NANOTECHNOLOGY FOR NEW MATERIALS

SMALLER, SMARTER, STRONGER AND LIGHTER

Photo by Jesper Scheel, Danmarks Tekniske Universitet

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Why nanomaterials matter

From aircraft made of nanocomposites to nanoparticles for drug delivery, self-cleaning windows and smaller and faster computers – nanomaterials are resulting in major advances, breakthroughs and solutions to a vast number of engineering challenges. At the nanoscale, new phenomena occur, resulting in unique and amazing properties: opaque substances become transparent (Cu), stable materials turn combustible (Al), insoluble materials become soluble (Au) and chemically inert materials become reactive (Au). These properties, together with advances in both manufacturing processes and characterisation techniques, have paved the way for products that are smaller, smarter, lighter and stronger.

With this brochure Nano Connect Scandinavia, an EU-financed project representing seven universities and institutes in south-western Scandinavia, presents a few examples of areas where the use of nanomaterials has contributed to improved products and helped solve engineering challenges.

WHAT IS NANOTECHNOLOGY?

Nanotechnology is the understanding and control of matter and processes at the nanoscale, typically, but not exclusively, below 100 nanometers in one or more dimensions where the onset of size-dependent phenomena usually enables novel applications. Nanotechnology is cross-disciplinary in nature, often combining medicine, chemistry, biology, physics and materials science.

WHAT ARE NANOMATERIALS?

Nanomaterials are materials where at least one dimension of the structure is in the nanoscale (1-100 nm). For example, nanomaterials are called nanofilms or lamellar if the nanoscale occurs in only one dimension, strands, wires or fibers if nanoscaled in two dimensions, and nanoparticles if nanoscaled in three dimensions. Nanocomposites/nanoalloys are when nanoparticles are mixed into a polymer or metal matrix.

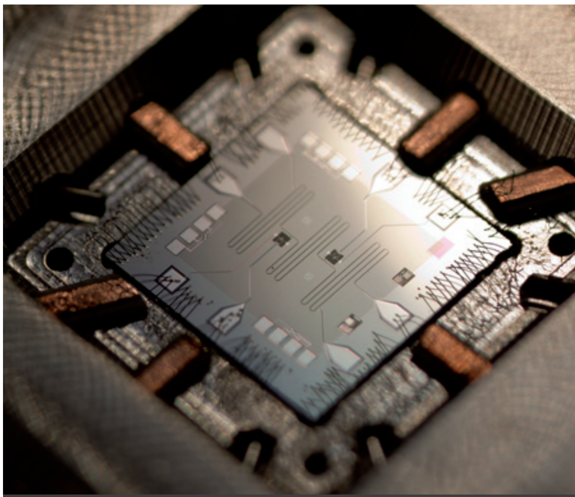
MORE POWERFULL PORTABLE ELECTRONICS

Smaller supercapacitors with higher power density can be achieved. Using layers of nano structured carbon separated by a porous polymer film filled with a liquid electrolyte - resulting in lighter, more functional and longer-running electronic devices, perfect for portable electronic applications (CAP-XX Pty Ltd).

SMALLER

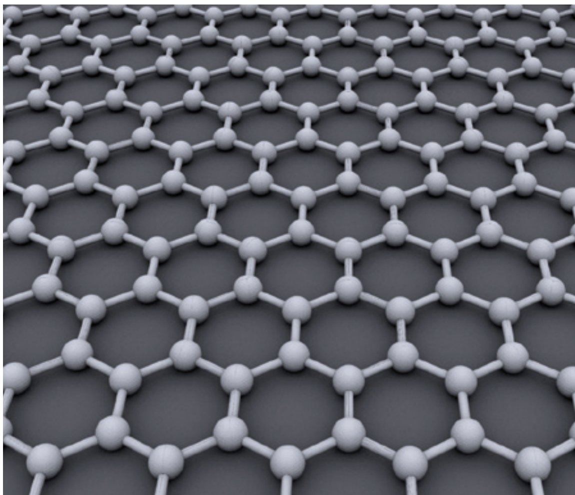
The advantages connected to the small feature size of nano-structured materials are being used in many different fields and applications.

