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The High-Tech Strategy for Germany

nanotruck

High-Tech from the Nanocosmos

"It's unbelievable all the things
you can do nowadays
with nano materials."

"Protecting the environment
with nanotechnology?
I'm with you all the way!"

"Nanotechnology ...
sounds intriguing, but what
are the job prospects?"

"We're developing today
what people can use
tomorrow."

HIGH-TECH STRATEGY

Igniting ideas!

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High-Tech from the Nanocosmos



Nanotechnology is one of today's most promising cross-over technologies, introducing us to the world of the tiniest dimensions. It enables us to study and process materials whose dimensions are less than a hundred billionth of a metre (100 nanometres).

Nanotechnology allows us to discover fascinating new things in the areas of energy, environmental and information technology and medicine, and to improve or develop new processes and products. It also opens new doors to interesting careers and exciting fields of work in virtually all the disciplines, which is why the Federal Ministry of Education and Research (BMBF) has created the "Nano Initiative – Action Plan 2010". The Ministry aims to promote this pioneering technology within the scope of the High-Tech Strategy for Germany.

Nanostructures are already part of our everyday lives. Powerful rechargeable batteries and brighter, but at the same time, energy-saving light sources are just some of the results of nanotechnology today. In the future, the term "high-tech" will be even more closely

linked to innovations from the nano-world: nano-medicine will fight tumours more effectively, while new versatile, lightweight and stable materials will ensure greater mobility, safety and convenience.

The nanoTruck gives people an opportunity to experience the rapid developments in this future technology under the motto "High-Tech from the Nanocosmos". I would like to invite you to visit the exhibition and events on board the nanoTruck and to discuss nanotechnology applications, their opportunities and potential risks with the experts!

Dr. Annette Schavan, MP
Federal Minister of Education and Research

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Recommended reading and web addresses pertaining to nanotechnology can be found in the internet under: www.nanotruck.de.

1. Welcome to the nanoTruck initiative!

Dear visitor, with its new campaign – the “nanoTruck – High-Tech from the Nanocosmos” – the German Federal Ministry of Education and Research (BMBF) is aiming to get nanotechnology out of the laboratory. It wants to provide you with more information about this promising field of technology and to talk to you about its potential as well as about how it will affect our futures.



We would like to invite you to take a look inside the nanoTruck, the BMBF's nanotechnology exhibition and communication centre on wheels. You will find “nanotechnology live” on two levels in the road-show vehicle.



Around 60 exhibits, about half of them interactive, illustrate the basic scientific principles and show the major fields of application along with innovative new products and processes. The Truck's team of experienced scientists can answer all your questions and take you on a tour of the nano-world. On location at trade shows, science events, on your local market square, outside schools, colleges, universities or companies, the nano-Truck features a laser show, multimedia presentations, guided tours, lectures and workshops.

Welcome to the nanoTruck!

2. Macro, micro, nano

2.1 Where does the nanocosmos begin?

Anyone who has ever looked through a microscope knows that there is an unknown and fascinating universe beyond the one perceived by the naked eye. The bacteria swarming around in a drop of water and made visible by the thousand fold magnification of the microscope are, on the average, one thousandth of a millimetre (a micrometre, $1\mu\text{m}$) thin. We are dealing here with a microcosmos. In comparison, the nanoworld, the topic of this brochure, is much tinier.

2.1.1 How large is a nanometre?

The linear measure of this tiny world is the nanometre (nm), a billionth of a metre (m), or to put it differently: 0.000,000,001 m, respectively 10^{-9} m.

Just how small this is, can be illustrated by the following examples:

- The size of a nanometre, in comparison to that of a metre, stands in the same relationship as the diameter of a 1 cent coin does to our globe.
- A nanometre is approximately 50,000 smaller than the diameter of a single, thin human hair (0.05 millimetres (mm)).
- More than 100,000 nanometres would fit into the full stop at the end of this sentence.

The origin of the word “nano” is Greek, incidentally, where “nanos” means “dwarf”.

2.1.2 Fasten your seatbelts – we are about to take off for the nanoworld!

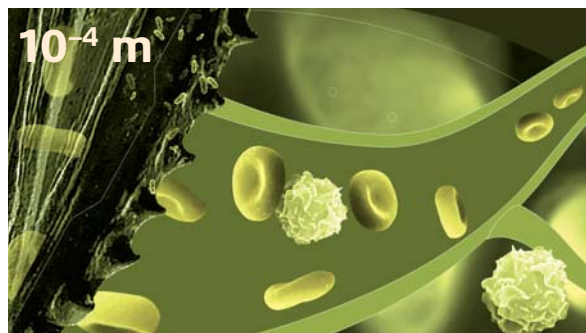
Imagine we are taking a journey through the layer of skin on the back of your hand. Right off at the first stage of our trip a single hair (diameter: 0.05 mm) towers

massively before us. A mosquito (length: approximately 1 cm) lands next to us and stabs its suction spout into the sulcated surface of the skin. Hitching a ride on the spout, we burrow through to the deeper layers of skin, coming to rest at a capillary vessel. Pulsating blood rushes past us.



10⁻² m: Our journey to the nethers of the nanoworld begins in the dimension of a centimetre.

A defence cell of our body's immune system, a white blood cell, floats towards us and we dock onto its acanthaceous surface. We pierce through its outer barrier, the cell membrane which in this cell has a diameter of just 0.012 millimetres.



10⁻⁴ m: We can recognize individual cells, for example, with a school microscope.

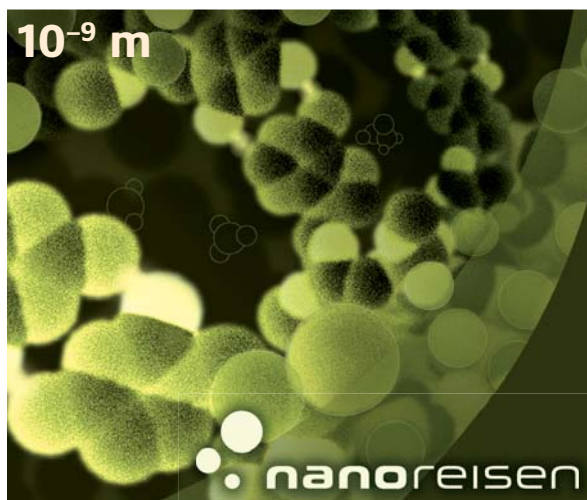
Our journey takes us deeper and deeper into the power stations and transport facilities of the cell's interior. Suddenly, we see a huge spherical shape in front of us. This is the cell nucleus, the control centre of the cell with a diameter of around 6 thousandths of a millimetre (6 micrometres).

Going deeper and deeper, we now pierce through the nuclear membrane interspersed with pores, pushing our way through the spaces between long, twisted threads made of convoluted packed genetic material, the so-called chromosomes. Measuring approximately 400 nanometres in diameter, they consist of packages of protein around which a long thread in the form of a twisted rope ladder (diameter: 2 nanometres) is wrapped.

This is the genetic molecule DNA (deoxyribonucleic acid) which carries genetic information. The atoms of the elements it is built of have a diameter of 0.1 to 0.4 nm.

We have reached the end of our journey: Welcome to the world of atoms, molecules and the structures which they form.

Welcome to the nanocosmos!



*10⁻⁹ m: Welcome to the nanocosmos – at the level of molecules and atoms!
Discover fascinating details on the “Ego Trip” and other astonishing walks on the wild
side in the nanocosmos! www.nanoreisen.de!*

2.2 New effects in the most minute of the miniscule

Though the diminutiveness of the world of atoms and molecules is fascinating in and of itself, there is the added piquancy that different principles seem to apply in this unbelievably tiny cosmos which can only be explained by the science of quantum physics. These principles are responsible for the fact that objects and structures measuring less than 100 nm demonstrate other effects than the objects of our “large world”.

2.2.1 Changes caused by miniaturisation

The era of quantum physics began around the year 1900 with the fundamental work of a number of eminent researchers such as Max Planck, Niels Bohr, Werner Heisenberg and many others. Quantum physics explains, for example, that particles act like waves under certain conditions. That sounds hard to imagine, but the principle has been confirmed by experiments. Leaving aside all the complicated details for once, the following points are important for understanding how the nanocosmos functions:

Particles, layers, structures and systems measuring less than 100 nm in at least one dimension (length, width, height) demonstrate other characteristics than larger objects of the same constitution.

There can be differences, for example, with regard to the following:

- optical characteristics
- electrical conductivity
- magnetism
- chemical reactivity
- melting behaviour
- hardness or flow characteristic of materials

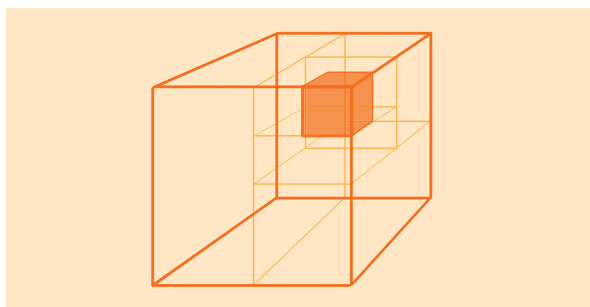
Read the following examples to understand these changes:

2.2.2 Take a cube of quartz ...

Imagine we are doing an experiment with a cube of quartz whose edge length measures a centimetre. The surface of one of the six sides measures 1 square centimetre, so that altogether we have a surface of six square centimetres.

Let us now use a slitting saw to cut through each side ten times. We end up with 1,000 cubes whose edge length measures a millimetre. The surface of one of these mini cubes measures 6 square millimetres, but the thousand cubes together have a total surface of 60 square centimetres. The miniaturisation thus resulted in a tenfold increase in surface in comparison to the surface of the original cube.

With the right tools and a lot of patience we could continue sawing apart these cubes – the edge length should now measure one nanometre. We now have a pile of sextillion (1,000,000,000,000,000,000,000,000) nano cubes in front of us, though they are now so small that we can no longer distinguish them with our naked eye. The sum of their surface adds up to 60 million square centimetres (60,000,000 cm², which is 6,000 square metres) – about three quarters the size of a soccer field!



Multiplication of the surface by means of miniaturisation

2.2.3 Small volume, large surface

Our experiment with cutting up the quartz cube into ever smaller pieces demonstrates an important principle of the nanocosmos, the large relationship of surface to volume. The volume remains constant, amounting to a cubic centimetre before and after sawing apart the cube.



Nano cubes for storing hydrogen: A dense network of fine pores can generate a huge surface.

In contrast, the total surface is ten million times larger after cutting the cube into the much smaller cubes each with an edge length measuring 1 nm.

2.2.4 The special physics and chemistry of nano objects

Every atom which a nano cube consists of has a shell made up of charged particles (electrons). The smaller the cube is, the more electrons are on the surface in comparison with the number of electrons inside the cube.

These electrons, for example, interact with light waves which create the impression of colour in our eyes. They are also responsible for chemical reactions by, for example, bonding with electrons of other atoms. That is why substances such as gold have another colour on the nanoscale or why nanoscale titanium dioxide acts as a catalyst.

Example: Gold turns red

In the shape of bullion or wedding rings the precious metal gold shows its sumptuous sheen. In contrast, gold nano particles measuring less than 30 nano metres are deep, purple red in colour. Why?

At the nanoscale there are considerably more electrons are on the outside surface of the nano-sized gold nuggets than inside them. They form an “electron gas” on the surface of the particle. Stimulated by the energy of the incoming light, the gas “swallows” (absorbs) a certain spectral component (light waves between 525 and 590 nm) within the range of visible light.

2.3 A brief history of nanotechnology

Particles and structures of just a few nanometres in size are found frequently in nature – in volcanic ash, the ultra-fine soot particles of forest fires or in semi-precious stones and pigments.

In the last instance every form of life is built of structures at the nanoscale. From the dawn of history people – unconsciously – have made use of the special properties of certain nano materials. It is modern technology, though, which has first made the nanocosmos comprehensible.

