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Nanotechnologies in Automobiles

Innovation Potentials in Hesse for the Automotive Industry and its Subcontractors

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Hessen Nanotech

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Volume 3 of the Aktionslinie
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Imprint

Nanotechnologies in Automobiles – Innovation Potentials in Hesse for the Automotive Industry and its Subcontractors

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Figure title: DaimlerChrysler (large)
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Middle: © NANO-X GmbH
Right: © Heraeus Noblelight GmbH

Contents

Nanotechnologies in automobiles – more individual mobility for everyone

Dr. Alois Rhiel

Hessian Minister of Economics, Transport, Urban and Regional Development

Individual mobility is a basic need of people and an important prerequisite for the development of modern societies. In this regard, the automobile will play a crucial role in the near future. The United Nations estimates that the world-wide vehicle fleet will double from 750 million today to approximately 1.5 billion utility and passenger vehicles by 2030. This development is driven by a rising demand in rapidly growing markets such as China, India, Korea, Brazil and Russia. The increasing prosperity of these regions will lead to a greater desire for more individual mobility of people, who will be buying more – and more frequently using – vehicles.

With the traffic volume increasing, the world-wide energy demand will rise as well. Questions concerning passenger safety, intelligent traffic guidance systems, pollutant reduction and effective recycling at the end of the value-added chain to save scarce resources are becoming more urgent.

Against this background, unique opportunities are developing for domestic automobile producers and suppliers. At the same time, finding themselves in a toughening international competition, they will face enormous challenges. Therefore, companies and research institutes worldwide are focusing their research and development efforts more and more on adapting the safety, comfort and eco-friendliness of the automobile to future needs, so that the advantages of individual mobility can be ensured in a sustainable way.

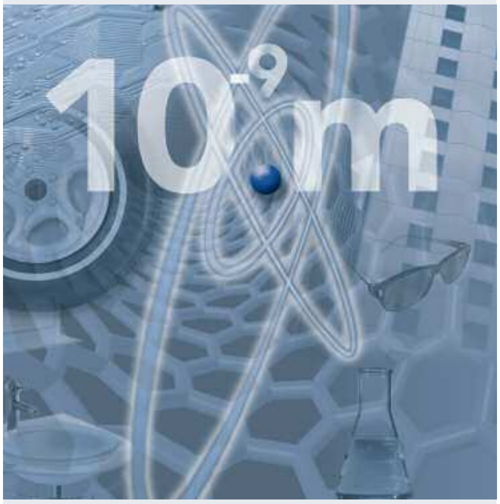
In this context, nanotechnologies are playing an important if not decisive role. It contributes crucially to necessary developments and to the production of innovative materials and processes in the automotive sector. Modern tyres for instance achieve their high mileage, durability and road grip through nanoscaled soot particles and silica. Materials with nanoparticles or layers at the nanoscale have beneficial effects on inner and outer surfaces, on the body or on the engine and drive.

However, it will be much more important to translate the pioneering results of nanotechnologies into products that are conducive to environmental sustainability and safety, so that vehicles can provide individual mobility to wide sections of the population without compromising the basis of people's livelihood. Apparently, only with the help of nanotechnologies will it be possible to incorporate all factors of the sustainability principle equally: ecology through conservation of the environment and of scarce resources, economy through the creation and safeguarding of competitive jobs as well as availability of individual mobility worldwide.

For the domestic industry, it is essential to use these unique innovation potentials of nanotechnologies in the global automobile mega market, thereby protecting and expanding their solid starting position. Unfortunately, the great opportunities they offer have not been identified sufficiently yet. The present brochure is therefore intended to identify current and future trends of nanotechnologies in automobiles, combining them with the strengths of domestic enterprises in this field.

It is my wish to point out promising possibilities of nanotechnologies in vehicle manufacturing and thereby initiate necessary innovation processes in Hessian automobile enterprises and their suppliers. Because only with innovative approaches will Hessian vendors be among the winners in the global competition.

Dr. Alois Rhiel
Hessian Minister of Economics, Transport, Urban and Regional Development



Summary

Nanotechnologies are becoming increasingly economically important worldwide. Today, numerous products already include nanotechnological components or they are made using nanotechnologies. Signs for a broad industrial process of transformation through nanotechnologies have been apparent from a scientific perspective since the 1980's. Today, a consensus prevails that nanotechnologies will have an impact on virtually all areas of life, and thus on the economy, in the mid and long term. Unlike many other high technologies, nanotechnologies have a cross-sectorial character and therefore possess a very broad potential of applications in many areas of the economy.

Nanoscaled fillers such as sooty particles are applied in car tyres, in printer ink or paints. The nanometre-sized dimensions of electronic components and functional layers in read heads allow a drastic improvement in performance of hard drives. Catalysts and air filter systems cause clean air inside and outside of the car. Optical layers for reflection reduction on dashboards or hydrophobic and dirt-repellent "easy-to-clean" surfaces on car mirrors are further examples of applications of nanotechnologies in automobiles. Nowadays, profits amounting to billions are being generated using such high-end products. Nanotechnologies are thereby incorporated as components into the product or into production technologies.

In the production technology of future automotive engineering, nanotechnological adhesives have an enormous economic potential since they allow energy savings in assembly processes. An interesting application relates to adhesives that are modified with magnetic nanoparticles. The coupling of thermal energy in the form of microwave radiation induces the chemical reaction necessary for the gluing process.

Through nanoadditives in plastics, clearly improved processing properties in injection-moulding machines can be achieved. Here, energy savings of up to 20 per cent are possible. Alternatively, the cycle time can be reduced by up to 30 per cent. Moulding tools can be designed more easily and new components can be built with thinner walls allowing for substantial material savings. Furthermore, the number of rejects is reduced, particularly in highly stressed parts, such as housings and functional elements of electric drives, in windscreen wiper arms, door knobs, reflectors, mirror systems, joining elements, sunroof elements, in boxes of locking systems and many more applications.

Practically all physical and chemical properties of polymers can be modified using fillers. The motivation behind this is to considerably improve properties such as scratch resistance or achieve higher mechanical stability. The latest developments make it possible to replace conventional car windows with plastics coated on the nanometre scale. In so doing, the focus is placed on the development of transparent, light, scratch-resistant and at the same time stiff materials. Another possibility to reduce fuel consumption and emissions and to increase energy efficiency is to coat cylinder tracks nanotechnologically. Thus, the remarkable loss resulting from friction in today's engines can be reduced significantly in the future. The fuel cell as the alternative drive and supply unit for the electronics of the car is being researched by almost all automotive manufacturers. Here, nanotechnologies can also give decisive advantages. Examples include the cell electrode, the diffusion membrane or systems for hydrogen storage. These and other examples will be presented in the present brochure.

Innovations and cutting-edge technologies are needed imperatively to maintain competitiveness in automotive engineering. Increasing government regulation in the fields of safety and environmental sustainability as well as increasing customer requirements concerning the performance, comfort and design of automobiles will become future drivers for the development of innovative technologies. The latter are critical components of integrated mobility management of the future. In Hesse, the initiative "No traffic jam in Hesse in 2015" was launched to develop concepts for traffic jam avoidance and traffic control.

Nanotechnological expertise will become one of the main competences in automotive engineering (Volkswagen 2003). It will be needed to maintain the international competitiveness of this industry that is so important for the German economy. Hesse is consistently building on nanotechnologies. The local conditions of this industry are excellent compared worldwide. Several major enterprises in the chemical industry that are among the world market

leaders in the field of nanotechnologies and also well-known automotive companies and their suppliers are based in Hesse. An increasing number of small and medium-sized businesses are using nanotechnologies for their products or production. Small businesses have demonstrated already that nanotechnologies can lead to sustainable entrepreneurial concepts. Well over 100 companies in Hesse are using nanotechnologies for their products or production. More than 20 of them supply the automotive industry with products related to nanotechnologies.

According to official statistics, the sector "Production of vehicles and vehicle components" with approximately 50,000 employees and a profit of 12,3 billion Euro in 2005 is the third largest industry sector in Hesse behind the chemical and mechanical industries (Bauer 2006). In these statistics a considerable proportion of automotive suppliers - companies selling the main share of their production to the automotive industry, but grouped into another industry statistically – are not included and must therefore also be included. Examples of such companies are car tyre manufacturers (rubber or plastics industry) or producers of electronic components and measurement and control technology for vehicles (electrical industry). If these supplier companies are included, then the automotive industry with its 64,000 employees is the second largest in Hesse after the chemical industry.

Besides Opel, important automobile producers such as DaimlerChrysler and Volkswagen have plants in Hesse. In addition, the automotive suppliers Siemens VDO, Continental Teves, Fulda Tyres, Pirelli, Dunlop and Delphi must also be mentioned. Furthermore, international groups such as Honda, Mazda, Hyundai and Isuzu have R&D centres in Hesse. Generally, the automotive industry in Hesse is focused on the production of automotive components and accessories. Its production ranges from complete systems such as chassis, gears, drive shafts and tyres as well as smaller components (for example brake discs, plain bearings and hoses) to a wide array of electronic parts and components (e.g. LCD screens, car multimedia, injection and telematics systems).

The present company brochure points out numerous applications of nanotechnologies for the automotive industry and its subcontractors that are either already existing or at the research stage. Based on important functionalities of nanotechnologies, different application examples for the outer skin of the vehicle, the body, interior, and chassis as well as the engine and drive system are described. In this context, the emphasis is put on the available economic potential and on the relevant research programmes, networks, contacts and associations. The objective of the brochure is to show the great variety of applications for nanotechnologies in the automotive domain to give the reader the opportunity to identify applications and opportunities for his or her field of activity.

[© pixelquelle.de]

Nanotechnologies – what is that?

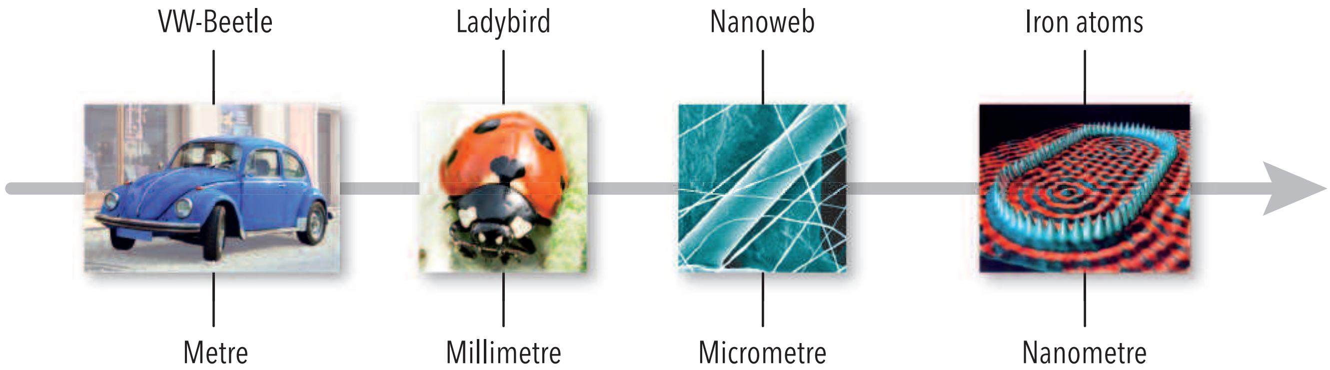
Nanotechnologies are interface technologies that include many different science and application areas. Among them are classical fields of knowledge such as chemistry, physics and mechanical engineering as well as new disciplines such as nano-bio technology and sub-areas of microelectronics. In that context, nanotechnologies have become increasingly important over the last few years. Today, nanoparticles with new characteristics are already being produced on a large scale and integrated into products. In most cases, the nanotechnological products currently available on the market are rather unspectacular and have become an almost unperceived part of daily life.

The purpose of nanotechnologies is the production and examination of functional structures smaller than 100 nanometres. A nanometre is a millionth of a millimetre. On this scale, material-dependent interface effects and large specific surfaces observable in larger structures become more important. On this order of magnitude, quantum effects appear that exhibit unique potential for novel functionalities. The critical size below which material properties change depends on the material itself. By changing the size of such components, the control of the chemical composition and the targeted manipulation of the atomic structure it is possible to produce macroscopic materials with radically new properties and functionalities.

Since nanotechnologies are solely defined by the geometric length scale and the related physical, chemical and biological effects, almost all branches of industry are affected by it.

The specific surface of a gram of nanocrystalline powder can have the size of a soccer field depending on the grain size of the material. It is estimated that the number of products based on synthetic nanoparticles currently available on the market alone is approximately 500. Among them are sunscreens with a high UV protection factor, nanoscaled ink particles for copying machines and printers, scratch-resistant car paints, hydrophobic and dirt-repellent textiles, golf clubs and tennis rackets with different types of carbon additives for increased stability, nanoparticle materials in baby diapers for improved moisture absorption as well as plastic wraps for higher tensile strength and gas permeability (BMU 2005).

Tyres are an example of the application of nanotechnologies in automobiles. Current tyre models achieve their high performance, durability and grip from fine sooty particles called "carbon black". Beyond that, a new class of this material, called nanostructured soot, achieves an even better performance and improves properties such as grip. Nanostructured soot is produced by thermal decomposition of soot oil. Here, advances in the field of analysis and measurement and a deeper under-



Comparison of Sizes

Hard drives as mass storages will be increasingly used in automobiles in the near future
[© Western Digital Corp.]

standing of the underlying processes have enabled the systematic modification of sooty particles. As a result, diverse structures and surfaces are adjustable and, consequently, properties controllable.

Another example is the integration of nanotechnologies in the fields of vehicle navigation and audio systems. At this stage, hard drives for use in vehicles are being produced that are able to store movies which can be viewed on navigation systems. This new hard drive technology is increasingly living up to the high requirements that have to be fulfilled for use in automobiles. Challenges that have to be faced to develop suitable hard drives include enormous temperature fluctuations in the vehicle's interior and high-frequency vibrations from the car engine.

But also the fuel consumption and the pollutant emission of diesel engines can be improved using fuel additives and exhaust catalysts that boost combustion efficiency through nanoscaled catalysts. These are exceptionally reactive given the large specific surface of the nanoscaled catalysts.

Optimisation of the combustion efficiency and reduction of fuel consumption of diesel fuels by fuel additives and exhaust gas catalysts
[© Oxonica]

Nanoscaled filler materials such as "carbon black" or silica are components of modern car tyres
[© Pirelli GmbH]

1 Functionalities of nanotechnologies

Nanotechnologies can be applied in almost all industries and technologies because of their effects and functionalities. Given their cross-sectional capacity, nanotechnologies are especially important in automotive engineering.

The functionalities of nanotechnological materials, products and processes discovered so far offer an application-oriented access to nanotechnologies for enterprises (Heubach 2005). These phenomena are closely related to the benefit and function of the product and thus to customer-oriented demand and provide the connection between nanotechnologies and automotive engineering. Functionalities relevant for automotive engineering are presented below (following TAB 2003).

Mechanical functionalities

The considerably improved mechanical properties of nanostructured solids are higher hardness, increased breaking strength and improved fracture toughness at low temperatures or super elasticity at high temperatures. Underlying these effects is a decrease in grain size so that dimensions are reached below which deformation mechanisms cannot occur in the grain itself. This results in benefits for users, such as a prolonged durability of production tools or more effective lubricating systems and optimised lightweight materials.

Geometric effects

Crucial reactions between gaseous or liquid and solid substances in the nanometre range often occur on contact surfaces. Interaction with such media makes special physical and chemical demands on the surface of particles, pores, fibres, semi-finished and finished products. With regard to protection functions, these demands include resistance against oxidation, corrosion, mechanical abrasion and high temperatures (BMBF 2002). Because of the small size of nanostructures, the extreme surface-to-volume ratio of these materials becomes more important. Therefore, the large specific surface and the surface properties of nanostructured materials influence chemical reactivity. In a material with pores at nanometre scale there are, as a result, partly totally new effects that can be used in nanofilters for instance.

