Nanotechnology and the Automotive Industry- A Review

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ABSTRACT

The application of nanotechnology started for commercial products in the early part of the twentieth century but most of the applications are confined to the use of passive nanomaterials in the bulk form. Few of the applications are the use of titanium dioxide and zinc oxide nanoparticles in sunscreen, cosmetics, and some food products; silver nanoparticles in food packaging, clothing, disinfectants and household appliances such as Silver Nano; carbon nanotubes for stain-resistant textiles; and cerium oxide as a fuel catalyst. The automotive sector is a major consumer of material technologies – and nanotechnologies promise to improve the performance of existing technologies significantly. Applications range from already existing – paint quality, fuel cells, batteries, wear-resistant tires, lighter but stronger materials, ultra-thin anti-glare layers for windows and mirrors – to the futuristic – energy-harvesting bodywork, fully self-repairing paint, switchable colors, shape-shifting skin.

Keywords

Nanoparticles, Nanomaterials, carbon Nanotubes, fuel cells, electro catalysts, PEM, energy harvesting

INTRODUCTION

The application of nanotechnology started for commercial products was confined to the use of passive nanomaterials in the bulk form in the early part of the twentieth century .Few of the applications are the use of titanium dioxide and zinc oxide nanoparticles in sunscreen, cosmetics, and some food products; silver nanoparticles in food packaging, clothing, disinfectants and household appliances such as Silver Nano; carbon nanotubes for stain-resistant textiles; and cerium oxide as a fuel catalyst.[1] As of March 10, 2011, the Project on Emerging Nanotechnologies estimated that over 1300 manufacturer-identified nanotech products are publicly available.[2]

Nanotechnology is being used in developing countries to help treat disease and prevent health issues. The umbrella term for this kind of nanotechnology is Nanomedicine.

Nanotechnology is also being applied to or developed for application to a variety of industrial and purification processes. Purification and environmental cleanup applications include the desalination of water, water filtration, wastewater treatment, groundwater treatment, etc. In industry, applications may include construction materials, military goods, and nano-machining of nano-wires, nano-rods, few layers of graphene,[3] etc. Also, recently a new field arisen from the root of Nanotechnology is called Nanobiotechnology. Nanobiotechnology is the biology-based, application-oriented frontier area of research in the hybrid discipline of Nanoscience and biotechnology with an equivalent contribution.[4]

Various product types such as Inks, papers, and holograms in the printing industrial sector are improved using carbon black, graphene, and silver nanoparticles. The petroleum industrial sector also exploits the advantages of nanotechnology in oils, lubricants, drilling mud, scavengers, down hole drills, and catalysts. Additionally, TiO_2 and SiO_2nanoparticles play the main role in both the assemblage of nanostructured solar cells and the self-cleaning improvement of silicon panels. Moreover, the properties of such sports equipment as balls, rackets, bats, eyewear, bicycle wheels, kayaks, and paddles are commercially enabled or enhanced using carbon-based nanostructures (e.g., carbon black, carbon nanotubes, graphite, and fullerene).[5]

APPLICATIONS OF NANOTECHNOLOGY

Nanotechnology has a large number of applications in various fields of which a few of the prominent applications related to the automotive industry are being highlighted in this paper.

NANOWERK SPOTLIGHT

Nanotechnology will play a major role in the car industry, but don't hold your breath to see anything like the Volkswagen Nanospyder futuristic concept car anytime soon. This entrance to the 2006 Los Angeles Design challenge was supported by hydrogen fuel cells, solar power, wheel-mounted electric motors, and inflatable organic body panels combine to form the unusual shape of the two-seater concept.

According to its creators – designers based at the Volkswagen Design Center in Santa Monica – the Nanospyder (Figure.1), would be formed out of a latticework of billions of tiny programmable nanodevices measuring less than half a millimeter in diameter. Each of these tiny devices can be programmed to be as strong or weak as required meaning active crumple zones can be created. Clothing the nano-lattice are panels formed out of a mix of organic materials some of which can inflate to provide further cushioning in the result of an impact. The material doubles as a power source as polysynthesis generate small amounts of electricity. This coupled with hydrogen fuels generates power to drive the tiny electric motors mounted within the hubs of all four wheels.