2.3.1 “Nano” throughout the centuries

Many ancient civilisations took advantage of the properties of nano materials, for example, the Maya with the use of the pigment “Maya Blue”. In ancient Egypt sooty inks were used whose special properties can be ascribed to their containing carbon nanocomponents – compounds which nanoscientists are avidly researching today.

The Romans employed a paste made of lead oxide and hydrated lime to cover up grey hair. Today we know that this dye paste contains lead oxide crystals which measure between four and fifteen nanometres. Arraying themselves evenly in the protein structure of the hair, they replace the missing, natural hair pigment melanin.

“The origin of all things is small.”

Marcus Tullius Cicero (106–43 v. Chr.)

Since the early Middle Ages glassmakers have mastered the art of producing ruby red glass by adding tiny amounts of gold to the glass melt. The ruby colour is derived from the nanogold particles dispersed throughout the glass and can be admired in numerous old church windows. Even nowadays one can find this so-called “gold-ruby” in some drinking glasses or decanters.

2.3.2 Science conquers the nanocosmos

In the year 1857 the English physicist Michael Faraday was the first person to surmise that there was a connection between the red colour of the gold ruby and the size of the gold particles in the glass.

It was some hundred years later, in the year 1959, that the American physicist Richard P. Feynman held his classic talk “There’s plenty of room at the bottom” at the annual meeting of the American Physical Society. With the bottom he meant the lower end of the measuring scale. In his thought experiment Feynman threw out the question whether it would not be possible to write all 24 volumes of the “Encyclopedia Britannica” on a pinhead – miniaturising its pages 25,000 thousand fold. Feynman was convinced that such a “downsizing” would be technologically possible because it did not stand in contradiction to any known law of physics:

“But I am not afraid to consider the final question as to whether, ultimately - in the great future - we can arrange the atoms the way we want; the very atoms, all the way down!”

Richard Phillips Feynman (1918–1988)

Feynman’s visionary postulate was confirmed by his fellow scientists in the 1980’s. Gerd Binnig from Germany and Heinrich Rohrer from Switzerland developed the scanning tunneling microscope with which one can actually see and move individual atoms. They were awarded the Nobel Prize in Physics in 1986 for their construction.

Together with his colleagues Calvin Quate and Christoph Gerber, Gerd Binnig constructed the atomic force microscope in the same year which is based on a similar principle.

2.4 Nanotechnology is everyone's concern

Nanotechnology interlinks a number of scientific disciplines. On the one hand, it is instrumental in promoting progress in basic research, while also acting as the driving force in applied research and production in almost every field of endeavour. This is why it is expected that nanotechnology will be able to make many positive contributions to the future of our health-care and quality of life.

2.4.1 What exactly is nanotechnology?

It was the Japanese scientist Norio Taniguchi, professor at Tokyo Science University, who coined the term “nanotechnology” in 1974. He understood it to mean production methods with a precision in the nanometre range. Today's concept of nanotechnology extends far beyond this limit.

Nanotechnology encompasses the analysis, production and application of particles, structures, molecular materials and systems which measure less than 100 nanometres in at least one dimension (length, width, and height) or which can be produced with this accuracy.

Nanotechnology studies, in other words, the fine structure of substances, as well as the building blocks of life on earth. Nanotechnology makes it possible to produce particles, discs, tubes, foams or layers in the dimension of nanometres. Such methods allow scientists, for example, to work on tiny measuring instruments which are able to offer all the services of a whole laboratory, but in a much smaller space.

2.4.2 What can nanotechnology do?

Internationally, nanotechnology is regarded as the key technology of the 21st century.

Areas of application range from chemistry and

materials technology to biotechnology, pharmacy, and medical technology and include energy generation, energy storage and environmental protection. Ship builders, auto manufacturers, the aerospace industry, the computer and telecommunications field and illuminant technology all profit from its processes and products.



Nanotechnology - Ideas for every area of life

2.4.3 Are there different “nanotechnologies”?

Nanotechnology is characterised as a cross-sectional technology due to the fact that the borderlines between the different disciplines are often blurred: For example, chemists, biologists and mathematicians are working together more and more frequently in interdisciplinary teams. This is true not only for universities and research institutes, but also for the research and development departments of small and larger enterprises worldwide.

As a general rule, one first studies a classic scientific or technical subject before specialising in nanotechnology. More recently, though, more and more universities have also been offering special courses of study in nanotechnology. There is also the possibility of acquiring advanced qualifications in the field of nanotechnology by means of extra-occupational further education and training measures. Specialised knowledge in nanotechnology is becoming more and more important in many scientific and technical work fields.

2.5 Venture into the nanocosmos

Scientists were first able to see and research the nanocosmos with the help of the electron microscope in the 1930s. Since then many effective procedures and powerful instruments have been developed to make atoms and molecules visible to the human eye and easier to research. The secrets of the nanoworld are becoming unveiled.

2.5.1 Revealing insights and their impact

The light-optical microscope is approximately 400 years old. It is standard equipment in schools, universities, enterprises and clinics. For many years, the prevailing opinion was that it could not reveal the nanocosmos to us. The reason for this is due to the physical nature of the visible light spectrum. Normal light-optical microscopes, namely, only reveal structures whose size is at least a third of the wavelength of the light used.



Electron microscopes are important instruments in nanoscience.

The smallest structures which we can make out with a conventional microscope are about 200 nm in size – still too large to be used in nanotechnology. To express it more precisely: With a light-optical microscope we

can just barely distinguish objects which are lying horizontally no closer than 200 nm and vertically no closer than 500 nm apart. After decades of work struggling to overcome these limits, today we have a number of powerful methods at our disposal. Among the most successful of these methods is the procedure of x-raying or scanning with electron beams in the field of electron microscopy. The most modern versions can reveal structures which are much smaller than a nanometre.

Since the invention of scanning tunnelling and the atomic force microscope by Gerd Binnig and others, we can now see individual atoms. An extremely sharp tip with a single atom at its end is used to scan a specimen surface whose profile can be depicted down to a single atom using a computer.

Using this and many other instruments, nano research can operate with an almost unimaginable precision.

Nanomaterials are analysed for the following purposes:

- chemical, physical and biological examinations
- a better understanding of nanomaterials
- quality control of nanomaterials
- monitoring nano production procedures
- monitoring conformity to standards and norms

The following are examples of applications involving the analysis of nanomaterials:

- the measurement of substance surfaces
- research into how cells function
- testing auto catalysts
- testing of electronic circuit elements consisting of a few molecules and measuring only some nanometres

2.5.2 “Fingers” for atomic surfaces: scanning probe microscopes

Scanning probe microscopes “feel” the nanostructure of surfaces. Their most important component is a sharp needle some few 100 micrometres long which, ideally, ends in a single atom. This point is placed in close proximity to the surface of the sample and scanned back and forth in raster form over it. The sensor “feels” a physical interaction which is dependent on the space between the two and serves as a measuring signal. Using a computer, this signal is then transformed into a three-dimensional picture.

Scanning probe microscopes can measure optical, magnetic or electrical interactions. They are not only ideally suited for life and materials sciences, but also for quality control at an atomic level.

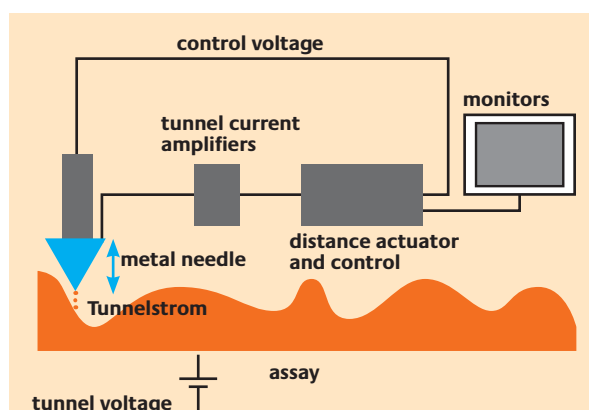
Example: The scanning tunnelling microscope

When imagining the nanocosmos, a picture of the scanning tunnelling microscope, STM, immediately comes to mind for many people. This is due, if nothing else, to the award of the Nobel Prize in the year 1986.

STM uses a sharp metal needle which is placed at a distance of just one nanometre over the surface of the sample. The needle then moves back and forth in

staggered lines across the surface but without touching it. If you apply electric voltage, electrons will flow between the point of the needle and the surface of the sample, creating the so-called “tunnel current”. This effect is also one that can only be explained using the example of quantum physics since there is nothing in the inter-space which could conduct the charged particles.

If the current is constant, the needle always maintains the same distance to the surface when moving back and forth over it. For example, if it gets close to an atom, this increases the tunnel current and the needle is mechanically raised and remains lifted until the pre-set intensity of current has been reached again. If the current sinks, the needle also sinks down. A computer is used to record all of the up and down movements of the needle and transforms them into an image of all of the atoms on the surface.



Simplified diagram: Construction and function of a scanning tunnelling microscope (STM)

2.6 Precision production measured in nanometres

Industrial manufacturers who use nanomaterials and nanostructures have a clear competitive edge. It is possible to manufacture new products altogether or to improve product features for the greater use of users and consumers. Thanks to nanotechnology, conventional processes can be made more efficient, more economical, more versatile and have less impact on the environment.

2.6.1 Miniaturisation with method

Nanotechnology has already become established in numerous industrial production and processing procedures. Particles, small discs, pipes, layers, surface structures or porous materials measured in nanometres are playing an increasingly important role in almost every branch of the economy. The production of nanomaterials occurs in either one of two possible ways:

The **“Top-down”** approach involves a miniaturisation, respectively, structuring of materials down to the dimension of nanometres. This is achieved by means of milling, etching, irradiating with energy-rich light or ion beams, as well as using an ultra-fine stamp.

The **“Bottom Up”** approach in technical terminology refers to the process by which nanoparticles, layers and many other structures are built up out of individual atoms, molecules or their complexes by means of chemical or physical processes.

For example, nanotechnology is used in production for the following:

- the modification of surfaces (e.g. to make them water-resistant or scratch proof)
- as a replacement for conventional substances in the form of particles, fibres or small discs
- for the manufacture of electrical and light switches

Nanotechnology, among other things, is also employed for the following:

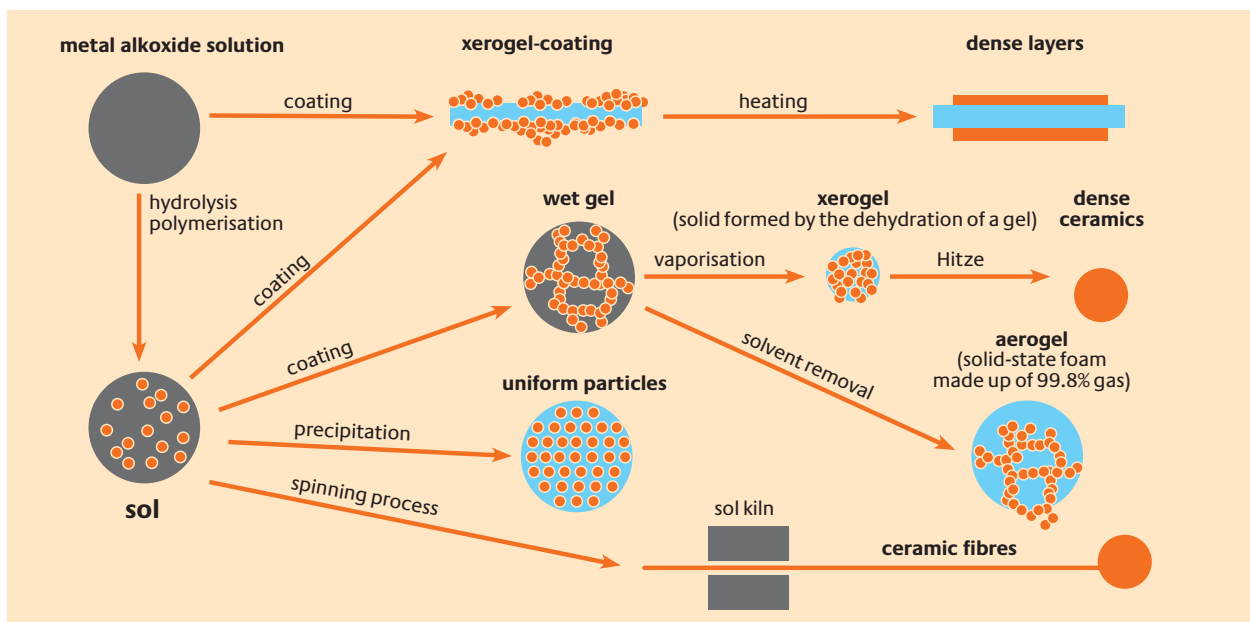
- catalytic particles and layers in chemical production processes
- medical instruments for hygienic improvement
- high-precision verification procedures in biotechnology
- more durable paints, bodywork and motor parts for cars

The most important procedures with which nanomaterials are produced using the bottom up approach are the sol-gel process, the gas phase synthesis and the chemical, respectively, physical vapor deposition. In the following we would like to illustrate the sol-gel process.