Electronic / magnetic functionalities

In the nanometre range quantum effects take place that cannot be observed in larger objects. Charge carriers that can move almost freely in the volume of solid materials are strongly influenced in their mobility by nano objects given their narrow dimensions. This behaviour can also be observed in a material with macroscopic dimensions consisting of nanocrystalline crystallites separated by grain boundaries. Scattering of charge carriers on boundary surfaces affects several electrical properties. Therefore, an increase in the specific electrical resistance and a change in the temperature dependency of the resistance in comparison to a material with crystals in the micrometer range can often be observed. The manipulation of the grain size of such a material allows tuning of the electronic properties.

Paramagnetism and ferromagnetism are among the magnetic properties of solids. By reducing magnetic domains, macroscopic magnetic properties (e.g. saturation magnetisation, remanence) can be influenced. In practice, the GMR (giant magneto resistive) effect is used in magnetic field sensors and in magnetic storage devices (magnetic RAM, MRAM) or in glues which are modified with nanoparticles such that the adhesive property becomes switchable.

Optical functionalities

As nanoparticles are considerably smaller than the wavelength of visible light, no reflection occurs from them. Dispersions of nanoparticles of usually opaque material can appear transparent. Nanoparticles can also cause dispersion effects where shorter wavelengths are deflected more than longer wavelengths, which can cause colour effects (TAB 2003). By tailoring the size of nanoparticles, a precise wavelength region (a colour) can be adjusted specifically where the material absorbs or emits light. This is exploited in transparent dispersions of nanoparticles or in optical functional surfaces, e.g. for lumenizing solar cells or in the field of optical analysis and information transmission. Another example that will become important concerns quantum dots. The latter may be used to construct lasers whose wavelength (colour) can be adjusted according to the size of the so-called quantum dots. The brochure “Nano Optik”, Volume 5, of the Aktionslinie Hessen-Nanotech series provides further information on this topic.

Chemical functionalities

The chemical functionality of nano objects is substantially based upon their surface structure. Nanostructured materials possess a significantly high share of surface atoms. Such atoms are highly reactive because of their unsaturated bonding. Lattice strain respectively leads to a markedly increased surface energy. This can be used for surfaces with tailor-made wetting behaviour, the layout of functional groups, for enhancing chemical reactivity and selectivity and also for chemical stability in diverse chemical processes.

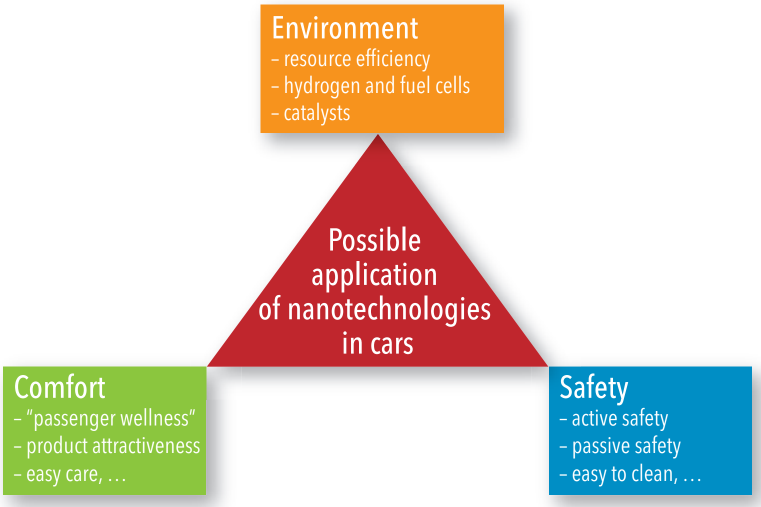
The following table gives a short overview of possible application fields of nanotechnological functionalities in automotive engineering. In future, we will be able to count on a number of further applications that will concern all branches of the automotive industry and its subcontractors.

Applications of nanotechnologies in automobiles — Existing applications — Possible future applications

Application / Effect	Functionalities	Car body shell exterior	Car body	Interior	Chassis and tyres	Electrics and electronics	Engine and drive train
							
Mechanical functionalities	Hardness, friction, tribological properties, breaking resistance	Nano varnish			Carbon black in tyres		Low-friction aggregate components
		Polymer glazing	Nanosteel		Nanosteel		
Geometric effects	Large surface-to-volume ratio, Poresize			Nano filter		Super caps	
			Gecko effect	Gecko effect		Fuel cell	
Electronic/ magnetic functionalities	Size dependent electric and magnetic properties		Gluing on command			GMR sensors	Piezo injectors
					Switchable materials (rheology)	Solar cells	
Optical functionalities	Colour, fluorescence, transparency	Ultra-thin layers		Anti-glare coatings			
		Electro chromatic layers					
Chemical functionalities	Reactivity, selectivity, surface properties	Care and sealing systems	Forming of high strength steel	Dirt protection			Catalysts
			Corrosion protection	Fragrance in the cabin			Fuel additives

[Icons: © RESOLUT DESIGN]

2 Applications of nanotechnologies in automobiles



Goals for the applications of nanotechnologies in automobiles
[following Steingrobe 2006]

According to a study by the bureau for technology impact assessment at the German Bundestag, nanotechnologies in automotive engineering belong to the future core capabilities that are crucial to maintain international competitiveness. The vehicle is meant for leisure and work - it ensures individuality and mobility. Worldwide, there are about three quarters of a billion vehicles in the streets with an upward trend. Thus the challenges posed by vehicle consumption, pollutant emissions, recycling and traffic volume are also opportunities opening up for the industry, both for the internationally potent German automotive industry and for its mainly mid-sized subcontractors (German Ministry of Education and Research / BMBF / 2004). The use of nanotechnological know-how for new functionalities aims to optimise environmental concerns / safety / comfort.

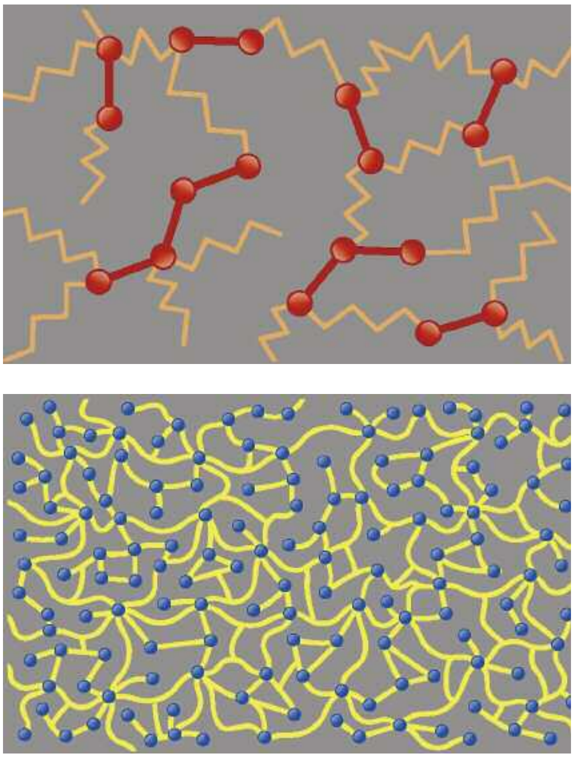
Today, there are already quite a number of nanotechnology applications in the automobile. The applications shown in the picture below are only some examples.

Examples for applications of nanotechnologies in automobiles
[Icon automobile: © RESOLUT DESIGN]

2.1 Nanotechnologies for the car body shell

In the domain of surface technology, nanostructured surfaces allow for example improved paint adhesion. Self-cleaning will become standard on windscreens and car body shells provided contemporary technological challenges are successfully coped with. Scratch-resistant, dirt-repellent and self-healing car paints are applications that already exist or are in development.

Besides the paint itself, innovative displacements or ultra-thin coatings for mirrors and reflectors as well as care and sealing systems are among the applications of nanotechnologies on the car body shell. In particular, numerous solutions in care and sealing systems are available on the market already. The following applications illustrate the status quo of the nanotechnology applications development for the car body shell with selected examples.



Upper left: Conventional paints consist of binder (orange) and cross-linking agents (red).

Lower left: Nano paints consist of organic binder with high elasticity (yellow) and inorganic nanoparticles with high strength (blue). The tightly packed nano particles make the paint scratch-resistant.

[© DaimlerChrysler AG]

Stable value and scratch resistance with nano-varnish

An unblemished car body shell should be guaranteed even after numerous car washes and several years of operation. Compared to conventional paint systems, nano-vanishes allow for higher scratch resistance and paint brilliance.

Mercedes Benz passenger car painted with nano varnish

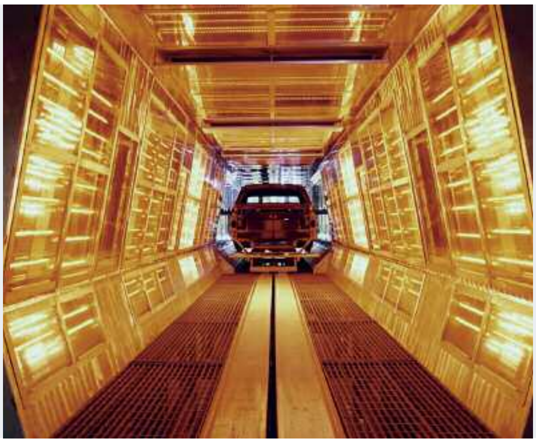
[© DaimlerChrysler AG]

The basis for this technological effect are embedded ceramics particles in the final varnish layer in the nanometre range. Nanoparticles such as Degussa's AEROSIL R9200 for car varnishes, which greatly account for the improvement in scratch resistance, are very much gaining in importance. Traditionally, AEROSIL can also be found in other layers of the car body shell, where it is used for pigment stabilisation, rheology control and corrosion resistance for example. These are special types of silica that play an important role in innovative car paints. Their basis are nanostructured powders produced in a gaseous phase synthesis in the flame and are therefore called pyrogenic constitute. Starting with silica tetrachloride, small, spherical single silica parts with a mean diameter in the range between 7 and 40 nanometres result from flame hydrolysis (Oberholz 2006). If the paint is liquid, these particles are initially randomly distributed in the solution. During the drying and hardening process they crosslink deeply with the molecular structure of the paint matrix. The result is a very dense and ordered matrix results on the paint surface. Thus the scratching resistance is tripled and the paint brilliance improves considerably. This novel paint system has been developed by DaimlerChrysler. These nanopaints are already being used in some models of the Mercedes-Benz make.

A procedure for hardening the nanopaints that supplies the required high temperatures is based on the usage of special infrared reflectors. Heraeus, a company located in Hanau, develops and produces these reflectors.

Hesse has a leading position in the production of nanopaints and their components. Examples of companies operating in this region are Merck KGaA, Solvadis AG, Lurgi Chemie und Hüttentechnik GmbH, DuPont de Nemours GmbH, Degussa AG, Deutsche Amphibolin Werke, Ciba Spezialitätenchemie, Akzo Nobel Powder Coatings GmbH and Clariant GmbH.

Originally developed for tests of the field of vision, the glass-domed automobile shows possible application fields of nanotechnologies. [© DaimlerChrysler AG]



Modern nanocoatings and special nanopaints can be successfully dried or hardened with infrared heat. This is shown by field tests in the application centre of the special light sources producer Heraeus Noblelight in Kleinostheim. [© Heraeus Noblelight GmbH]

Scratch-resistant polymer discs for the lightweight construction

Nowadays, up to 6 m^2 of glass are processed in a car – 1.2 m^2 just for the wind shield. Glass panes will become increasingly important for reasons of design. The lightweight construction potential this technology holds is enormous; it can by tapped by the substitution of mineral glass by polymer glass. The latter has to be shielded from scratching, abrasion and climatic influence.

Polymer glasses, especially polycarbonate with excellent impact strength and light weight, have already been used serially for a longer time in headlight covers and lenses respectively. In order to make them even more scratch-resistant, they are coated with acrylate or polysiloxane paints. In these paints extremely hard aluminium oxide nanoparticles are placed in the substrate matrix during the hardening process, thereby achieving a high abrasive resistance with solid impact strength. Due to the small size of the filler particles and their fine distribution, this coating is highly transparent as well.

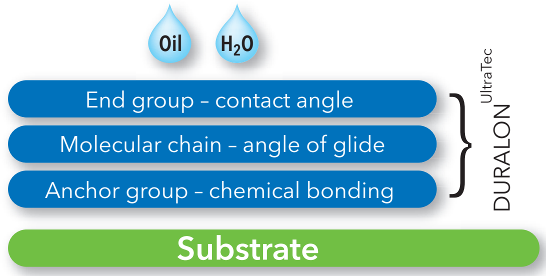
In premium optical glazing, e.g. glass panes, an extremely even coating of the scratch-resistant layer is important. Therefore, new processes are being developed to apply hard materials directly from the gaseous phase to the polymer glass. The so-called PVD (physical vapour deposition) and CVD (chemical vapour deposition) procedures as well as plasma polymerisation create a highly cross-linked polymer layer in the range of few nanometres with organic and inorganic components using a vacuum-coating process.

Scratch-resistant high-strength plastics offer new possibilities, especially with regard to advanced injection moulding techniques. The easy formability of the plastic is opening up new design possibilities – from transparent roof tops and car body shell parts to whole car modules made of plastics with integrated lights and aerodynamics elements. Currently, almost all known automotive producers are active in this field.

Further information on this topic can be found in the brochure "NanoOptics", Volume 5, as well as in the brochure "NanoProduction", Volume 6, from the Aktionslinie Hessen-Nanotech series.

Ultra-thin layers for mirrors and reflectors

Modern mirrors and headlights with superior optical quality and efficiency are based on glass and plastics components that are equipped with an ultra-thin reflecting layer of aluminium oxide. In the last few years, superior coating processes have been developed for ultra-reflecting layers with thicknesses below 100 nanometres.



Left: Schematic illustration of the effect of a perfluorinated coating for the adjustment of hydrophobic and oelophobic properties
[© Cotec]

On a large industrial scale, the coating of aluminium takes place in vacuum vaporisation facilities. Thereby, the aluminium is heated by tungsten filament and evaporates. Newly developed and specially formed evaporation structures of Cotec from Nidderau improve the rate of coating significantly. They allow a better exploitation of aluminium and avoid evaporation defects. The temperature strain on the coated materials is low in this process, as are technical expenditure and running costs.

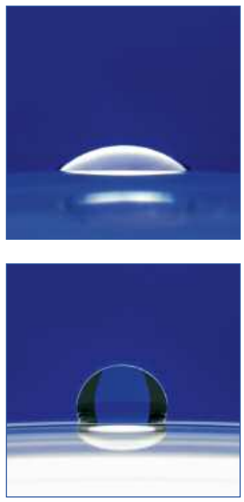
A further application field for glasses and mirrors in automotive engineering is being opened by the possibility to equip surfaces with water, fat and dirt-repellent features. These so-called hydrophobic and oelophobic layers are being produced using CVD processes (chemical vapour deposition).

Plating of reflector housings
[© Cotec]

Cotec has developed a fluor-organic material which exhibits both hydrophobic and oelophobic qualities when segregated on a workpiece. The layer with a thickness of 5 to 10 nanometres results in a super smooth surface, which is easy to clean for impurities such as water drops, oil, dust, dirt, sweat and fingerprints. Due to its good dynamic friction properties, there is only low abrasion during cleaning, which results in a longer durability of the layer. This layer consists of molecular chains that have an anchor group at one end with which the layer forms a chemical bond on the surface of the substrate and thereby “digs in”. The functional group at the other end is responsible for the water-, fat- and dirt-repellent effect. A superior application potential for this new coating technology is expected for polycarbonate discs.

The focus of Cotec GmbH is on the application and development of nanotechnologies for diverse application fields, such as precision optics and automotive engineering. The layer systems developed by Cotec are used in the automotive industry and its subcontractors for the coating of mirrors, injection-moulded components and reflectors. Apart from Cotec GmbH, Genthe-X-Coatings GmbH in Goslar is also engaged in this business using other technologies.

Further information on this topic can be found in the brochure “NanoOptics”, Volume 5, from the Aktionslinie Hessen-Nanotech series.



Adjustment of surface properties on glass plates (above untreated, below hydrophobic)
[© Cotec]

Electro-chromatic layers for anti-glare rear mirrors

Safety requirements for automobiles are constantly increasing. The number of electronic assistance and service systems that support the driver is also rising at the same rate. Thus the idea suggests itself to support the human senses to achieve optimal attention for safe driving. Nowadays, already rear view mirrors in upper-class vehicles are dimmed automatically for an optimal view at dawn and at dusk.

