Nanotechnology

from small dimensions to big business

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Nanotechnology. It is difficult to overstate the potential of this newcomer to the technology world, and equally difficult to overlook its presence when the press daily trumpets *'New investments in nanotechnology…'*, *'Nanotech center opened at…'*, *'Nano-scientific breakthrough in…'*

What is the real potential of nanotechnology? Does it have practical applications? And, most importantly, what significance does it have for ABB?

The last three years have seen a tremendous surge of interest in nanotechnology. Research, development, investment and patent activity have all experienced double-digit growth rates. Global governmental funding in 2002 topped the $2 billion mark, and a similar amount was invested by private enterprise around the world. In all, some 100 investment firms were active in the field in 2002.

It is becoming obvious that nanotechnology is an enabling technology that will impact a wide range of disciplines: electronics and computing, materials and manufacturing, energy, transportation, medicine and defense. The challenges, opportunities and rewards are great and, by participating in the nanotechnology community, ABB can take advantage of the huge potential for technological advance and business impact.

This is why, in 2000, ABB launched its nanotechnology research program. This program follows the development in nanotechnology, secures technology transfer from the scientific community to ABB, and finds ABB business opportunities. The program strategy is to focus on nanotechnology areas which are less exploited and have direct relevance for ABB, like electrotechnology, nanocoatings and nanosensors. The strategy is to add new or improved functionality based on nanotechnology solutions to our existing business. The program is biased towards applications rather than material development, which should be carried out in collaboration with universities or subcontractor.

Nanotechnology is technology involving structures or elements engineered on a nanoscale level, 1–100 nm, in at least one dimension.

Size does matter!

So how are nanomaterials different from ordinary materials? The most exciting, and fundamental aspect is that in the sub 100 nm domain, quantum mechanics start to take over from classical physics, leading to completely new properties. A second, potentially revolutionary characteristic is the dramatic increase in the surface-to-volume ratios of the particles. This strongly influences most chemical, physical or electrical interactions that take place on the particle grain boundaries. Particle interaction with the matrix in different composites will also change because the nano building blocks are of the same order as several other material characteristic dimensions, like crystallites, free volumes, mean free paths, depletion widths, and so on.

ABB is concentrating on three aspects of nanotechnology: electrotechnology, nanocoatings and nanosensors.

Electrotechnology

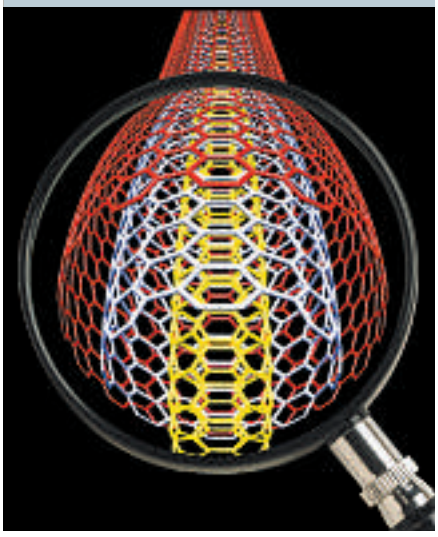
The idea here is to expand the electromagnetic property windows of essential materials and components in ABB products. This will lower the losses in electrical transmission and distribution network components and reduce the weight and cost of systems. Important areas are:

- Cables – eg, new or improved cable terminations and cable insulation systems.

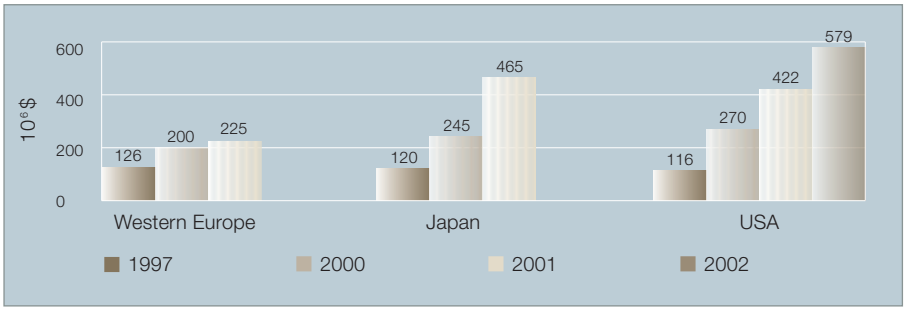
Carbon nanotubes

Carbon nanotubes (CNTs) are a form of carbon that was discovered in 1991. These tubes have diameters in the range of 1 to 100 nm and their length can be up to 100 micrometers or more. CNTs can be either single- or multi-walled. Depending on the detailed crystal structure of a given tube it will display metallic or semiconducting properties.

