

Nano Materials

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Introduction

Nanomaterials is a new step in the evolution of understanding and utilization of materials. Material science started with the realization that chemical composition is the main factor in determining what a material is. Hereafter it was discovered that the fabrication and after fabrication steps could influence those properties substantially. Also small additives proved to be able to modify these properties. Finally with the arrival of nanotechnology, it was discovered that the ability to create small particles could expand the capability to create and modify materials.

Nanotechnology is as well as evolutionary as revolutionary in nature. Evolutionary are the many applications where the same material is incrementally improved by using nanotechnology. (Examples of this are seen in cosmetics). Revolutionary it can be called where new (enabling) properties originate from nanotechnology like for example in quantum dots. Those new properties can be divided in:

- Properties based on the fact that the surface is large compared to the weight/volume.
- In addition to size, low energy dissipation and high processing speeds are important.
- New properties not found in bulk or micro sized particles.

Nanotubes

From a Mancef patent investigation it was learned that carbon nanotechnology (mainly nanotubes, but also fullerenes and nanodiamonds) and cosmetic applications are the focal points of interest. Carbon nanotubes are produced in many variants, the most important classification is in single or multi wall nanotubes: A single-walled carbon nanotube (SWNT) consists of a single cylinder, whereas a multi-walled carbon nanotube (MWNT) comprises several concentric cylinders. It depends on the fabrication method which one is produced in chief, although always a mixture can be expected and separation/cleaning is a very important part of the fabrication process. Nanotubes can be made application specific by adding chemical groups to them, and they can also be made out of other materials than carbon. They have outstanding properties when compared to other materials:

- Electrical conductivity -- probably the best conductor of electricity on a nanoscale level that can ever be possible.
- Thermal conductivity -- comparable to diamond along the tube axis.
- Mechanical -- probably the stiffest, strongest, and toughest fiber that can ever exist
- Chemistry of carbon -- can be reacted and manipulated with the richness and flexibility of other carbon molecules.
- Molecular perfection -- essentially free of defects.
- Self-assembly -- strong van der Waals attraction leads to spontaneous alignment of nanotubes.

It must be stated that uniformity and price still is an issue. It is very difficult to produce pure samples and prices, although rapidly decreasing, are therefore very high for high purity nanotubes.

van Heeren, H. (2007) Nano Materials. In *Nanotechnology Aerospace Applications – 2006* (pp. 3-1 – 3-4). Educational Notes RTO-EN-AVT-129bis, Paper 3. Neuilly-sur-Seine, France: RTO. Available from: <http://www.rto.nato.int/abstracts.asp>.

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Nano Materials

At this moment nanotubes are studied for a number of applications like:

- electron emitters for flat-panel displays and cold cathodes,
- mechanical improvement additive for plastics,
- Li-ion batteries for portable electronic devices,
- ultra-strong high-tech composites,
- conductive composites and coatings for lightning protection,
- EMI shielding,
- supercapacitors,
- fuel cells,
- hydrogen storage, and
- semiconductors.

Nanoparticles

Particles in the nanorange are being investigated for a number of applications, like: wear resistance, scratch protection, blocking of light. A good example of this last application is the blocking of ultraviolet light by zinc oxide particles for cosmetics. The blocking power is directly related to particle size, size distribution, particle loading and the dispersion.

Other application examples of nanoparticles are:

- Filter media. The active component is an alumina (AlOOH) fiber two nanometers in diameter. The nano alumina fiber is highly electropositive, and will attract and retain particles.
- Silver has long been known to inhibit oxygen exchange, effectively killing bacteria. Nanosilver has been demonstrated to enhance that effect, and is currently being used in wound dressings for critical-burn victims but also in textile for preventing smelling.
- Other nanoparticles can be used as pharmaceutical carriers to specifically deliver disease-fighting drugs to afflicted body areas, thus minimizing secondary effects.
- In fuel cells perovskites are being discussed as electrode materials for use as cathodes. Specifically the high surface area and the high ionic conductivity of the material are of interest.

Other materials

Besides these general classes, there are many other nanomaterials. To name a few:

- Metal rubber, a self-assembled nanocomposite material that combines the high electrical conductivity of metals with the low mechanical modulus of elastomers.
- Nanoclay: a 2-to-1 layered smectite clay mineral with a platey structure having an unusually high aspect ratio.
- Nanoshells: optically tunable nanoparticle composed of a dielectric core coated with an ultra-thin metallic layer. Tuned to absorb or scatter certain wavelengths.
- Quantum dots, being semiconductor nanostructures that act as artificial atoms by confining electrons and holes in 3-dimensions.

Future expectations

In the future much is expected from Molecular Nanotechnology to make chemical reactions happen under programmed control. In theory, this allows to build a large range of molecular shapes. To make the creation of new materials a more planned activity, several companies are offering SW for the modelling and simulation of chemical and biochemical substances and a few start-up companies are working to develop specialized SW for nanotechnology .

Concluding remarks

The area of nanotechnology is a fast growing one, and many materials are newly introduced or dramatically improved by it. From our investigation we can identify a number of focal points as shown in the following picture.

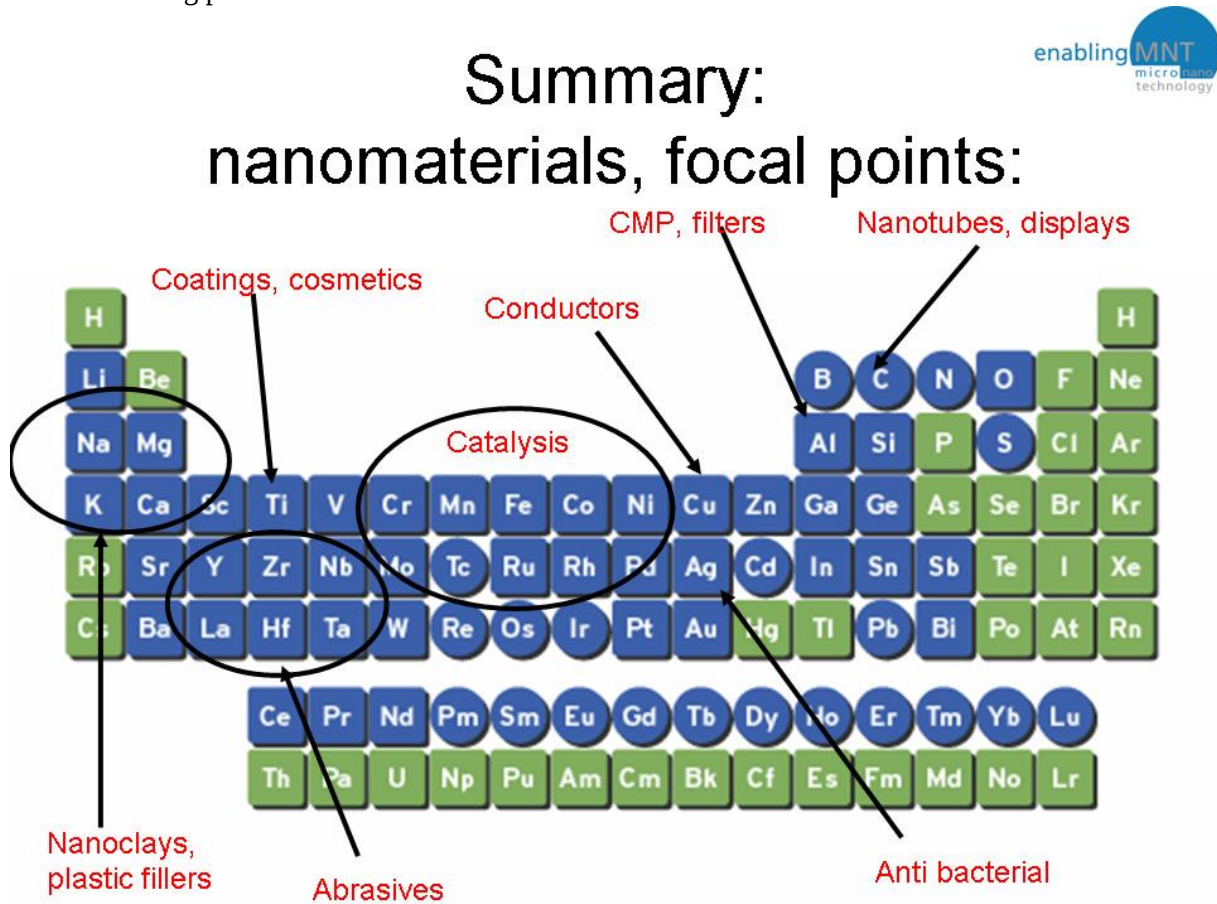
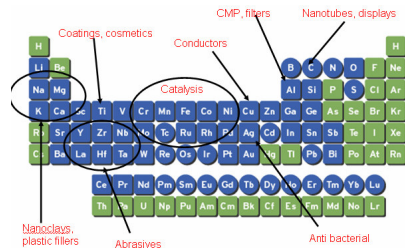
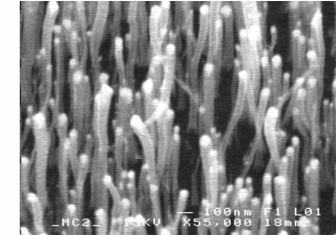
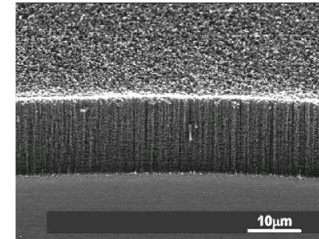
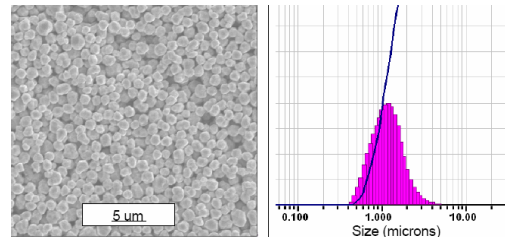
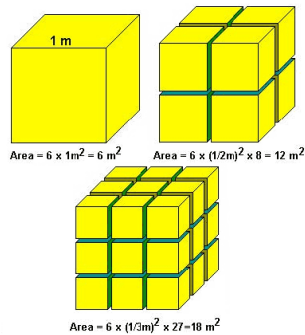


Figure 1: Focal points of nanomaterials



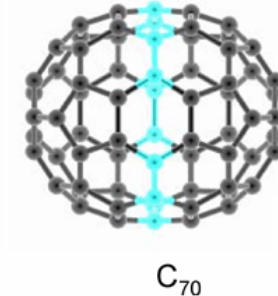
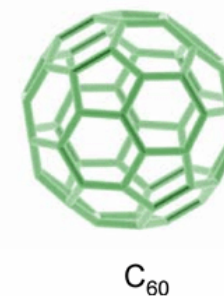
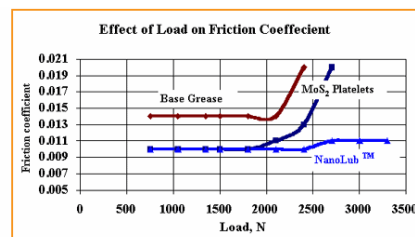
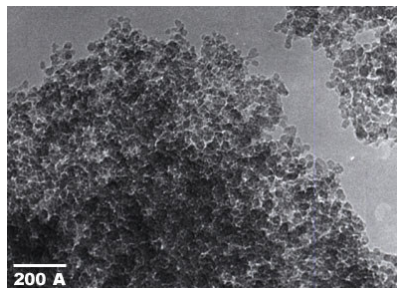
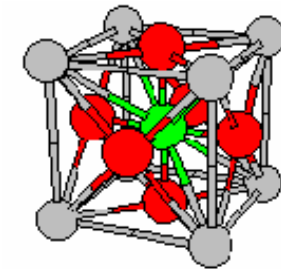


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Market

- The nanomaterials/nanotechnology sector is an important market for the chemical industry.
“Conservative estimates predict an annual growth rate of between 10-15%, with an expected products market volume of €500 billion and components (nanoporous materials, formulations, nanocomposites, thin films and coatings, etc.) market volume of approximately €50 billion for 2010.