Here, so-called electrochromic glasses are being applied. The mirror glass is equipped with a functional layer composite. An applied voltage moves the charges into the intermediate layer and causes a change in the optical properties. The ions form colour centres at the electrodes, which absorb incoming light and only reflect a small part. This effect can be reversed by pole change so that the glass gets back its original properties. This process can be compared to the charging and discharging of a car battery and analogies to overloading and memory effect also exist, so that an adequate control unit has to regulate the colouring.

A forward-directed sensor on the rear mirror recognises weak ambient light and signals the system to pay attention to glaring light. For the purpose of optimal dimming, a rear sensor measures the glaring light of the following vehicles and controls the intensity of the light. If the glaring light disappears, the initial state of the mirror glass is recovered.

Gentex Corp. based in the USA has developed its own market segment with the successful production of electrochromic layers and the company is the market leader in the field of automatic anti-glare mirror systems.

Effect of electrochromic coating demonstrated by the example of a rear view mirror
[© Gentex GmbH]

Normal rear view mirror
[© Gentex GmbH]

Maintenance and sealing products for clean surfaces

Maintenance and sealing products are being developed and offered for a series of exterior and interior applications in vehicles.

Left: Anti-finger print on stainless steel **Right:** Anti-limestone
[© NANO-X GmbH]

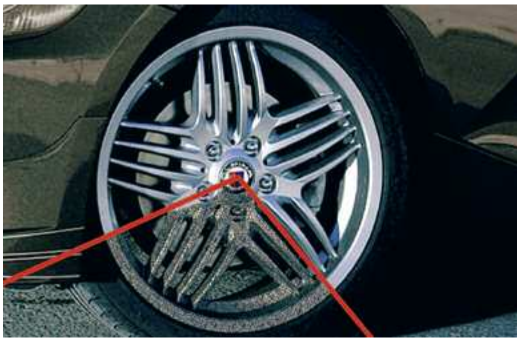
Especially anti-mist and anti-dirt products are used to tune the surface with water- and fat-repellent nanoparticles. Applications include panes and mirrors but plastics and textile surfaces too, making use of the principle of self-organisation where nanoscopic components arrange themselves independently. With the result that an invisible ultra-thin layer in the nanometre range prohibits bonding of oils, fats, water and dirt with the surface. Such surface seals consist of nanoparticles that tightly bond with the subsurface and other components, giving the coating the necessary hardness. The components responsible for hydrophobic and fat-repellent properties adjust themselves towards the surface.

Most of the surface modifications or coatings against dirt known so far are hydrophobic, which means water-repelling. The wettability is so low on these surfaces that the water just rolls off the surface when it is inclined in a certain way, thereby pulling the dirt with it. Many of those surfaces are smooth, others function on the lotus principle. However, practice has shown that the rain drops rolling off leave dirt stains on panes that are clearly recognisable as streaks when dried. Besides, hydrophobic substances tend to produce streaks when used in cleaning substances. If, however, surfaces are constructed such that water can wet it evenly and roll off faster, no runs can develop and the surface will stay clean longer. For this purpose, hydrophilic, which means "water-loving", nanoparticles can be used. The nanoparticles are chosen so that they can adhere to glass especially well. The particles are applied to the surface, where they autonomously form an even, invisible layer.

Their negative charge keeps the neighbouring particles at a distance and the surface becomes "water-loving". Today, this technology is integrated in all window cleaners of Henkel (Henkel 2005).

For paint care, ARAL is using Nanoshine in car wash plants. The nanoparticles used there form a smooth layer, virtually a second skin on the car paint and other surfaces. The nanoparticles fill out uneven surfaces and cavities, producing an extremely smooth surface. As a result, the light rays reflect evenly and the brilliance of the colours is enhanced. A well-known producer of nano-based maintenance and sealing products in Hesse is, amongst others, Da Cie GmbH.

Currently, the term "Nano" is being used in an inflationary way, especially in maintenance and sealing systems. Sometimes products are advertised as "Nano" although their working principle is not based on nanoscale mechanisms.



Dirt protection on car rims with the nano rim protector (protected above the red mark, unprotected below [© De Cie GmbH]

2.2 Applications of nanotechnologies for the body of the car

The safety of road users is an important objective for the development of nanostructured materials and substances. High-strength but flexible nanostructured car body parts could be used as highly efficient crash absorbers. Thus, materials and weight and, consequently, fuel consumption could be reduced. For the supplier industry, the aspects relating to the production technology will be the most interesting in the near future.

Nano steel – stable and inexpensive

Steel is traditionally one of the most important materials in car body construction. Light metals and plastics are increasingly being used in cars given current requirements for lightweight construction, so that the share of steel in cars is decreasing overall. In the mid-70's, a middle-class vehicle had a proportion of steel of maximally 75 per cent in its total weight. Meanwhile, this share has dropped to 50 per cent and is supposed to drop further (Rudolph 2006).

The types of steel used are changing continuously towards high-strength steel grades in order to satisfy future requirements for lightweight construction and crash safety.

A possible way to produce such high-strength steels is using nanotechnologies. Embedded nanoparticles of metallic carbon nitride can multiply the permanent strength of steel. This property is desirable especially in long-lasting constructions such as sky scrapers or suspension bridges, where the material used is subjected to high-temperature fluctuations and is not allowed to fatigue even over a longer period of time. But even in the automotive industry, "fatigue-free" nano steels can be of great interest due to the increasing quantity of goods traffic e.g. in the utility vehicle sector.

When the chromate layer is damaged, the Chrome-VI contained in it can reproduce a protective layer by chemical reaction. Trivalent passivations usually do not show self-healing. [following Langer 2006]

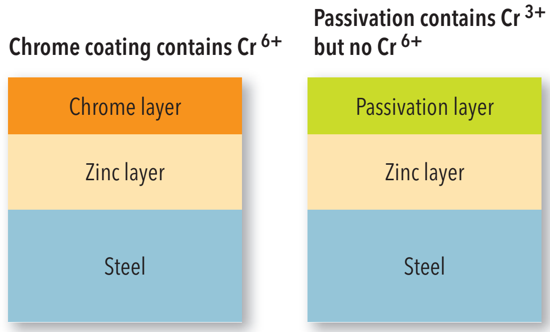
Fine particles that are uniformly distributed over the entire matrix, exploiting the process of dispersion hardening, are responsible for the currently used high-strength steel alloys. However this process is not economical for the production of high quantities of steel. This disadvantage could be history if nanoparticles of metallic carbon nitride were used. Steel with a chrome share of 9 per cent produced by Japanese scientists was additionally variagated with carbon, nitrogen and other hardening substances (Taneike 2003). In long-term loading tests of up to 10,000 hours, it was observed that a share of 0.002 per cent of finely dispersed carbon can increase the stability of the steel significantly. The small size of only five to ten nanometres of carbon nitride particles is responsible for the outstanding properties. The main advantage is that the new material, which is much more stable compared to currently available high-strength steels produced in conventional production processes, can be manufactured considerably cheaper.

Corrosion protection without Chrome-VI

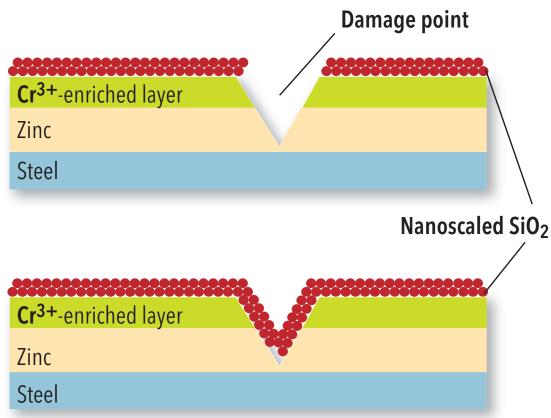
An important topic in automotive engineering is corrosion protection. According to the EU's Old Car Ordinance, the employment of electrolytes containing Chrome-VI has to be discontinued as from 2007 in the frequently used galvanic processes. The reasons for this are health hazards and environmental perils arising from Chrome-VI. Nevertheless, the changeover to Chrome-III containing or chrome-free passivations proves to be difficult. Chrome-III passivated surfaces have an inferior protection, whereas so-called chromate layers based on Chrome-VI have a self-healing effect so that the parts treated in this way whose surface is damaged during transport or further processing are nevertheless protected sufficiently from corrosion.

Application areas of nanotechnological corrosion protection [© Holzapfel-Metallveredelung GmbH]

In contrast to Chrome-VI, Chrome-III (chemically: Cr^{3+}) does not have "long-term protection". Using nanotechnologies it has been possible to eliminate this disadvantage through Silica (SiO_2) nanoparticles in the electrolyte. The passivation achieved through galvanisation processes consists of a Cr^{3+}-enriched layer and a layer containing SiO_2 nanoparticles in a Cr^{3+} matrix.

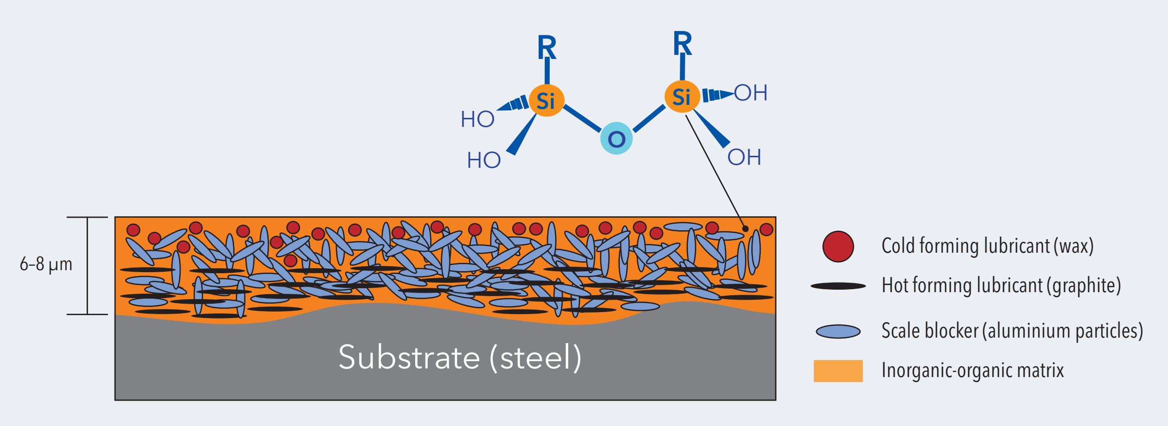


If the zinc layer is exposed due to damage, a positive surface charge builds up. The SiO_2 particles have a negative charge and migrate to the damaged area. The damaged area is thereby covered. The result is "self-healing". Nano passivation is suited for zinc and zinc-iron layers. The layer thickness is approximately 400 nm.



Corrosion protection and self-healing of the surface. If the zinc layer is exposed due to damage, the SiO_2 particles migrate to the damaged location and cover it [© Langner 2006]

At Holzapfel-Metallveredelung based in Sinn (Hesse) and at Herborner-Metallveredelung the special process for transparent zinc-iron layers was integrated successfully into a galvanisation process adapted to the coating of high-value bulk articles. In the fog test, the coated parts resist for 360 hours till white rust and 720 hours till red rust (360h WR/720h RR). Thus there is no loss of corrosion resistance even at temperatures of 120°C over a period of 24 hours. The Chrome-VI free process is already being used successfully for parts of chassis, brakes and doors.



Schematic set-up of nanocomposite coating for hot forming

[© University of Kassel]

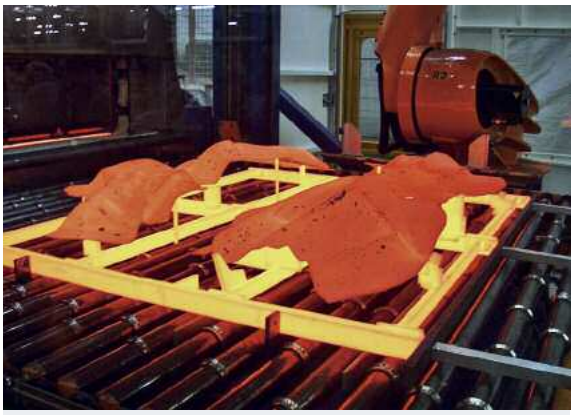
Nanotechnologies for the forming of high-strength steels

In the manufacture of body parts, automotive producers had to make an enormous effort to fulfil increased requirements for crash and passenger safety. Forming and joining technologies for ultra high-strength steel plates are being sought. The recasting of high-strength steel materials in cold state leads to problems relating to size accuracy and unwanted spring-back effects. An alternative to recasting special high-strength steel grades while avoiding these disadvantages is what is called hot forming, where steel sheets are heated to almost 1000°C and formed in the forming tool and cooled discretely. Using this process, parts of the highest strength and of perfect fit can be produced e.g. for a safety cabin.

For the hardening process, the steel sheet is heated up to a temperature of 950°C and pressed red hot into the form directly from the furnace until it reaches its final geometry. The hardening takes place by quick and selected cooling to temperatures below 200°C in the form. The coating of the plates, which has to fulfil several functions, is crucial for the control of such forming processes. The coating has to avoid the impurities of the unit surface caused by the heat treatment process through oxidation of the workpiece surface – called scaling. Furthermore, the friction between the workpiece and the tool has to be reduced and a sustainable corrosion protection assured.

Based on a novel approach of the University of Kassel, a multifunctional coating system was developed that is capable of solving the problem of scaling at high temperatures. The multifunctional protective coating was realised through a combination of a nanotechnological approach with the principles of conventional paint technologies. Thereby, vitreous and plastic-like materials in the nanometre range are bonded and connected together with aluminium particles to form a protective layer.

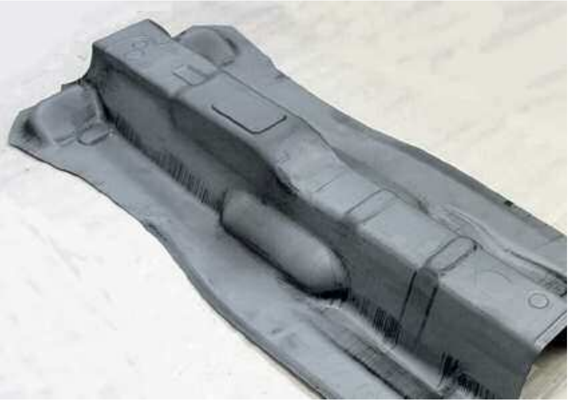
In a project syndicate of the partners Presswerk Kassel of the Volkswagen AG, ThyssenKrupp Steel AG, NANO-X GmbH, Dortmunder OberflächenCentrum GmbH and the Faculty of Forming Techologies of the University of Kassel this development was ready to start series within six months only. Including all application problems arising within the process chain, from the creation of the primary material at the steel producer to the application in the production line of the automobile manufacturing.



Sheet plate components pre-heated to 950°C

[© Volkswagen AG, Presswerk Kassel]

Pre-finished form-hardened tube of the new VW Passat
[© Volkswagen AG, Presswerk Kassel]



Application centre for metal forming (AWZ)

In future, nanotechnologies could gain in importance even more through the introduction of the new application centre for metal forming in Baunatal in 2007, financed by the EU and the state of Hesse amongst others. The AWZ is the first segment of an R&D centre for the "mobility economy" of Northern Hesse. Here, metal manufacturers are called upon to improve their products and processes in the process of fabrication by innovative procedures, e.g. from nanotechnologies, in order to be able to produce more economically, quickly and more qualitatively. A new building for the technicum, test laboratory and workshop sectors are planned. Apart from regional companies, the University of Kassel as the main partner is supplying a part of the machinery and the staff. The scientific supervision is done by Prof. Dr. Kurt Steinhoff, who has a chair for forming technologies at the faculty of mechanical engineering. The AWZ will benefit the approximately 600 enterprises in the whole region but will also be able to offer services for national companies.

Further information on this topic can be found in the brochure "NanoProduction", Volume 6, from the Aktionslinie Hessen-Nanotech series.

