranges. The optimization of surface preparation techniques (such as polishing) through a combination of conventional and totally new production procedures is required.

Analytical instrumentation for nanostructures

In order to check production quality quantitatively, new nano−analytic procedures and instrumentations will be used. This new equipment needs to exploit electrons, ions, neutrons and photon beams, as well as field emission and tunnel effects in order to be able to observe these new nanostructures. Additionally, boundary surface interactions such as diffusion, corrosion, re−crystallization, phase transformations, etc., must be monitored. As a result, new methods of analysis are necessary. Atomic-force microscopy and high resolution electron microscopy are of high importance in this context.

Atomic resolution

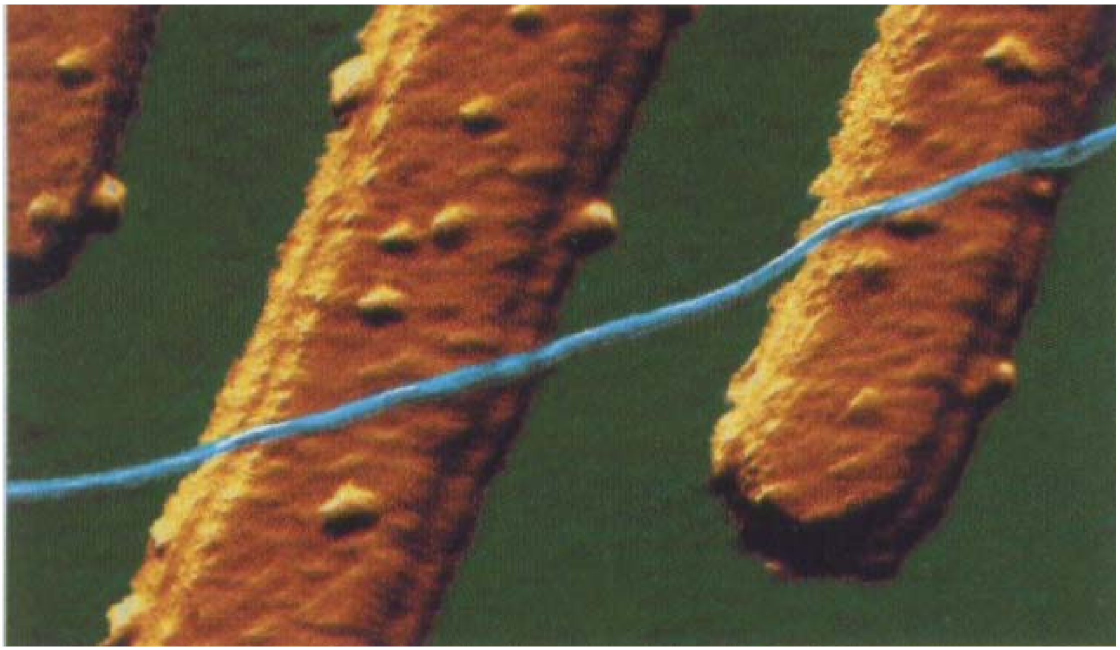


Scanning tunneling microscope (STM) image of 48 iron atoms in a circle on a copper crystal surface. (Courtesy IBM Corporation, Research Division, Almaden Research Center).

Integration of nanomaterials and molecular structures

Nanoparticles have emerged as a new material defined in size between atoms, molecules and solid-state bulk material. As a result, their physical, chemical and electrical characteristics settle between these two extremes. Such new physical and chemical characteristics are clearly different from both the individual atoms/molecules and the bulk. This creates new opportunities to define new products and applications. In order to advance the understanding and manufacturing of macroscopic products from nanostructures, we need to control the reproducibility, the characteristics and reliability of the newly created structures.