Example: From sol to gel

In the sol-gel process the source material is initially in solution. If you add energy or a catalyst as a “chemical helper”, they react to particles (clusters). In order to achieve the desired particle size, one stops the accretion of further atoms or molecules on the surface of the particles by the addition of adjuvants. If the particles are also provided with a special protective coating, they are kept in solution through the interaction with the surrounding substance. They do not form clumps and fall to the bottom. This state is referred to as “sol”.

A gel is supposed to form from the sol. You are on the right track if you are imagining something along the lines of gelatine or a cooling gel for a sprained ankle. If the particles in the sol can be bonded by means of chemical bridges, a three-dimensional network of particle chains is formed in whose empty cavities water or other solvents can find room. One slowly removes the solvent from this network until the gel forms. The aerogels are a special case: an inorganic or organic solvent is completely replaced by air which can end up having a proportion of around 95 percent.



The sol-gel process and its products

2.6.2 Top-down: Structuring with nano-precision

The top-down process miniaturises objects or structures till they have reached a desired size which can be measured in nanometres. This functions most easily by very finely grinding a powder. Much more sophisticated are other methods such as (the) lithographic structuring by means of nano-stamp technology or the use of energy-rich ultra-violet light, respectively, ion rays.

Example: Mini-grinders at work

The nanoparticles used for the print colours of high resolution ink-jet printers, for example, are derived from the most modern high energy grinders. The core component of such precision grinders is a quickly rotating drum in which very hard ceramic balls measuring some millimetres in size serve as “mini grinders”. These so-called ball mills generate centrifugal forces which are 95 times more powerful than gravitational accele-

ration. The faster the drum rotates, the harder the ceramic balls are pressed against the wall of the drum and the smaller the particles are which are formed by the grinding procedure.



Colour particles measuring just nanometres generate the best results for printing inks.

3. Nanotechnology today and tomorrow

3.1 Chemistry and materials science

The basis of all nanomaterials is chemistry. Whether we are talking about glass, metal, ceramics or bio fibres – everything consists of chemical elements. Chemistry surrounds us everywhere in the form of animate as well as inanimate nature. By applying our knowledge of chemistry in a scientific, as well as a technical manner, we can learn about natural nanostructures, on the one hand, and on the other improve processes and materials.

In nanotechnology, chemistry and the materials sciences make a perfect match. Using chemical processes, objects and structures can be produced which are measured in nanometres. They can then be used on their own, mixed into the components of other materials or applied to their surfaces.

Nanotechnology can be used in chemistry and the material sciences for the following:

- to produce nanoscaled objects (e.g. pellets or fibres)
- to create new or improved features (e.g. chemical reactivity or hardness)
- to individually adjust substances
- to solve complex problems in an intelligent and efficient manner

Nanotechnology is already in use today for the following applications:

- as catalysts in chemical production and the decomposition of harmful substances
- automobile construction (e.g. anti-reflex glass for the dashboard, protection against corrosion for motor components)
- medical field (miniaturised diagnosis systems, longer lasting and more compatible implants)

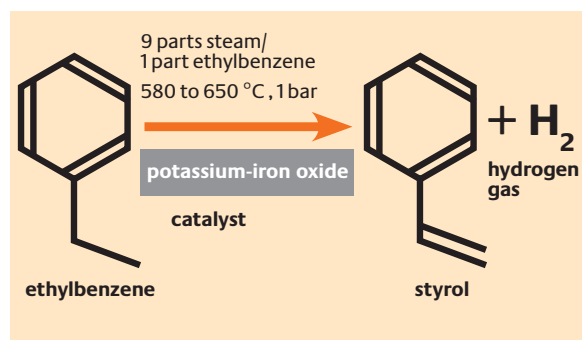
- energy production and storage (compact and longer lasting accumulators, dye-sensitized solar cells for higher energy yield)
- architecture and construction (ultra-light building materials, self-cleaning facades and roofs)

3.1.1 Nanochemistry for production: Heterogeneous catalysis

Catalysts facilitate or enable chemical processes. This is true for the exhaust gas treatment in cars, as well as for around 90 percent of all technical processes in the chemical industry.

The catalyst itself is not changed or consumed by the chemical processes. Without the tiny reaction accelerators these processes would take place only very slowly or not at all. Heterogeneous catalysis refers to the process in which source material in fluid or gas form is diffused and adsorbed onto the solid catalyst surface.

The field of surface chemistry attracted worldwide interest with the award of the Nobel Prize for chemistry on the 10th of October 2007 to Professor Gerhard Ertl.



Styrol synthesis: conventional production process

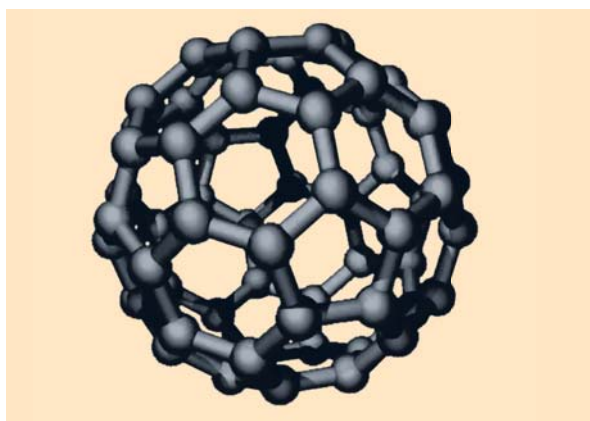
Example 1: New catalysts for styrol synthesis – “nano-onions”

An example for a catalyst reaction is the synthesis of styrol. Styrol serves as the base material for the production of the synthetic material polystyrol which is in widespread use. Till now the process for extracting styrol from ethylbenzene called for a potassium-iron oxide compound as catalyst. Since the reaction, however, takes place at a temperature of 650 °C, this process required huge amounts of energy when one takes into account the global production volume of 25 million tons of styrol a year.

On closer examination of the styrol synthesis it was discovered that the actual catalyst was not potassium-iron oxide, but graphite which is precipitated on it.

Instead of graphite, a new process uses so-called carbon nanotubes, respectively nested nanoballs.

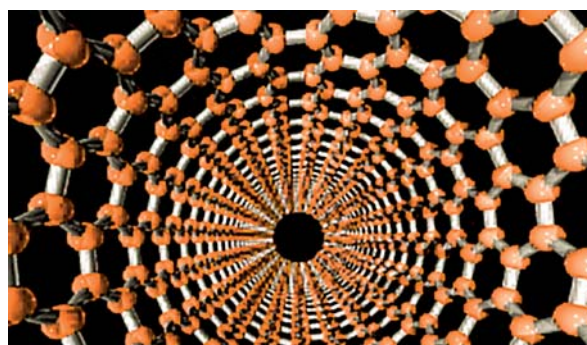
With these nanoballs the styrol synthesis on the laboratory scale can take place at a temperature of only 550 °C. Using this method would thus translate into enormous energy savings when operated on a commercial scale.



The C_{60} -fullerene: a “football” made of carbon

Example 2: More than just catalysts – carbon nanotubes (CNTs)

Carbon nanotubes are extremely versatile nanomaterials whose potential applications go far beyond that of their



Insight into a carbon nanotube

function as catalysts: they have ten times the tensile strength of steel at just a sixth of the weight. Depending on the “winding” of the molecular meshwork, nanotubes can also conduct electric current even better than copper. In addition, carbon nanotubes are also very good heat conductors.

Due to their versatility, CNTs are regarded as key materials for improving numerous substances made of resins, ceramics and metals. As additives, the tubes furnish components with greater stability or display anti-static properties.

3.1.2 Remarkable materials

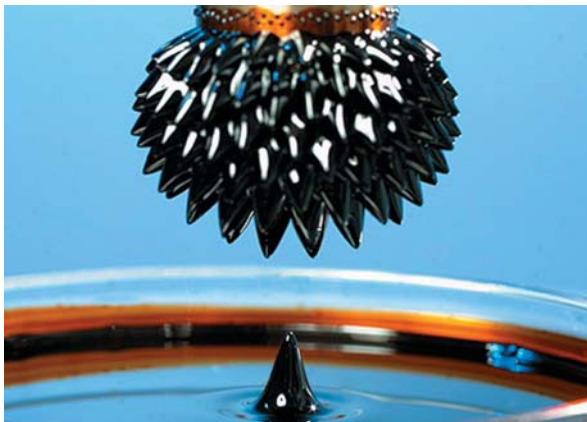
Among the many different types of known nanomaterials, the nanoparticles which are dispersed in fluids, in particular, exhibit remarkable properties. An example of magnetic behaviour should illustrate this phenomenon.

Example: Fluid magnets

Similar to the well-known experiment with iron filings from physics classes, certain nanoparticles made of iron, cobalt or nickel compounds measuring 5 to 10 nanometres also react to a magnetic field in a particular manner. Their dispersions in polar and non-polar solvents are characterised as “ferrofluid” (lat.: “ferrum” = “iron”, “fluidum” = “fluid”). Depending on the solvent, the nanoparticles are enclosed in a sheath of ions or fatty acids. Thus, the tiny magnet particles cannot clump

and sink to the bottom but rather, in a magnetic field, order themselves along the streamlines of the field. Depending on the strength of the field, the fluid forms spiked structures because the particles partly align themselves or repel each other and in the process are held together by the surface tension of the fluid. This effect is called “Rosensweig Instability”, named after the American scientist Ronald Rosensweig who theoretically described the behaviour of magnetic fluids for the first time.

Ferrofluids are already being used for technical purposes. It is an advantage that they can be kept in a certain position or moved with a strong permanent



Ferrofluid: “fluid iron” in a magnetic field

magnet. They can be found, for example, in hi-fi loudspeakers between the voice coil and the magnet arrangement and cushion the oscillations of the membrane. In other applications, such as shaft driven devices, they take over the function of fluid gaskets with less frictional resistance.

3.2 Health

Till today only a small portion of all known human diseases can be treated effectively. The causes of many diseases can only be determined with a great deal of effort and a high degree of unreliability. Patients lose a lot of time – often time crucial to their survival – before their disease can be diagnosed with any certainty. This is a challenge, in particular, in the case of virus diseases or cancer. Healthcare in the future should be faster, more reliable, more effective and well tolerated – also with the help of nanomedicine and nanobiotechnology.

Molecular biology has been providing important insights into the pathogenesis and the clinical picture of diseases for some time now – more recently nanotechnology has also been helping us to better understand diseases.