Ferrite dispersions of different concentrations
[© SusTech GmbH & Co. KG]

Gluing and detaching of components on command

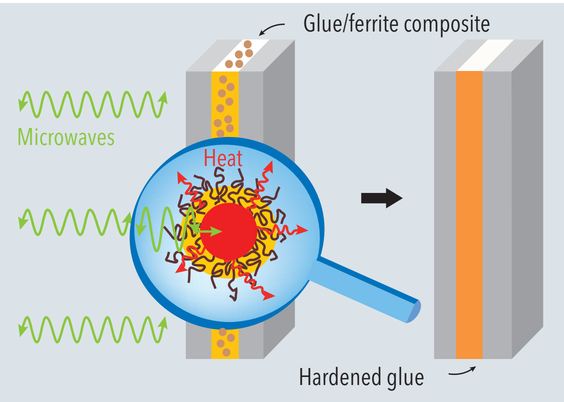
Gluing is gaining in importance in industrial construction processes, as different materials can be joined together and a processing of the joint can be omitted. Furthermore, the use of glued connections promises cost advantages. The share of glued joints is especially increasing in automotive engineering. Gluing processes can easily be integrated into automated manufacturing sequences. Unlike common glues, many industrial types of glue do not harden at room temperature. Additional energy, mostly in the form of heat, has to be applied externally to launch the gluing process. In practice, the parts to be glued are treated in a furnace or with a hot air stream at approximately 180°C. Since the gluing surfaces are often covered, the connecting parts are heated as well. The energy consumption and the thermal stress of the components are accordingly high.

One approach is to only heat the glue layer selectively by microwave radiation (SusTech 2003). The glue is tuned with special particles acting as aerials. They receive the electromagnetic energy, convert it to heat and emit it to the surrounding glue. This is called "gluing on command". Here it is necessary to provide particles that are substantially compatible with the glue on the one hand and meet the physical requirements to absorb the energy radiation effectively on the other hand. The solution is ferrite, i.e. doped iron oxides, which have a particle diameter of 10 nanometres. Due to their large specific surface, these nanoferrites are highly suited for the gluing process. Their optimum absorption frequency can be adjusted to the radiation source through chemical composition and the particle size. These nanoparticles heat up the glue layer uniformly and selectively. Another advantage is the "implemented overheating protection". The higher the temperature, the lower the ability of the ferrites to absorb additional radiation and to produce heat. This prevents local overheating within the gluing layer.

This newly developed process consumes significantly less energy. At the same time, the gluing process is accelerated and thereby the cycle length reduced. A further advantage is that in future painted parts and heat-sensitive plastics can be glued because of the economical glue hardening. This could open up new possibilities in the field of lightweight construction.

SusTech from Darmstadt has developed the first relevant system solutions that can be used not only for "gluing on command" but also for the reverse process, "detaching on command". Normally, higher temperatures are required for this purpose. When the vehicles need to be disposed, the glued parts can be detached "on command" again using the same principle. In this way, the joined parts can be separated non-destructively. This enables the substitution of single parts during repair, homogeneous recycling or even re-use.

SusTech was founded by six scientists from the University of Technology in Darmstadt together with Henkel KGaA. The focus of the enterprise is on the field of new materials. SusTech Darmstadt, a successful public-private partnership project, has already developed numerous nanotechnology-based processes and products in different application fields.

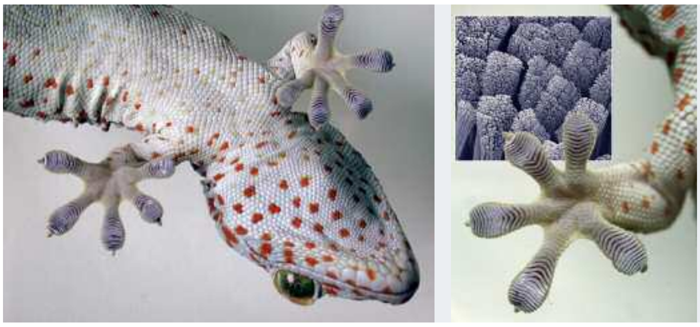


Principle of microwave adhesion [© SusTech GmbH & Co. KG]

Further information on this topic can be found in the brochure "NanoProduction", Volume 6, from the Aktionslinie Hessen-Nanotech series.

Gecko effect for automotive production

Geckos are true porch climbers. They can climb any wall, run headfirst on ceilings or hang on the ceiling on just one leg. Special trials to assess the dependency of the adherence and the feet geometry have



Left: Gecko on a glass plate

Right: Enlargement of the foot

[© Dr. Stanislav Grob, Evolutionary Biomaterials Group, MPI for metal research]

shown that the macroscopic size and shape of the geckos' feet hair dictate their adherence properties. The hair is approximately 100 micrometres long and branches into smaller hair of approximately 10 to 20 micrometres in length. These end in very thin plates, called terminal plates, which are 10 nanometres thick. This structure enormously enlarges the contact surface on the trap. It's assumed that that the climbing abilities of the gecko are based on the weak molecular Van der Waals forces, which become strongly adhesive through the individual tiny hairs and their nanoscopic size. The contact of 10 per cent of the hair is just enough to carry the gecko.

The first synthetic gecko hair ends have been made of polydimethylsiloxane and polyester. The ends from both materials adhere just like the natural examples. There are numerous possible extensive applications of these biologically inspired adhesive microstructures in production and products, even though questions regarding series manufacturing methods need to be clarified further. Universal grabbers for production facilities are imaginable, as a result of which grabbing tools do not have to be changed and can also be used surface-independently. Their use in the joining industry would also be possible, where the adhesive areas would be detachable again and no glue would be required any more.

In the interior of the car, dirt-repellent seats, air filters designed to filter particles and gaseous pollutants, but also anti-glare coatings of dashboard covers play an important role. Here, not only the comfort but also safety aspects of passengers are crucial.

Nanofilters for clean air in the interior of the car

The automotive industry tends to especially provide to its customers enhanced comfort besides improved safety and reduced fuel consumption. Here, the climate inside the car is an important factor among other things, mainly influenced by the air quality. For the improvement of the air quality in cars, a great importance is attached to filtration of particles and gaseous pollutants. Meanwhile, cabin air filters belong to basic equipment in new car models after having been applied for the first time 10 years ago.

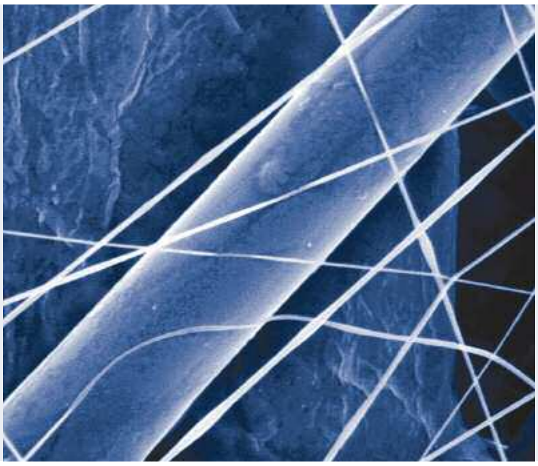
High-quality interior air filters have to remove a great amount of particles (e.g. pollens, spores, industrial dust) as well as odours from air entering the car. The filter has to function at temperatures between –40°C and +100°C under changing humidity conditions and endure vibrations, water and microbiological fouling.

Novel filters covered with nanofibres exhibit even superior filter properties in comparison to conventional solutions. Since the fibres are in the nanometre range, the classical laws of fluid dynamics are not applicable any more. The result is lower air resistance, so that energy is saved and the air can be transported almost without any loss of pressure. The generation and the application of the nano fibres is done by electro spinning, a speciality of the professors Dr. Andreas Greiner and Dr. Joachim Wendorff from the Philipps University of Marburg to name just a few. Air filter systems are produced by helsa-automotive GmbH & Co. KG for example.

Nanofiltration is also used in newly developed soot filters. Their objective is to significantly reduce the pollutant emissions in passenger and utility vehicles. Sooty particles are removed from the fuel gas stream and collected on a metallic fleece, thus eliminating them from the exhaust gas. The particles are deposited in the tiny pores of the fleece and are burned continuously at temperatures above 200°C.

Hollingsworth & Vose from Hatzfeld/Eder has been combining the production of filter media with the production of very fine fibres on a nanotechnological basis for several years. Within the project NANOWEB©, special high-performance filters have been developed in cooperation with the Philipps University of Marburg on the basis of refinement with nanofibres. At Hollingsworth & Vose the electro-spinning procedure is applied. The project NANOWEB© was awarded the innovation prize of Hesse in 2004. Another producer of special fuel filters is Faudi Aviation Fuel Filtration GmbH, also based in Hesse.

Other developments concern the supply of the filtered and conditioned air in the car cabin. To avoid the mentioned draught through the air conditioner, the air could be discharged through special foam on the car roof. Using nanotechnologies, the foam could be fitted so that the dirt particles in the air do not adhere to the foam material and thus do not pollute it. The heat insulation of foam will also be improved significantly using nanotechnologies.



Magnified section of a Nanoweb® filter
[© Hollingworth & Vose]

By decreasing the air bubble size in foams from 0.1 millimetre to 100 nanometres, a substantial reduction of the number of the molecules per cell is achieved. The isolated molecules thus have no chance to transmit their energy to other molecules. Collisions of molecules that are partly responsible for the heat transfer are thus largely eliminated. Desirable heat insulating properties can be achieved with clearly thinner insulating layers.

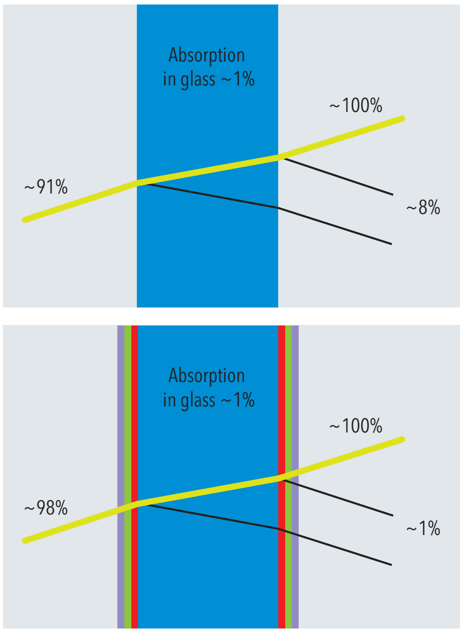
Further information on this topic can be found in the brochure "NanoProduction", Volume 6, from the Aktionslinie Hessen-Nanotech series.

Anti-glare layer for improved vision

Anti-glare coating on dashboards [© Volkswagen AG]

The avoidance of unwanted reflections on dashboards and cockpit instruments helps improve traffic safety. A surface coating in the nanometre range can directly influence the behaviour of light penetration into the transparent material.

The surface structuring in the micrometre range allows the prevention of reflections for a wide range of wavelengths. This functional principle has been copied from the moth's eye. An additional nanostructuring of the surface results in a refraction index gradient moving from the outside to the inside, so that light waves are practically not reflected. This surface structure is interesting from the aspect of cost reduction. Instead of multiple coating steps, these special surface structures can be realised in one process step. Ideally, the structuring step is combinable with the production process. Another anti-glare method is the production of nanoscaled air inclusions on the surface. These pores reduce the total refraction value of the layer. Pores smaller than 1/20th of the light wavelength can't be dissolved by light and thus do not have any unwanted diffusion effects. Apart from questions regarding optical properties, possibilities of integration into the existing production processes are also being investigated as well as their suitability from the viewpoint of mechanical stability (Volkswagen 2003).



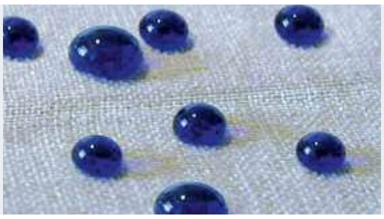
Schematic representation of the function of anti-glare coatings on glass [© Volkswagen AG]

Anti-reflection coatings are not only interesting for instruments. Another focus of the work is the avoidance of reflections of the instrument panel on the windscreen. Depending on light conditions, streaks and reflections on the windscreen can result if bright instrument panels are used. Technically, the problem is solved using black or at least very dark instrumentation boards. If the reflections on the windscreen could be greatly reduced, attractive design possibilities could result. For physical reasons, a sufficient anti-reflection coating of the windscreen is only possible if both sides are coated. But especially the outer side of the windscreen is subjected to such extreme stress for which no currently known system seems to sufficiently meet the high quality requirements of automobile producers.

Further information on this topic can be found in the brochure "NanoOptics", Volume 5, from the Aktionslinie Hessen-Nanotech series.

Contamination control and fragrance for new car seats

Car seats often come into contact with wet or dirty clothing. When the door is opened, rainwater or snow can get onto the seats causing water and dirt stains. Theses unwanted effects can be minimised or even avoided by using materials for the impregnation of fabric and leather coverings. Such substances have spread rapidly in the last few years and are being offered by many producers of accessories in spray cans or fluids. There are products for tissues, leather, and leatherette alternatively that are commercially offered on inorganic-organic hybrid materials based on aqueous or alcoholic solutions.



Left: Oil drops on impregnated fabric [© De Cie GmbH]

Right: Water drops on impregnated leather [© De Cie GmbH]

After a dipping or spraying application, a thin invisible film builds up covering the fibres. The impregnated layers have a significant hydrophobic and fat-repellent effect. Thus the rate of humidity penetration in case of water and pollutants entering is reduced. A similar clever effect is exploited to produce specific fragrances on leather seats. Dispersions with micro capsules that can be sprayed contain scents. Aqueous micro capsule dispersions offer the possibility to furnish for instance leather with diverse fragrances (Bayer AG, 2005). On the one hand, the capsules have to be small enough to penetrate the leather; on the other hand, they have to be big enough to adhere between the fibres. After spraying the capsules penetrate the leather reaching different depths. The shell of the capsule is only a few nanometres thick and made of polycarbamide. The scent is placed inside. Only when the capsule is stressed mechanically does the nano film burst and release the fragrance. If the seat is unused, the capsules stay intact and the scent stays enclosed. What is working on leather already can be applied on textiles as well.

One producer of impregnation substances that consist of inorganic-organic hybrid materials is De Cie GmbH located in Hesse. Aqueous micro capsule dispersions are produced by Bayer AG.

2.4 Chassis and tyres

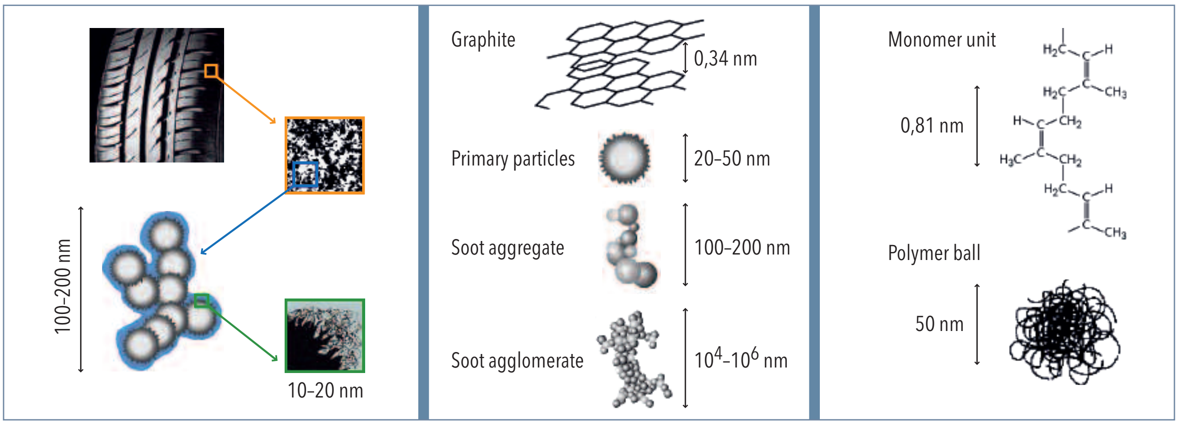
Tyres are definitely the most often cited applications of nanotechnologies in automobiles. Here, today profits amounting to billions are being made. Nevertheless, tyres are high-tech products that are being developed continuously. The application of new nanoscaled particles leaves room for future improvement of running qualities and reliability.