Nanoelectronics



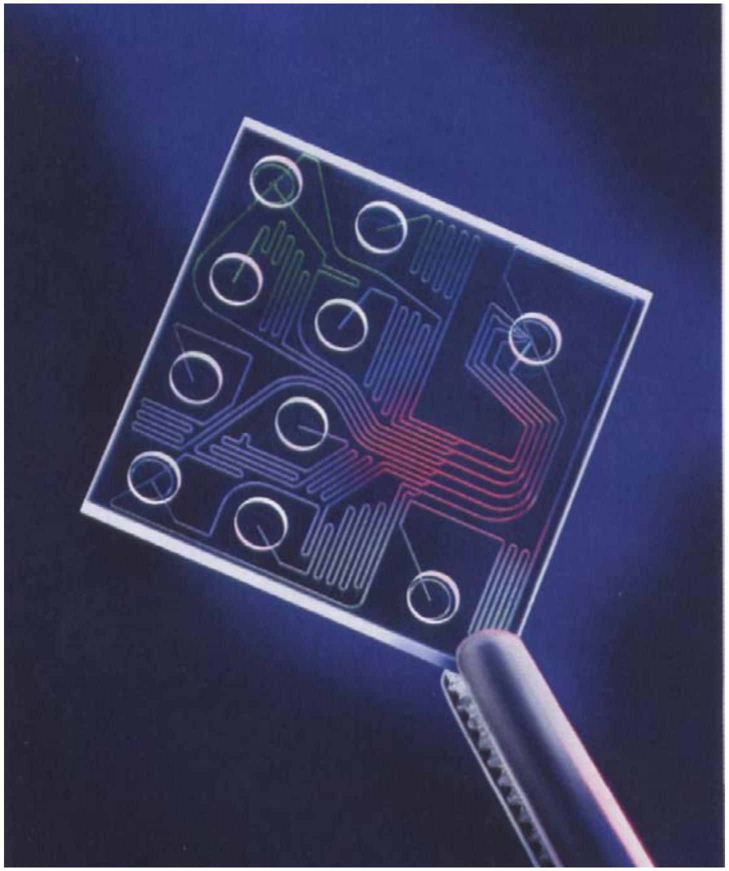
Two electrodes made using E-beam lithography. The blue structures a carbon nanotube.

Courtesy of the Dekker Group, Delft Institute of Technology

Nanotechnology and biotechnology convergence

Biotechnology and nanotechnology are merging. These extremely potent technologies will drive technological innovation and commercialization during the 21st century. Biotechnology recently was able to solve the human genome puzzle and to identify the 23 separate pairs of chromosomes. These chromosomes that are essentially the fabric of life are each made of a pair of very long DNA molecules. It is remarkable that the DNA molecules are themselves a nanometric particle. On one hand, nanotechnology teaches us how to exploit novel properties of materials when they become nanoscopic. We are even able to build working devices on a nanometric scale and interface these nanometric devices on a molecular level. On the other hand, these devices can be built with features so small that they can interact with cells, biomolecules and DNA. This is why nanotechnology and biotechnology are converging. Ultimately, biological structures can serve as components for mechanical and electrical nanosystems and *vice versa*.