OK, back to today. The automotive sector is a major consumer of material technologies – and nanotechnologies promise to improve the performance of existing technologies significantly. Applications range from already existing – paint quality, fuel cells, batteries, wear-resistant tires, lighter but stronger materials, ultra-thin anti-glare layers for windows and mirrors – to the futuristic – energy-harvesting bodywork, fully self-repairing paint, switchable colors, shape-shifting skin.

Fig 1. Nanospyder

NANOTECHNOLOGY FOR CARS

The basic trends that nanotechnology enables for the automobile are:

- lighter but stronger materials (for better fuel consumption and increased safety)
- improved engine efficiency and fuel consumption for gasoline-powered cars (catalysts; fuel additives; lubricants)
- the reduced environmental impact from hydrogen and fuel cell-powered cars
- improved and miniaturized electronic systems
- better economies (longer service life; lower component failure rate; smart materials for self-repair)

The existing and possible future applications of nanotechnology in cars is shown in the table.1

Where will nanotechnology take us in the automotive sector? The following examples are but an overview of a large number of efforts and applications involving nanotechnologies in the automotive industry:

Nanotechnology for Chassis and exterior

Vehicle weight reduction is a key part of car manufacturers' strategies to improve fuel economy. Ford's "Atoms to Engines" team, for instance, looked at the structure of cast aluminum alloys at near atomic levels. From this work, a detailed analysis of the structure/property/process relationship of the aluminum alloy engine blocks has led to reduced engine weight and, in turn, increased fuel efficiency.

Another area is the substitution of mineral glass windows by polymers. However, until recently some key performance specifications had not been reached; scratch resistance and long-term ultraviolet resistance remained challenges. Recent advances involving nanotechnology are helping polycarbonate window developers to overcome these challenges

Nano-engineered thermoplastic materials allow a weight reduction of up to 40% compared to traditional steel chassis parts.

Table. 1 Applications of nanotechnologies in automobiles. (Source: Hessian Ministry of Economy, Transport, Urban and Regional Development)

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

With regard to paints and surface coatings, nanostructured surfaces result in improved paint adhesion and color durability. Self-cleaning will become standard on windscreens and car body shells. Scratch-resistant, dirt-repellent, UV-resistant and self-healing car paints are applications that already exist or are in development.

Nanotechnology in Tires

Tires are one of the early applications of nanostructured materials in automobiles. Carbon black was the first nanomaterial to be used by the automotive industry in tires as a pigment and reinforcing agent.

The key to tire performance is the mixture of the rubber – but its optimization requirements can be contradictory (highly complex chemical and physical interactions between the rubber and the filler material): While the tire needs good grip its rolling resistance has to be low as well.

Some 30% of the tire cover consists of reinforcing filler which makes possible wanted properties such as grip, abrasion resistance, and resistance to initial wear and tear, and tear propagation. There are three products that significantly improve the properties of natural rubber are soot, silica, and organosilane. Now being produced in nanoscale form, these particles, as well as the cross-linking with the natural rubber molecules, play a key role for tire properties.

Researchers have also printed carbon nanotube sensors that monitor tire wear in real time.

Nanotechnology for Automobile Propulsion

Building an electric car needs to take into account four basic requirements – powerful and safe energy storage to give the car a sufficient driving range; engines and associated electronic components that make best use of the stored onboard energy; light-weight components to compensate for the (at the moment still) extra weight of the batteries; and all that at a price that can compete with gasoline-powered automobiles.

Lithium-ion batteries are currently being intensively developed worldwide for use in electric vehicles. The consensus view among researchers is that the battery will be of the lithium-ion type, but which of the lithium-ion chemistries to use is still a major question.

Nanotechnology holds great promise for improving the performance and lifetimes of the Li-ion batteries. It also has the potential to enhance the energy and power density, shorten the recharge time, as well as decrease the size and weight while improving the safety and stability of the batteries. A large number of companies such as Altair Nanotechnologies, mPhase Technologies, A123 Systems, Li-Tec Battery GmbH, NanoEner Technologies, Next Alternative Inc., Nexeon Ltd. etc. are actively pursuing the development of nano-enabled batteries while some others are already producing them.