High-tech tyres with nanostructured soot

An important role in the properties of tyres is played by rubber mixtures. They determine the performance of the cover of tyre that makes contact with the road. Usually, 30 per cent of the cover consists of reinforcing filler which makes possible wanted properties such as grip, abrasion resistance, resistance to initial tear and tear propagation (Klockmann 2006). For the optimisation of tyres, contradictory requirements sometimes have to be fulfilled. On the one hand, the tyre needs good grip while, on the other hand, its rolling resistance has to be low. Furthermore, it needs to be resistant to abrasion while being slip-proof, prohibiting the vehicle to slide.

The mechanisms behind these tyre properties that partly contradict each orther are many highly complex chemical and physical interactions between the rubber and the filler material (Oberholz 2001).

Right: Modern passenger car tyres – here the layout of a so-called RunOnFlat tyre by Dunlop – are very complex technical products, whose development and production make the highest demands on modern manufacturing technologies. [© Dunlop GmbH & Co. KG]



Layout of a tyre running surface. Comparison of size between individual components. [© Volkswagen AG]

There are three products that significantly improve the properties of natural rubber: soot, silica and organosilane. Soot is added to the rubber mixture, whose exact composition is secret, as are silica, which need organosilica for the chemical bonding with the rubber. After being produced, the soot and the silica particles have dimensions in the nanometre range. The size and form of the particles as well as the cross-linking with the natural rubber molecules play a key role for tyre properties.

Tyre components: Soot (carbon black) above, Silica bottom left and Organosilane bottom right [© Degussa AG]

Soot and silica, which are the two most important reinforcing chemicals in tyres, originally had differing functions: while silica scores higher in passenger cars, especially on the cover of tyre, soot prevails in utility vehicles not only because of its excellent abrasion resistance (Oberholz 2006). By using nanostructured soot as a filler in tyres, prolonged durability and higher fuel efficiency can be achieved. These novel soot particles have a coarser surface than those that have been used so far. Due to the increased surface energy of the nanoparticles, interactions with the natural rubber molecules increase. This leads to a reduction of inner friction and, consequently, to better rolling resistance.

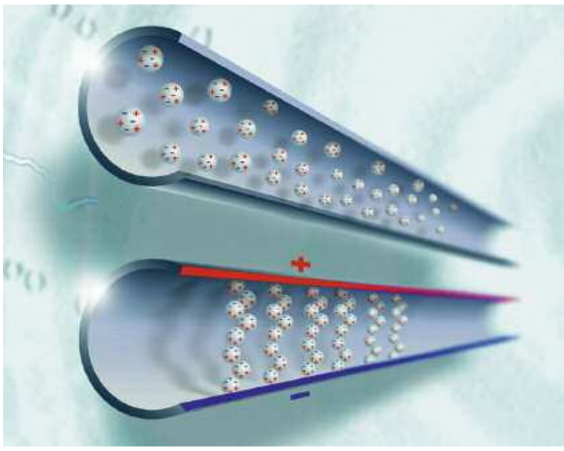
At the same time, the strain vibrations that occur within the material at high speeds are reduced. The consequence is a superior traction, especially on wet roads.

For the production of nanostructured soot, a modified burning process was developed by Degussa AG, which ensures the profitableness of this production technique. Hesse is strongly represented in Germany in the field of tyre producers and suppliers for automobiles and motorcycles. Apart from leading tyre producers such as Good-year Dunlop in the Hessian plant in Fulda and Hanau, Pirelli in Höchst, Continental in Korbach and Bridgestone Germany in Bad Homburg, world market leaders in the supply of tyre fillers such as Degussa and Cabot are located in Hesse.

Driving comfort through switchable materials

In the design of an automotive chassis, there is always a conflict between comfort and safety. A "soft" chassis is considered comfortable, a "hard" one, on the other hand, is considered safe. In adjustable damping systems, the optimal hardness can be adjusted depending on the situation.

The core of these adjustable damping systems is the so-called magneto- or electro-rheologic (MR/ER) fluid, which is classified as "a smart material". In these fluids the viscosity can be changed instantly, stepless and reversibly by applying a magnetic or electric field. The effect is based upon the fact that polarised particles in the substrate fluid arrange themselves along the field lines and form chains. The effective viscosity is thus increased, which means that the flow resistance of the fluid rises. If the magnetic or electric field is removed, the chains decompose and the fluid becomes thin again.

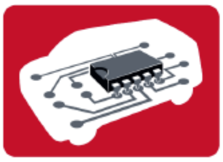


Viscosity control by application of an electrical field [© Fludicon GmbH]

This change can happen very quickly. In milliseconds a fluid can be transformed into a tenacious gel. A special oil of Fludicon (Darmstadt) can switch between fluid and solid states 1500 times per second. Such speeds are especially interesting for hydraulic systems, since modern high-pressure systems nowadays can only close 400-500 times per second. Another advantage over conventional systems is that they can be built more simple and compact. Less mechanical parts are needed, which can result in weight reduction. Fludicon has used this property to design valves without moving parts. Classical application fields in the automobile are dampers, actors and gears. In the field of actuators, the dream of an active chassis could soon come true. Chassis can be realised that are able to even out irregularities of the road and compensate driving dynamics.

This has been developed under the Federal Ministry of Education and Research (BMBF) project "Adaptronic Transportation System". Within another BMBF/WING project, the integration of the adaptive system into the chassis was successfully made. Research by the Frauenhofer LBF in Darmstadt is being supervised by Prof. Hanselka, who is also responsible for the BMBF's lead project Adaptronics.

Adaptronic transportation system for maintaining the position of a transport medium [© Fludicon GmbH]



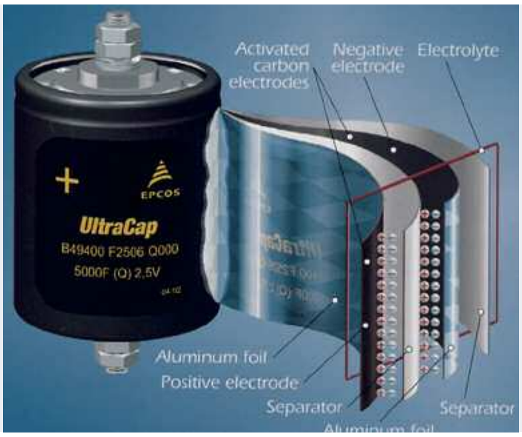
2.5 Electrics and electronics

At his stage electronics is an innovation driver in the automotive sector, since more and more components are being controlled electronically, electromechanically or electromagnetically. Nanostructured actor components could substitute current microsystems technology-based direct injection systems for instance. The replacement of tungsten filaments by economical and durable LEDs is current practice today and will certainly expand. Alternative proposals for car drive lines, such as fuel cell technologies that are currently topical in the R&D of almost all OEMs, could get some innovation push from nanotechnologies, for instance in the field of hydrogen storage.

Super caps as efficient energy storage

With the spreading of different hybrid drive concepts, systems for the reuse of braking energy, known as recuperation, are being enhanced. Thereby, the moving energy is converted into electrical current via generator during braking and stored in accumulators or super caps. This energy is available at the restart for acceleration. Principally, caps can buffer very quickly and almost without any loss compared to accumulators. Nevertheless, so far only caps with a low capacity have been available for the automotive sector.

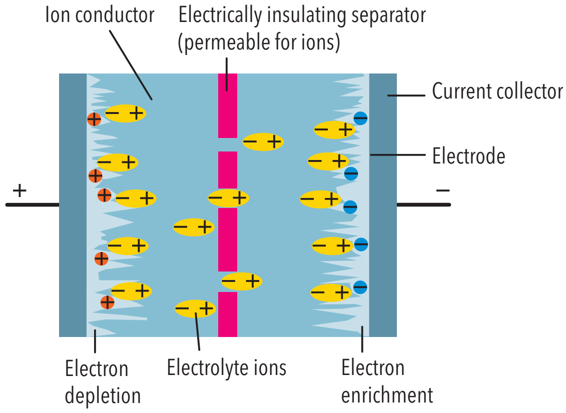
Using nanotechnologies, super capacitors – short super caps, ultra caps or scaps – with high-energy capacities are currently being developed and realised. Super caps consist of a metallic contact foil and of highly porous layer electrodes with nanostructure, electrolytes and a separator foil. In super conductors there are 10 to several 1000 Farad in one package. If a 100-Farad super cap has the size of a match box, this would correspond to a capacity of 100 million standard capacitors connected in parallel with a capacity of 1 Farad. Therefore, the super cap is the link between the common capacitor and the battery (Fischle 2005). It combines the advantages of a capacitor, which is a quick current supplier, with those of the battery, which is an appreciable energy storage device. In comparison to conventional caps, a material that conducts ions but no electrons is used instead of non-conducting electrolyte. The charge concentrates on both sides of the boundary surface on a very thin layer of approximately one nanometre, which leads to a high capacity. On the other hand, the application of highly porous layer electrodes allows for a large effective surface, which also contributes to the high capacity (Böcker 2006). Super caps feature very high power densities and low internal resistances and are applicable for short-term maximum current supply. Therefore, they are flexibly usable high-power storage elements with almost unlimited durability and a solid energy balance and eco-balance.



Set-up of a super capacitor [© EPCOS AG]

In future, a large number of super caps is expected to be applied in hybrid vehicles. But also in fuel cell vehicles, super caps complete the short-term energy supply of power-intensive driving. Further potential automotive applications also include the supplementation of the battery storage of the 42-V automotive power supply system. An increasing number of power-intensive consumer applications, such as electromagnetic door locks and valve actuation or catalyst pre-heaters, have to be supplied on short notice. Start/stop operation with the alternator also requires a high short-time power supply, which could be recovered by means of braking energy. In this regard, enormous fuel saving potentials are being predicted.

Nanotechnologies are also being applied in high-performance lithium ion batteries, the main future power source of hybrid drives. Lithium ion batteries are increasingly gaining in importance since they are smaller, lighter and more powerful than lead- or nickel-metal hydride alternatives. Up to now semi-permeable membranes have been used as separators in lithium ion batteries for the separation of the anode and the cathode (Oberholz 2006).



Schematic illustration of a super capacitor. Extremely high capacitances are achieved through the formation of double layers on the electrodes and their large specific surface. [following Bauer 2005]

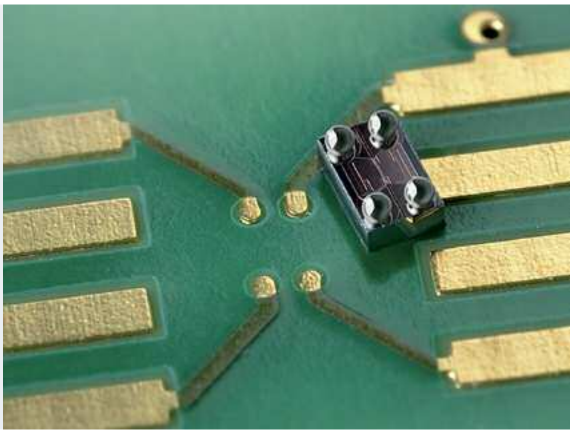
However, such separators have serious disadvantages. For instance, they are not sufficiently temperature-stable and combustible. The separator developed by Degussa overcomes these problems. It concerns a two-sided ceramic coating of a PET polymer matrix, which shows inappropriate chemical and thermal stability while being flexible at the same time. The starting point of the ceramic layers are nanoscaled powders of different metal oxides. Meanwhile, Degussa holds 25 patents for this special technology covering products and processes as well as applications.

Paper produced by the special paper manufacturer Oberschmitten GmbH for operation as separator material in super caps. The main advantage of the paper is its fine and dense structure with simultaneous good permeability for the electrolyte. [© Spezialpapierfabrik Oberschmitten GmbH]

Nanosensors in automotive applications

Steering angle sensor based on the GMR effect [© Robert Bosch GmbH]

Sensors that are sensitive to the driver's intention and are capable of monitoring the state of a number of aggregates are basic components of today's mechatronic systems in automobiles. In moving systems, position and angle sensors play a key role. In order to improve the reliability of mechatronic systems, contactless magnetic field sensors are increasingly being applied that operate on the magnetoresistive principle. There are a number of applications in automobiles for such magnetic field sensors. Examples include ABS, door windows, sun roofs, control of driving dynamics or steering angle sensors.



Magnetoresistive GMR sensor which has multiple layers with thicknesses of 2 nm and which is reversely positioned onto a board using Flip-Chip Assembly with four 300 µm thick lead balls. [© Sensitec GmbH]

The measuring principle of a magnetic field sensor consists of the conversion of a position or movement information of a magnet to an electric signal, using the giant magnetoresistive effect (GMR). The GMR effect only takes place in extremely thin layers. The thickness of these layers is only a few nanometres. In its simplest form two magnetic layers enclose a non-magnetic layer. If the two magnetic layers are magnetised inversely, the electrical resistance in the layer system is higher than in the case of rectified magnetisation. Because of the noticeable change in resistance, which in practice can add up to 50 per cent, this effect is called "giant".

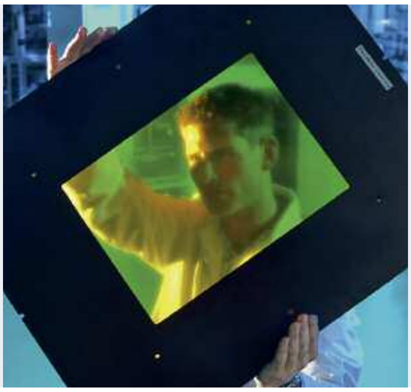
GMR sensors can be built much smaller than conventional magnetic sensors. Further advantages of the GMR sensor are a low power consumption and a significantly lower temperature dependency of the measured signal. Even at high temperature fluctuations, they provide relatively constant measurement values and thus can be applied at high temperatures as well, e.g. in the vicinity of the motor. A special challenge facing production technology is the reproducible manufacture of nanometre thin layers, which so far have been brought to serial production only by a few companies.

Sensitec GmbH from Lahnau in Hesse has been the first European company to start the series production of GMR sensors. The company has been successfully operating in the field of GMR sensors for industrial and automotive applications. The sensors are being applied in electrical power control for instance. At the moment, Sensitec is the owner of the currently most capable chip factory for magnetic sensors in Europe.

Fuel cells for the car of the future

The electronics in the automobile is an intrinsic innovation driver with ever-new applications. Power consumption in automobiles has risen drastically over the past few years. Apart from entertainment electronics, new safety and comfort functions have gained in importance. These electricity consumers are increasingly stressing the energy supply in the automobile. Also due to the low degree of efficiency, today up to a third of engine power has to be used for electricity generation. Because of the increasing shortage of fossil fuels and the resultant high fuel prices, alternative and efficient energy sources are becoming more and more important. Fuel cells could solve a series of problems. Probably the biggest advantage is the high efficiency of the fuel cell, which can be used to substantially reduce fuel consumption. In combination with an accumulator, it could equally produce sufficient power for the vehicle's system and relieve the engine drive, which could then be given smaller dimensions.

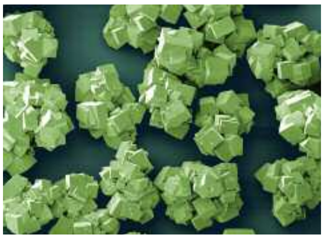
The fatigue strength and sustainability for everyday use of the fuel cell car HydroGen3 was tested successfully by GM and Opel through a marathon tour. On the 10,000 km long journey through Europe in June 2004 the prototype crossed 14 countries. [© Adam Opel GmbH]



Preparation of the membrane electrode unit in the production facility [© PEMEAS GmbH]

Pure fuel cell vehicles can completely do without a combustion engine and concentrate on a combination of the fuel cell as energy converter and the electro-engine or several electro-engines for the drive respectively. The accumulator or a super cap takes up power peaks while the fuel cell runs evenly, recharging the battery. The high-temperature PEM fuel cell, which operates at 160°C-180°C, tolerates impurities and can be easily cooled, has excellent prospects.