The use of nanotechnology in the medical field contributes, among other things, to the following:

- a better understanding of biological processes, as well as the pathogenesis and course of diseases
- development of new methods of diagnostics and therapy
- identification of diseases at a very early stage
- providing better medication
- cost savings in healthcare

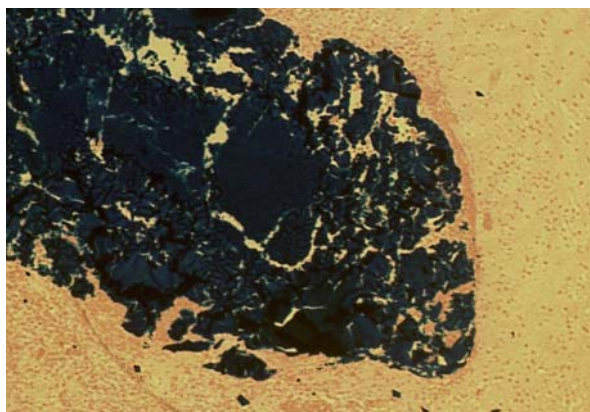
Nanomedicine is already used today for the following applications:

- systems for documented evidence of conformity in biomedical research (“Lab-on-a-Chip”)
- medical image processing (nanoscaled contrast media in computer tomography)
- cancer therapy (locally confined destruction of cancer cells with magnetically generated heat, precise, individual dosing of medication by means of the so-called Nano-Containers)
- medical-technical aids (catheter with anti-bacterial surface coating)

Example: Nanoparticles against cancer

After the first successes in cancer therapy studies with magnetic nanoparticles, more advanced studies involving patients show promise of later being able to use the process in the treatment of the disease. In this new, target-oriented therapy, iron oxide particles encased in a biological shell are introduced into the cells.

A selected group of patients with a rare brain tumour (glioblastoma multiforme) received injections of the nanoparticle dispersion into the tumour. This resulted in an increased accumulation of nanomagnets in the cancer cells. The afflicted area of the brain was then exposed to a precisely dosed, strong alternating magnetic field. This warmed the tumour up to just under 40 °C, making its cells particularly vulnerable to supplementary treatment measures, e.g. radiation therapy.



Magnetic nanoparticles are absorbed by the cancer tissue (black area).

In some cases, this so-called magnet field hyperthermia therapy (MHT) led to a complete tumour regression. In the year 2007 the studies were extended to include patients with prostate, oesophageal, uterine and ovarian cancer. In addition, future plans call for nanoparticles to also be used to transport pharmaceutically active agents directly to the afflicted parts of the body.

3.3 Environmental protection

Environmental protection is becoming increasingly important. Soil, air and water that are already contaminated need to be rid of such impairments as effectively as possible. In the future, we will have to exercise more consideration and responsibility in using the resources of our environment. Nanotechnology can make a considerable contribution towards achieving this aim.

Nanomaterials can make conventional products and processes more environmentally friendly by either improving their qualities or replacing them altogether, for example, with respect to the catalysts and additives in chemical processes.

Nanotechnology in environmental protection has the following aims:

- to avoid the development of contaminants (more efficient production processes with less by-products)
- to better retain contaminants (high performance filters)
- to verify the existence of contaminants (substance-specific nanosensors)
- to degrade contaminants more completely, quicker and at lower costs

It is made use of, for example:

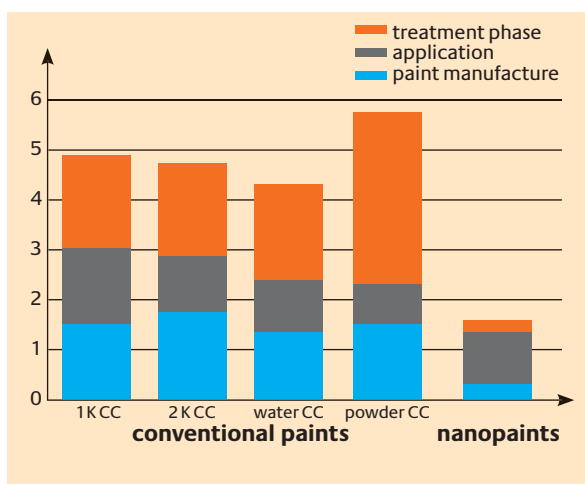
- in the chemical industry (e.g. paint industry)
- in environmental analysis
- for dust particle filters in the workplace (employee protection)
- for cleaning up contaminated soils
- for air and waste water filters

Example: Avoidance of contaminants in painting processes

When painting, for example, the aluminium parts for car manufacturing, the paint to be applied will only stick if the surface has been cleansed in advance and

the surface material is suitable for painting.

Using nanotechnology, a German enterprise developed an environmentally friendly alternative to the otherwise common chromate coating method which is very harmful for the environment: The “nanopaint” contains nanoparticles that are made of organosilicon compounds (silanes) and measure 40 to 50 nm in diameter. The paint hardens on its own by the cross linking of the nanoparticles which results in the formation of a solid, three-dimensional gel. Due to the fact that the paint solidly adheres to metals and plastics without aids and without preliminary chromating, the number of required pre-treatment steps – in particular rinse cycles – are reduced from ten to two. This results in the use of less energy and water, as well as a reduction in the amount of waste. When processing nanopaint, 65% less organic material evaporates which contributes to the protection of the atmosphere. In comparison to conventional paints, nanopaint forms thinner layers but with the same quality which, in turn, translates into material savings.



A comparison of conventional paint and ecology efficient nanopaints with regard to the release of volatile organic material into the environment (g/n² painted auto surfaces)

3.4 Lighting engineering

“More light!” were Goethe’s last words. In today’s age of nanotechnology, we can say: “More light with less energy!” What is meant are ultra bright, energy saving sources of light such as light-emitting diodes which are now a common feature of our everyday lives and owe their high degree of efficiency to nanolayers. “Smaller, brighter and more efficient!” is the motto for future developments in the area of lamps and lighting.

Despite their very low efficiency rate of five percent, conventional incandescent lamps still have a high share of the market in comparison to new sources of light because their light resembles that of the sun and is, therefore, congenial for us. The alternative, utilizable energy saving lamps generate a less friendly light and are larger in comparison to conventional illuminants.

The need for artificial lighting is on the increase. In 2007 around eight percent of the energy consumption in Germany and 19 percent worldwide was used for illumination. Thus, in the long term, energy savings can only be achieved by using new forms of illumination. Nanotechnology with its light-emitting diodes based on semi-conducting nanolayers offers a viable alternative for solving this problem.

With regards to lighting engineering nanotechnology has the following potential:

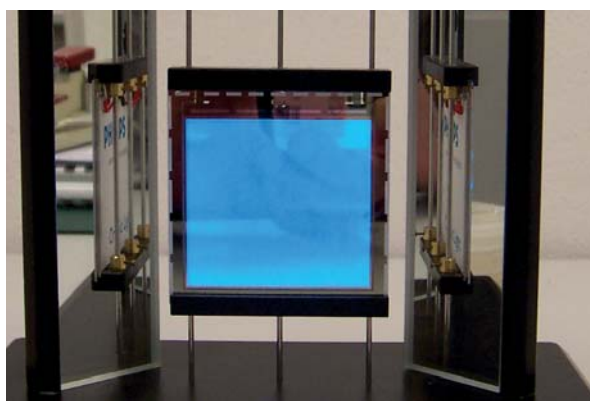
- to manufacture white light-emitting diodes with a degree of efficiency of over 50 percent
- to vary form, colour and brightness of light-emitting diodes
- to use organic layers (OLED=Organic Light-Emitting Diode) for new forms of illumination
- to develop new uses such as holographic 3D television

Examples of present-day and future applications are:

- mini-torches, forehead lamps for cyclists
- mobile phone and PDA displays, computer monitors and televisions
- car tail-lights and traffic display panels
- cockpit function indicators for the aerospace industry
- indoor illumination
- outdoor illumination of buildings

3.4.1 OLED: brilliant and flexible

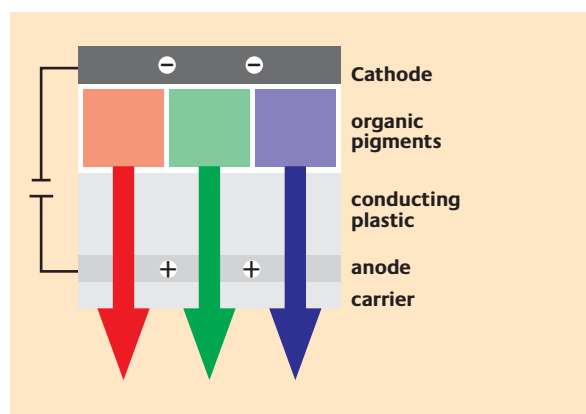
Worldwide, research institutes and companies in the illumination and electronics industry are working intensively on developing the next generation of light-emitting diodes, the OLEDs. Such OLEDs are already being used in car radios, mobile phones and the displays of cameras and MP3 players. In the year 2007, it was announced that the first OLED-based flat screen televisions with a screen just three millimetres thin would soon appear on the market.



Prototype of an organic light-emitting diode

Similar to the already established light-emitting diodes, OLEDs also consist of many layers measuring up to 100 nm in thickness which are applied to a thin

layer of glass or flexible plastic. The first layer consists of indium tin oxide (ITO) as an anode which is electro-graphic and, at the same time, a transparent, semi-conducting compound, followed by layers of electro-graphic plastic and an organic pigment and finally a cathode layer. When you apply a voltage, electrons are transferred to the pigment and it begins to glow brightly.



The principles of the form and function of an OLED pixel

OLEDs are ideally suited for ultra-thin displays or flat screen displays with a high degree of colour fastness. They do not require any kind of background illumination since the surface glows on its own and consumes very little electricity. In addition, images form very quickly on the screen (one thousandth of a millisecond) and the images and colours remain clear even from very flat perspectives (over 170 degrees).

The disadvantage at present is the short lifecycle of OLEDs in comparison to light-emitting diodes, but intensive research efforts might very well solve this problem within the near future. Their versatility and flexibility make organic light-emitting diodes ideal for a number of applications which now seem to be visions of the future: illuminated carpets and tiles, displays on clothing or laptop monitors which are as thin as a sheet of plastic and can be rolled up.

3.5 Energy generation and storage

Nowadays life without electricity barely seems imaginable. As a matter of course, we generate energy in power stations or convert sunlight into electricity using solar cells on our rooftops. Different forms of energy storage, ranging from car batteries to the accumulators in our mobile phones, have become an indispensable part of our daily lives. In the future, new technologies should help us to generate energy with even higher output and to make that energy even more accessible.

Supplies of fossil fuels for generating electricity, such as coal or gas, are finite. That is why researchers and entrepreneurs are working intensively on new concepts for the use of renewable forms of energy.

Nanotechnology can help support energy technology in the following ways, among others:

- to optimise combustion processes
- to optimise the use of solar energy
- to convert heat into electricity (thermo-electricity)
- to optimise the generation, storage and transmission of electricity using the least amount of space possible

Examples of application are:

- nanoparticle additives for fuels to improve combustion
- anti-reflex glass for solar cells
- flat and flexible dye-sensitized solar cells
- fuel cells for hydrogen engines

Example: Solar energy – higher light output with nanoballs

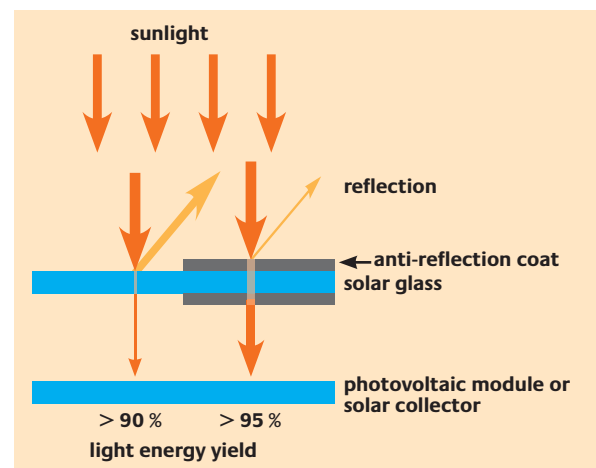
An alternative source of energy is the sun. Solar collectors and photovoltaic systems convert the energy of the sun into heat and electricity.

Around 10 percent of the incoming energy of the sun is lost due to reflection on the glass covering of the

solar modules. Nanotechnology can cut down on this reflection.