(According to SusChem, the forum jointly initiated by the European Chemical Industry Council (Cefic) and the European Biotechnology Industry Association (EuropaBio) and supported by the European Commission)

Categorization

- Nanoparticles (nano in 3D)
 - Nanocomposites: nano filler in matrix
 - Nano-nano composites
 - Metaloxides etc
- Nanowires, nanowhiskers etc. (nano in 2D)
- Coatings (nano in 1D)

Evolution of Science

- Chemistry:
 - chemical composition matters: NaCl is not the same as Fe
- Materials science:
 - fabrication process matters: rapid quenching is different from slow cooling
- Material science:
 - small additions matters: pure Fe is different from Fe with a little bit of C
- Nanotechnology:
 - size matters too!!

Examples of fabrication technologies

- Chemical Vapor Deposition: carbon nanotubes
- Chemical (Co-) Precipitation: Single- and multi-metal oxides
- Electro-Explosion: metal and alloys, APS 60-100 nm.
- Explosion: diamond nanopowders, APS 3-15 nm.
- Gas Jetting: for brittle powders.
- Hydrothermal Method: oxides, APS 20-80 nm
- Laser Induced Chemical Vapor Deposition: Si, SiC, and oxides, APS ~10, 50, 100 nm
- Low Temperature Physical Method: for brittle powders, APS < 1 μ m
- Mechanical Milling: (1) for brittle powders, APS down to 20 nm, (2) for breaking down aggregated nanopowders & tangled CNTs; (3) for agglomerating nanostructured metals, alloys, oxides, carbides, and their mixtures.
- Micro-emulsions: oxides and compounds, APS down to 5 to 10 nm.
- Wet Chemistry: metallic nanopowders, free from aggregation, easy coating.

Fabrication method and material structures (Inframat)

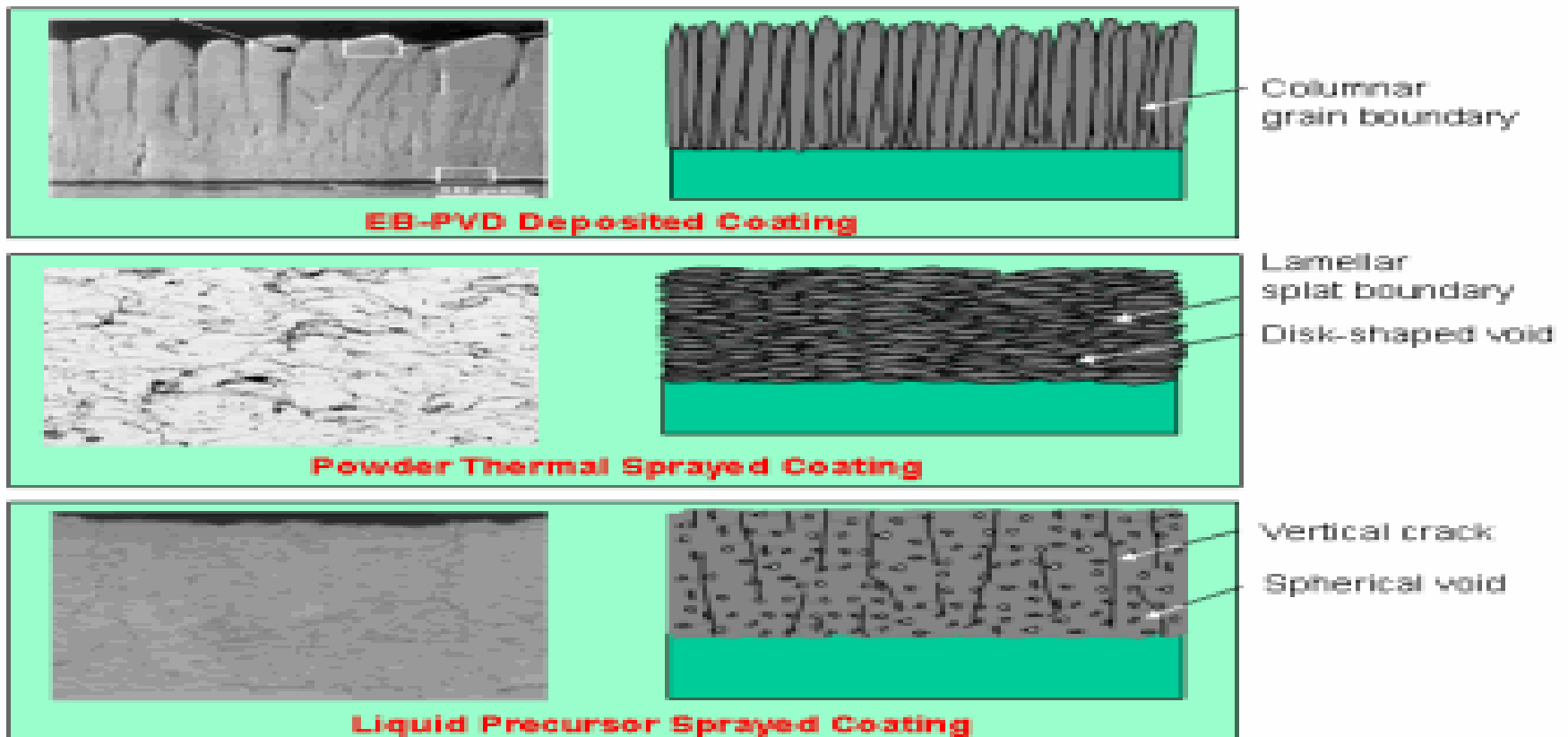


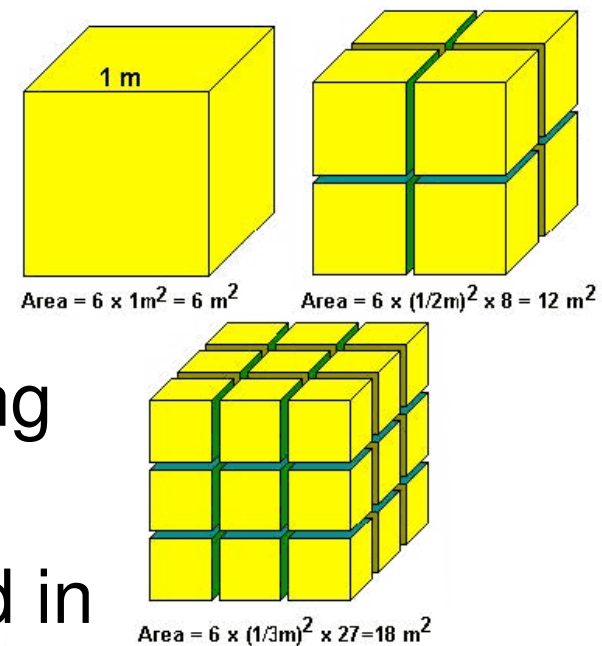
Fig. 5. Microstructures of Ceramic TBCs by Various Processes

Nano Materials

- Evolutionary and Revolutionary in nature
- Evolutionary
 - Paints, lip gloss, steel, skincare, chemical etc
 - Large firms will dominate
- Revolutionary
 - Large and small firms
 - Initially niche markets
 - Food services, functional paints etc
 - E.g
 - » Metallicum steel for stents
 - » Ferrofluidics – magnetic materials

Nanomaterials, why special (1)

- Enabling properties based on the fact that their surface is large compared to their weight/volume.
- With small sizes, low energy dissipation and high processing speeds become possible.
- Obtaining properties not found in bulk or micro sized particles

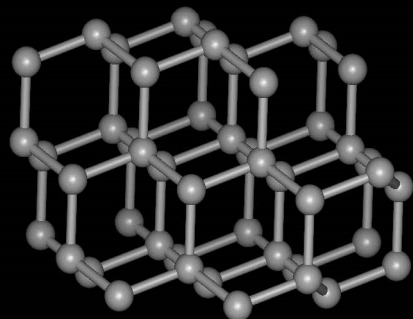


Nanomaterials, why special (2)

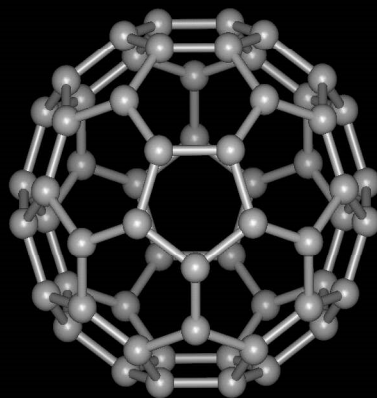
- Four important ways in which nanoscale materials may differ from macroscale materials
 - Gravitational forces become negligible and electromagnetic forces begin to dominate
 - Quantum mechanics is used to describe motion and energy instead of classical mechanics
 - Greater surface to volume ratios
 - Random molecular motion becomes more important
- At the nanoscale, some properties don't make sense, one example is boiling temperature
 - Vapor pressure becomes less and less meaningful when you have smaller and smaller numbers of particles
 - When you have 50 molecules there are no bubbles!

Nanomaterial applications

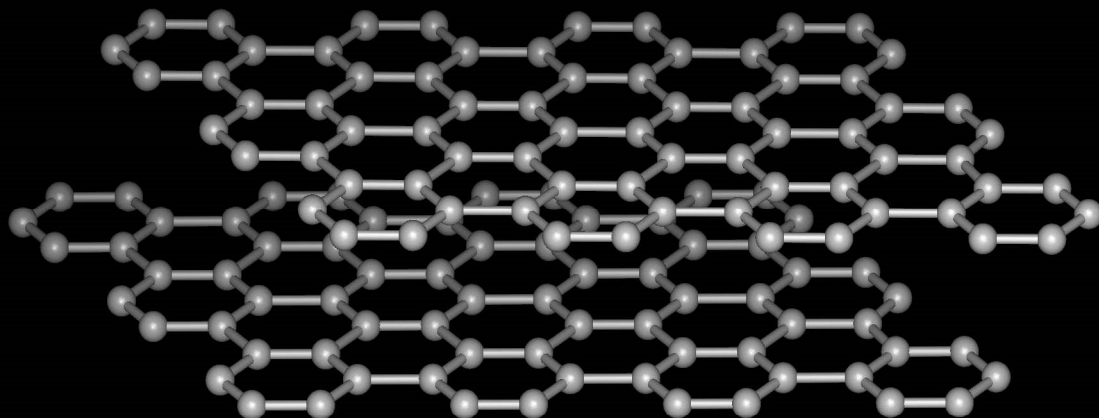
Ultra-fine wiring	Nanoparticles can apply to ultra-fine wire printing on integrated circuit or circuit board for higher circuit density and simplified circuit manufacturing.
Light emitting element	If substances become nanometer size, light emitting spectrum can be controlled on their size.
Catalytic substance	The smaller size of catalysts become, the larger surface area of catalysts equal in volume you get. And catalytic nanoparticles could offer new attractive features.
Battery	Reactivity of nanoparticle can be apply to efficient solar cell or fuel cell.
Coating	Coating of nanoparticle could offer new attractive features for surfaces of glass, lens, film, electrode, etc.
Doping	Doping or imprinting of nanoparticle could offer new attractive features for metal, ceramic, epoxy-material, fiber, semiconductor, etc.
Primary particle	Nanoparticles can be available to the primary particles for abrasives, bonds, etc.
Nano fillers	Matrix material with nanoparticles or fibers
Medical application	DDS(Drug delivery system), biomarker, DNA chip, etc.