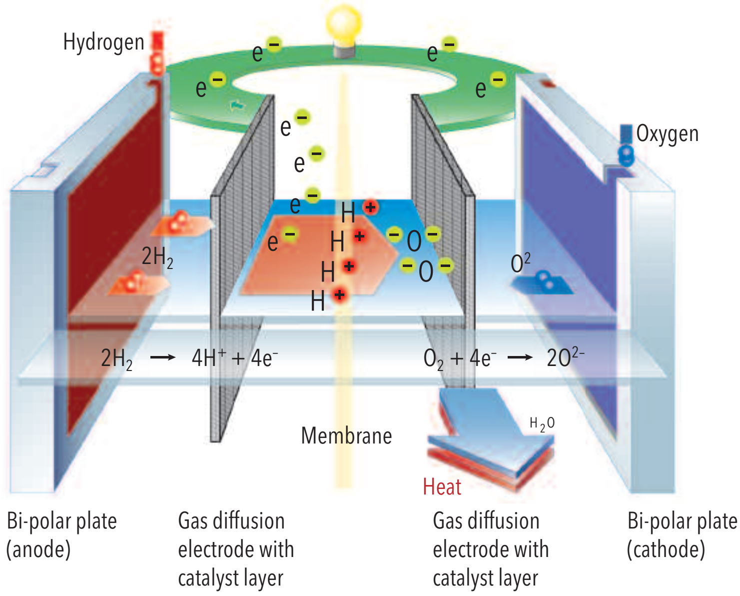
The actual chemical reaction between hydrogen and oxygen that results in current and heat occurs in the core of the fuel cell, the so-called membrane electrode unit (MEA). The splitting of the hydrogen molecules at the anode into ions and electrons and of the oxygen molecules at the cathode takes place between the gas diffusion electrode with catalyst and the membrane. A surface of the catalyst that should be as large as possible is essential for the operation of the membrane electrode unit and therefore for the performance of the whole system. The enlargement of the active surface can be achieved using nanoscaled platinum molecules. There are different concepts for the effective bonding of the platinum molecules. The challenge is to distribute these particles equally, to keep the surface free and to avoid an agglomeration during the operation.



Highly porous nano cubes for hydrogen storage [© BASF AG]

But effective hydrogen storage, which in the view of current science can only be solved by nanocrystalline materials, is a challenge too. Even though the application of fuel cells in automobiles has been delayed, fuel cells are largely being used in prototypes and test vehicles already.

PEMEAS in Frankfurt has established itself as the leading provider of core components and subsystems for the booming fuel cell industry. Since the company is continuing the fuel cell activities of former Hoechst AG, which was set up as early as 1994, it can look back on more than 10 years of experience. PEMEAS is continuously improving membranes and catalysts to enhance fuel cell performance, and to increase its robustness and cost efficiency. Umicore, which is located in Hanau, is another important world-wide important producer.



Schematic representation of the functionality of a fuel cell [© PEMEAS GmbH]

In academic research, the workgroup of Prof. Dr. Fröba of the Justus Liebig University of Gießen is engaged in the synthesis and characterisation of nanoporous materials for gas storage. A team headed by Prof. Dr. Scheppat from the University of Wiesbaden is working on different aspects of fuel cell technology.

Solar energy in automobiles

Solar cells have long been discussed as an additional source of energy supply for the electric and electronic components in automobiles. Normally, silica-based solar cells are used to generate electrical current from sunlight. Their production is costly and complicates their use on a large scale, since the semiconducting materials require extremely clean atomic lattices for this application. In 1991, a solar cell invented by the chemist Michael Grätzel of the "Eidgenössische Hochschule Lausanne" and which is based on biological principles made news. He then predicted low production costs and durability. The cell referred to as the "Grätzel cell" is geared to the photosynthesis of plants for energy generation from sunlight.

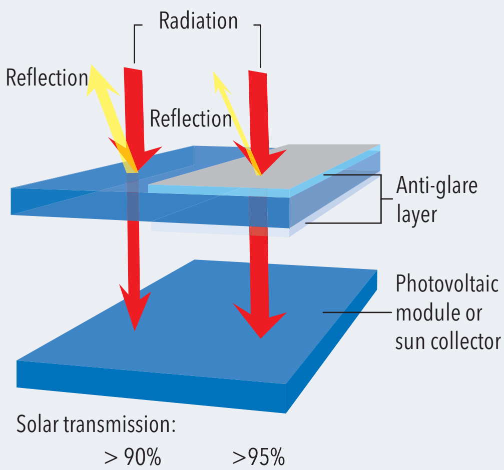
In the conventional cell, the silicon supplies the needed electrons when exposed to sunlight. These can migrate to the electrodes owing to the electrical conductivity of the semiconductor. In the "Grätzel cell" both those functions are fulfilled by different substances. An organic substance, such as chlorophyll, handles the electron supply. A nanoporous titan oxide layer with a large surface is used for the transmission to the electrodes. The design is such that two glass plates have a transparent electrode each. Plate 1 carries the layer with the dye-sensitised titan oxide layer. Plate 2 is coated with platinum as catalyst; in between there is the electrolyte solution.

The low-light efficiency compared to silicon-based solar cells is compensated by the specific property to deliver current even at weak light radiation. Due to its simple design, the possibility to realize large surfaces and a low environmental impact during production, the "Grätzel cell" is said to have a enormous future potential.

Micro-structured solar cells integrated in car sunroofs could be substituted by nano solar cells in future [© DaimlerChrysler AG]

The costs for future high-volume production are estimated at 20 per cent of the silicon-based solar cells.

Further information on this topic can be found in the brochure "NanoOptics", Volume 5, from the Aktionslinie Hessen-Nanotech series.



A 150 nm thin layer of silica balls reduces surface reflection on glass from eight to two per cent. [© Merck KGaA]

A difficulty concerning conventional solar cells is the efficiency loss due to the reflection of light at the solar glass pane. This loss represents almost 10 per cent even in high-quality solar glass panes. The companies Merck KGaA and Centrosolar Glas GmbH & Co.KG together with the Fraunhofer Institutes ISC and ISE have succeeded in developing a glass coating on the basis of the sol gel technology. The coating reduces the reflection of the sunlight and thus increases the efficiency of solar systems by up to 6 per cent. The special know-how of the scientists from Merck has contributed to the development of the sol. It consists of a mixture of silica balls in two sizes distributed in a solvent mixture. The desired nanoporous layer, which applies a wideband antireflection coating, results from a combination of particles with diameters of 10 nm and 35 nm. In order to coat the glass pane with SiO_2 hybrid sol Solarpur©, they are dipped into a tank containing the sol and pulled out at constant speed. The thickness of the antireflection layer can be influenced by the drawing speed. The optimum thickness for solar applications is 120 nm. When the panes are dried using a gel, the sol becomes the nanoporous layer, which is hardened at 600-700°C together with the glass. The low refractive index of the layer (of only 1.25) causes a reflection reduction over the whole energetically usable spectrum of light from 400 nm to 2500 nm. The solar transmission (AMI 1.5) increases from 90 per cent (high-quality solar glass) to over 95 per cent.

Preparation of the engine block for nano coating (left) and coating of the engine block (right) [© DaimlerChrysler AG]

Measures to improve combustion efficiency, such as a fully variable valve control and ultra-precision fuel injection, optimise the combustion process and lead to improved fuel consumption. But also the minimisation of engine friction by new nano layer systems can result in fuel savings in future.

Low-friction aggregate components for fuel saving

In modern passenger cars 10-15 per cent of the fuel consumption is influenced by engine friction due to the friction loss at the moving mechanical parts. Among these parts are, apart from the piston aggregate, comprising the cylinder wall and the piston, the elements of the crank drive (crank shaft, connecting rod and bearings) as well as the valve drive group, including the cam shaft and the valves. The friction of the piston aggregate causes the major part of the mechanical friction losses. Nanotechnologies can help reduce fuel consumption by reducing friction.

Nanocrystalline coating materials applied onto the cylinder wall reduce friction and abrasion and thus fuel consumption. DaimlerChrysler AG has started the research project "Nanocrystalline composite coatings for cylinder tracks with nanostructured surface and abrasion prediction for highly stressed petrol and diesel engines NaCoLab" together with other partners from the industry and universities within the framework of the lead innovation project Nanomobil of the BMBF. The aim of the project is to directly coat the tracks of the aluminium crankcase with nano materials. Thereby it has been possible so far to remove the cylinder barrel needed in aluminium crankcases. Coating materials with embedded nanocrystals with a size from 60 nm to 130 nm on the basis of iron carbide and boride result in extremely hard surfaces with low friction properties.

Piezo injectors for ultra-precise fuel injection

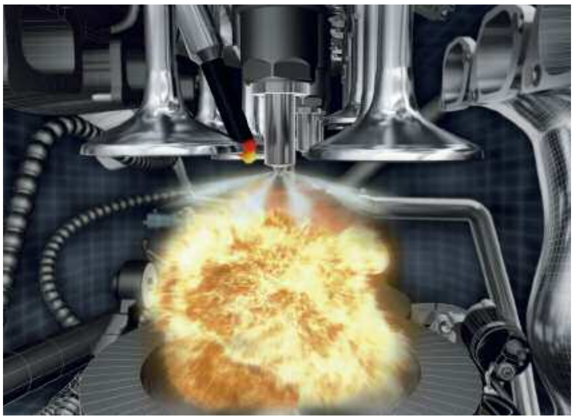
Modern high-efficiency diesel systems work on the basis of high-pressure injection systems. In the case of direct injection, a pump first builds up high pressure before it shoots the fuel finely dosed into the combustion chamber of the cylinder via a nozzle. The precision with which this happens directly influences the combustion process. The higher the pressure and the more precisely the dose and time of injection can be controlled, the more efficient and hence eco-friendly fuel combustion will be.

Piezo-ceramic materials allow realizing higher forces and speeds in comparison to conventional actuators for fuel injection and thereby clearly reduce consumption, pollutant emission and noise, using the piezoelectric effect to enable the opening and closing mechanisms of the injection valve.

Piezo injector for the direct injection of petrol [© Robert Bosch GmbH]

The piezoelectric effect causes a geometric change when an electric voltage is applied or, reversely, a charge movement if mechanically deformed. If an electrical voltage is applied to such a material, it deforms very quickly. From this high mechanical forces result that can be used for the control of the fuel injection. The practically controllable regulating distances are in the nanometre range or below. In order to achieve higher regulating distances, the piezoelectric elements are stapled. Increasingly, nanocrystalline piezoelectric materials are being used. An often-used material is lead-zirkone titanate.

Piezo injectors enable several finely dosed injections per combustion cycle in powerful diesel engines at 1600 bar injection pressure.



Piezo inline injector in operation [© Robert Bosch GmbH]

The members of the staff of Robert Bosch GmbH and Siemens VDO Automotive were awarded the German future prize of the federal president for their work on piezo injectors.

Exhaust emission catalyst for the reduction of exhaust emissions

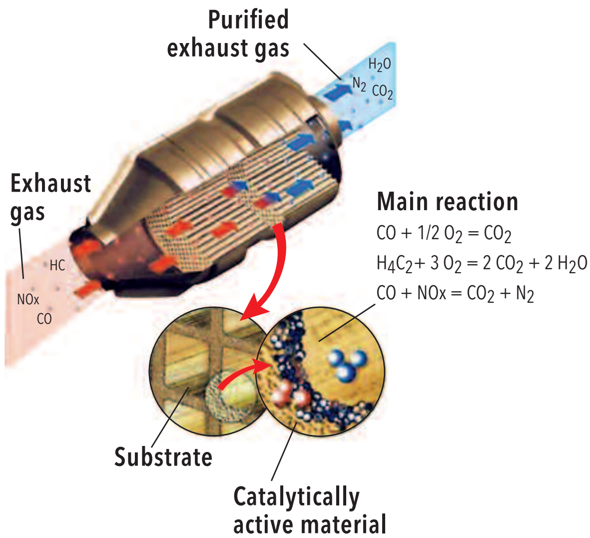
Today the reduction of exhaust emissions in automobiles is not imaginable without catalysts any more. They consist of high-grade steel housings that include catalytically active materials used for the conversion of pollutants to nitrogen, steam and carbon dioxide.

Most of the passenger cars operate on stoichometrically driven Otto engines. In such engines the petrol air mixture is composed in a way that theoretically a complete combustion of the fuel is achieved. For exhaust cleaning, systems based on three-way catalysts are used. These can convert the three main pollutants or pollutant types – carbon monoxide, nitric oxides and hydrocarbons – as far as possible and thus remove them from the exhaust gas.

During the conversion of toxic to non-toxic gases nanotechnologies play a crucial role. The impact of catalysts generally depends on the size of the surface. If the material used for the catalytic function is scaled to the nanometre range, the specific surface increases drastically. The composition and structure are chosen such that exhaust gases interact optimally with the catalytically active coating, and their chemical transformation into harmless substances is accelerated.

Several engine manufacturers work together on Otto engines that are equipped with a direct petrol injection system and tuned "lean" – meaning a mixture rich in air – to be in accordance with today's ecological requirements. These engines consume up to 15 to 20 per cent less fuel than normally tuned Otto engines. However, the chemical reduction of the produced nitric oxides in this oxygen enriched atmosphere poses a big challenge for the exhaust post treatment. NOx-absorber catalysts or NOx-storage catalysts were developed to solve this problem. Umicore delivers NOx-absorber catalysts for direct injectors as the first European manufacturer.

The Umicore AG & Co.KG is one of the leading enterprises in the field of exhaust emission catalysts. Catalysts for petrol engines, exhaust emission cleaning systems for engines with petrol direct injection, catalysts for diesel engines, diesel particulate filter as well as production of fuel cell components belong to the product lineup. One of the two major global research locations of Umicore is located in Hanau near Frankfurt.



Functionality of a car exhaust catalyst
[© Umicore AG & Co. KG]

3 The economic potential of nanotechnologies for the automotive industry and its subcontractors

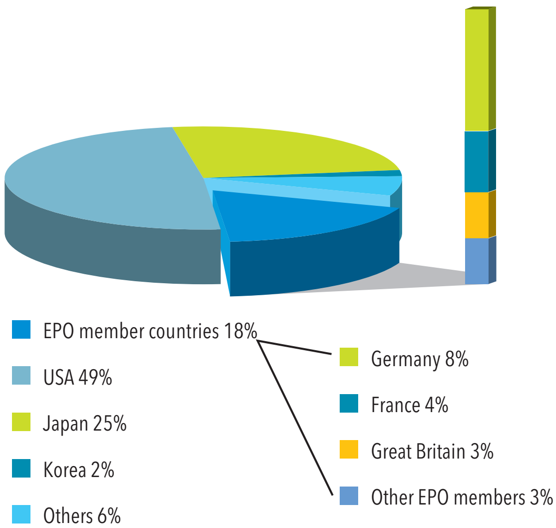
The terms smaller, quicker and highly productive are trademarks that are becoming more and more important and which are of strategic importance for international competitiveness (BMBF 2002). Within the framework a study funded by the federal research department on the "economic potential of nanotechnologies in Germany" (Luther et al. 2004) a comprehensive survey was undertaken by the German nanotechnology enterprises. The survey shows that the enterprises attach great importance to nanotechnologies. More than 75 per cent of the companies see the chance that nanotechnologies could open up new markets for them. More than 60 per cent of the companies expect a decisive advantage from the use of nanotechnologies.

A study conducted in Hesse in 2005 shows comparable results (HA 2005). Nanotechnologies with their numerous application possibilities could give an impetus to innovations in many industries that are important for Hesse, including the automotive industry. Nanotechnologies have a significant impact on materials and substances. In the view of the companies questioned in Hesse, this will allow many innovations in numerous other industries. About 100 Hessian enterprises use nanotechnologies in their production processes or products already. Mostly, this either concerns large companies where nanotechnologies make up a small part of the enterprise, or rather smaller companies specialising in these technologies.

The results of the survey clearly show that the sectors of chemistry and materials are of the greatest importance to German nanotechnology companies. The central functional properties in these two sectors lie in improved material properties and surface functionalisation, followed by protective and optical functions, i.e. classic and application-near requirements, which are also applied in automobiles.

Patents and families of patent families respectively are an important indicator that allow comparing economic potentials and their implementation in relation to other countries. According to a 2004 survey by the European Patent Office (EPO), EPO member states account for 18 per cent of patent families, Japan for 25 per cent and the USA for 49 per cent (Scheu 2004).