The German physicist and optician Joseph von Fraunhofer discovered in the early 19th century that layers with tiny pores can reduce light reflection. Based on this principle, modern anti-reflection layers for solar glass are now produced out of densely piled nanoballs. The resulting space between the nanoballs reduces the reflection of the solar glass. A double-sided nanocoating of the cover glass also allows a broader wavelength spectrum of sunlight to shine through, resulting in a better exploitation of the generated energy and an increase in energy yield of six percent.

With modern nano solar glass, a solar collector can convert six percent more light into heat annually and a photovoltaic facility, independent of location and climate, generates three percent more electricity per year.



Comparison of the yield of light energy for a solar collector with and without anti-reflection solar glass

The utilisation of organic materials or nanostructures will make it possible in the future to exploit solar energy even more efficiently.

3.6 Mobility and transport

Totalling approximately 750 million in the year 2007, the fleet of automobiles crowding roads worldwide is steadily increasing. Improving protective measures for passengers, as well as lower emissions of pollutants, are thus a priority. A steady increase in the number of cars also entails more recycling and the disposal of the used car components. Researchers, developers and users all perceive the application of nanotechnology as an opportunity to improve the safety, comfort and environmental friendliness of our “runabouts on wheels”.

There are an increasing number of products offering special finishings for the bodywork, aluminium rims or the car glass. These products are based on a nanoparticle dispersion, which makes the surfaces of the automobile moisture repellent and soil-resistant. This is only the “tip of the iceberg”, however, since almost every type of material used in car manufacturing can be optimised or customised with the help of nanotechnology.

With regard to the automotive industry, the three main goals of nanotechnology go far beyond simply keeping cars cleaner. The aims are:

- to increase environmental friendliness
- to increase passenger safety
- to improve driving comfort

Some of the current and future applications are, among others, the following:

- to optimise fuel combustion using nanoparticle additives
- fuel cells for cars with hybrid drive (future)
- light but very high-tensile metal and plastics for bodywork parts
- car electronics with extremely small sensors and amplifiers, e.g. for the anti-block system
- anti-reflection glass so that the glass of the controls and instruments is glare-free

- **fast responding shock-absorber systems which are based on “intelligent” fluids whose solidification can be reversed by means of electrical or magnetic impulses**
- **“electrochrome “ front and rear mirrors which automatically tint themselves in response to an electrical signal when the sun shines brightly on them**

Example: Nanoparticles in tyre rubber

Even something as simple as an auto tyre is full of high-tech. A special combination and cross linking of caoutchouc compounds (rubber) with different reinforced filler material is a decisive safety factor. The filler material (up to 30 percent of the tyre material) influences, among other things, holding power as well as abrasion resistance and tensile strength. In interplay with the rubber material, they often fulfil contradictory tasks: On the one hand, the tyres should have a good grip on the street and, on the other hand, a low rolling resistance. They should have low wear-and-tear, but with good grip to prevent the car from slipping.

This complex interplay is governed by an interplay with the right mix of nanoparticles made up of industrial soot, silicon dioxide and the so-called organosilicons – an outstanding technical achievement in high performance tyres.

Nano filler materials also offer advantages, though, for environmental protection: They increase the lifecycle of car tyres and reduce fuel consumption.



In modern car tyres, nanoparticles ensure improved road holding.

3.7 Information and communication

In 1986 a portable telephone weighed 8 kilogrammes and cost around 4,000 US-dollars. Over the next 20 years the face of our information and communication society has radically changed. Without advances in nanotechnology, modern computer hard disks, as well as flat screen displays with millions of colours, would have been unthinkable.

Since the development of the first integrated circuit (chip) by the American Jack Kilby in the year 1958, it has been possible to make such chips smaller and smaller each year. If the conducting paths are thinner than 10 nanometres, the materials lose their conductivity. In the future, new strategies of nanotechnology will have to be developed to overcome the physical limits of electronics.

The computer of the future would be able to have all the operating data immediately available without first having to boot and load them from the hard disk. Such a computer would have to be constructed according to the principle of non-volatile memory, such as MRAM (=magnetoresistive random access memory) technology, which has been the subject of intense research efforts since 1990.

The aims of nanotechnology in the field of information and communication are, among others:

- use of light to store and process information
- structuring of electronic and optical components measuring just nanometres
- optimising the construction of computer chips and storage media (e.g. using the tunnel effect in flash memory)
- increasing processing power and speed, while, at the same time, cutting back on costs

Possible areas of application include:

- mobile telephones, handheld computers
- PCs and internet
- mobile navigation
- car electronics (sensors and controls)
- medical data processing (e.g. image processing of computer tomographs)

Example: Nobel Prize for nanolayers in hard disk reading heads

The German scientist Professor Peter Grünberg (Research Centre Jülich) and the French scientist Professor Albert Fert (CNRS/THALES, Paris) received the Nobel Prize in physics in the year 2007 for discovering giant magnetoresistance. Their work established the basis for a new area of research, Spintronics. This field strives to harness and utilize the magnetic moment (the quantum mechanical spin) of electrons for information and communication technological applications.

As early as 1997, the introduction of the first hard disk reading heads based on the GMR effect opened up a billion dollar market for considerably smaller hard disks with a storage capacity measured in gigabytes.

Information is stored on the hard disk in microscopically small areas with different magnetic orientations. The larger the density of the information is on the hard disk, the smaller and weaker the magnetic fields become. The information is retrieved by having the reading head scan the hard disk to register any magnetic changes and to transmit a current as an output signal. The sensitivity of the GMR effect for even the smallest magnetic fields is generated by alternating nanolayers of magnetic and non-magnetic metals in the reading head. Extremely weak magnetic changes generate very large changes in the electrical resistance of the read-write head, thereby creating strong electrical signals for the transmission of information.

3.8 Architecture and construction

With new technologies, construction materials such as steel, concrete and glass can comply with the steadily increasing requirements concerning stability, durability and design. Nanotechnology can make important contributions in this field. Used in walls, on roofs or facades, one of its biggest advantages is its contribution to climate protection by saving energy. Furthermore, nanotechnology products also serve to confer an especially attractive or interesting appearance to buildings and constructions.

Nanotechnology can improve the features of buildings and constructions or make them more energy efficient. It is an important topic for the whole building industry, in particular for the manufacturers of building material, the construction industry and trade businesses.

In the field of construction, for example, nanotechnology can:

- improve indoor environments, living comfort and safety
- increase the durability of buildings (e.g. facades, windows, doors, roofs)
- decrease energy consumption

It is employed, among other things, for the following:

- infrared protection layers to prevent surface glass from overheating
- ultra-hard concrete with nanoparticles to reduce weight and increase stability
- self-cleaning roof tiles and facade paintwork with photocatalytic titanium dioxide nanoparticles which chemically decompose dirt when exposed to the sunlight
- chemical and mechanical durability of interior and exterior surfaces based on ceramic foils
- shiftable, self-toning (electrochrome) windows with nanoporous layers

Example: Nanoparticles for high performance building materials

The admixture of nanomaterials to conventional building materials can transform them into “intelligent high performance materials”. Among other things, the use of nanomaterials increases the firmness and life cycle of building materials.

In Kassel, ultra high-strength concrete has already been used to build the 140 long and five meter wide Gärtnerplatz Bridge. The building material contains nanoparticles which make for a compacter and firmer grain packing. This effects a steely hardness which is ten times higher than that of conventional concrete.



The Gärtnerplatz Bridge in Kassel

Building with such high-tech materials has obvious advantages for the environment by thus also reducing CO₂ emissions. About five percent of the annual CO₂ emissions can be booked to the account of cement manufacturers. In the future, with its high degree of sturdiness and lower material requirements, the new special concrete could contribute to saving 60 percent of the raw materials needed to construct buildings and to lowering carbon dioxide emissions by 40 percent.

3.9 Textiles

Technical textiles (for example as coverings for car seats or in the air filters of air conditioners) have to fulfil special requirements in keeping with their different applications. With nanotechnology, the specifications of textile fibres can be customised according to particular requirements.

As one first discovered with the leaves of the lotus plant, nano- and microstructured surfaces demonstrate an astonishing ability to keep themselves clean: Oily soot can also be rinsed off the surface with water and even glue simply drips off. The researcher Professor Willhelm Barthlott from Bonn has been studying this phenomenon since the 1970s. He was the one in 1992 who coined the term “lotus effect”. “Lotus surfaces” are very sensitive with regard to mechanical load and quickly lose effect even at the slightest touch due to the film of oil on our skins.

That is why the so-called “easy-to-clean-effect” is used more often, although its rate of effectiveness is not as high as that of the lotus effect. Very smooth nanolayers or dense arrays of water and fat repellent nanoparticles, also allow drops of water to easily roll off the surface. Dirt particles, however, are not bound to the surface of the drops so that, after being carried along for awhile, they are left behind.

Nanotechnology, for example, makes it possible to do the following in the textile industry:

- to manufacture new or established textiles with entirely new features
- to refine textiles by means of coating (e.g. with nanoparticles), to structure or furnish textiles with new functions
- to outfit textiles permanently with layers of nanomaterial in order to achieve a lubricating effect, electrical conductivity and magnetic shielding, catalytic self-cleaning, controlled dispensing of substances or flame resistance.

The following are areas of application:

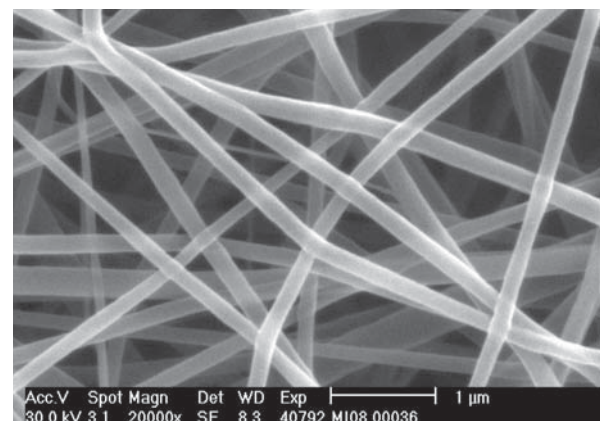
- manufacturing processes
- casual wear and workwear
- air purification, waste water and dust filtration (e.g. industrial facilities, automobiles)
- absorbent gauze and surgical sewing material for the medical field
- Self-cleansing sunshades and awnings

Example: Finest fibres, multiple functions

Researchers in Marburg have been able to produce nanofibres made of plastics or metals which are only some 100 nm thick.

With so-called “electrospinning”, a heated solution or melt is accelerated to a fine stream in an electric field and, while the solvent evaporates, it is stretched thinner and thinner. Depending on the process conditions, the fibres can be hollow or punctured by nanopores. This feature makes it possible, for example, to embed pharmaceutical agents in the textile.

Nanofibres also considerably improve the performance of conventional filters simply by being applied as a thin additional layer onto the surface of the filters. This does not make the filters significantly thicker so that existing filter facilities can be improved without much effort and without having to change the manufacturing processes.



Nanofibres for filter media

3.10 Safety engineering

Approximately ten percent of the goods traded globally are forgeries. This translates into damages for companies and their customers amounting to between 200 and 300 billion euros annually. The expiry date labels for foodstuffs are another important aspect of consumer safety. Label and tags based on nanotechnology can offer protection in this area because they cannot be as easily circumvented.

Nanotechnology offers a number of possibilities for applications in the safety-related field. Labelling systems which have already become established or which are now being tested consist of, among other things, biomolecules with colour change, artificially produced genetic material (DNA), colour layers which are dependent on the viewing angle or nanoparticles which emit visible light when exposed to ultra-violet or infrared rays.

The aims of nanotechnology in the area of brand-name and product protection are:

- to effectively label products and brand-names
- to make forgery more difficult
- to check the authenticity, as well as other features (e.g. shelf life), of products during their manufacture and in the flow of commodity

The technology can be applied in the following areas:

- brand-name articles of automobiles, fashion clothes, telecommunications and entertainment electronics, software
- documents, identity cards and credit cards
- packaging for foodstuffs and pharmaceutical products

3.10.1 A biopigment as “invisible ink”

Certain salt-loving bacteria contain a special biopigment in their capsules: the protein bacteriorhodopsin (BR). The fact that the protein changes its colour from purple to yellow when exposed to light makes it an interesting resource for protection against forgery and the optical storage of data.