In electronics, devices such as transistors, are becoming smaller and smaller, reaching already quantum behaviour. Apart from smaller, electronic devices are also becoming more powerful and less costly. The implementation of new nanomaterials, such as graphene, depicting for example extremely high electron mobility and thermal conductivity, is expected to take the development of the electronics field even further.



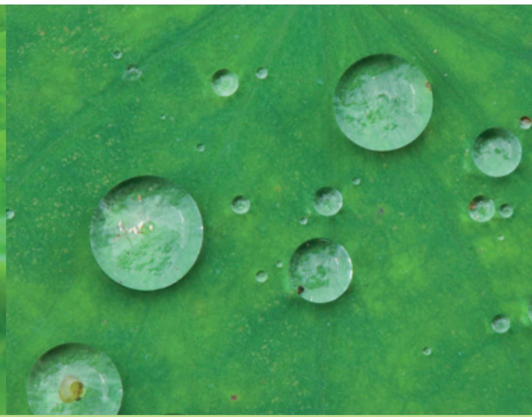
Quantum computing chip
(Image courtesy of Erik Lucero)

In medicine, the small size of nanostructured materials can be used in a wide range of applications, from diagnostics to disease treatment. Nanoparticles can for example be used for targeted drug-delivery. Since nanomaterials can be very sensitive to chemical and biological stimuli, they can give us new sensors for the development of smaller, portable, point-of-care diagnostic tools. The biomedical analysis is moved from the laboratory environment into the patient's home or hospital environment. Although not yet commercially available, Carbon Nano Tubes (CNT) are being used to develop sensors for salmonella detection. Novel multi-marker nanosensors using mechanical cantilevers functionalized with self-assembled monolayers are also being developed for faster diagnostics and monitoring of HIV markers. When available, such devices will enable HIV patients to cut down on the number of medical visits since they can easily monitor the state of their disease by themselves at their own homes.



Graphene is an atomic-scale honeycomb lattice made of carbon atoms.

The energy field is also taking advantage of nanomaterials and their size-scale, for example in miniaturised batteries and smaller, higher recharging-rate supercapacitors.



Self-cleaning behaviour is normally achieved using hydrophobic surfaces with nanostructured features. These are inspired by the Lotus flower leaves that combine a surface roughness at the nanoscale and a water repellent wax. It can be engineered, or mimicked, using nanocomposite materials made up of nanoparticles in a polymeric matrix. The nanoparticles provide the surface with a critical roughness that further enhances the water repellent properties of the material. Examples of products based on the Lotus effect are house paint, ceramic roof tiles, and textiles (for parasols and sails). Anti-freezing and/or anti-icing behaviour is also achieved by using composites of polymers and nanoparticles.

SMARTER

The use of nanomaterials enables the development of products and devices with higher performance and novel/smarter properties. These properties can be manifested in amazing characteristics, such as biocompatibility, self-cleaning, self-healing, anti-microbial, anti-reflection, anti-corrosion, decreased friction and abrasion, fire-retardancy, UV absorption, controlled release, catalytic behaviour, among many, many others. Many of these characteristics are achieved either by tailoring nanocomposites, depicting specific and improved properties, or by the functionalisation of surfaces in order to protect and/or introduce new functionality to the same surface.

Anti-reflection glass uses coatings of alternate SiO_2 and TiO_2 (50-100 nm thick), applied to both sides of the glass (Conturan). Sun-protecting glass uses infrared reflecting nanolayers embedded into sheets of glass (Sekurit). Anti-microbial behaviour is obtained by using Ag (silver) nanoparticles and applied where a sterile environment is desired. By using nanocomposite tribocoatings, Applied Nano Surfaces has developed a novel surface finishing process to decrease energy consumption and wear in combustion engines.

Examples of components with a nano-composite antifriction coating by Applied Nano Surfaces

The Fraunhofer Institute has developed self-healing car paint by including liquid-filled nano-capsules (containing healing agents) in the electroplated layer, that rupture when the layer is scratched. Nissan developed Scratch Guard Coat, for general purposes, including IPhone cases, containing a heat-activated, high elastic resin that expands and fills fine scratches.