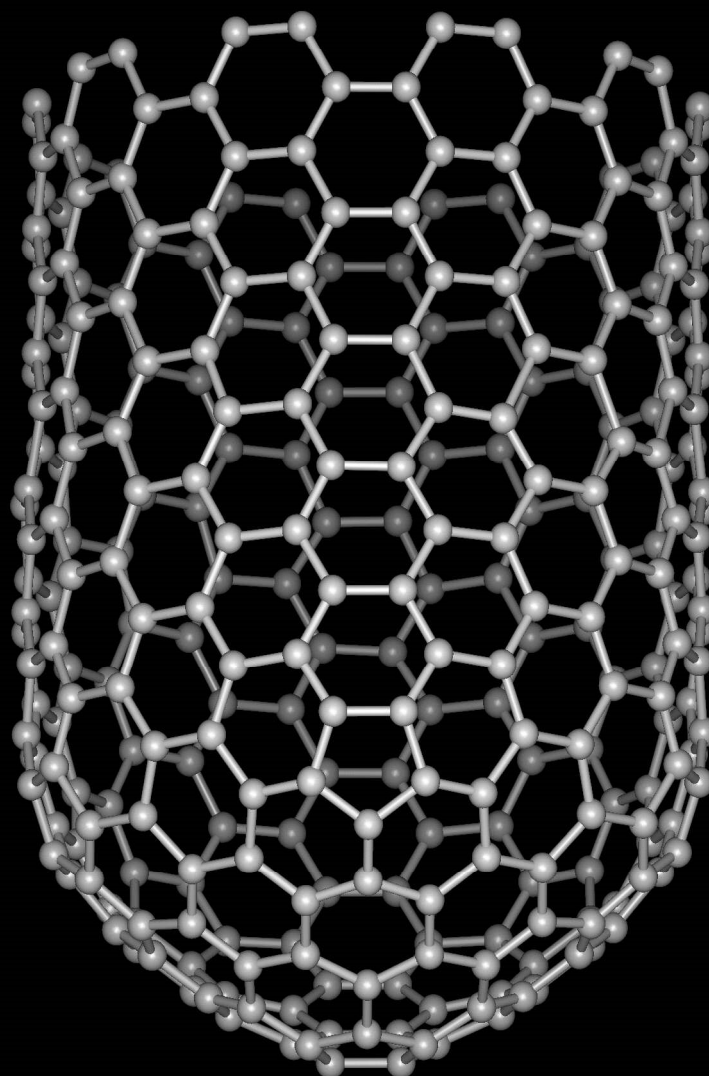
diamond



C_{60}
"buckminsterfullerene"

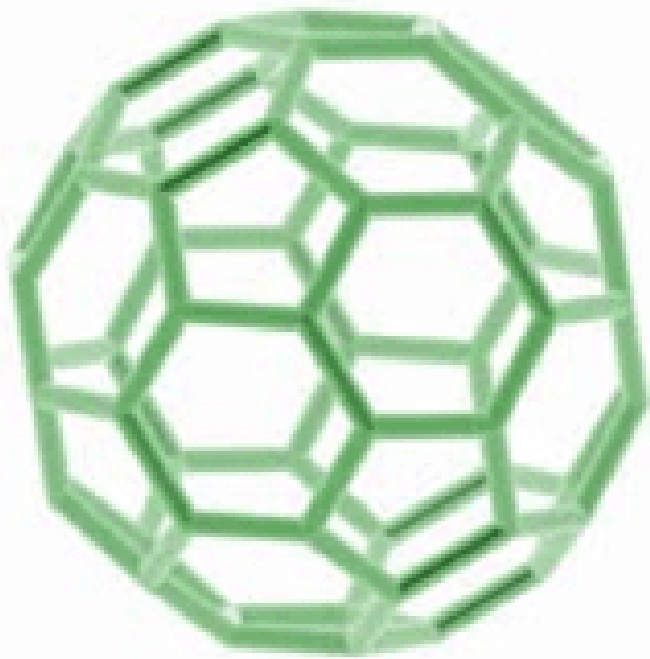


graphite

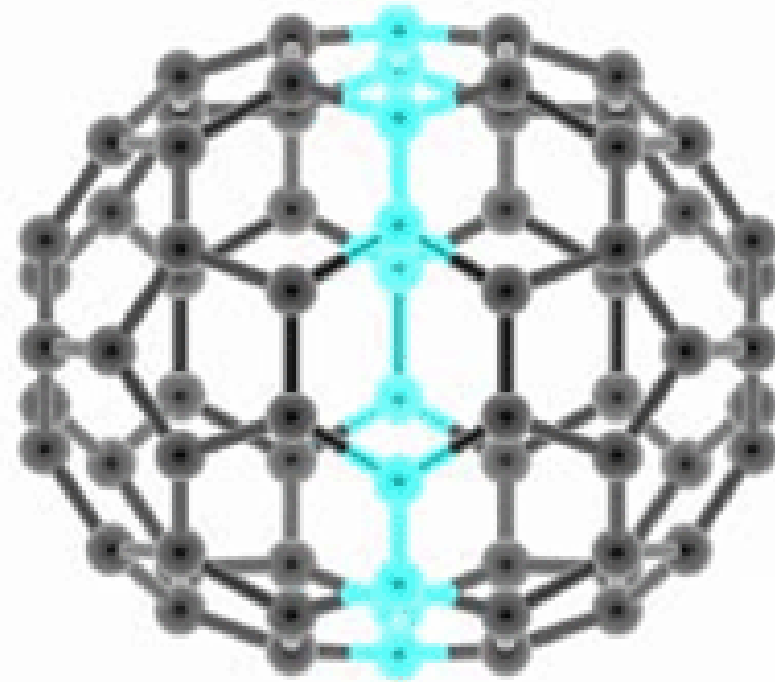


(10,10) tube

Fullerenes



C_{60}



C_{70}

Fullerene applications:

- Optimising surfaces for anti-wear applications
- Antioxidants
 - Fullerenes are powerful antioxidants, reacting readily and at a high rate with free radicals, which are often the cause of cell damage or death
- Polymer Electronics and Bulk Polymers
 - polymer additives to modify physical properties and performance characteristics.
 - Polymer solar cell (a fullerene/polymer blend), where the fullerene acts as the n-type semiconductor

Fullerenes price levels (\$/g)

Purity (%)	Mixed 60/70	95	98	99	99,5	99,95
C60	12			25.5 (2005: 28)	26.5	57 (2005: 170)
C70	12		240 (2005: 350)	300 (2005: 525)		
C76		35000	55000			
C78		35000 (2005: 65000)	50000 (2005: 55000)			
C84		20000 (2005: 42000)	30000 (2005: 50000)			
C60/F48			2000			

Nanotube applications:

- Li-ion batteries for portable electronic devices
- Ultra-strong high-tech composites
- Conductive composites and coatings for lightning protection
- EMI shielding
- Supercapacitors
- Fuel cells
- Solar cells
- Hydrogen storage
- Electron emitters for flat-panel displays and cold cathodes
- Artificial organs
- Molecular electronics
- Nanoprobes
- Conductive plastics

SWNT versus MWNT

- A single-walled carbon nanotube (SWNT) consists of a single cylinder, whereas a multi-walled carbon nanotube (MWNT) comprises several concentric cylinders.
- It depends on the fabrication method which one is produced.
- Chemical groups can be added to them.
- Not only carbon nanotubes.

Nanotubes properties

- Molecular perfection: essentially nearly free of defects
- Electrical conductivity: probably the best conductor of electricity on a nanoscale level that can ever be possible
- Thermal conductivity: comparable to diamond along the tube axis
- Mechanical: probably the stiffest, strongest, and toughest fiber that can ever exist
- Chemistry of carbon: can be reacted and manipulated with the richness and flexibility of other carbon molecules.
- Self-assembly: strong van der Waals attraction leads to spontaneous roping of many nanotubes.

Nanotube physical properties

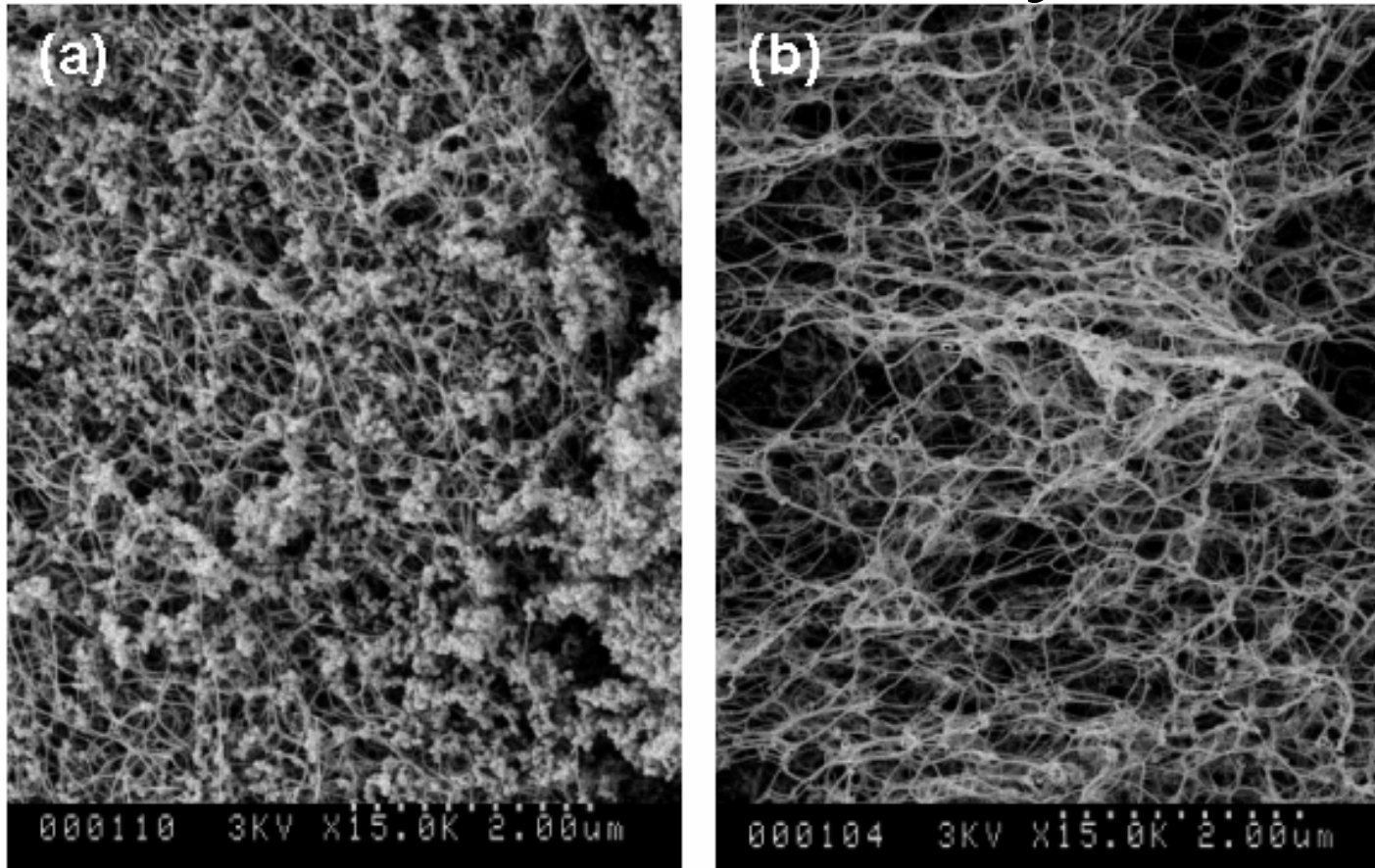
Characteristics	Values	Comparison
specific surface	1250 m ² /g	Active carbon : 600 m ² /g
Electronical	Gap Semi-metallic : 0 eV Semi-conductor : 0.5 eV	
Mechanical	Tensile strength : 150 GPa	300 times steel values
	Young Modulus : 1 Tpa	6 times steel
Electrical	Resistivity: 10 ⁻⁴ Ohmcm	Same as copper
	Max. current density : 10 ⁷ -10 ⁹ A/cm ²	Copper 10 ⁷ A/cm ²
Thermal conductivity	>3000 W/mK	Copper 400 W/mK

Nanotube application related properties

- Inertness/ability to form continuous networked protective layers: fire retardants
- Large surface area/good thermal conductivity: fast heating/cooling of liquids/gasses
- Large surface area/good electrical conductivity; batteries/capacitors/fuel cells
- Stiffness: probe tips
- Low threshold for emission/good electrical conductivity/small diameter: field emitters in displays
- Thermal/electrical conductivity/high aspect ratio: with a limited amount of CNT's improving properties of polymers

Shown below are scanning electron micrographs (SEMs) of SWNTs produced by the electric arc.

But, uniformity?



(a) Typical purity and (b) high purity regions from the same sample

And defects

- On average one defect each 4 mu of nanotube (1 in 10^{12} carbon bonds):
- Much better than Si, but each defect has a much larger effect (no way around it!)