German scientists have succeeded in precisely changing the chemical structure of the bacterial protein. By these means, they have not only been able to generate more variations in colour, but also to systematically control the time lapse for the colour change. With comparative ease bacteriorhodopsin can be applied as a thin film to identity papers, check cards or documents or it can be imprinted on patterns or lettering. When exposed to light in a copy machine or scanner, the protein instantly changes its colour. The copy then appears yellow instead of purple and is thus useless as forgery. A dummy document without a layer of bacteriorhodopsin can also be immediately identified as a forgery because it remains purple coloured when exposed to light.



Identity card with imprinted copy protection made of bacteriorhodopsin pigment.

3.11 Sports and recreation

In competitions in which a tenth of a second makes a difference, highly effective materials can be a decisive advantage, help avoid damage, unhealthy body strain or offer the athlete more comfort. Sporting and recreational articles in which nanomaterial has been incorporated, can already be found on the shelves of today's outfitters.

Products made with nanotechnology are already being offered for a number of different types of sports activities. Tennis players, mountain bikers, sailors or hikers can profit from them, both for training purposes and in competitions.

The aims of nanotechnology in the field of sports and recreation, for example, are:

- to offer lighter and more stable equipment
- to enable an optimal use of body strength during games
- to reduce the negative impact of the climate and sun

Among such applications are the following:

- light and, at the same time, highly resilient tennis rackets, hockey sticks and bicycle frames
- wrinkle-free, water-repellent coatings for sails
- waterproof and breathable outdoor clothing
- hygienic sprays against the smell of perspiration in sports shoes

Example: Nanotubes for effortless swing

How nanomaterial can be used for sports equipment can be explained by the following example:

Known as “nanocarbon”, carbon nanotubes are already being used in high performance plastics to make not only tennis rackets and hockey sticks, but also mountain bike frames. Despite their tininess, nanotubes form a fascinating substance: They are notably tear proof,



Carbon nanotubes (CNT) make bicycle frames light and, at the same time, very stable.

elastic, and hard-wearing. The tubes have the tenfold tensile strength of steel at just a sixth of the weight.

They offer a high degree of resilience and an enormous amount of energy transfer to the piece of sports equip-



CNT reinforced tennis racket frames minimize strain on the playing arm.

ment, particularly at the points of the material which are especially subject to stress. More energy transfer with less weight also means less muscle strain, in the long run, and helps to avoid, for example, tennis elbow.

4. Safety first

4.1 Focusing on possible risks

Every kind of future technology not only brings with it new chances, but also potential risks. Foresight and a sense of responsibility in researching and implementing nanotechnology is a matter of highest priority in order to exploit the potential of this technology to the fullest. Through its funding of relevant programs, the German Federal Ministry of Education and Research actively supports the primacy of safety in dealing with nanotechnology. Any possible negative effects on people or the environment should be able to be scientifically detected at an early stage, thoroughly evaluated and, in the long term, brought under control or avoided altogether.

In theory, nanoparticles are potentially harmful if they gain entry into human bodies and, for example, cause inflammatory reactions in the lung. Medical doctors know from experience with work related diseases (e.g. in mining), that health hazards due to the harmful effects of the natural particles in inhaled air, are worse the smaller the particles are.

Contact of employees and consumers with industrially manufactured nanoparticles should be ruled out as much as possible. In contrast to natural or unwanted particle emissions, this can be controlled much better in industrial processes. Compared to the amount of nanoparticles occurring naturally in our environment (for example, from volcanic eruptions or forest fires), the number of industrial produced nanoparticles, at present, is negligibly small. With increasing production and implementation of nanoparticles, however, this could change in the future. A possible increase in particle immission is naturally dependent, to a large degree, on the type of production and application.

While industrially produced nanoparticles and nanomaterials are only comparatively slowly being deployed in manufacturing processes and everyday products, it makes sense to take precautionary and protective measures into consideration right from the start. Breaking new ground with the widespread application of a new form of technology also means not yet being able to calculate

all the possible risk factors, because not enough scientific data is available.

This is why, both on a national and international basis, representatives from the scientific, economic and political walks of life are working together with public authorities and organisations to develop solid policies concerning safety with regard to nanotechnology. For this purpose, numerous national and international research projects are being promoted.

Risk-related research is looking into such matters as the following:

- the characteristics of nanomaterials subject to, for example, their size and interaction with other substances
- possible means of incorporation into the human organism
- the lifecycle, spread and effects (allergies, intolerance carcinogenic etc.) of nanomaterials
- the behaviour of nanomaterials in the environment

The results are used for:

- safety (protective) measures at the workplace
- environmental protective measures
- development of new safety standards, changes in the relevant legislation (e.g. chemical law, pharmaceutical law, cosmetic law, food law)
- measures to inform and protect consumers

4.2 Risk-related research in practice

The German Federal Ministry of Education and Research is currently aiding risk-related research, among other things, by means of the following projects and support measures.

NanoCare: The NanoCare project is being funded by the Federal Ministry of Research till the year 2009 with 5 million euros, while a further 2.6 million euros is being contributed by industrial partners. The aim of the project is to acquire knowledge about the effects of nanomaterials on our health, to prepare and edit the scientific findings and to make the results available to specialists, as well as the public at large. The NanoCare Project also involves improving and developing new measuring procedures that can be used in everyday life. The research results are presented and discussed at official public events. In addition, the relevant data is structured and presented in an understandable manner for internet publication: www.nanopartikel.info

INOS: This german acronym stands for “Identification and assessment of the effects of engineered nanoparticles on human and environmental health”. Till 2009 this project is being funded by the ministry to the amount of 1.1 million euros. Ceramic and metal nanoparticles are being tested here. The INOS project also plans to publish the results of its research in an internet database: www.nanotox.de

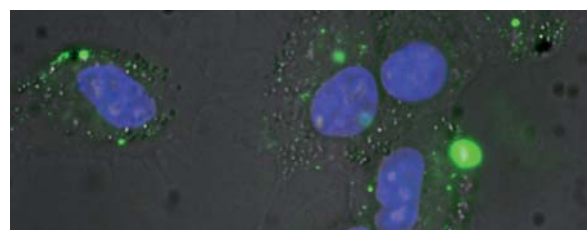
Tracer: The “Toxicology and health risk assessment in carbon nanomaterials” is the topic of the TRACER project, with the German Federal Ministry of Education and Research (2009) and industrial companies both contributing 1.5 million euros each to finance it.

The project partners are researching the biological effects of carbon nanotubes at the different intermediate stages in the production chain – from the manufacturing of the basic material through to the function samples. This work offers the basis for determining the size and

amount of released carbon nano-objects, as well as recommendations for preventive and protective measures. You can find further information about this project on the following website: www.nano-tracer.de

NanoNature: Nanotechnologies for environmental protection – the effects of synthetic nanomaterials on the environment have to do, for example, with the questions of how synthetic nanoparticles, respectively, nanomaterials, as well as products which contain nanomaterials, behave in the air, water or earth and whether they can develop toxic properties there. In this connection, procedures are also being developed for measuring particle sizes “in the field”. Furthermore, the project is also supposed to help in better utilising the opportunities of nanotechnology to protect the environment.

Projects on a European level: There are also numerous, further international research projects in which scientific institutes and companies in Germany are active participants.



Study of the effects of free nanoparticles (fluorescent green in the photo) on human cells (the cell nuclei are coloured blue.)

Project NanoDerm (www.uni-leipzig.de/~nanoderm) focuses on the absorption and effects of nanoparticles on human skin, for example, in cosmetics. Until now, no evidence has been found which indicates that nanoparticles of zinc oxide and titanium dioxide penetrate through to deeper tissue layers.

Working together with numerous European partners, the **NanoSafe** project (www.nanosafe.org) is concerned with the responsible production and use of nanomaterials in industry.

4.3 Safety at the workplace

On the basis of a survey of German chemical companies in the spring of 2006 regarding the topic “Dealing in a responsible manner with nanomaterials at the workplace”, the Federal Institution for Industrial Safety and Industrial Medicine (BAuA= Bundesanstalt für Arbeitsschutz und Arbeitsmedizin) and the German Chemical Industry (VCI= Verband Chemischen Industrie) developed a set of guidelines. These recommendations for industrial safety measures for companies which are active in the nanotechnology field, however, are by no means the last word, but rather are subject to revision in accordance with the latest state of the scientific and technical knowledge.

The rules and standards already in place for dealing with other chemical substances – for example, the Health and Safety at Work Act or the Ordinances on Hazardous Substances – are also valid for dealing with nanomaterials.

Even in such cases, though, in which the basic chemical material does not pose a health hazard, the particles which are manufactured from the material might sometimes have features which would require, as the case may be, individual industrial safety measures, e.g. for nanoparticles or nanopowders.

Dealing in a responsible manner with nanomaterials is based on the following important points:

Responsibility of the employer: The employer is responsible for assessing possible hazards to employees at their workplaces and implementing the appropriate industrial safety measures. For example, only authorised persons should be allowed access to the corresponding work areas and only as many people should be employed as are absolutely necessary. It is a matter of principle to always minimize any endangerment of employees.

Considering alternatives: One should always consider whether less hazardous alternatives are available to replace the materials and processes used. Dust-forming nanomaterials should, for example, be contained in

pastes or fluids.

Technical safety measures: Depending on the degree of danger, a large number of complementary safety precautions should be in operation at industrial plants. Isolation chambers with exhaust and air filtering facilities lend themselves where dust or particulate matter can form. Clean protective clothing is also an absolute must (e.g. facemasks, goggles, special gloves).



Wearing protective clothing is mandatory when dealing with nanomaterials in some areas of research and production.

Organisational protective measures: Exercising due caution for employees means making sure the absolutely necessary information is provided. Such information includes detailed specifications about the product (labels, hazardous material data sheets) and the work processes and steps involved in which exposure, i.e. contact with the nanomaterial, might be possible. Warning signs and operating instructions also serve this purpose.

In addition, employees have to know which protective measures are already in effect and which health precautions exist in the workplace. Regular courses of instruction and safety measure briefings ensure that employees are kept up-to-date on the latest developments and lead to such safety measures becoming a matter of second nature for all involved.

A thorough documentation of the work in the form of records and reports proves whether safety standards are being adhered to or if safety requirements have to be upgraded in accordance with the material employed.

4.4 Research in an open forum

An open discussion between all those involved and interested offers the best forum for evaluating the potential risks, as well as the wide reaching opportunities of nanotechnology for our economy and society. In this way, research problems can be more quickly solved and the required basic conditions concretely ascertained in the interest of all those involved. Based on facts and goal-oriented, the latest developments can be discussed taking into account different points of view and experiences.



Measurement station to determine nanoparticle exposure at the workplace

In Germany – but also far beyond our national borders – researchers, entrepreneurs, politicians, official delegates, members of public organisations, as well as representatives of the church, are intensely discussing the matter together. Examples for such exchanges are the Citizens' Dialogue NanoCare of the Federal Ministry for Education and Research (BMBF) and the Nano-dialogue of the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU). At present, the focus of the discussion is on the topics of the utilisation and safety of nanomaterials and products derived from such material (e.g. in foodstuffs, cosmetics, articles of daily use, pharmaceutical products, medical engineering) for consumers

and employees.

The discussion is not just limited, however, to the current research results or the planning of future research and support strategies. Unanswered questions with regard to ethical, ecological and economic issues are also being strongly debated. The stakeholders in German nanotechnology continue to have a strong sense of responsibility towards the public at large which is exhibited in the many events, information initiatives, brochures and internet offerings designed as open platforms for discussion.