Nanotechnology is also key to improving fuel cell performance of future generations of hydrogen-powered cars.

One of the leading fuel cell technologies developed, in particular for transportation applications, is the proton exchange membrane (PEM) fuel cell, also known as polymer electrolyte membrane fuel cells – both resulting in the same acronym PEMFC. These fuel cells are powered by the electrochemical oxidation reaction of hydrogen and by the electro-reduction of the oxygen contained in air.

Although nanotechnology promises cheap bipolar materials using nanocomposites, more efficient non-platinum electrocatalysts, and thermally stable and more durable membranes to become available in the near future, the precious metal platinum still remains the workhorse of PEM fuel cells. One way to minimize platinum usage is to increase catalytic efficiency by nanostructuring the platinum metal; another way of eliminating the use of platinum altogether is by exploring the use of much cheaper non-precious metal catalysts where the nanostructured surfaces match or exceed the catalytic properties of platinum.

Nanotechnology under the hood

For fuel cell cars, hydrogen sensors will be a critical component for safety and widely needed. They will detect leaks long before the gas becomes an explosive hazard. Researchers have already developed thin, flexible hydrogen sensors using nanostructured materials, i.e., single-walled carbon nanotubes decorated with palladium nanoparticles.

Of course, we will be stuck with gas-guzzling cars for quite some time to come. Improved fuel efficiency and the reduction of harmful exhaust emissions are two key areas where nanotechnology applications will make an impact.

In today's automobiles, 10-15 % of the fuel consumption is influenced by engine friction due to the friction loss at the moving mechanical parts (piston, crank drive, valve drive). Nanocoatings applied to mechanical parts, and nanostructured lubricants, help reduce friction and abrasion and thereby improve fuel efficiency.

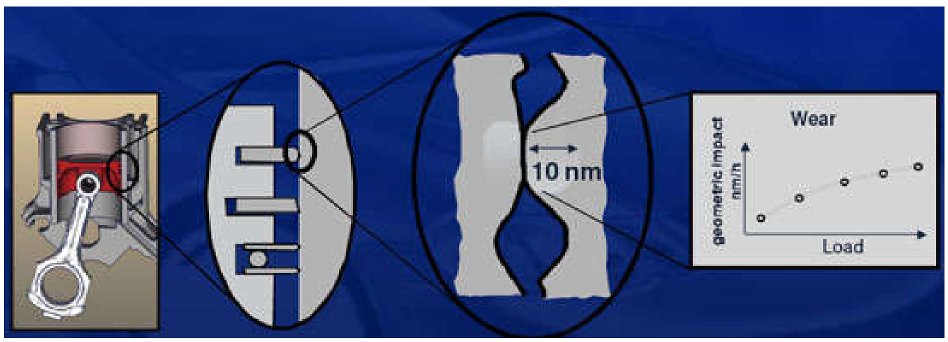

Fig. 2 The tribological processes at the piston/cylinder wall interfaces take place at the nanoscale. (Source: Daimler AG Research & Development)

Another example of the many aspects of the above-mentioned "Atoms to Engines" project by Ford is developing a thermally sprayed nanocoating that could replace the heavier cast iron liners that provide the necessary wear resistance of cylinder bores in aluminum block engines. This thin wear-resistant coating reduces weight and improves friction performance while delivering equal durability and reliability to the product(Figure 2).

Piezo fuel injection technology is now used not only in diesel engines but also in their petrol counterparts. 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 fuel combustion will be. Nanocrystalline piezoelectric materials will improve these piezoelectric materials.

For exhaust cleaning in petrol-powered cars, 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 nanometer 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.

Interior

Car interior application will mostly deal with comfort issues – dirt-repellent and antimicrobial textiles and surfaces, nanoparticulate air filters, anti-glare coatings of mirrors and instruments. Or how about climate-controlled car seats based on thermoelectric materials that convert electricity directly into heating or cooling.