Nanotube price levels (\$/g)

Purity (%)	20-30	40-60	>80	>90	>95
DWNT (5-20 nm	210	295		1500	
SWNT		17,5 (2005: 50)	145	85 (2005: 500)	

MWNT with functional groups: ~2000 \$/g

Comments:

- What you see is not allways what you get
- Prices go down fast
- Not yet an esthablised market

Nanotube wire

- Carbon Nanotechnology Laboratory (CNL) is working on a prototype power cable made entirely from carbon nanotubes.
- The work will involve development of "quantum wires," which can conduct electricity up to 10x better than copper but weigh just one-sixth as much.
- By 2010, CNL is expected to have a one-meter-long prototype of quantum wire.
- It will require new development and manufacturing methods: only about 2% of current types of nanotubes are suitable to conduct electricity well enough for quantum wires, and researchers will have to find ways to combine them into large-scale fibers and wires.

Boronnitride nanotubes (Reade)

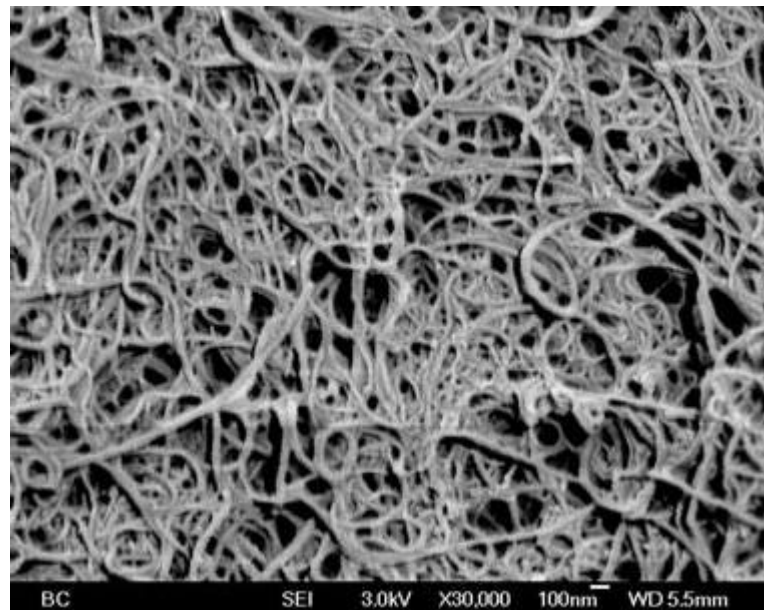
- Properties: similar to carbon nanotubes, but far more resistant to oxidation than carbon (up to 800 °C and therefore suited for high temperature applications in which carbon nanostructures would burn.
- They are expected to be semi-conducting, with predictable electronic properties that are independent of tube diameter and number of layers, unlike tubes made of carbon.
- Applications: Semiconductor devices, sensors, biosensors, and nano-motors, flat panel displays, atomic force microscopes, conductive plastics, & superconductors , hydrogen storage.

Other inorganic nanotubes (Reade)

- Description: WS₂, MoS₂, and NbS₂ nanotubes
- Properties: similar to carbon nanotubes
- Applications: Semiconductor devices, sensors, biosensors, and nano-motors, flat panel displays, atomic force microscopes, conductive plastics, & superconductors

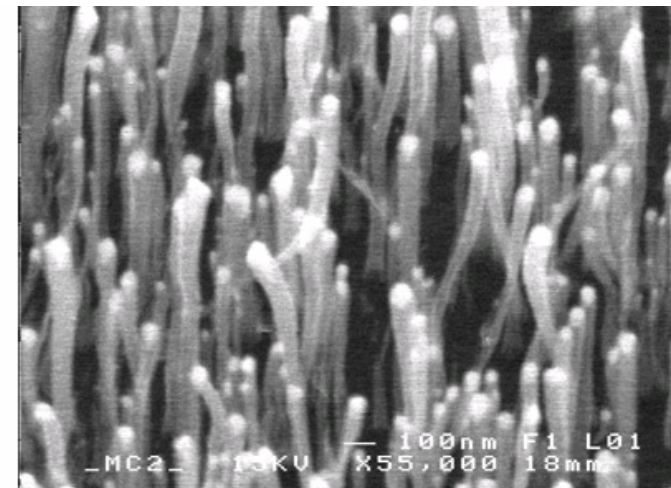
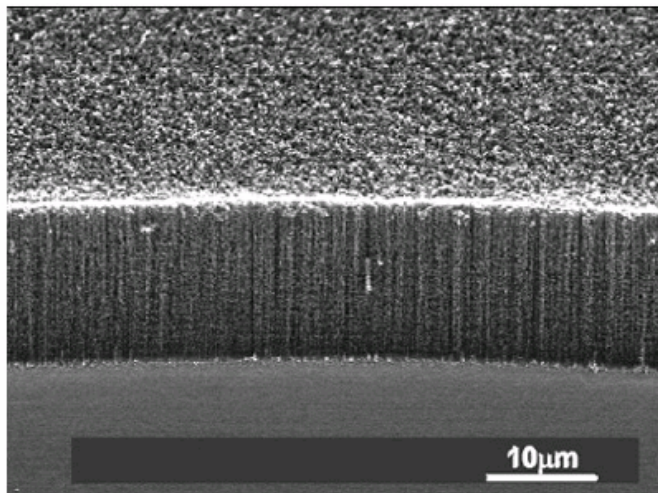
Nanotube paper (Nanolab)

- Common uses for nanotube paper include electrochemical electrodes and cell culture experiments.



Nanotube devices

- The ability to precisely align nanotubes in a up-scalable process is the key factor for the successful industrialization and commercialization of nanotube based devices.



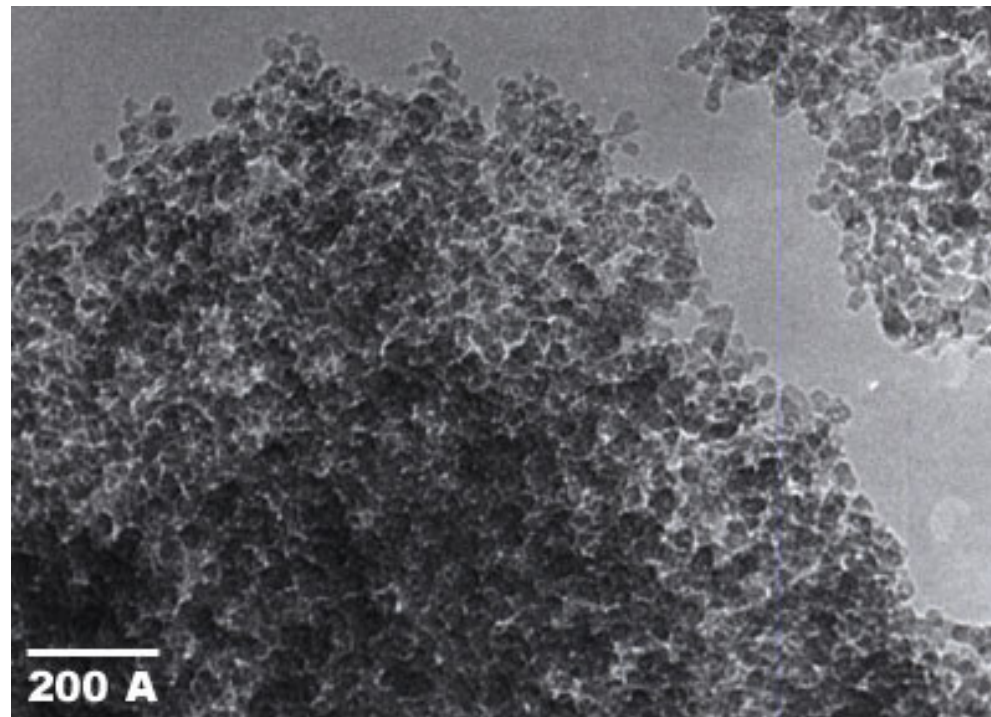
World demand for nanotubes (\$ million, Freedonia Group)

	2009	2014	2020
World demand	215	1070	9400
Electronics	90	395	4530
Motor vehicle	31	165	1130
Aerospace & defence	10	65	640
Other	84	445	3100

Nanodiamonds (PlasmaChem)

Pure NanoDiamonds and Raw Diamond / Graphite
Nanomixture, average cluster size ca. 4 nm.

Compatible with
different media,
give stable
suspension without
caking, for lapping
and polishing
applications



Nanodiamonds applications

- Lapping and polishing:
 - Memory Disk
 - Eyeglass Lenses
 - Miniature and Precision Ball Bearings
 - Orthopedic Prostheses
 - Stainless Steel Sheet
 - Metallic Mirrors and Precision Metal Polishing
 - Acrylic Sheet, Aircraft Windows and Canopies
 - Contact Lenses
 - Etc.
- Other applications:
 - Surface germination for following growth of diamond-like CDV- and PECVD-films
 - Ni-Diamond and Cr-Diamond electroplated hard coatings:
 - Molecular sieves
 - Lubricant additive to engine oil
 - Reinforcing fillers for plastics and rubbers
 - Chromatographic carriers

Metal Plated with Nano-Particles

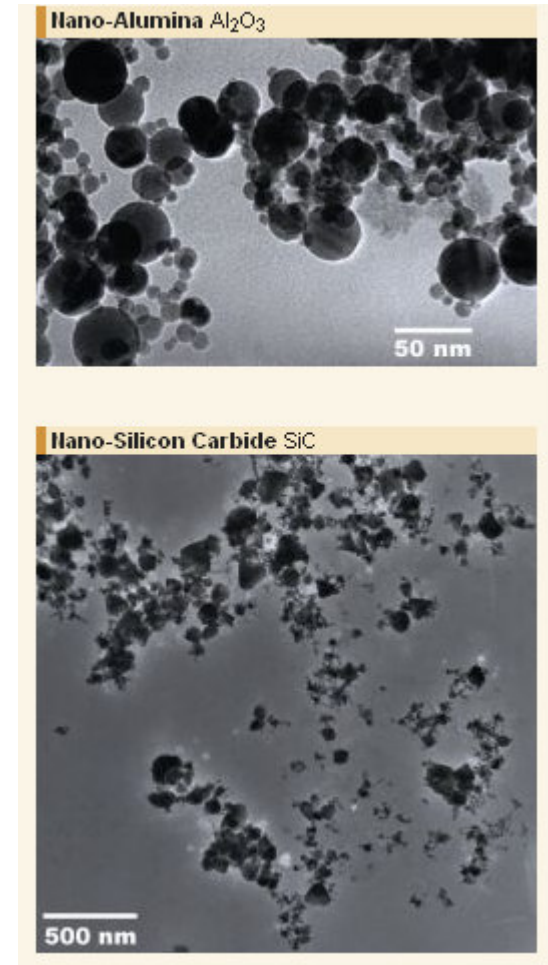
Increase of Wear Resistance

Material plated: Times increase:

Cr	2 – 12
Ni	3 – 4
Cu	5 – 7
Au	1.5 – 4
Ag	3 – 6
Sn	2 - 3

NanoCeramics applications (PlasmaChem)

- Lapping and polishing
- Low temperature sintering
- New Ceramic alloys
- Ceramic-metal electroplated hard coatings
- Ceramic-reinforced metal alloys
- Cold ceramic nanoglues
- LIGA-technology (micromechanics)
- Bioactive carriers
- Ceramic nanofilters
- Special glasses and crystals
- Oral Dentifrices
- Magnetic Media Ingredient
- Translucent High-Strength Ceramics
- Semiconductor Products