Marshalling their forces, eight federal ministries are coordinating these many activities within the framework of the “Nano-Initiative – Action Plan 2010” of the German Federal Republic. Institutions such as the Federal Institute for Risk Assessment (BfR), the Federal Environment Agency (UBA) and the Federal Institute for Occupational Health and Safety (BAuA) have produced a research strategy regarding the effects of nanomaterials. On the part of the industry, the DECHEMA (Society for Chemical Engineering and Biotechnology) and VCI (Chemical Industries Association) have initiated, among other things, the committee “Responsible Production and Use of Nanomaterials”.

5. Nanotechnology in Germany



Nano-map: Shows all the active players on Germany's field of nanotechnology

Germany's trump cards in the global game of competition are its brainpower and its strong position in the modern key technologies. Much has already been achieved, but much more still needs to be done. Through innovation, nanotechnology offers Germany enormous opportunities for education, employment and economic success and a chance to solidify its position. Continued growth and our competitive edge can only be ensured in the future by means of active, foresighted supportive measures and the joint commitment of research, industry, politics and society.

Germany is the European leader in the field of nanotechnology. Contributing to this leading edge are an excellent, well-networked research and a growing number of successful companies working in the area of nanotechnology. Approximately half of the European nanotechnology firms have their headquarters in Germany, with approximately the same number of companies concentrating on nanotechnology in Europe as in the USA.

The consistent policy of the German Federal Government to support nanotechnology has played a decisive role in contributing to this positive development. At a very early stage the Federal Ministry for Education and Research (BMBF) realised the importance of making Germany a centre for nanotechnology and has been supporting projects in this technological field since the early 1990s. In the year 2007 the ministry donated approximately 168 million euros in grant money to nanotechnology projects. Another 169 million euros in federal and state funds went towards supporting scientific institutions (institutional support). This is a record among the European nations. In comparison: The European Union spent approximately 740 million euros in public funds to support nanotechnology, almost as much as the USA.

5.1 Central location, major challenges

In particular, the number of patent registrations on inventions sheds light on the economic importance of nanotechnology. In 2005, Germany came in third, just behind the USA and Japan, for the number of registered nanotechnology patents. With regard to the number of scientific publications, nano researchers in Germany are in fourth place.

In January 2008, 132 large-sized companies and 557 small and medium-sized enterprises were listed in Germany as having to do with the development, application and distribution of nanotechnology products. Nanotechnology now provides jobs for more than 50,000 people in Germany.

The international edge in Germany's nanotechnology know-how, the positive attitude of the general population towards nanotechnology and the interest demonstrated by the younger generation in this new area of development, are all further advantages of Germany as a centre of nanotechnology. Nonetheless, putting into practice the theoretical findings of nanotechnology research takes much longer here in Germany than, for example, in the USA or Japan.

To maintain its position as a major player in the big league of nanotechnology, Germany in the future has to master considerable challenges:

- **The pace of putting into practice the research results of technological innovations for many different types of applications has to be accelerated.**
- **Further fields of endeavour and enterprises have to be brought into contact with nanotechnology.**
- **Hurdles on the path to scientific and economic progress have to be overcome and favourable basic conditions must be created.**

- **Discussions concerning the chances and risks involved in nanotechnology have to be intensified between representatives from the fields of research, economy and politics and the public at large.**

5.2 Fields of special support

With the “Nano Initiative – Action Plan 2010” the Ministry for Education and Research has initiated an important and integral element in the federal government’s high-tech strategy. It constitutes a catalogue of measures for setting future directions and solving problems. Within the framework of the federal government’s high-tech strategy – and in accord with the Federal Ministry of Employment and Social Affairs (BMAS), of the Environment, Nature Conservation and Nuclear Safety (BMU), of Food, Agriculture and Consumer Protection (BMELV), of Defence (BMVg), of Health (BMG), as well as of Economics and Technology - the prerequisites have been established for mastering the duties and responsibilities at issue.

Funding of the Ministry of Education and Research is especially focused on the so-called innovation fields. These are the areas of nanotechnology application in which cooperation between researchers, developers, manufacturers, users and customers promise the greatest impact on growth and employment. This is the strategy for reinforcing existing markets and opening up new ones.

The following innovation fields in part have received government funding through the Federal Ministry for Education and Research since 2001:

- **Nanobiotechnology**
start: 2001, funding: 60 m euros
- **Automobile construction (“NanoMobil”)**
start: 2005, funding: 37 m euros

- **Chemistry (“NanoMicroChem”)**
start: 2005, funding: 31 m euros
- **Medical field (“NanoforLife”)**
start: 2005, funding: 24 m euros
- **Lighting technology (“Nanolux”)**
start: 2004, funding: 10.6 m euros
- **Energy**
start: 2005, funding: 20 m euros
- **Textile industry (“Nanotex”)**
start: 2005, funding: 31 m euros
- **Architecture and construction (“NanoTecture”)**
start: 2008, funding: 15m euros (planned)
- **Nano goes into production**
start: 2008, funding: 15 m euros (planned)

In the “Nano Initiative – Action Plan 2010” there are additional support measures for the following fields:

- **Medical / health field (“BioMicrosystem technology”)**
- **Measuring technology**
- **Machine and facility construction**
- **Integration of nanotechnology and microsystem technologies (“Micro-nano Integration”)**
- **Environmental protection**

The following innovation alliances are also supported by the Federal Ministry of Education and Research:

- **Carbon nanomaterials conquer markets – CNT**
funding: 40 m euros
- **Lithium-ion battery LIB 2015**
funding: 60 m euros
- **OLED initiative**
funding: 100 m euros

- **Organic photovoltaic**
funding: 60 m euros
- **Technology initiative molecular image processing – MoBiTech**
funding: 150 m euros

5.3 Big opportunities for small enterprises

Experts assess that in the medium term most of the new jobs in Germany in the area of nanotechnology will be created by small and medium-sized enterprises (SMEs). Such firms are often spin-offs of university research projects.

At the start, the main field of activity for many of these companies is the research and development of new products, processes and services. As direct vendors, suppliers or service providers, such established SMEs produce single components or offer customised system solutions, as well as different services. The usually small teams of such firms are very flexible in their modes of operation, are highly creative and place a great deal of value on remaining in steady contact with their former universities and research institutes.



Small and medium-sized enterprises often offer customised solutions to also improve conventional products.

In addition, many German SMEs also work in close cooperation with large enterprises which adopt the research results or preliminary products for the purpose of further development into marketable products that can be sold on a broader basis. The SMEs are thus an important link in the chain of transferring knowledge and technology from the field of research to the industry at large.

Considerable financial resources are required to build up an enterprise and to successfully conclude the first research results. Such projects can either be government sponsored or financed by venture capitalists. The Federal Ministry of Education and Research supports new start-up companies with a number of support measures. Aid takes the form of proffering financial security, offering access to counselling services or supporting and motivating particular founders. SMEs that already work with nanotechnology, as well as those who are planning to work in this field in the future, can profit from this support.

The project “SME – Innovative Nanotechnology – NanoChance” of the Federal Ministry of Education and Research is an example of such a support measure. It aims to reinforce the innovation potential of small and medium-sized enterprises active in cutting-edge research and to make the research funding for these firms more attractive. The NanoChance project has three important objectives: to give support to newly founded companies in the development of their enterprises, to ease the transition of SMEs from research to production oriented enterprises, and to support established companies to expand their range of products through the use of nanotechnology.

5.4 Nanotechnology for the next generation

Nanotechnology is a fascinating field with enormous educational opportunities and interesting careers. Nationwide, bright-minded and inventive young people have numerous opportunities to learn and study, to

qualify themselves and to play an active role in this new and exciting field. It is possible to specialize in this field or take advantage of one of the many further educational offerings already in place for promoting young talent: for pupils and students, young researchers and entrepreneurs. The Federal Ministry of Education and Research offers comprehensive information about vocational training measures or courses of studies in the field of nanotechnology and provides an overview of the further educational and vocational training measures which are available:

www.techportal.de (see “Bildung & Beruf”)
www.nano-bildungslandschaften.de

5.4.1 Nanotechnology in the classroom

Research and production in the nanocosmos seem to hold a great deal of fascination for many pupils. This is why young people should be able to show their interest in nanotechnology at an early stage and receive comprehensive information about this topic – ideally in their science classes. For example, nanostructured semi-conducting material would be a suitable topic, among other things, for a class in physics. Catalyst particles and molecular layers could be treated in chemistry classes and bio-scientific research in the nanometre range, for example, with scanning probe microscopes, would enrich biology lessons.

There are already a number of initiatives which are bringing nanotechnology into the classrooms, for example by means of experimental kits and teaching material developed specifically for nanotechnology. Some research institutes and universities also appoint nano experts as “teaching ambassadors” to the schools.

5.4.2 Vocational training measures for nano enthusiasts

Those who are interested in nanotechnology can also, for example, start a course of vocational training after graduating from middle school or high school. Upon

completion of the training, it is not rare to find an exciting and multifaceted position as part of an interdisciplinary team in a company or at a university. The range of tasks and responsibilities which one assumes are as manifold as the different fields of nanotechnology: In the area of research this could mean, among other things, being solely responsible for independently planning, implementing, evaluating and documenting scientific experiments. Other vocational jobs are in the area of production or service. Tasks here involve maintaining facilities, monitoring processes, controlling the quality of products or setting up and installing systems in cooperation with customers.

Examples for vocational jobs in the field of nanotechnology research and applications are (status: December 2007):

- **Biology laboratory assistant**
- **Biology technical assistant**
- **Chemical technical assistant**
- **Electronics specialist – automation technology (industry)**
- **Mechatronics specialist**
- **Microtechnologist**
- **Technical assistant for physics**

5.4.3 Course of studies: specialising in nanotechnology

An alternative path to a career in nanotechnology can be taken by choosing one of the classic courses of studies (e.g. chemistry, physics, biology, biotechnology, medicine). After a solid foundation of relevant introductory courses, specialised knowledge in fields with direct reference to this exciting technology of the future can be acquired.

At the end of 2007, 19 universities in Germany were already offering special courses of study which could be completed with a certificate, diploma or bachelor or master's degree in science or engineering – a good foundation for a future career as a centre or department

leader working in the industrial or academic field, or also to be appointed to a professorship.

For further information visit:

www.techportal.de (see „Bildung & Beruf“)

www.nano-bildungslandschaften.de

Examples of German course offerings in nanotechnology (status: December 2007):

- Biotechnology and nanotechnology
- Electrotechnology/encompassing micro- and nanoelectronics
- Materials science/micro- and nanotechnology
- Micro- and nanostructures
- Nano and surface technologies
- Nanobiophysics
- NanoEngineering
- Nanostructure Science
- Physics/Nanoscience



The competence map of German nanotechnology

5.4.4 Talent competition for nanotechnologists

Supporting highly qualified specialists in the field of nanotechnology has a direct influence on the success of this technology in Germany. With their innovative ideas and creativity, young scientists provide new knowledge and valuable solutions for important questions.

This is why the Federal Ministry of Education and Research has launched the “Talent Competition for Nanotechnology – Nanofuture”. The competition offers young researchers with experience the opportunity to work together in their own team on new and independent research projects in the area where basic research interfaces with application-oriented, industrial research. Simultaneously, while further qualifying them for a career in academia the project also offers this group of junior nanotechnology scientists the opportunity to lay the foundation for the later industrial application of their work.



Dr. Martina Gerken, prize winner of the Federal Ministry of Education and Research's talent contest “Nanofuture” for the purpose of promoting young talent in the field of nanotechnology.

The distinction of being selected as a member of Nanofuture has already proved its merit as a valuable instrument in qualifying suitable junior scientists in the field of nanotechnology and improving their career prospects. A number of award winners, namely, have already been appointed professorships.

Glossar

A

Adhesion Adhesion refers to the physical attraction between the molecules of two different substances, respectively, the joining of two substances or bodies to each other.

Aerosol Aerosol is a mixture of materials made of gaseous material and fluid or solid, finely distributed elements

Aggregation Accumulation

Aggregation, states of The three states solid, fluid and gaseous are termed the aggregation states of a substance. They depend on external conditions such as, e.g., pressure and temperature.