Lab-on-a-chip

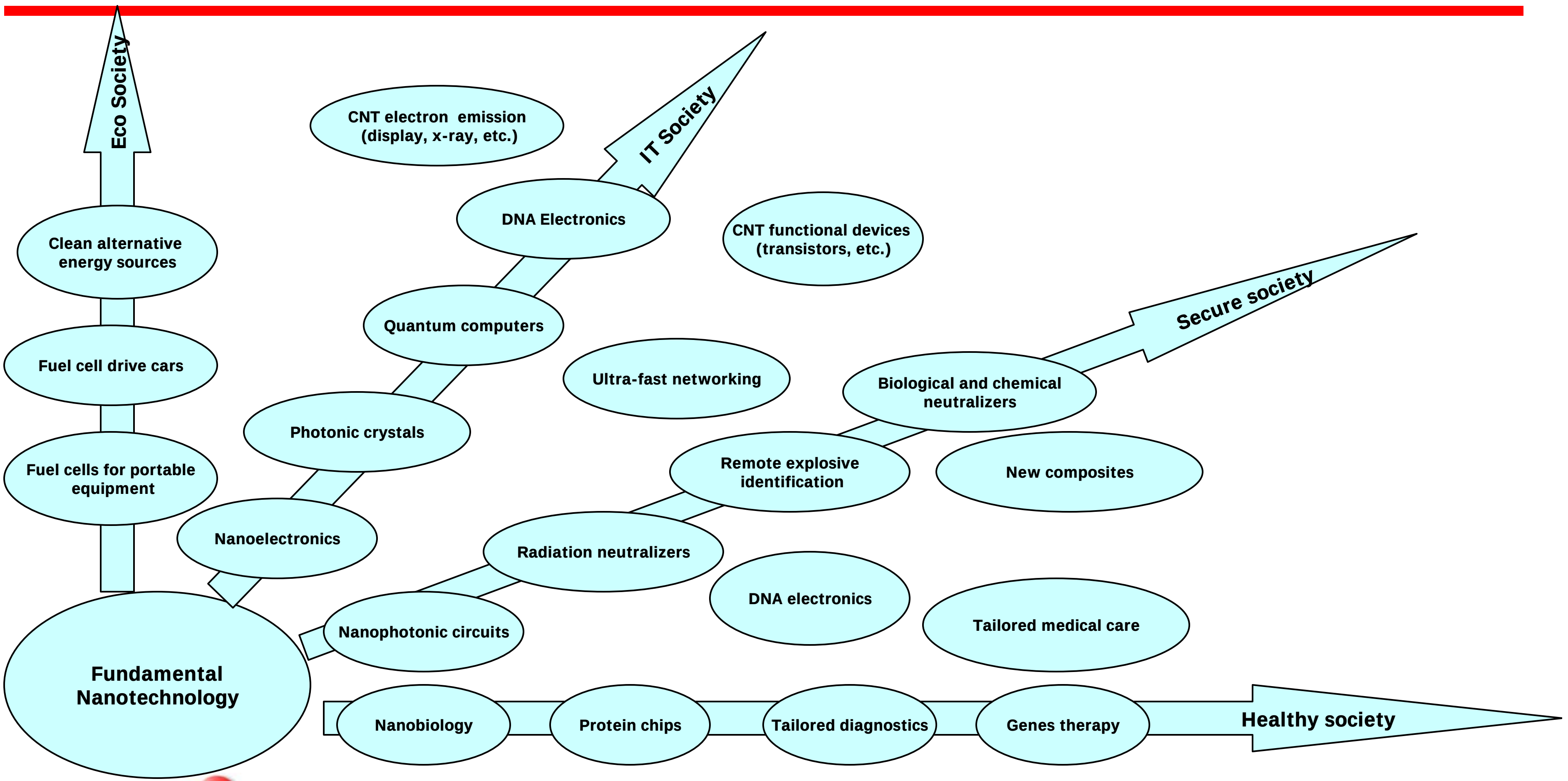


A lab-on-a-chip. Courtesy of Agilent Technologies, Inc.

Alternative nanotechnology definition (3)

Nanotechnology is the "perfect scientific storm" in a place where all natural sciences congregate and intersect each other at the nanoscale. Nanotechnology is a creative and transformational technology.

Nanotechnology service to our society



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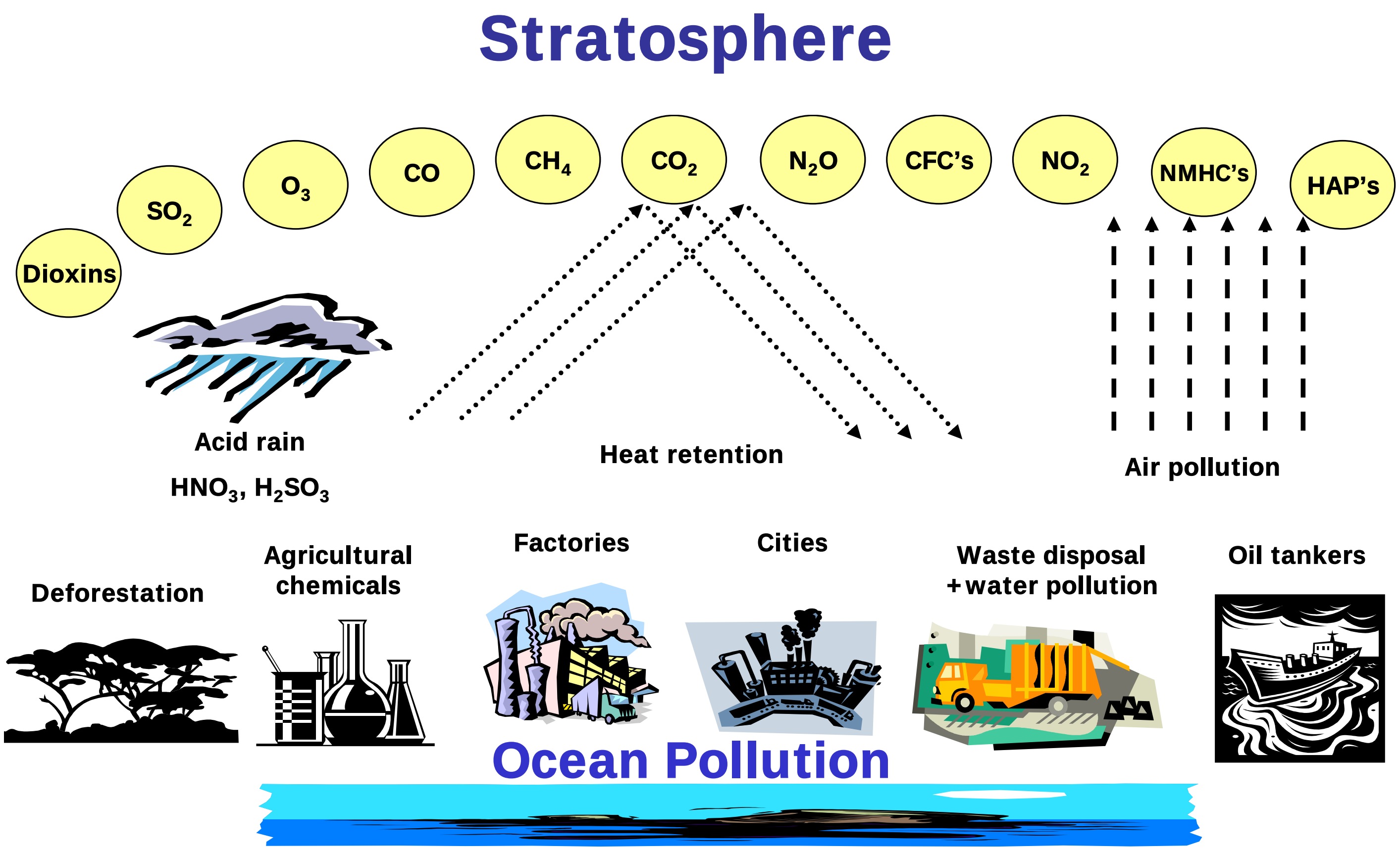
Eco-minded nanotechnology