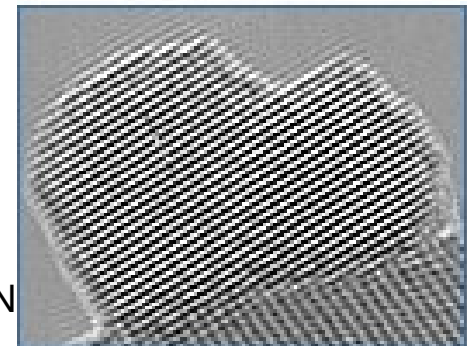
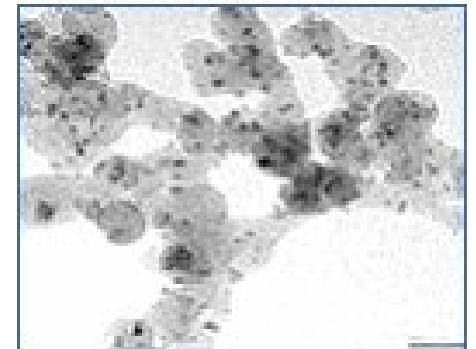
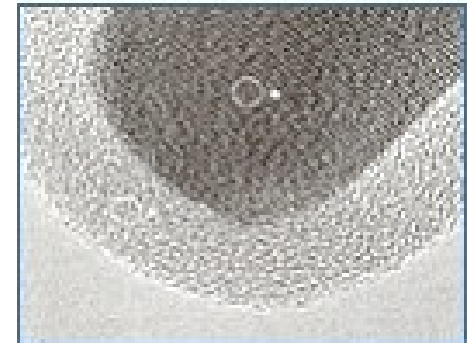
Indium Tin Oxide (AdNano)

ITO surfaces offer high transparency combined with

- low haze
- anti-static property
- increased scratch resistance
- heat-repellent properties

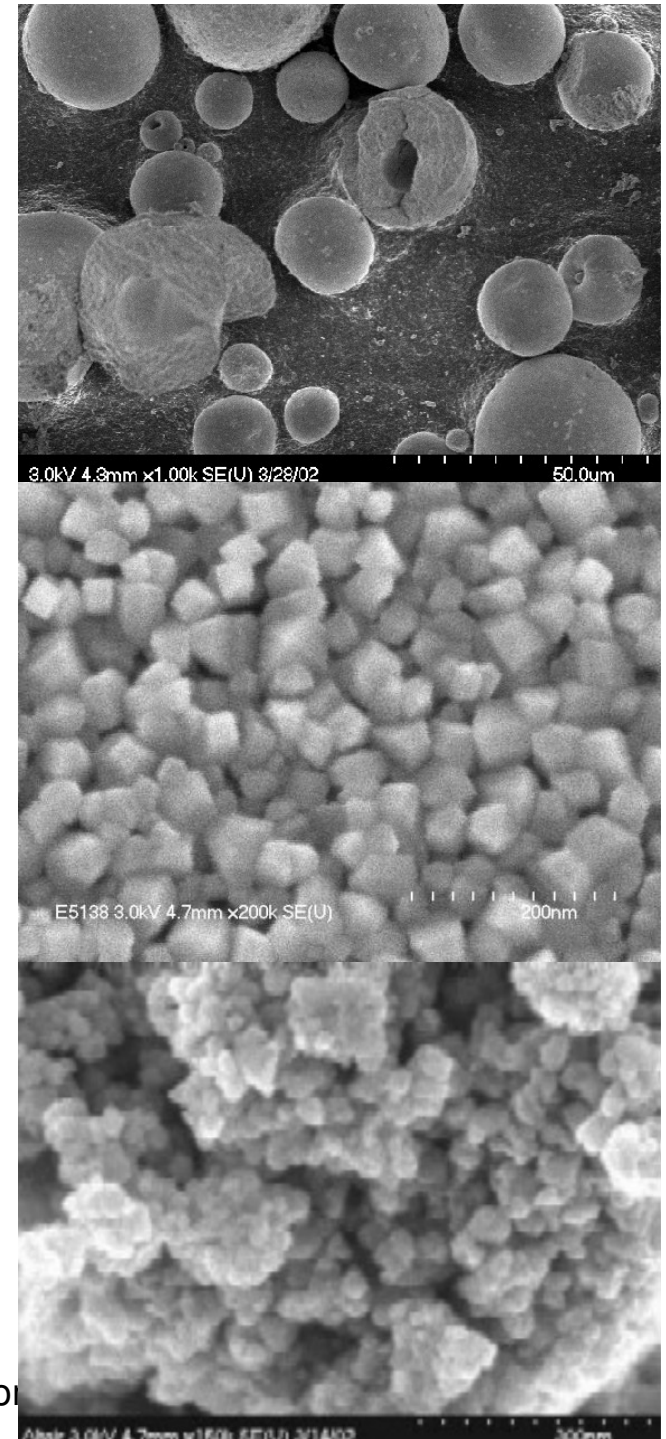
Applications in the field of:

- electronics
- coatings
- construction industry
- automotive industry

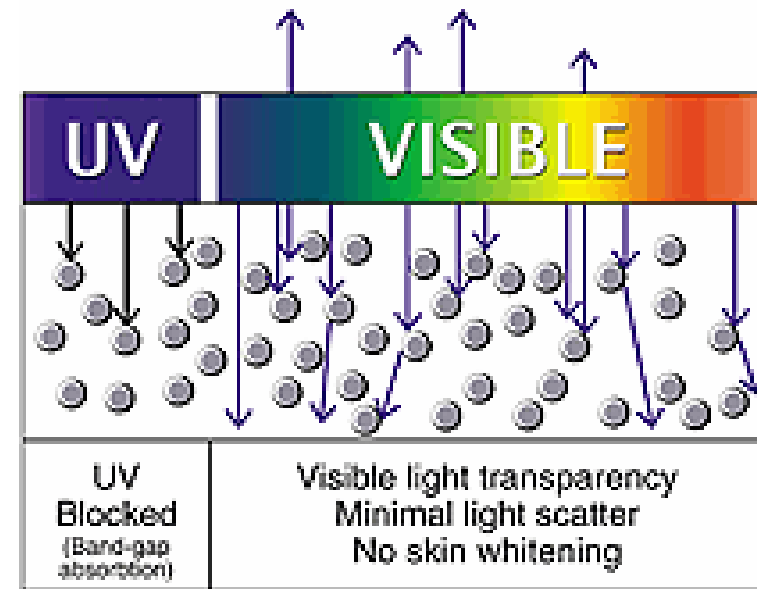
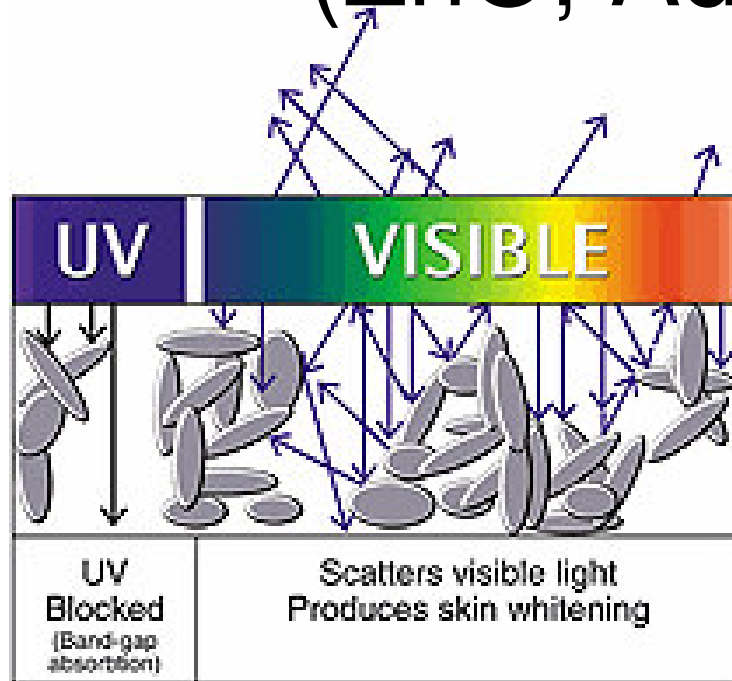


Effect of fabrication technology on materials (Titaniumdioxide, Altair)

- Spray dried
- Dispersed slurry
- Jet Milled powder

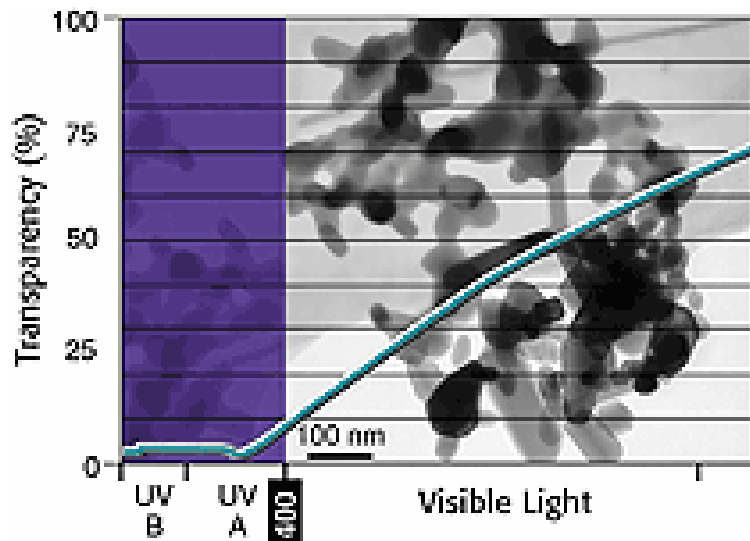


Optical layers (ZnO, Advanced Nano)

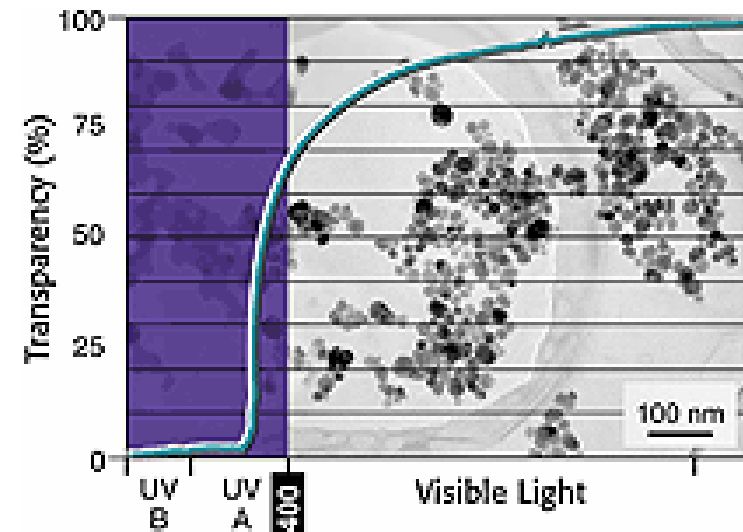


Whitening in sunscreens and cosmetics is a result of visible light scatter produced by large particles and poor dispersion.

Optical layers (ZnO, Advanced Nano)



- Narrow particle size distribution
- Free of hard agglomeration
- Enhances UV blocking
- No whitening



- Wide particle distribution
- Some hard agglomeration
- Poor dispersion
- Whitening
- Reduced UV blocking

Waterfiltration (1) (Argonide)

- Filter media, whose active component is an alumina (AlOOH) fiber two nanometers in diameter.
- It can be pleated to produce a high surface area cartridge with a high filtration efficiency, and with a dirt holding capacity tens or twenty times greater than microglass, meltblown or membrane filters.