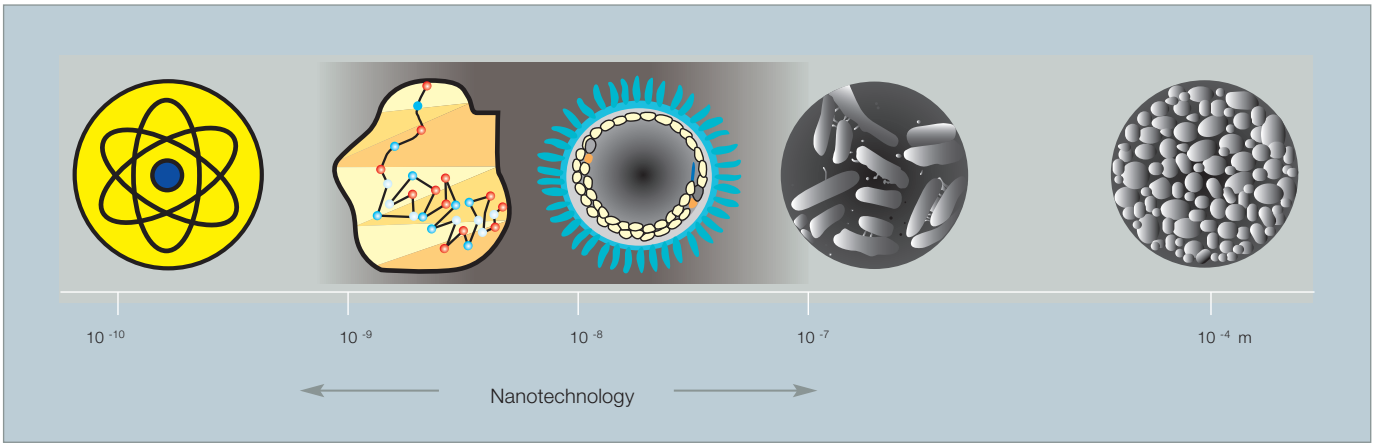
The field of CNT research is very active and has drawn a lot of attention due to novel properties in the electrical, thermal and mechanical areas.



Section of a multi-walled carbon nanotube



Worldwide nanotechnology government R&D funding in US$ million (source: NNI)



Nanoperspective. Far tinier than sand grains, the nano region straddles the dimensions of large molecules, viruses and small bacteria.

- Conduction – new electrical conductors and improved thermal conduction.
- Contacts – new concept for electrical contacts based on or improved by nanotechnology.

Nanocoatings

Nanomaterial surface coatings will give rise to new classes of products with added functionality, enhanced energy efficiency as well as better reliability, availability and lifetime. Coatings with anti-stick, low-friction, high-friction, thermal barrier and diffusion barrier properties are some example of coatings being investigated in ongoing projects.

Nanosensors

Nanotechnology will make highly sensitive and very specific sensor systems with fast response times and long-term stability possible. The sensing concept should be based on, or strongly improved by, a nanotechnology (or biotechnology) solution.

1 nanometer = 1/1000,000,000 m, or 1/10,000 of the thickness of a human hair.

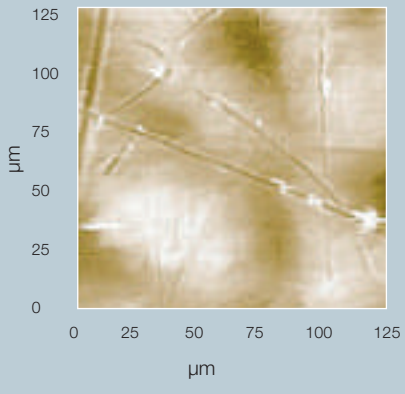
sively studied with the aim of replacing ball bearings by less expensive and improved performance sliding bearings. These are harder, more slippy, more robust and adhere better to substrates. As such, they are ideal for products like circuit-breakers, where high performance and high reliability in different environmental conditions are essential.

Ongoing ABB activities

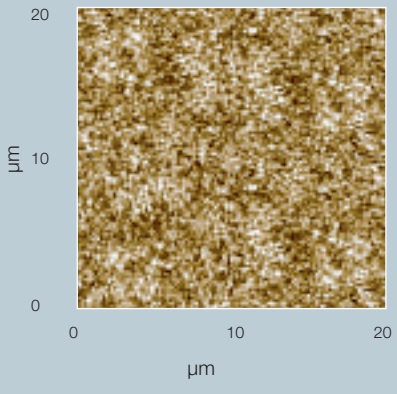
The two examples given in the following are representative of ABB's activities in this field. One, a nanocoating, is closer to possible productization, while the other is a more long-term university collaboration in the area of electrical conduction.