Within Europe, Germany is leading with 8 per cent, followed by France with 4 per cent and Great Britain with 3 per cent. On the one hand, this shows Germany's leading position in Europe, but on the other hand, it makes clear that the USA and Japan possess considerably more patents. This can be understood as a sign that the USA and Japan will lead in the commercialisation of nanotechnologies if this country does not succeed in quickly transferring nanotechnological developments into marketable products.



Worldwide regional distribution of nanotechnology patents. Germany leads in Europe in patent families issued.
[© European Patent Office (EPO), Scheu 2004]

The impact caused by nanotechnologies will have massive consequences for Germany's future development in particular in the automotive sector, since it is perceived as the internationally leading and national key industry of the German national economy (BMBF 2004). About a third of the R&D of the German economy is done by the automotive industry. In 2001 alone, 14 billion Euro were raised to ensure Germany's extraordinary position in the automotive industry through cutting-edge technology, including nanotechnologies.

Taking into account the components in the automotive industry influenced by nanotechnologies, the current world market volume can basically be attributed to profits from car tyre sales (Frost & Sullivan 2004). A rapid increase in the market volume of automotive components influenced by nanotechnologies is expected over the next few years (Frost & Sullivan 2004). Between 2012 and 2015 an average annual growth rate from more than 20 per cent to more than 50 per cent is expected. Here paints, electronic equipment such as sensors/actuators and lightweight construction in particular are expected to play an important role. Consequently, the automotive (supplier) industry and process technology will be of great importance.

In the automotive industry a continuous trend towards the reduction of vertical manufacture has been observed for car manufacturers for a long time. This means new sales potential for suppliers since they can offer complete modular solutions that only need to be fitted together by car manufacturers. Practically for all suppliers it is essential to expand their technology competency in future. The application of nanotechnologies can strengthen the competency of suppliers even more and secure the unique selling position of products or production techniques.

A crucial aspect is the recruiting of qualified employees and the advanced training of existing employees respectively. It will thus be necessary to pay attention to a mix of qualified personnel, where a change from the classical mechanical engineer or machinist to the scientist or more versatile worker, such as the mechatronics technician, will take place. The build-up and preservation of (nano-)technological competence begins with the cooperation with institutes and universities.

[© Audi AG]

4 Research programmes, financing schemes and networks

Germany is one of the first countries to apply specific funding programmes for nanotechnologies in connection with automotive technologies and to lead the way in this technology field. With the lead innovation project NanoMobil, a four-year support measure by the Federal Ministry of Education and Research (BMBF), the research and development activities for nanaotechnological applications in traffic engineering, especially in the field of automotive industry and its suppliers, are to be encouraged. Research institutes, suppliers and automotive companies are participating in numerous interdisciplinary projects. Research and development topics of the lead innovation project NanoMobil are especially concerned with fields of higher importance such as safety, ecology/sustainability and comfort. The projects are meant to have a signal function and act as catalysts for further R&D activities in the industry.

The lead innovation project NanoMobil started at the end of 2004. The programme is being coordinated by Jülich (PtJ) for the federal government. The possible market potential of the products concerned and the relevant consequences for the job situation in Germany play an important role in the selection of the funded projects. Pure niche developments without potential for a later broad impact were not accounted for within the framework of this lead innovation. A budget of 32.5 million Euro was planned for the measures, including a co-investment by the industry of the same amount.

Information: www.bmbf.de/de/1846.php

In Hesse, nanotechnology companies were subsidised within the framework of a model and pilot project funding by the Ministry of Economics, Transport, Urban and Regional Development in Hesse 2006–2008. The technology programme supervised by HA Hessen Agentur and co-funded by the EU was used by small and medium-sized companies in Hesse proposing to develop nanotechnologies or to apply them to product or process innovations. Eligible for funding are individual and joint projects as well as technology transfer projects with universities and development centres. This measure was designed to place the focus of support primarily on projects in the field of nanotechnologies and material technology.

Information: www.nanohe.de

Under its Hessen NanoMatTech corporate financing programme (2006–2008), the state of Hesse supported companies in funding innovations, product developments and market penetrations / introductions in the field of nanotechnologies. In particular, companies that not only make use of nanotechnological methods, but also provide ideas and are active in developing such methods, could receive allocations of up to 750,000 euros in the form of junior loans, thus helping to strengthen their equity capital base.

Information: www.nanohe.de

On the European level, nanotechnology research was funded under the 6th funding programme with priority 3, with focus on nanotechnologies and materials. Overall, the programme provided about 370 million Euro annually for nanotechnology projects (Wagner 2006). Aspects relevant for the automotive industry, e.g. hydrogen storage for fuel cells, are funded under various projects. Within the framework of the 7th funding programme, a sum of 5,940 million Euro is planned as funds for the transportation sector and another 4,832 million Euro for the “Nanosciences, Materials and new Production Technologies” sector over the period from 2007 to 2013.

Information: http://cordis.europa.eu/fp7/breakdown.htm

Funded projects within the lead innovation project NanoMobil

Co-operative project	Companies and institutions in charge of project implementation
Transparent nanocomposites on polymer basis	Bayer MaterialScience corporation, BMW corporation, Hella KGaA Hueck & Co, Fraunhofer Institute for Silicate Research (ISC), Neue Materialien Würzburg GmbH, SKZ-KFE gGmbH
Application of innovative nano materials in rubber mixtures for the improvement of the functionalities of tyres and technical elastomer products in the automotive sector	Continental corporation
Innovative nano-structured substances for techni cal elestomer products in automotive engineering	ContiTech AG
NanoElastomer	Süd-Chemie corporation
New elastomer products on the basis of nanocomposites	German institute for Rubber Research Inc.
New tyre rubbers on basis of elastomer nanocomposites (Montmorillonite-Silica-Hybrid (MSH) Nanos)	Leibniz institute for polymer research Dresden Inc.
Development and research of a prototype facility for the production of nanocrystalline coatings on cylinder tracks in passenger car aluminium crank shaft housings	GTV Abrasion resistance-GmbH & Co.KG
Development of novel wire injection techniques for coating cylinder tracks in highly charged petrol and diesel engines	Opel Powertrain GmbH
Nanocrystalline composites – Coatings for cylinder tracks with nano-structured surfaces and abrasion prediction for highly stressed petrol and diesel engines – NaCoLab	Dr. Ing. h.c. F. Porsche corporation, DaimlerChrysler corporation, Ford plants GmbH, University of Kassel, University of Duisburg-Essen, Carolo-Wilhelmina University of Technology Braunschweig, Federal Mogul Burscheid GmbH, Gehring GmbH & Co. KG, Durum abrasion protection GmbH
Nano coating through PTWA injection technology	Ford research centre Aachen GmbH
Application of new wire injection techniques for coating cylinder tracks in highly charged petrol and diesel engines Part: PTWA coating technologies – process and layer development	RWTH Aachen University
Nano-structured high-temperature semi-conductors for integrated exhaust gas sensors in diesel engine applications and lean-mix engine applications – NanoHoch	Robert Bosch GmbH, MAN Utility vehicles corporation, MicroGaN GmbH, Fraunhofer Institute for Ceramic Technologies and Sintered Materials (IKTS)

Co-operative project	Companies and institutions in charge of project implementation
Nano particle-based refinement and functionalisation of textile surfaces for the improvement of the ambient climate and hygiene in automobiles	NANO-X GmbH, Johann Borgers GmbH & Co. KG, Isringhausen GmbH & Co. KG, German Institute for Textile and Fibre Research Denkendorf (DITF), NANOCRAFT
Improvement of performance in hydraulic displacement units by nanocomposites	Bosch Rexroth corporation, Robert Bosch GmbH, ZF steering systems GmbH, FUCHS Europe lubricants GmbH, CemeCon corporation, RWTH Aachen University
Development of stream hardening water-based nanocomposite paints for scratch-resistant coatings on 3D vehicle parts	German Amphibolin Plants of the Robert Murjahn foundation & Co. KG, Alberdingk Boley GmbH
Nano paint part-project: Development of customised acrylate polymers and oligomers; characterisation of nanoparticle-filled dispersions and layers	Fraunhofer Institute for Reliability and Micro-integration (IZM)
Enhancement of active and passive safety of vehicles through novel multifunctional nano coatings – NanoSafe	BMW corporation, DaimlerChrysler corporation, Siemens corporation, Sachtleben Chemistry GmbH, Degussa corporation, Pilkington Automotive Germany GmbH, Hella KGaA Hueck & Co, University of Hannover, Fraunhofer Institute for Silicate Reaearch (ISC), Fraunhofer Institute for Layer and Surface Technology (IST), Genthe-X-Coatings GmbH, NANO-X GmbH, Hermsdorf Institute for Technical Ceramics Inc., FHR plant engineering GmbH
Lightweight construction with thermoplastic nanocomposites (LB-Nanos)	DaimlerChrysler corporation, Leibniz institute for polymer research Dresden Inc., GE Global Research Center, Süd-Chemie corporation
Synthesis, cleaning and functionalisation of Multi-walled Carbon Nanotubes for use in thermoplastic nanocomposites	Leibniz institute for Solids and Materials Research in Dresden
Nano-MMC: Ultra light weight on basis of compacted aluminium alloys with a high content of Mg_2Si and nanoparticle strengthening	PEAK materials GmbH, EADS Germany GmbH, University of Bremen, MAHLE GmbH, Foundation Institute for Materials Science (IWT)
PM alumina high-performance materials	Powder Light Metals GmbH, Ford Research Center Aachen GmbH, BBS Automotive Technology corporation

Information: http://oas2.ip.kp.dlr.de/foekat/foekat/foekat

Regional activities and networks

In 2005 the Ministry of Economics, Transport, Urban and Regional Development started the **Aktionslinie Hessen-Nanotech** series of publications. With the series economic and technological activities in the state of Hesse in the fields of nanotechnologies and material-based technologies are being pooled and coordinated. The aim of the series is to represent competencies in Hesse in the areas of nanotechnologies and adjacent technologies, such as material and surface technologies, microsystem technologies and optical technologies both nationally and internationally. The international competetiveness and innovative power of science and economy in Hesse is to be strengthened by technological and locational marketing as well as through the funding of networks. The Aktionslinie Hessen-Nanotech series of publications especially supports the cross linking between technology suppliers and users. The strongly developed application fields of automotive, chemistry, pharmacy, biotechnology and medical technology, environment and energy as well as information and communication technologies rank prominently in the ministry's series of publications. Hessen-nanotech works together with NanoNetworkHesse at the interfaces to the nanosciences. The organisation in charge of the projects of the series of publications by the Hessian ministry is HA Hessen Agentur located in the state of Hesse.

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NanoNetworkHesse (NNH) was established by the five universities and five technical colleges in March 2004 with the assistance of the Hesse state government to start close innovation-oriented co-operation in the field of nano science based on a co-operation agreement. The NNH initiative is aimed at pooling existing competencies at Hesse's universities, initiating co-operation and developing Hesse as a location for the nanotechnology industry. NanoNetworkHesse is co-ordinated by the University of Kassel. Scientists from the fields of physics, chemistry, biology, pharmacy, medicine, material science and various other branches of engineering and even the humanities, work at Hesse's universities in the area of nanotechnologies. This interaction of classical disciplines is considerably strengthening the innovation potential of this branch of science and offers excellent starting conditions for co-operation in Hesse. The technologies currently available at the state universities cover a wide range, going from nanoscaled and nanostructured materials, nano systems technologies via nano medicine, nano material chemistry, and nano biotechnology to nano analytics. Pursuing research and development tasks in these fields with the co-operation of scientists, developers and users and pooling the efforts of those involved, resources and activities, not only helps the participants in the network to tap additional resources, but also combines science with its practical application more than before, thus contributing to a faster conversion of nanotechnological knowledge into products, production processes and services.

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Since 2001, the universities and leading trade associations in the state of Hesse have joined in the **TechnologyTransferNetwork (TTN)** to link possibilities that are being offered to support the transfer of knowledge and technology and enable medium-sized enterprises to access the scientific and technological potential of the universities and research facilities. In order to achieve this goal in the field of nanotechnologies, the TTN works together with its Aktionslinie Hessen-Nanotech network partners. Typical examples of co-operative work are company surveys and technology-oriented presentations that are jointly undertaken. At the IHK–Innovationsberatung Hessen in Darmstadt, Giessen, Fulda, Kassel and Offenbach regional advice centres for technology transfer were set up. Their purpose is to actively approach the companies and provide assistance with access to application-oriented know-how of the universities. Concomitantly, a common platform is provided at www.ttn-hessen.de for the marketing of co-operation offers by the universities. Under the roof of TTN-Hessen, the universities in Hesse have united in the joint patent exploitation action group HIPO, which supports innovators in applications for patent rights and patent explotations agreements also in the field of nanotechnologies. The TTN-Hessen is supported and co-financed by the Hessian Ministry of Economics and Science, the HA Hessen Agentur GmbH (branch office), the Consortium of Hessian CCIs and the European Social Fund (ESF).

Since the beginning of the 80's, the Chambers of Commerce and Industry of Hesse have been offering a special, free-of-charge service to support companies in their innovation effort: the **IHK-Innovationsberatung Hessen** (innovation consulting). At a time when technology and market changes call for increasingly shorter innovation cycles, the competence centre offers its practical and company-related support especially to small and medium-sized companies. The IHK-Innovationsberatung is a neutral innovation agent and actively supports the interlinking and clustering of technology-oriented companies and research. Besides concrete innovation aids, such as individual consulting and publications, the CCIs in Hesse encourage the intense exchange between representatives from the economic, scientific and political communities by technology- and branch-oriented events. Since 2004, a special focus has been on nanotechnology and its potential for the economy. So a series of events has been started together with the regional advice centres of TTN-Hessen and the Ministry of Economics that highlight the use and application possibilities of nanotechnologies in different branches. The topics are for example "Nanotechnologies in tomorrow's automobiles", "Nanotechnologies in medical technology", "Nano-electronics" and "Nano surface technologies".

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5 Statements by important associations

Association of German Automobile Manufacturers (VDA)

The Association of German Automobile Manufacturers (VDA) promotes nationally and internationally the interests of the whole German automotive industry in all fields of transport economics, relating, for example, to economic, traffic and environmental policy, technical legislation, standardisation and quality assurance. Additionally, the VDA organises the annual international automotive exhibition (IAA) under its own control. In odd years, the passenger car IAA is on the programme and in even years, it is the utility car exhibition.

The VDA is in favour of consistently strengthening individual mobility. The VDA has more than 570 affiliated firms. Both automotive manufacturers and suppliers are organised under the umbrella of the VDA. They account for an annual revenue of 235 billion Euro and 767,000 employees. The VDA headquarters is located in Frankfurt am Main. Moreover, the VDA maintains offices in Berlin and Brussels. The president, the three VDA executives and most of the 80 employees are located in the Frankfurt am Main branch.