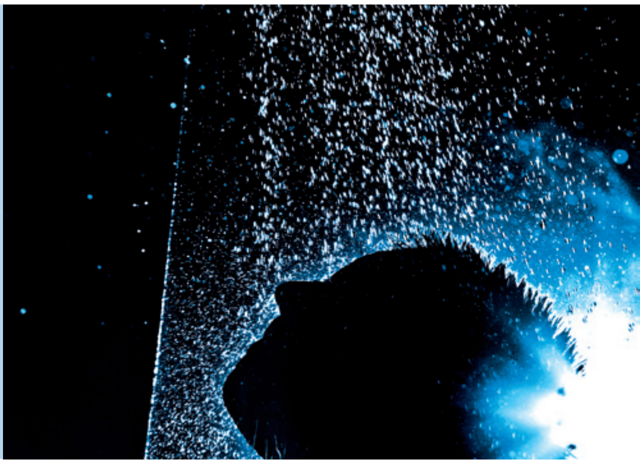
Nanomaterials can also function as UV or gas (e.g. O_2 and CO_2) protection barriers, mainly for food and drink packages. This is achieved by using nanoparticles (e.g. clay) as fillers in polymers. An example is the multi-gas barrier nanocomposite from Nanocor (Nano-N-MXD6) that contains clay nanoplatelets. Such coatings lead to extended shelf life and preserved product quality. Honeywell has also developed a composite using both active (specific O_2-captors) and passive (nanoclay) O_2 barrier properties. Nanoclay can also be used for thermal stability and flame retardancy purposes.

Materials with the above mentioned smart characteristics can be used in a wide variety of applications, such as buildings (e.g. windows, interior and exterior walls and roofs) vehicles (e.g. cars, planes and boats), household products (e.g. food and drink packages, refrigerators, cookware), and textiles (e.g. clothes and bed-linen). They can also be used to make buildings smarter, for example by giving better insulation so that less energy is used for heating and cooling purposes.

Furthermore, nanotechnology, together with advances in molecular biology, can lead to novel and revolutionary medical solutions. For example, these developments can lead to new implants that help the body to regenerate lost tissue.

NANOFIBERS MAKE WORLD'S MOST WATER-EFFICIENT SHOWER

Shower hundreds of times using the same water - this is possible since the water is continuously cleaned and recycled using a nanotechnology-based filter. After an 8-minute shower you have only used 8.5 l of water! The filter technology is based on electro-positive aluminium nanofibres that attract all types of particles, including bacteria and viruses. The filter only needs to be replaced after a flow of 110.000 l.



SELF-CLEANING WINDOWS

Self-cleaning windows use a nanolayer of TiO_2 nanoparticles, which besides being transparent and hydrophilic are also photocatalytic, meaning that in the presence of UV light, they can decompose dirt (organic materials such as fat, oil and plants). The dirt is removed when the next rain shower wets the surface and washes off the dirt.

STRONGER AND LIGHTER

The ability to make stronger, lighter and more resistant materials is very advantageous for many applications, such as vehicles (e.g. cars, boats and airplanes), structural construcions (e.g. windmills) and sports equipment (e.g. skis, fishing rods, and golf clubs). For automotive and airplane manufacturers, lighter materials lead also to decreased fuel-consumption, more economical travelling and lower environmental impact.

Nanostructured materials can be used as reinforcement fillers in composite materials, improving the overall mechanical properties of products. Much smaller amounts of filler are needed compared to conventional composites. The reason for this is that a few percent by volume of very small particles is a huge amount of particles. Adding only 2 vol. % of Silicate nanoparticles to a polyamide resin increases its strength by 100%! The possibility to manufacture stronger polymer-based nanocomposites means that they can replace metallic materials in different applications, resulting in lighter components and structures.

The strength of metals can also be increased by means of nanotechnology - for instance by means of nano-precipitation strengthening, (e.g. using nanosized carbide or Cu precipitates), or by achieving nanoscale microstructures. Many companies worldwide, such as Sandvik, Arcelor Mittal, JFE steel, Nippon Steels, The NanoSteel Company, and Metallicum have developed nanometals. Ultra-strong, low-weight nanostructured titanium was developed by Metallicum Inc. (acquired in 2008 by Manhattan Scientifics), using a rapid spinning technique. The NanoSteel Company develops super hard steel (SHS) alloys for use as thermal spray coatings and weld overlay where corrosion, erosion and wear resistance are key issues.