Electric systems and electronics

Electronics is an innovation driver in the automotive sector as 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.

Spintronics promises to revolutionize computing. While conventional complementary metal-oxide semiconductors (CMOS), a technology used today in all types of electronics, rely on electrons' charge to power devices, the emerging field of spintronics exploits another aspect of electrons – their spin, which could be manipulated by electric and magnetic fields. With the use of nanoscaled magnetic materials, spintronics or electronic devices, when switched off, will not have a standby power dissipation problem(Figure 3). With this advantage, devices with much lower power consumption, known as non-volatile electronics, can become a reality.

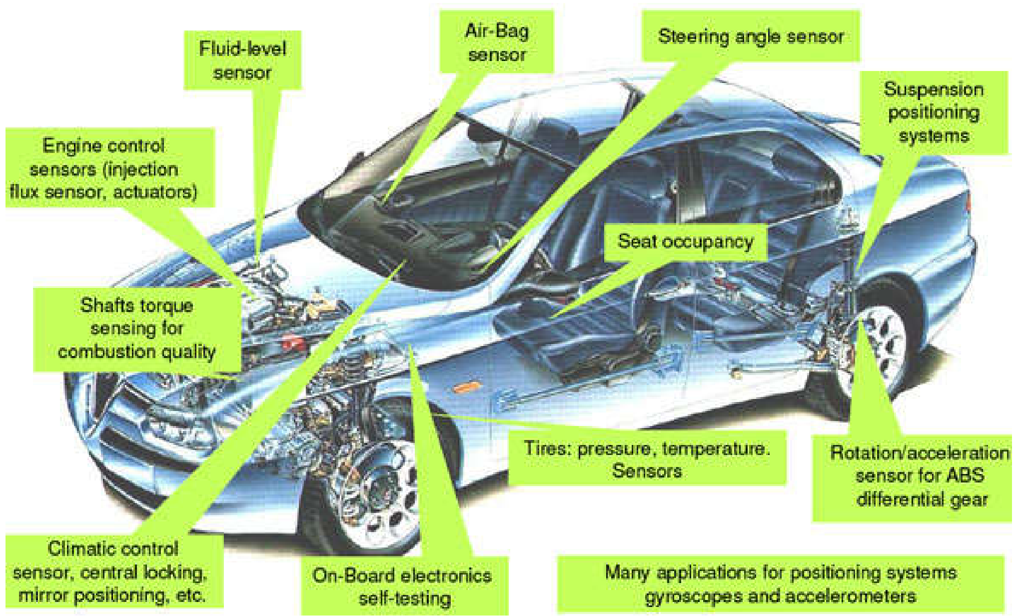

Fig. 3 Spintronics applications in cars. (Source: Centro Ricerche FIAT)

The quickly emerging hybrid car sector not only uses batteries to store energy for the electric drive mode, but it also pushes recuperation technologies, i.e. the re-use of braking energy. Here, the moving energy is converted into electrical current via generator during braking and stored in accumulators or super or ultracapacitors. Nanotechnologies are expected to have a major impact in this area. For instance, scientists are already producing ultra-lightweight, bendable batteries and super capacitors in the form of everyday paper.

Micro-structured solar cells can already be integrated into sunroofs and are offered as options on some cars. Using nanostructured and flexible plastic solar cells with a thickness of less than 1 micron, it will become possible to cover larger areas of the car exterior with solar energy harvesting thin-films.

The overall electrical to optical efficiency for lighting applications in today's cars is only about 1%. This will be considerably improved by the development of diffractive and micro-optics, new light sources, and their integration with the power supply.

NanoMobil

In 2004, Germany, through its Federal Ministry of Education and Research (BMBF), established a specific nanotechnology funding program – NanoMobil – in connection with automotive technologies and in order to keep the German car industry and its suppliers competitive. Numerous research institutes, suppliers and automotive companies have been participating in several interdisciplinary projects. The following chart shows the range of topics covered by NanoMobil and gives an indication of the wide range of nano-applications within the automotive sector (Figure 4).

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 elastomer 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-Wil-helmina 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)
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

Fig. 4 Nano-applications in Automobile industry

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