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Statement by the VDA

The German automotive industry owes its global leadership to its recognised innovative power. Materials act as the driving force for innovative industrial product development. They are a characteristic feature of the technological capacity of the automotive industry and enhance the companies' competitiveness. Nanotechnologies are core competencies in the automotive industry that help maintain a competitive edge. The automotive industry is the motor of application-oriented nano science. Current developments are being analysed with regard to their chance for further development. The implementation of new and attractive functions in automobiles has only been made possible by nanotechnologies. Product differentiation under the conditions of the international competition and customers' benefit regarding their safety, environment and comfort figure prominently. Nanotechnologies have long had a firm position in the automotive industry. Electrochromic mirrors avoid the blinding of the driver and, beyond that, antiglare instruments and heat-absorbing panes are examples of nanomaterial applications. With the help of nanoparticles, tyres adhere better on different road surfaces/layers and in different conditions. With the help of nanoparticles, the car of the future can provide visions of a more intelligent response to environmental stimuli and the driving behaviour. Panes and mirrors will adapt to outdoor light conditions and multiple sensors will anticipate the state of driving in changing weather conditions or the risk of collision. Aesthetic-functional properties that have been developed using nanotechnologies will also become important: the vehicle will be given an individually adaptable outer appearance through switchable colour change of paints and modifications in lightweight constructions. For the car's body, chassis and engine, lightweight construction composites with new properties will be used that are lighter and more crash-resistant. Especially for drive units and components, nanotechnologies offer a vast optimisation potential regarding further consumption and emission reduction. Nanoparticles are the basis for the production of catalytic converters already. As the abrasion of components influences the functional properties of the vehicle, such as lifetime, consumption, emission and noise, new potentials are being opened up by nanotribology. The abrasion resistance can be increased through optimal nanotechnological manipulation. In the reduction of consumption and emissions in view of a sustainable world-wide mobility, not only the optimisation of the combustion engine, but especially the further development of alternative drive concepts is taking centre stage. The future of drive concepts belongs to the fuel cell as the true 'zero-emission' vehicle. Nanotechnological products are being used to optimise the diffusion membranes of fuel cells. Cell electrodes composed of carbon nano tubes can achieve a higher energy density. Certainly, the application of new technologies always involves new risks. These risks are to be analysed in the field of basic research and have to be answered if the respective projects are to pass from principle suitability to the stage of project suitability. Partnerships with research centres worldwide are of the greatest importance here. The automotive industry will enable the use of new materials in co-operative application-oriented research with materials producers, research institutes and suppliers. Based on new requirements in vehicle construction, innovative suppliers are taking over important research tasks in the field of nanotechnologies. The application of nanotechnologies enhances and increases the profitability and competitiveness of the automotive industry in Germany. The political and scientific communities together with the automotive industry are called upon to ensure a breakthrough for nanotechnologies.

Field of competence 'Nanotechnologies' of the Association of German Engineers (VDI)

The VDI, with its approximately 125,000 individual members, is Germany's biggest technico-economic association and an international leader in its field. It generates its enormous knowledge in the different domains and cross-sectoral areas as well as the training of its engineers by drawing on the networks of its members and co-operation partners and on collaboration with Germany's economic and scientific communities. As one of the most important technico-scientific associations in Europe and the recognised technology spokesman in Germany, the VDI considers it its duty to further and participate actively in technology development for the benefit of science, industry and society. In this effort, nanotechnologies are playing a prominent role as an innovation driver for the beginning millennium.

The main emphasis of the VDI's field of competence 'Nanotechnology' is the focused transfer of knowledge by establishing highly qualified networks and expert forums, formulating VDI guidelines and intensive public relations. In this way, the exchange of knowledge and the discussions of ideas and opinions is carried out intersectorally to recognise synergy potentials early, exploiting them for the benefit of all.

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Statement by the nanotechnology field of competence of the Association of German Engineers (VDI)

The automotive industry plays an outstanding role in the German industry. In 2004, the annual profit of the German automotive industry amounted to approximately 226 billion Euro. Every seventh workplace in Germany is dependent on the automotive industry. Furthermore, more than one third of the cumulative industrial R&D budget in Germany is funded by the automotive industry.

On the other hand, in the view of leading experts, the nanotechnologies are becoming this century's major key technologies. As early as today, many studies estimate that the current world market volume runs up to approximately 100 billion Euro, an amount that will be rising dramatically in the years to come. Therefore, it is obvious that the nanotechnologies, which are being used today in certain areas of automotive engineering, will become more important in the industry. The driving force behind the increasing process of innovation in the automotive industry is the demand of customers and society for advances in the field of economy and ecology as well as for higher comfort and safety. Nanotechnologies contribute substantially to all these requirements.

Today's applications of nanotechnologies in the automotive industry are to be found e.g. in the use of nanoscaled sooty particles in car tyres, which are instrumental in such excellent properties as a low rolling resistance, longevity and solid grip both in dry and wet conditions. Nanoparticle-enhanced varnishes or ultra-thin anti-reflex and anti-glare layers are further examples. Super hard amorphous carbon layers are increasingly being used due to their high hardness and low-friction coefficient.

Nanoparticle-enhanced materials, possibly even on the basis of carbon nano tubes or easy-to-clean surfaces, seem to be practicable in the medium term. In the distant future, even application of nanotechnologies, such as self-repairing paint and switchable colours will be imaginable. Given the economic importance of the automotive industry for Germany, the application of nanotechnologies in this field is of major importance. These technologies should be developed systematically for the sake of the optimal strengthening of Germany as a location for research and economic development.

Central Association of the Electrical and Electronic Industry (ZVEI)

The ZVEI represents the economic, technological and ecological interests of the German electrical industry on a national, European and international level. The association provides specific information about the economic, technical and legal framework of the electrical industry in Germany.

The ZVEI promotes the development and use of new technologies through research, technology, environmental, educational and scientific policies. It supports market-oriented international standardisation activities.

The activity of the association is based on the exchange of experiences and ideas between its members about the current technical, economic, legal and social topics in the field of the electronics industry assisting them in working out common platforms.

The close contacts between the ZVEI and the political community and public administration and the exchange of ideas within the association results in a broad range of information about developments that are relevant for the market and for competition and which relates specifically to needs of the electronics industry. The member associations use this edge in know-how and knowledge to improve their international competitive standing.

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Statement by ZVEI on nanotechnology application in automobiles

Market success in vehicle construction is driven by innovations in the world of automotive. However, not only conspicuous innovations e.g. in the field of multimedia applications are instrumental in such developments, but also, and especially, safety concerns will figure most prominently in future. The main objective is to make driving easier, safer and more comfortable. That is an objective that cannot be realised in modern vehicles without electronics any more.

And the share of electronics in cars is still rising as more and more applications can achieve their functionality through electronics only. This is a great challenge in terms of technically co-ordinating individual developments in the shrinking space of the vehicle. But especially a challenge in terms of every single electronic component that needs to be smaller and still more efficient. Precisely at this point nanotechnologies comes in, so that these requirements regarding the individual electronic components and their application in a minute space as well as their highest functional safety can be achieved.

Fortunately, Germany has become a technology leader in the field of nanoelectronics. Happily, this position can be expanded even further. The German economy profits in the field of nanoelectronics from the high intellectual share in economic value creation. Hence the often-cited high production costs only play a minor role in the German economy as far as nanoelectronics is concerned. The ZVEI appreciates this very positive situation in the field of nanoelectronics and will make an all-out effort to advance the status of the German economy in this field as much as possible.

Faraday Advance – The Transport Node of the Materials Knowledge Transfer Network

The Materials Knowledge Transfer Network (Materials KTN) is one of 23 networks funded by the UK Technology Strategy Board, an arms length Government body, to:

- provide UK businesses with the opportunity to meet and network with individuals and organisations
- encourage knowledge transfer between the supply and demand sides of technology-enabled markets
- encourage the flow of people, knowledge and experience to and from industry and the science base
- attract and optimise the use of funding resources
- provide a forum for a coherent industry voice to inform government policy making
- provide advice on the various support mechanisms available to the research base and business
- provide advice to government and public bodies

Faraday Advance is the Transport Node of the Materials KTN providing a continuum of services to the automotive, aerospace, rail and marine sectors to support the exploitation of ideas and innovation, including fundamental university-based investigations, short-term problem solving, multi-disciplinary development programmes, project management services, and technical consultancy. Our activities include:

- Large-scale multi-partner collaborative projects
- Consortium and project building
- Project management
- Technology focused networks
- Consultancy
- Briefing packs, state of the art reviews
- Conferences and meetings
- Overseas missions

Advanced Materials and Nanotechnology

Against a background of concerns about the environment, resource and energy pressures and increasing global competitiveness, new strategies for materials innovation and application are increasingly vital to sustain advanced manufacturing and to foster the development of a range of activities around new, sustainable, high performance materials.

Europe's large transport industries demand lighter, safer vehicles with a smaller environmental footprint both in their manufacture and in their use.

New materials are required for sustainable transport and are therefore critical to achieving the ambitious objectives being set by national and international regulatory authorities.

The UK Technology Strategy Board has identified five priorities for action relevant to transport materials:

- Materials for energy production and distribution
- Materials in the development of sensors and diagnostic technologies
- Structural materials, in particular composite and high temperature resistant lightweighting alloying technologies
- Multifunctional materials, including damage tolerant, self-diagnostic, self-healing materials
- Nanomaterials, in particular developments that will enhance business capability in working at the nanoscale

Nanotechnology will be critical to implementing many innovative ideas in the transport sector not only in primary structures and drive systems but also in enhanced passenger and driver experiences.

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ACstyria Autocluster GmbH

The ACstyria Autocluster in Austria is the heart of a pulsating network of the international automobile and automotive supply industry in Styria.

Since the day it was founded in 1995, the main focus of the Autocluster has been on the interlinkage of economy, industry, research and the public authorities as well as identifying and supporting fields of strength and synergies. In brief, ACstyria is pooling forces that exist within the value added chain of the automotive industry. In the field of technology the Styrian Autocluster is committed to enhancing its innovative power and international competitiveness – indeed, with great success: Today, there are 180 partner companies involved in ACstyria, employing a workforce of 46,000 and generating a turnover of 11 billion Euros last year. The Styrian model of the Autocluster has won international recognition and many followers because they see that behind their profitable cluster model there are people with far-reaching visions.

Especially today, in view of an increasingly unpredictable economic development, the significance of research&development is higher than it has ever been. Alternatives to pure mass production have to be found and new ground has to be broken. This is one direction that ACstyria is also supporting in the area of nanotechnology.

Nanotechnology is a key technology of the 21st century and is considered as a seminal cross-sectional technology by the Styrian Autocluster. Completely new functionalities are developing given the nano-scaled structures, which allow for versatile applications in automobile and tool production. Weight reduction, enhanced energy conversion and driving dynamics, emission reduction and increasing recyclability go hand in hand with the social needs for ecology, safety and comfort.

Nanotechnological developments are being used today to enhance the product "automobile". Fields of application range from material for tyres, non-fogging rear view mirrors and anti-glare coatings for instrument panels to car paints with diverse colour effects. This versatile technology will decisively influence tomorrow's evolution of the automobile. New developments in nanotechnology will be the optimisation of fuel combustion, self-healing paints or functional car-glazing. A large potential will have nanoparticles for ceramic engine parts, nanofibres in polymers and nanostructured catalyser surfaces.

For the future, nanotechnology in automobile manufacturing will belong to those key competencies that are capable of opening up new possibilities and thus be essential for maintaining competitiveness. Many developments relate to the areas of electronics, sensor systems, engine and driving train. By using nanotechnology, the reactive surface within fuel cells is enlarged in order to increase their efficiency, to mention just one example. Another example is the minimisation of the emission of respirable dust and thus environmental pollution as a result of the application of nanoporous filtration systems.

This potential was seen by the Styrian Autocluster already some time ago – numerous partners of the network are actively researching in this area. AVL List, the Hydrogen Center Austria, Joanneum Research or the Materials Center Leoben are just a few examples.

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6 Appendix

6.1 Glossary

- **Colour centres**

A colour centre is a lattice deformation in a crystalline solid with a vacant negative ion position (gap) and one or more electron(s) occupying these positions. Such effects absorb light and make colourless crystals appear coloured.

- **Cylinder tracks**

Component of the combustion engine where the power is generated. There is a shaft in the cylinder which moves up and down as a result of the combustion of the fuel air mixture. The walls within the cylinder are termed cylinder tracks.

- **Electro-rheology**

Electro-rheology is the change in the fluidity/rheology of a material due to the effect of an external electric field.

- **Grain size**

The term grain size describes the size of particles. If particles were perfectly spheric, the sphere diameter could be used as the measure for the grain/particle size. In practice, the shapes of the particles differ. The equivalency diameter is used to describe their size, that is, measured values are related to spheres of equal size.

- **Hydrophobic**

This term from chemistry relates to substances that do not mix with water, mostly rolling it off the surface. A surface with a contact angle above 90° in relation to water is classified as super hydrophobic. Water rolls off these surfaces very easily. Hydrophobic surfaces generally consist of hydrophobic substances or are covered by them. An example is the coating of surfaces using PTFE, commonly known as teflon. The surface of lotus leaves and flowers is an extreme example of a hydrophobic surface.

- **Lotus effect**

The lotus effect is based on a combination of a hydrophobic surface (natural wax) with a special surface structure composed of wax scales. A water drop rolls off significantly better than it would from a smooth surface made of the same wax, simply picking up the adherent dust. This effect is increasingly being transferred into technology and used in 'easy-to-clean surfaces' for instance.

- **Nanostructured materials**

Nanocomposites that are produced through procedures and processes of mainly chemical nanotechnologies. Here, the main focus is on the production and pinpoint use of nanoscaled structures for the sake of the fabrication and improvement of material features.

- **OEM (Original Equipment Manufacturer)**

An Original Equipment Manufacturer is a producer of finished components or products, who produces them in his own factory without distributing them further. In many branches the opposite meaning of the term has established itself. In the automotive industry for instance, the OEM designates a company that is not the original manufacturer of the product, but processes a finished product further and distributes it in their own name on the market.

- **Oleophobic**

Fat-repellant; Oils and fats cannot adhere to or penetrate oleophobic surfaces. They can easily be removed. Compare "hydrophobic".

- PET

Polyethyleeterephtalate (abbreviation PET) is a thermoplast belonging to the polyester family.

- Piezoelectric effect

Piezoelements produce electricity if stretched or bulged, which also applies to the spark in "electronic" lighters. Reversely, the piezoelectric crystal can be deformed very precisely to a fraction of an atom diameter by applying an electric voltage to it.

- Remanence

The remaining magnetisation/residual flux density of a ferromagnetic body when the external magnetic field is switched off. Materials with high remanence are classified as 'magnetic'.

- Silica

The oxygen acids of silicon are referred to as silica. In German all possible types of synthetic silicon dioxide are commonly referred to as silica.

- Stoichiometric

Stoichiometric means: reacting according to quantitative laws.

- Van der Waals bonding

A Van der Waals bonding is the attraction between dipole atoms and the interaction between unpolarised molecules. The reason for the attraction between unpolarised molecules is a momentary asymmetric electron distribution. A temporary dipole is established that polarises the neighbouring molecules and thereby induces further dipoles that cause electrostatic attraction. The Van der Waals bonding rises as the size of the molecules increases. However, this bonding is very weak compared to other bonding types such as ion and atom bonding.

- X-by-Wire

The X can be representative of any function in the car: for gas-by-wire with the function of a carburettor, the injection, exhaust feedback, or for power-by-wire with the functions of the starter, alternator, ignition, etc. or for shift-by-wire with the control functions for gears, all-wheel drive and coupling or in drive-by-wire for information feedback about the unevenness of the road. The steering motion is transformed into an electrical signal that is available as a control signal to the control unit for the steering.

6.2 Internet links on nanotechnologies

- Hessen-Nanotech series of publications
  www.hessen-nanotech.de
- Platform for nanotechnologies in Hesse
  www.nanotech-hessen.de
- HA Hessen Agentur GmbH
  www.hessen-agentur.de
- Funding initiative NanoHE
  www.nanoHE.de
- TTN-Hessen TechnologyTransferNetwork Hesse
  www.ttn-hessen.de
- Portal of the German Federal Ministry of Education and Research (BMBF) and of the Association of German Engineers (VDI) on nanotechnologies
  www.techportal.de
- Competence Networks in Nanotechnologies in Germany
  www.kompetenznetze.de/navi/de/Innovationsfelder/nanotechnologie.html
- Information server (Cordis) of the EU for priorities concerning nanotechnologies under the 6th funding programme
  www.cordis.lu/nanotechnology/
- Internet portal "Nanoforum" of the EU for nanotechnology activities within the EU
  www.nanoforum.de
- „NanoNetworkHesse"
  www.nanonetzwerkhessen.de
- Lead innovation NanoMobil
  www.nanomobil.de
- No traffic jam in Hesse in 2015
  www.staufreieshessen2015.de
- Internet platform for the responsible use of nano materials

  As a service for the companies operating in Hesse, the hessen-nanotech series of publications by the Ministry of Economics, Transport, Urban and Regional Development in Hesse has provided an information platform on the internet for the responsible use of nano materials. It is intended to help companies, but also scientists as well as users and the interested public, to get a quick and good overview of current research activities and discussions about potential risks of nanotechnologies.
  www.nanotech-hessen.de/infoplattform-nanorisiken

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