Nanotechnology opportunities

- Medicine/biology
- Chemistry
- New materials
- New nanoelectronic technology integrated with current microelectronics
- Optics and displays
- Applied research commercialization
- Defense and security

Medicine/biology

- Convergence of nanotechnology and biotechnology
- Functionalization of biocompatible nanoparticles
- Artificial tissues and membranes
- Lab-on-the-chip (≈$10 billion market)
- Achieving pharmacological effects at the morbid regions only
- Drug-carrying and externally triggered delivery (≈ $10 billion market)
- Biosensors (≈ $2 billion market)
- Security (anti-terrorism)

Chemistry and new materials

- Corrosion inhibitors
- Magnetic nanomaterials
- Smart pigments (colloids)
- Smart adhesive layers
- New energy sources
- New light absorbers and emitters
- Advanced ceramics
- New composites

Nanoelectronic/microelectronic technology

- New breakthroughs due to transition from continuum to quantum
- Nanosensors
- Quantum dots
- Nanotransistors
- Nanooptoelectronic devices (diodes and lasers)
- New nanomemory devices (RAM only ≈ $35 billion market)
- Self−organization
- Solution to Moore's Law
- Single electron logic

Optics and displays

- Ultra−smooth surfaces (polishing)
- Solar cells
- FEDs (CRTs ≈ $40 billion market)
- LCD backlights (≈ $5 billion market)
- Photo-sensitive particles
- Use of optics for nano−analytical equipment
- Use of optics to control nano−manufacturing

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The nanotechnology food chain

Idea

→ **Simulation**

→ **Nanosynthesis**
Nanostructures
Nanocomposites
Nanopowder
Nanosurface
Nanoelectronics

→ **Assembly**
Characterization
Replication
Integration
Machining
Analytical equipment
Tips and probes

→ **Production**
Processing
Services

Creativity and nanotechnology are related

Creativity definition (Webster dictionary):

"The ability to **create meaningful new** forms"

Nanotechnology:

"creates meaningful new forms" from nano-structures

The great socio−economical transitions

Age		Input
Agricultural	←	Land/human labor
↓		
Industrial	←	Raw materials/manufacturing
↓		
"Nanotechnical"	←	Knowledge/creativity (human intelligence)

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Traditional model for economic growth

- Companies
- Jobs
- Technology

Nanotechnical age model for growth

- Technology → Innovation and high tech industry
- Talent → Creative capital (not necessarily "human capital")
- Tolerance → Different kinds of people generating new ideas

The "3 Ts" model of Richard Florida

Creativity & nanotechnology are multidimensional

- Constantly revising (processes, products,…)
- Constantly enhancing (process, products,…)
- Constantly interacting (society, culture,…)
- Constantly inventing (processes, products,…)
- Constantly influencing (economy, society,…)
- Constantly changing (regions, fields,…)
- Constantly vastly interdisciplinary

Nanotechnology & creativity economical impacts

- Creative firms are clustering in specific places
- These places are concentration of talented and creative people
- Talented people foster innovation and economic growth
- Concentration of resources create competitive advantage
- Regional growth strongly relate to endowment of talented/creative highly educated people
- These places are centers of innovation and high tech economy

The symbiotic relation between nanotechnology and creativity

- Foment creative activity
- Need broad regional ecosystems that nurture and support creativity
- Channel creativity into innovations
- Facilitate firms' formation and economical growth
- Have a strong socio−economical effect by raising and sustaining standards of living

The driving force of nanotechnology

The rise of human creativity is the key factor in the nanotechnology influence on economy and society

Human creativity as our ultimate economical resource

The "Nanotechnical Age" paradigm

> Human creativity is the ultimate economic resource. Each of us has creative potential that we love to exercise and that can be turned in valuable ends."
>
> Richard Florida

Alternative nanotechnology definition (Final?..)

Nanotechnology is not a science, it is multi-scientific. Nanotechnology is not an industry, it is multiple industries.

Nanotechnology is a new fresh expression of human creativity.