For construction purposes, besides polymers and metals, concrete can also take advantage of nanotechnology. Concrete can be made more dense and stronger if nanoparticles of silica are blended into the concrete mix, resulting in a material with better water-blocking and corrosion properties. Paints and coatings can also be made scratch resistant using nanotechnology.

NANO MAKES STEEL STRONGER

Sandvik Nanoflex is a precipitation-hardened steel alloy developed by Sandvik that depicts high strength, high formability and corrosion resistance. It is based on the 2011 Nobel prize discovery, quasicrystals, and designed for lightweight and rigid constructions, such as chassis, shaver components (e.g. cutter head) and medical equipment (e.g. needles).

NANOHITEN is a precipitation-hardened steel developed by JFE Steel Corporation. It uses nanometer-size, thermally stable carbide precipitates, which result in a material with enhanced strength and formability. It is intended for automotive applications.

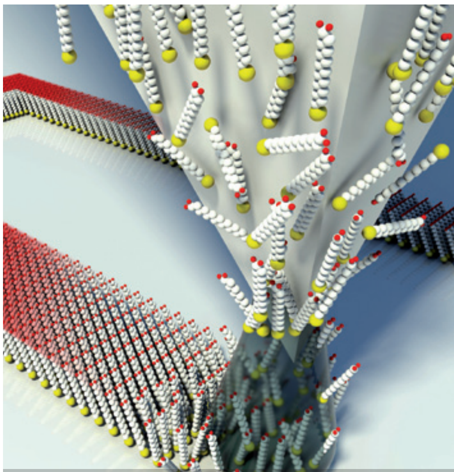
CARBON NANOTUBES MAKE MATERIAL STRONGER AND LIGHTER

Bianchi uses CNTs to fill the small spaces that exist between the carbon fibres and epoxy resin in a carbon fibre road-racing bicycle frame. This creates a more compact material, with less micro cracks, and with a 27% increased shear strength. By using CNTs, Bianchi was able to design a bicycle frame with the same mechanical properties as a traditional carbon fibre frame, but weighing 250 g less.

MANUFACTURING METHODS

In order to make devices at the nanoscale, new and more accurate manufacturing methods are needed. There are both top-down methods, such as mechanical milling, spark erosion, and lithographic methods, (e.g. photolithography, colloidal lithography, nano-imprint lithography, and Electron Beam lithography (EBM)), and bottom-up methods, such as plasma etching, Chemical Vapour Deposition (CVD), Molecular Beam Epitaxy (MBE), sol-gel synthesis and molecular self-assembly. Electron Beam Lithography is the lithographic method that offers the highest resolution combined with a flexible and versatile pattern formation. Nanoimprint is another important method where devices and components can be made with accurate and repeated nanopatterns.

Apart from new manufacturing methods, a key issue for the development of nanoscale materials and devices is the advances in characterisation methods and microscopes such as SEM, TEM and AFM.



Dip-pen nanolithography. Image courtesy of Paul Stiles. Wikimedia Commons

SAFETY

The European commission adopted, on October 18th 2011, the definition of a nanomaterial. The definition is supposed to provide clear criteria to help in identifying materials for which there is a need for specific risk assessment considerations. The definition only takes into account the size-scale of the constituent particles.

There are today only some pieces of legislation related to nanomaterials. The REACH legislation applies to all substances manufactured or imported at 1000 kg or more per year. Although, it contains no explicit reference to nanomaterials, these are covered by the definition of a “substance”.

The new cosmetics regulation, EG 1223-2009, applicable from July 11 2013, takes nanomaterials into account. Besides identifying the need for a suitable definition, it also mentions that nanomaterials have to be assessed and products are to be labelled as containing nanomaterials.

You can find more information about safety and regulations in the brochure “Regulatory Landscape” from Nano Connect Scandinavia.

Would you like to know more?

This brochure is part of a series, covering different application areas of nanotechnology, including life science, materials, electronics & sensors, and the regulatory framework for nanomaterials. Please visit www.nano-connect.org for more information.

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Connecting people who

think big

about very

small things

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