Low-friction coatings

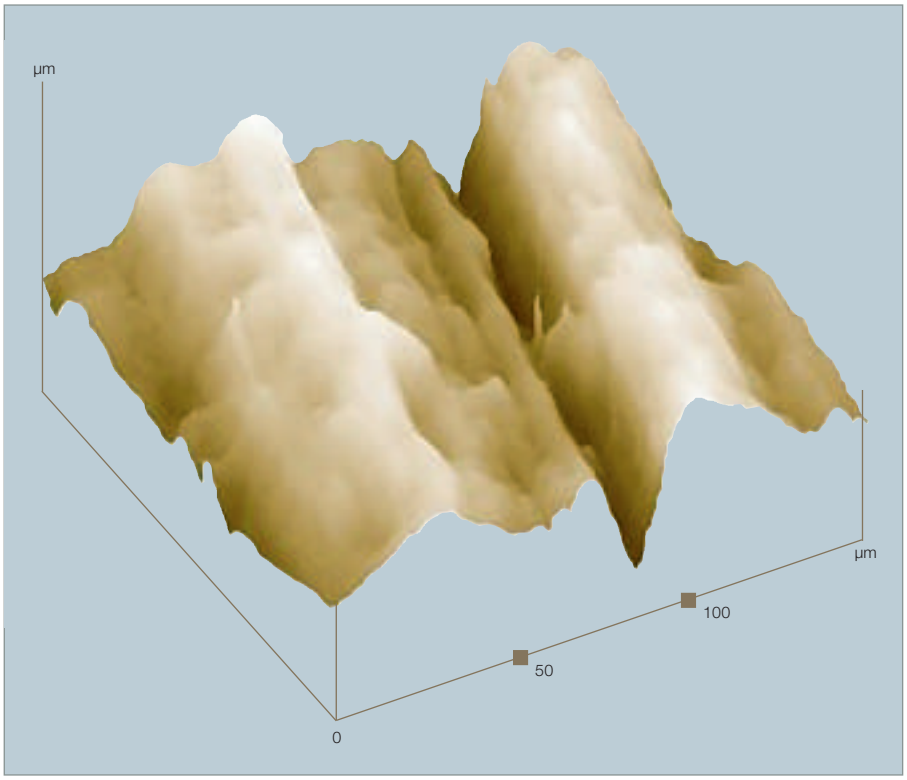
Nanocoatings for tribological purposes, anti-stick surfaces and protective coatings can be radically improved by nanoscience. ABB has built its expertise with short-term research activities targeted for use in real products. In particular, the field of low-friction tribological coatings has been exten-



AFM image of filled PTFE after sliding tests



Nanoparticles before sinterization



3D profilometry of surface sample by AFM

A complete friction, wear and hardness characterization of differently nanostructured thin-films has been carried out, on both the micro- and macroscale. This work was extended to characterize what happens to these films when applied to real products.

In particular, different compositions of water dispersions of polymer nanoparticles have been evaluated. The choice of waterborne polymers has been made with environmental compatibility in mind.

The sliding bearing consists of a cylinder made of a porous metal, onto which a coating based on PTFE (poly-tetra-fluoro-ethylene, a plastic polymer with anti-stick and anti-friction macroscopic characteristics) is deposited and sintered.

Ballistic conduction

In a normal conducting metal, such as copper, the conduction electrons are scattered by crystal impurities and thermal vibration of the metal atoms. This scattering reduces the speed and momentum of the electrons and gives rise to what is normally referred to as resistivity. In a high-quality CNT, such scattering is rare. In some tubes the electrons can go from one end to the other without being scattered. This type of conduction is called ballistic conduction and gives rise to the phenomenon that the resistance of a CNT can be independent of the tube length.

The adherence to the substrate, the endurance of the coating and the technical performance in terms of tribological properties are all ensured by the nano-