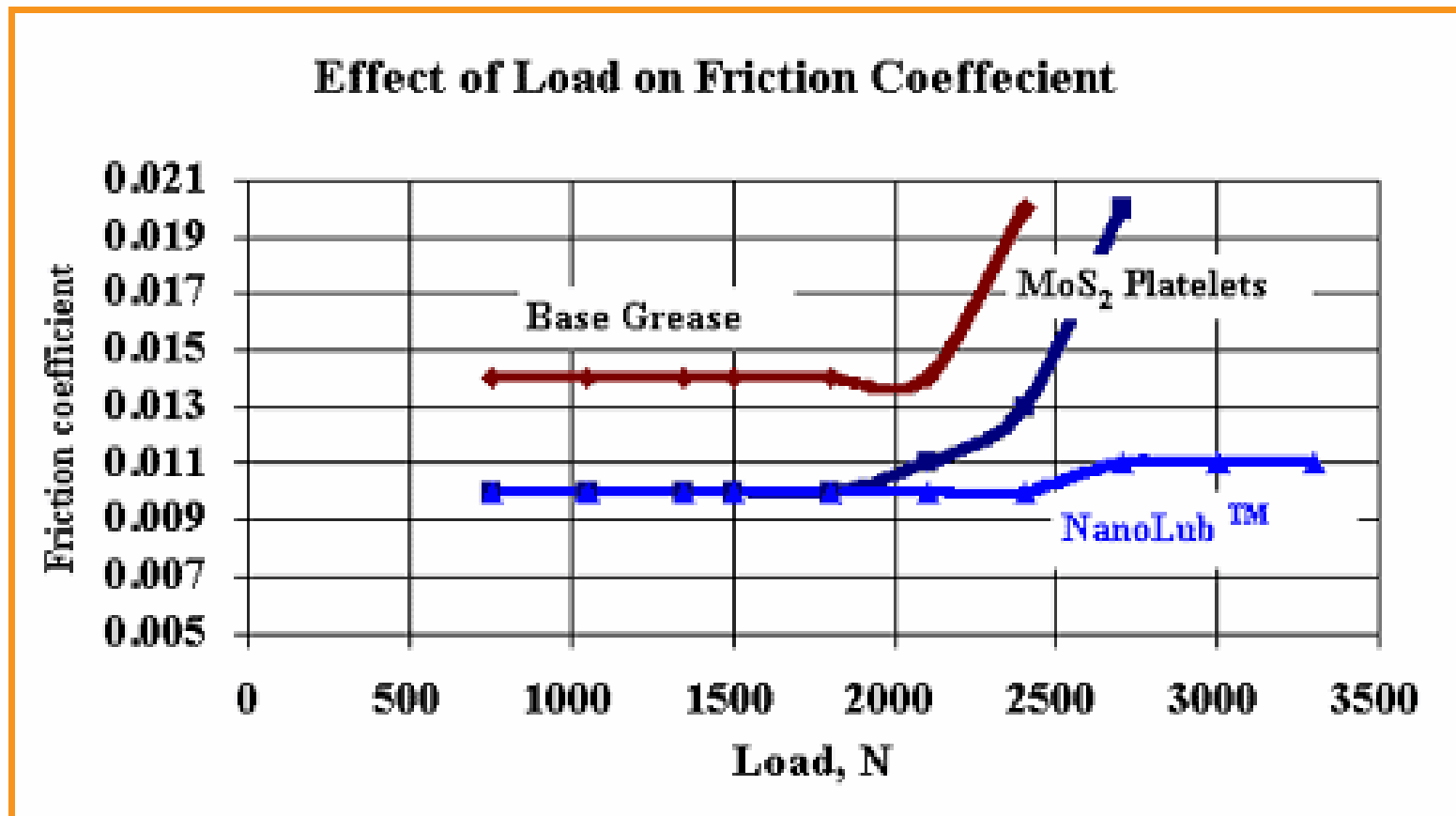
Waterfiltration (2) (Argonide)

- The nano alumina fiber is highly electropositive, and will attract and retain particles, no matter how small.
- The nano fibers are dispersed throughout a microglass fiber matrix resulting in a media with 2 micron average pore size and with water flux typically of that pore size.
- However, the media functions as if it were a 0.03 micron pore size filter.

MoS₂ nanospheres (1) (Apnano)

- Common solid lubricants are layered compounds like graphite, molybdenum disulfide (MoS₂), and tungsten disulfide (WS₂).
- Their layers slide past each to reduce friction.
- The relative large size of the layered platelets prevents them from entering the pores of metal parts and thus they tend to accumulate on the surface and stick to the surface of the parts they are meant to lubricate.
- Due to the structure of nested spheres of NanoLub particles and their small size they can lubricate by rolling like miniature ball bearings

MoS₂ nanospheres (2) (Apnano)



Magnetic Nanoparticles (1)

(Reade)

- Offering exciting new opportunities for delivering drugs to targeted areas in the body, replacing radioactive tracer materials, improving the quality of noninvasive medical imaging.
- They can bind to drugs, proteins, enzymes, antibodies, or organisms and can be directed to an organ, tissue, or tumor using an external magnet or can be heated in alternating magnetic fields for use in hyperthermia.

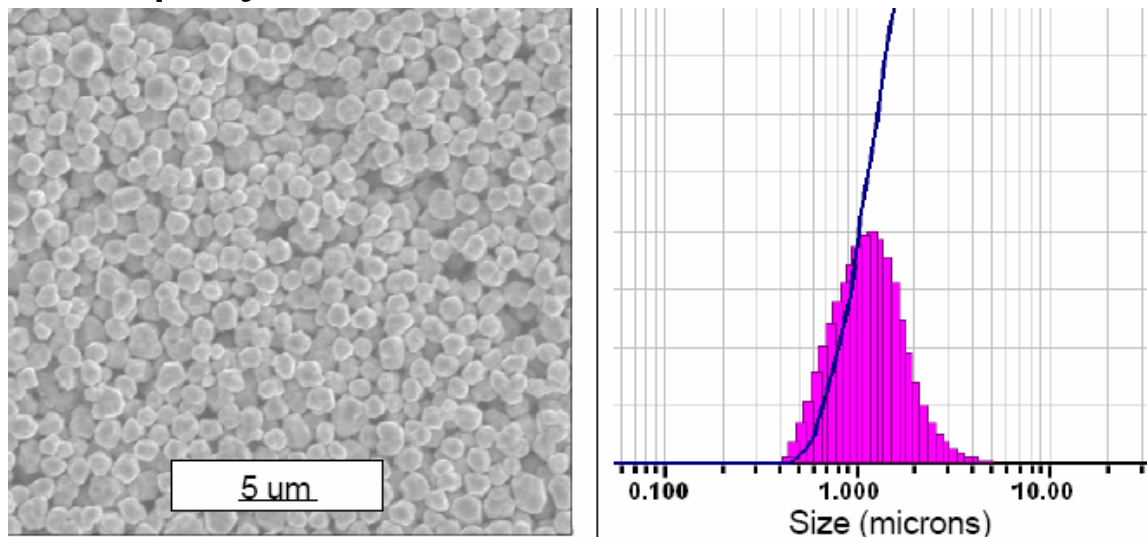
Magnetic Nanoparticles (2)

(Reade)

- Applications:
 - Data storage nanostructures (Magnetic nanocrystal arrays)
 - Optoelectronic
 - Smart imaging probes
 - Biomagnetic separations
 - Magnetic fluid seals

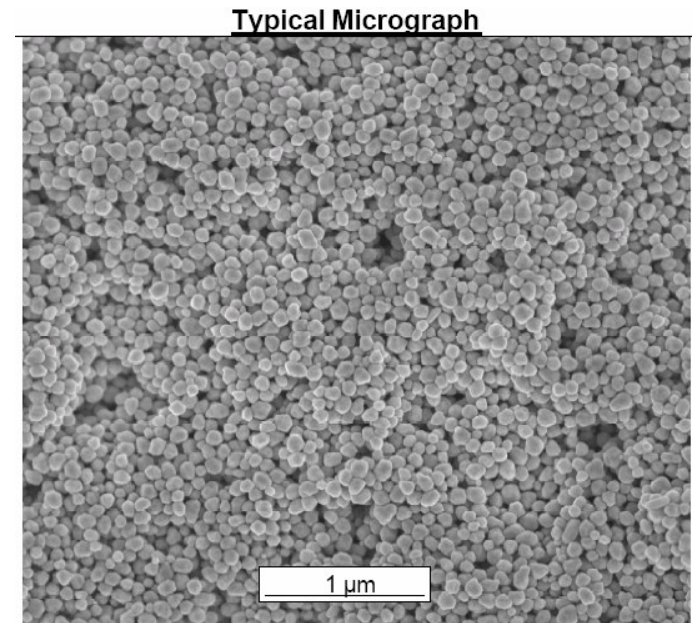
Conductive powders (Cu, Nanodynamics)

- Available in sizes from 200 nm to 3 microns.
- The crystalline structure provides low oxidation and excellent conductivity.
- For printed conductors, dipped terminations, and conductive polymers



Anti microbiological paste (Nanodynamics)

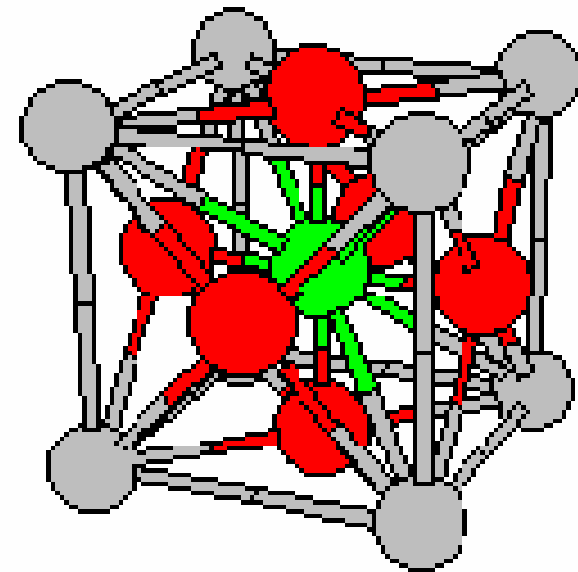
- Silver has long been known to inhibit oxygen exchange, effectively killing bacteria.
- Nanosilver has been demonstrated to enhance that effect, and is currently being used in wound dressings for critical-burn victims.
- Other nanoparticles can be used as pharmaceutical carriers to specifically deliver disease-fighting drugs to afflicted body areas, thus minimizing secondary effects.



Cathode materials for fuel cells (1)

(Fuel Cell Materials)

- Perovskite electrode materials for use as cathodes in solid oxide fuel cells or as electrodes for other ceramic electrochemical devices.
- Standard formulations include lanthanum strontium manganite (LSM), lanthanum strontium ferrite (LSF), and lanthanum strontium cobalt ferrite (LSCF).



Cathode materials for fuel cells (2)

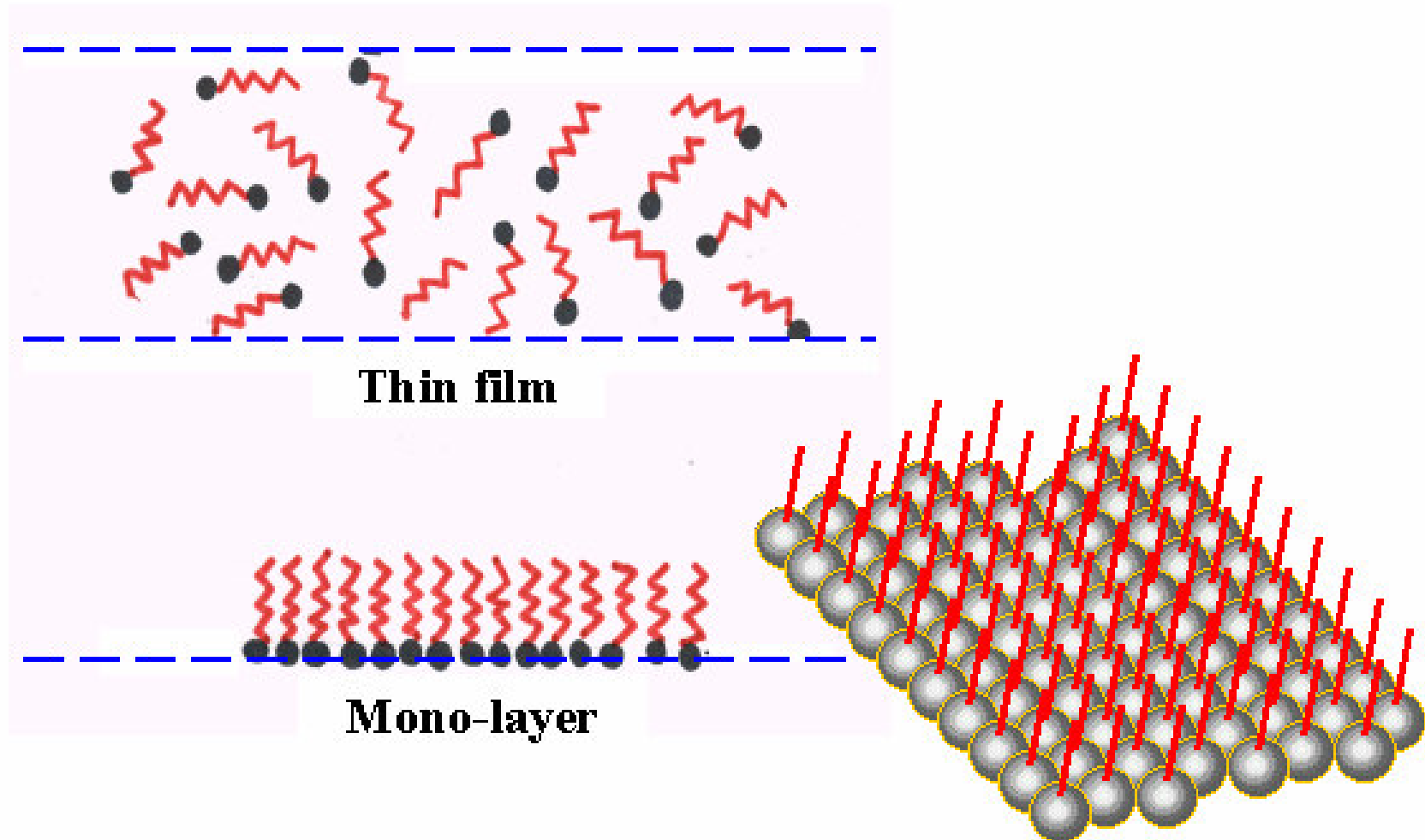
- High ionic conductivity
- Composite cathodes based on mixtures of electrolyte and electrode materials have been shown to improve electrode performance at lower temperatures by increasing the volume of active sites available for electrochemical reactions.
- The key to achieving high performance in composite electrodes is optimizing the dispersion of the electrolyte and electrode phases.