Acceleration voltage With acceleration voltage electrically charged particles, i.e. the smallest components of matter, are accelerated to high speeds. The acceleration voltage is important for generating the electron beams used in electron microscopes

Amino acid Component of proteins; up to 20 different amino acids can be found in proteins

Antigen An antigen (contraction of antisomatogen) is a molecule that the organism recognises as being allo-genic, thus prompting the generation of anti-bodies. Antigens can be either endogenous, i.e. are elements of the body's own building materials (e.g. as in the case of autoimmune diseases) or exogenous, i.e. have entered the body from the outside (e.g. poison, bacteria)

Antigen-anti-body response This is one of the most important defence mechanisms of an organism; component of the immune response.

Anti-bodies The body's own proteins (immunoglobulins) which are formed by the B lymphocytes in the course of an immune response; they recognize when foreign substances have entered the body (e.g. bacteria) and help, within the framework of a comprehensive immune response, to fight them off.

Atom This is the smallest part of a chemical element. The lightest atom is the hydrogen atom.

Atomic force microscope The atomic force microscope measures forces which occur between the atoms of the sharp tip of the microscope and a sample specimen. Below a certain distance, the electrons of the atoms lead to the deflection of the tip from the sample. At larger distances, in contrast, the forces are attractive. The method is similarly precise as that of the scanning tunnelling microscope. In addition, it is a useful and relevant tool in biological research because non-conducting material can also be examined with it.

Atomic number The atomic number corresponds to the number of protons in the nucleus of an atom of that element. It is denoted by the letter Z.

B

Bottom up "From the bottom up" ; a design principle of nature: Small components (e.g. cells) evolve into larger, highly ordered structures (e.g. plants, humans).

C

Carbon Black Name for industrial soot. Powdered solid consisting of between 80 to 95.5% carbon

Catalyst These are substances which improve, intensify, accelerate or make a process possible without themselves being consumed.

Cluster A cluster in chemistry is a compound of at least three metal atoms that are connected to each other in a metal-metal bond (metal cluster), in physics it is a mesoscopic system lying in the overlapping area between individual atoms/molecules and crystals.

Coating process Standard coating processes are electron beam vaporisation, sputtering, anodic and cathodic sections of a light arc, plasma-CVD, as well as hot-wire CVD

Colloids Colloids are very fine substances with particle sizes of between 1 and 100 nm

Colloidal solution In a colloidal solution, as well as colloid or sol (in a solid state gel), a substance is very finely distributed throughout the solution. The colloid, as well as the solution, can be in the form of a solid, fluid or gas.

Composite material A complex material in which two or more different substances which match each other structurally (e.g. metals, ceramic, glass and polymers) are combined to generate structural or functional features which the components do not possess on their own.

Contact angle A contact angle is the name for the angle which forms between a drop of fluid and the surface of the solid in which it is in contact.

CVD (chemical vapour deposition) The CVD process can be used to produce nanotubes or to coat wafers with silicon nitride or silicon oxide. Quartz boats are used in horizontal and vertical ovens. The material to be applied is conveyed into the oven where it decomposes and settles to the bottom.

D

Diagnostics is the way to recognize and evaluate diseases. The more accurate the diagnosis is, the more goal-directed the therapy in most cases can be.

Dispersion A mix of at least two substances which cannot, or only marginally, dissolve into each other or bond together chemically.

DNA Abbreviations for deoxyribonucleic acid. This is a thread-like molecule which is a carrier of genetic information.

Double helix Two screw-shaped threads of DNA wound up in each other, with the single strands are binding to each other via hydrogen bonds between the bases. One can picture the double helix as a kind of twisted rope ladder.

E

Electron is a negatively charged particle. Electrons form a cloud around the atomic nucleus. The name comes from the Greek word Elektron and means amber on which electricity was first observed.

F

Ferrofluid are substances which consist of nanoscaled magnetic nanoparticles in a carrier fluid.

Fuel cell is a device in which hydrogen and oxygen react flame-free to form water, thereby producing a high yield of electrical energy. Fuel cells convert chemical energy into electricity.

Fullerene Fullerenes are a separate class of carbon clusters. They consist of closed surface structures.

G

Gas phase reactor A gas phase reactor is a facility in which different precursors are brought to react (together) in a gas flow.

H

Hydrophilic “water loving”; hydrophilic substances are water soluble. Hydrophilic surfaces are dampened particularly well by water

Hydrophobic substances which are referred to as hydrophobic (“hate water”) do not dissolve in water, or only with difficulty. Hydrophobic surfaces are water-repellent.

Hyperthermia Hyperthermia is used to supplement other known forms of cancer therapy (surgery, chemotherapy and immune therapy) to reinforce the effects of the therapy by raising the temperature of the cancer cells.

I

Inert We refer to chemical elements or compounds as inert if they are sluggish in reaction. This means that they almost never react with other substances. Inert substances are, for example, the noble gases, porcelain and glass.

Interference Interference is an overlapping phenomenon which occurs when two or more waves traverse the same space.

Ions Ions are atoms which have an electrically positive or negative charge due to a missing or an extra electron. A cation is a positively charged ion; an anion is negatively charged.

L

LEED Abbreviation for low energy electron diffraction. LEED is an analysis technique that allows one to draw conclusions about the structure and array of the surface by the backscattering of low energy electrons and the diffraction on the grid of the surface atoms.

Lithography Lithography (from the Greek lithos = stone and graphein = writing) is a technical printing process

Lotus-effect The Lotus effect gets its name from the fact that lotus blossoms and lotus leaves are always immaculately clean. Even extremely adhesive pigment powder can easily be rinsed off with water and not even glue sticks to the surfaces of the lotus plant. The reason for this lies in the chemistry and structure of the plant's surface.

M

Magnetic field lines The magnetic field lines determine the direction of the force which a magnetic north pole would be subject to if one were to place it at this position. They emanate from the north pole and run to the south pole.

Metal-alkoxide solution is the solute form of a compound of metal ions and deprotonated alcohol.

Molecule A molecule is a particle that is composed of at least two bonded atoms.

Microfluidics Microfluidics stand for the manipulation of fluids in the sub-microlitre volume

Microfilm detector Microfilm detectors are modern semi-conducting detectors. They are used to measure the position and depict the path of ionising particle beams

Monofilm Monofilms are layers on surfaces which consist of exactly one layer of densely packed atoms or molecules

N

Nanoanalytics Nanoanalytics is the term used for all measuring procedures which are able to provide information about nano-like objects and structures. Nano-analysis methods form the basis for researching new materials and testing the quality of manufactured substances.

Nanomaterials Substances measuring or structuring less than 100 nanometres.

Nanoscaled In the size range of between 1 and 100 nanometres.

Nanoproduction Nanoproduction encompasses methods of production and processing in the nanometre range.

Nanotubes Nanotubes have a diameter of just a few nanometres and special physical properties. Carbon nanotubes have been particularly well researched.

Nanometre A nanometre is one billionth of a metre.

Nanoparticle A particle which measures less than 100 nanometres.

O

OLED This is the abbreviation for organic light emitting diode. OLEDs are manufactured from nanostructured polymer films. They consist of one or more semi-conducting, organic layers which are enclosed by two electrodes. These contain light emitting materials which glow when an electric voltage is applied. OLEDs are applied to glass or transparent, pliable carrier foils such as transparent electrical conductors. The anode is coated by the ultra-thin light-emitting layer, the cathode is vacuum-metallised. This results in a component which is no more than 200 nm thick.

P

Photonic crystal A Photonic crystal consists of the regular lattice structure of a material in which another material with a high refractive index has been embedded. Photonic crystals prevent the light propagation of certain light wavelengths (band gap). This property is similar to the semi-conductors which are used in computer chips. In semi-conductors electrons are also limited in their movements by a band gap. It is exactly this property, however, that constitutes the enormous potential of semi-conductors in electronics.

Photo-lithography Photo-lithography is a lithographic reproduction process in which patterns are imprinted on materials by means of light exposure. It plays a very important role in print technology and semi-conductor technology.

Plasmons When conduction electrons of a metal are collectively induced, one speaks of plasma oscillations whose energy quantum are called plasmons. A plasmon has the energy of a few electron volts and cannot, therefore, be thermally induced, i.e. be stimulated by heat.

Plasmon induction can be generated, however, by exposure to light if the energy and impulse balance of the induction process correspond to the known laws of conservation of momentum.

Polymer A polymer is a chemical compound which consists of a series of simple, basic elements (monomers). Most plastics are made of polymers.

Precipitation The chemical separation of a solute from a solution.

Pyrogenic silicic acid The oxygen acids of silicon are called silicic acids. Pyrogenic silicic acids are produced when silicon tetrachloride reacts with water which has been generated by a hydrogen flame.

Q

Quantum mechanics/quantum physics A field of modern physics which was established in the first half of the twentieth century. It describes the relationship of matter and energy in small dimensions.

Quantum dot Quantum dots are microscopic islands, usually made of semi-conducting material, which, due to their size of around ten nanometres, resemble the physical behaviour patterns of "giant atoms".

R

Radicals Extremely reactive, short-lived chemical fission products which immediately go on to react with other molecules are referred to as radicals. They are generated when the electron pair bonds in a molecule are split in such a way that each fragment receives an electron.

Reducing agent A reducing agent is a substance which can reduce another substance, that is to say, it releases electrons, thereby oxidizing itself.

Refraction index The refraction index is an optical term and refers to the bending of a light wave, when it passes into another transparent medium of a different density.

Ribosome Protein-nucleic acid complex on which the protein bio-synthesis takes place using mRNA as a template.

S

Scanning electron microscope The scanning electron microscope scans a sample with a bundled electron beam. The interaction between the beam and the sample are registered and depicted three-dimensionally. The procedure achieves a resolution in the nanometre range, in other words, single large molecules can be recognized. Since the sample has to conduct electricity, a thin metal-film is vapour-deposited on, for example, biological sample material.

Scanning probe lithography Scanning probe lithography is regarded as a very promising alternative to photo-lithography which, as it has become apparent in recent years, is reaching the limits of its potential.

Scanning tunnelling microscope A scanning tunnelling microscope is used to examine conductive material. A quantum mechanical effect occurs between the metal tip of the microscope and the sample: Although there is a tiny distance separating the tip of the microscope and the sample, a measurable current flows through it with some electrons managing to “tunnel” their way through this insulating barrier. Depending on the distance, the tunnelling current is larger or smaller. There is a very high resolution when there is only a very small distance between the tip and sample.

Self-organisation Self-organisation is a thermodynamic process in which order seems to occur spontaneously, i.e. “on its own”.

Semi-conductors are materials whose electrical conductivity lies between that of a metal and that of an insulator.

Solid A solid in physics is an expanded (macroscopic) body which consists of many atoms.

Spin process Nanofibres are generated by accelerating a liquefied material or solution in an electric field.

Sputtering Sputtering refers to removal of material from a so-called target by bombardment with ions.

Suspension A suspension is a heterogeneous (not mixable) mixture of materials consisting of a fluid in which a solid is finely distributed. The solid is distributed throughout the fluid, respectively suspended. A suspension, therefore, is a disperse, solid phase in a continual, fluid phase. If you let a suspension sit, the solid will sink to the bottom as sediment (sedimentation), if the particles are not too small.

T

Top down “From top to bottom”; the generation of small structures by means of progressive miniaturisation.

Tunnel current Tunnel current refers to the electrical current which occurs as a result of the quantum mechanical tunnel effect and which does not require a conductor. Elementary particles are able to make their way through (“tunnel through”) an energy barrier with this effect.

U

Ultra-violet rays These are electromagnetic waves whose wavelength is less than 400 nanometres. Ultra-violet light is not visible and borders the violet of visible light.

X

X-rays X-rays are electromagnetic waves whose energy is higher than that of ultra-violet light. They have a wavelength of between 0.001 and 10 nanometres.

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