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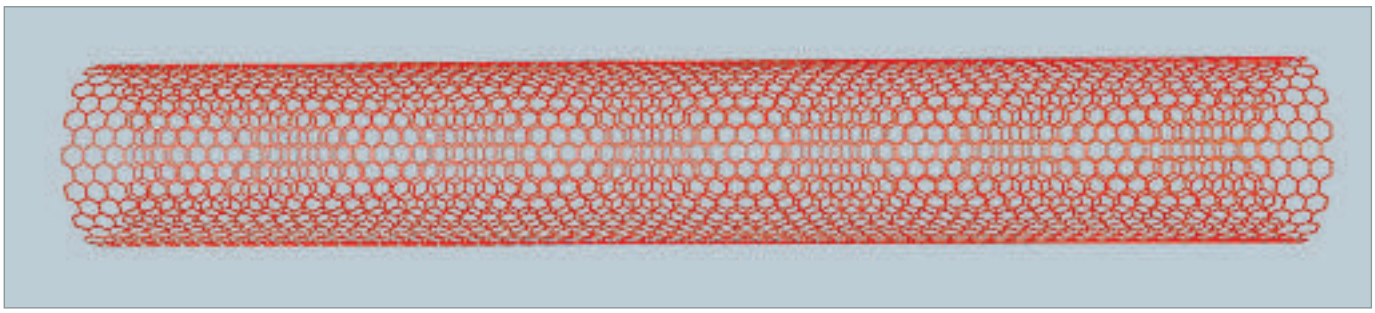
structure of the coating and of the substrate surface. In fact, the substrate surface morphology is structured at nanoscale level to facilitate the adhesion



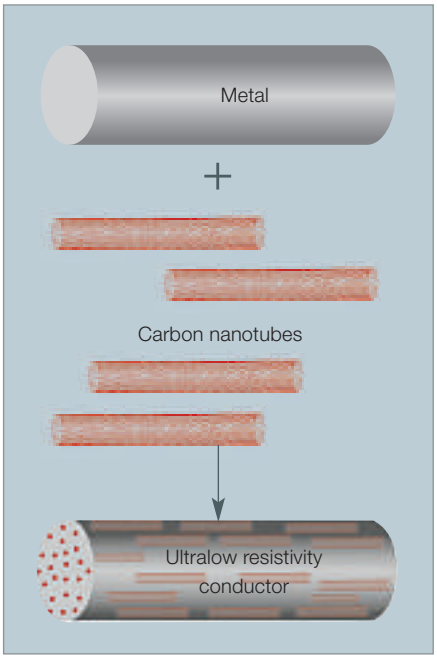
Single-walled carbon nanotube

Stanford University

ABB has been collaborating with Prof. Hongjie Dai at Stanford University since 2000, focusing mainly on understanding the novel electrical properties of CNTs. This work has proven, for the first time ever, that single-walled CNTs can be ballistic conductors. Such conduction in tubes up to 4 micrometers long has been confirmed. At present, experiments on even longer tubes are being prepared.

and the coating material is obtained by sintering nanopowders.

Nanostructure does not mean nanometric: the final coating thickness is on the micron scale, the nano-dimension is in the precursors (surface morphology, powder particles dimension) that contribute to the manufacturing process of the coating itself, and that give the coating its unique final properties. The new technology concerning sintering of PTFE from nano-dispersion has been tuned to ABB requirements, resulting in a higher compactness and mechanical strength of the coating after sintering.



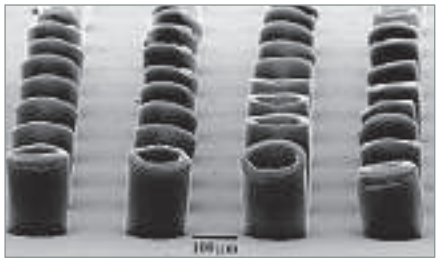
Ultralow resistivity conductor

Although PTFE's dry lubricant properties have been known for a long time, applications, such as in cookery ware, have not required the nanoscale engineering used here.

Ultra-low resistive material

As an example of a longer timeframe research project with a very high potential, we shall now look at a concept aimed at producing a conductive material with a room-temperature conductivity twice as high as copper. The concept is based on the novel electrical property of so-called ballistically conducting carbon nanotubes (CNTs) (see panel). These have a resistance which is independent of the length of the tube, implying that tubes longer than about one micrometer might have a resistivity which is lower than copper. The idea is that long CNTs with a high conductivity should be embedded in a metal matrix. If the tubes are in good contact with the matrix material, the new metal composite would have a resistivity which is lower than the resistivity of the host material.

Theoretical estimates show that a conductivity twice that of copper at room temperature is a realistic goal. Such a new conductor material, with a conductivity much higher than that of the conventional conductors aluminum, copper and silver, would have a huge impact. Large resistive energy losses could be avoided and the new material would also permit completely new system solutions, since the present ones are tailored for conventional conductor use. To gain a deeper understanding of the basic electrical properties of CNTs, a collaboration with Prof. H. Dai at Stanford University has been established (see panel).



Carbon nanotube towers grown on a patterned array (courtesy: Center for Nanotechnology, NASA Ames Research Center)

These two examples show the potential nanotechnology has to improve ABB business in the short term as well as to considerably impact our business over a longer period. ABB will continue to add new or improved functionality based on nanotechnology to existing products to take full advantage of the unfolding promise of this new science.

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