Metal rubber (Nanosonic)

- A self-assembled nanocomposite material that combines the high electrical conductivity of metals with the low mechanical modulus of elastomers. The self-assembly process allows the simultaneous modification of both conductivity and modulus during manufacturing.
- Maximum electrical conductivity: $5 \times 10^{-6} \text{ Wcm}$.
- Maximum elongation $\sim 200\%$.
- Electrical conductivity varies slightly with elongation.
- Operating Temperature Range $\sim -60^\circ\text{C}$ to 170°C

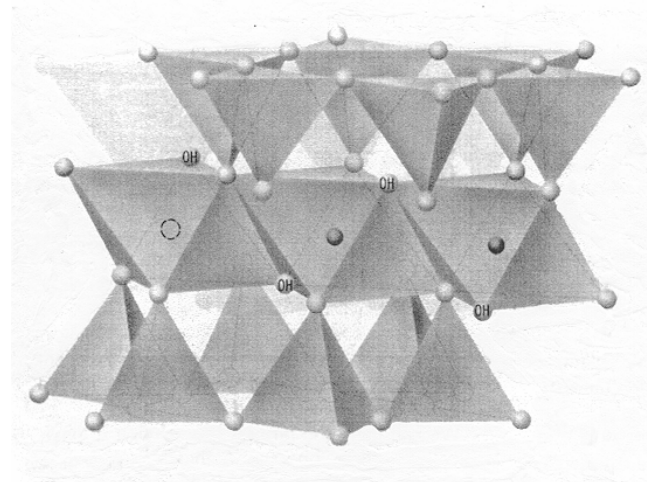


Metal rubber (Nanosonic)



Nanoclay (Nanocor)

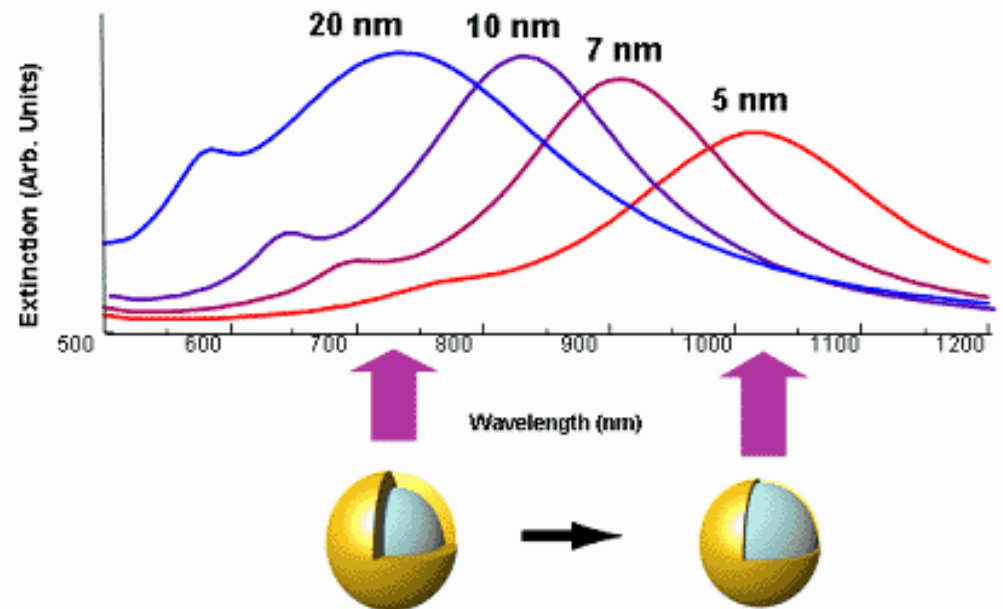
- Nanoclay: montmorillonite, a 2-to-1 layered smectite clay mineral with a platey structure. Individual platelet thicknesses are just one nanometer but surface dimensions are generally 300 to more than 600 nanometers, resulting in an unusually high aspect ratio.
- Chemical modified to enable applications:
 - To slow the progress of water through soil or rocks
 - In drilling muds to give the water greater viscosity
 - Nanocomposites: as an absorbent to purify and decolor liquids; as a filler in paper and rubber
 - As a base for cosmetics and medicines



Nanoshells

(Silica/Au, Nanospectra)

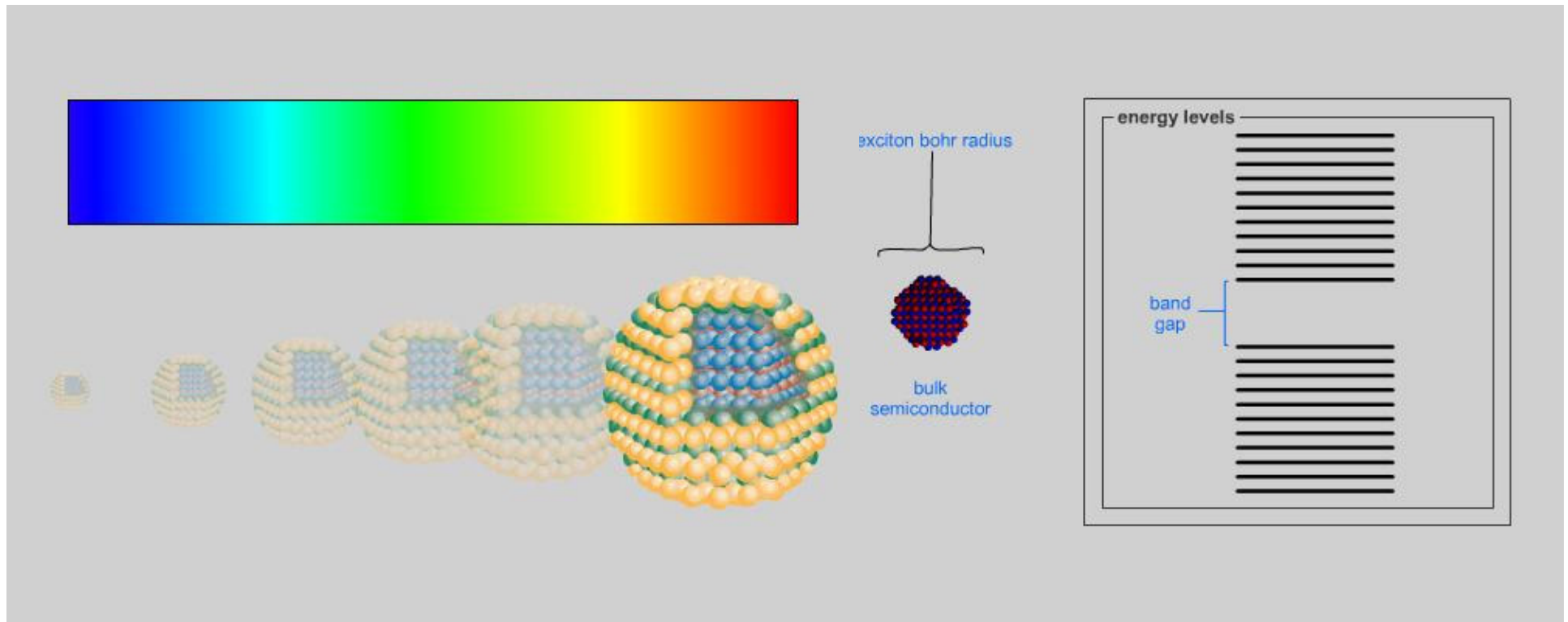
Optically tunable nanoparticle composed of a dielectric (for example, silica) core coated with an ultra-thin metallic (for example, gold) layer. Tuned to absorb or scatter certain wavelengths.



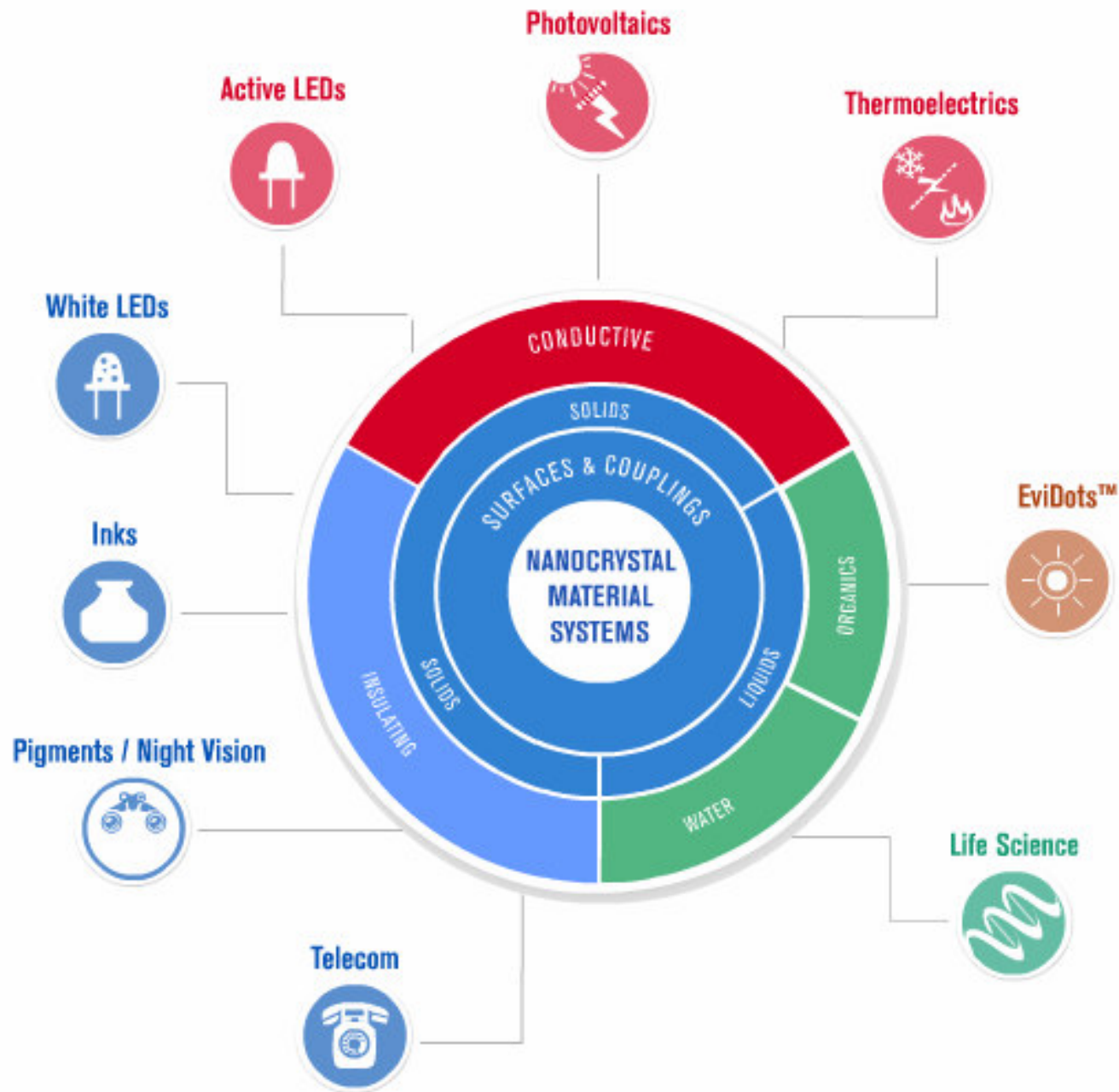
Application example: to target specific cells or tissues and non-invasively ablate using an external laser without damage to surrounding tissue.

Quantum dots (Zia Laser)

- Quantum dots (QD) are semiconductor nanostructures that act as artificial atoms by confining electrons and holes in 3-dimensions.
- Quantum dots absorb light, then quickly re-emit the light but in a different color
- Extremely sharp (delta-function-like) density of the available energy states and the strong confinement of electron and hole wave functions inside the dots. As a result, electrons are confined to specific – discrete – energy levels, similar to conditions that resemble those in an individual atom.
- Main applications: lasers, LEDs



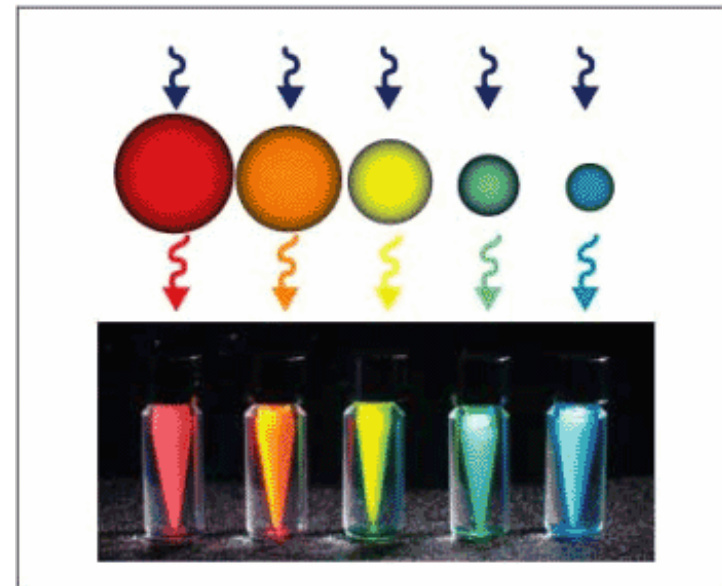
As with bulk semiconductor material, electrons tend to make transitions near the edges of the bandgap. However, with quantum dots, the size of the bandgap is controlled simply by adjusting the size of the dot.



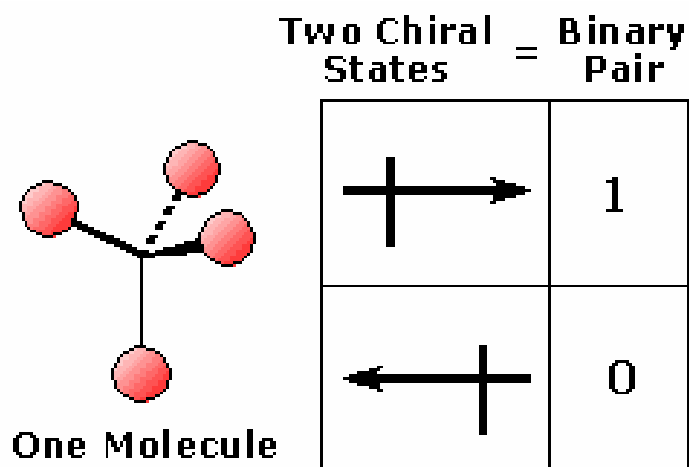
Quantumdots (Invitrogen)

With semiconductor nanoparticles, as particle sizes decrease, a quantum effect causes the material to fluoresce when exposed to ultra-violet light.

The most striking property is that the color of quantum dots (both in absorption and emission) can be "tuned" to any chosen wavelength by simply changing their size.

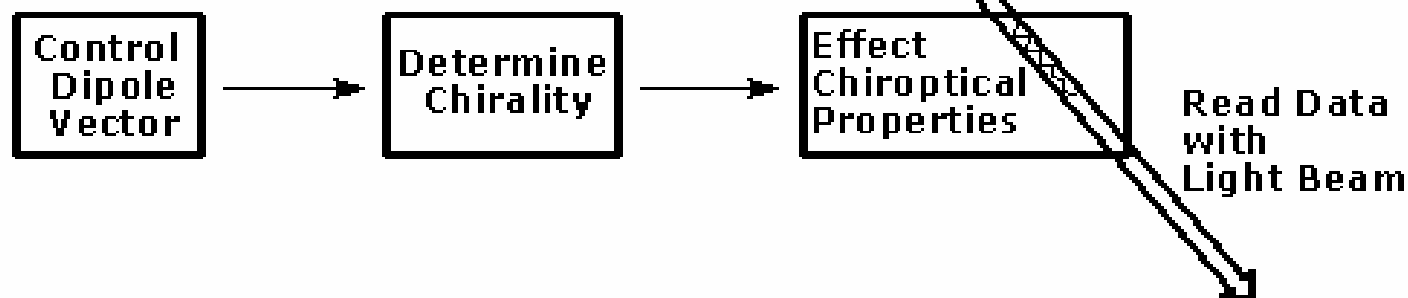


Molecular optical switch (Calmec)



and having the following switch action:

In operation, the dipole switch is triggered by light and controlled with an electric field, actions that change the direction of the molecule's electric dipole by 180° thereby reversing the molecular chirality



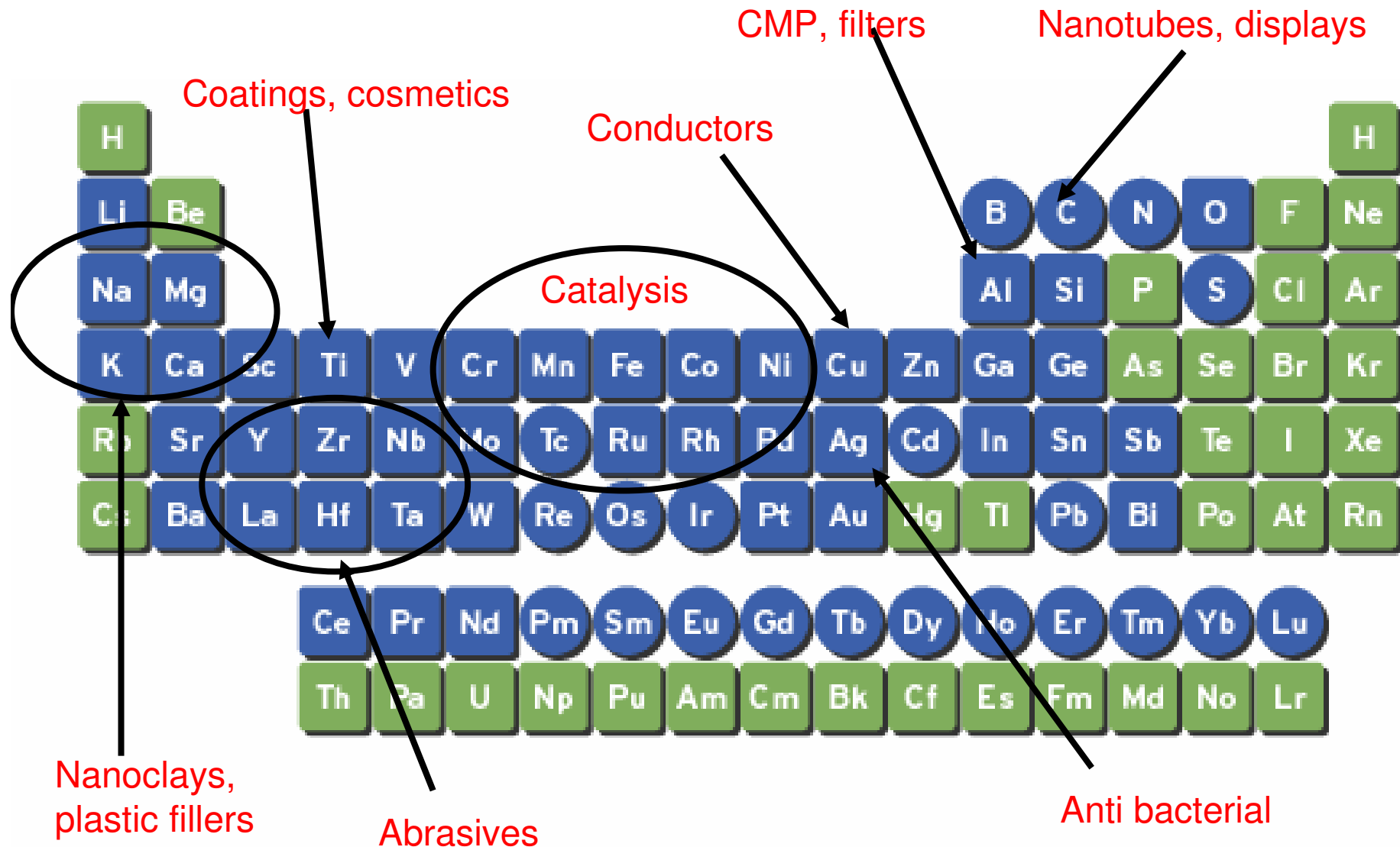
Future: molecular nanotechnology

- The key point of Molecular Nanotechnology is the ability to make chemical reactions happen under programmed control.
- In theory, this allows to build a large range of molecular shapes.
- With careful control, and assuming a suitable chemical toolbox can be developed, a mechanochemical manipulator should be able to build shapes physically as complex as itself.
- Molecular manufacturing should provide a variety of advantages, including less complex fabrication, extremely predictable results and strong, efficient products.

Software for nanotechnology

- Trial and error or design of materials?
- Compared to MST/MEMS the nanotechnology area is less well developed as yet. Several companies offer SW for the modelling and simulation of chemical and biochemical substances and a few start-up companies are working to develop specialized SW for nanotechnology

Summary: nanomaterials, focal points:



General	SusChem European Chemical Industry Council EuropaBio Freedonia Group enablingMNT	www.suschem.org www.cefic.be www.europabio.org www.freedoniagroup.com www.enablingmnt.com
Fabrication nanotubes	Inframat Nanostructured & Amorphous Materials Reade Nanoledge Carbon Nanotechnology Laboratory	www.inframat.com www.nanoamor.com www.reade.com www.nanoledge.com www.rice.edu
Nanotube paper	Nanolab	www.nano-lab.com
Indium Tin Oxide	AdNano	www.advanced-nano.com
Titaniumdioxide	Altair	www.altairnano.com
AlOOH	Argonide	www.argonide.com
Perovskite	Fuel Cell Materials	www.fuelcellmaterials.com
Metal rubber	Nanosonic	www.nanosonic.com
ZnO, optical layer	Advanced Nano	www.advancednanotechnology.com
MoS ₂ nanospheres	Apnano	www.apnano.com
Copper powders	Nanodynamics	www.nanodynamics.com
Nanoclays	Nanocor	www.nanocor.com
Nanoshells	Nanospectra	www.nanospectra.com
Quantumdots	Applied Nanoworks Zia Laser Invitrogen Evident Technologies	www.appliednanoworks.com www.zialaser.com www.invitrogen.com www.evidenttech.com
Nanodiamonds	PlasmaChem	www.plasmachem.com
Molecular opt. switch	Calmec	www.calmec.com

About enablingMNT

- The enablingMNT team utilizes its members' extensive experience and its wide network of industry contacts to offer organizations customized services in the fields of micro and nano technologies.
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