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Future nanotechnology developments for automotive applications

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Abstract

In the automotive industry, nanotechnology applications are manifold. They reach from power train, light-weight construction, energy conversion, pollution sensing and reduction, interior cooling, wear reduction, driving dynamics, surveillance control, up to recycle potential and much more. Additionally, visions of "nano in cars" reach from contributions for CO_2-free engines, safe driving, quiet cars, self-healing body and windscreens, up to a mood-depending choice of colour and a self-forming car body. All this will meet the present society trends and customer demands for improved ecology, safety and comfort, often summarised by the term sustainability. For automotive components nanoparticles, -dots, -pores, -fibers, -tubes, -whisker, -layers, either dispersed within a matrix material and called "nanocomposites", or arranged on surfaces or used as a discrete material and then called "nanostructures", offer exclusive potential. Volume effects like diffusion, absorption and mechanical strength might be tailored, furthermore surface effects like adsorption, hardness, and catalytic reaction. Self-organisation of structures will play an essential role in growth, deposition and etching. We will present an overview about existing nanotechnologies in cars already on the market, applications with short-term and medium-term potential as well as long-term applications such as light-weight construction using nano-carbon nanotubes which are presently investigated in research labs worldwide and have a high potential if they can be used for automotive bodies.

Keywords: Automotive industry; Nanotechnology; Nanocomposites; Nanoparticles

1. Introduction

The nanocosmos will make a revolution in macrosystems. Automotive components will also benefit. The automotive industry in Europe which is regarded as a "lead industry" has just to strengthen its effort in the emerging nanotechnology, in order to preserve their excellent position. The applications are manifold, from power train, light-weight construction, energy conversion, pollution sensing and reduction, interior climate, wear reduction, driving dynamics, surveillance control, up to recycle potential and much more (see Figs. 1 and 2). Visions of "nano in cars" reach from contributions for CO_2-free engines, safe driving, quiet cars, self-cleaning body and windscreens, up to a mood-depending choice of colour and a self-forming car body. All this will meet society trends and customer demands for improved ecology, safety and comfort, often summarised by the term sustainability.

Nanotechnology is already in mass production for automobile components. Antireflection coating based on multiple nanolayers on glass (trade name Schott Conturan) is used for instruments, e.g. by Audi and by DaimlerChrysler trucks (www.schott.com.sg/conturan.htm).[1] Sun protecting glazing with infrared reflecting nanolayers embedded into sheets of glass (trade name Sekurit Thermocontrol) is presently already used in buses (e.g. Evobus) (http://www.saint-gobain-sekurit-transport.com/bus/confort/index.htm#1/). Thermoplastic nanocomposite with nanoflakes (trade name Basell TPO-Nano) is used for stiff and light exterior parts like the step-assist by GM (www.sae.org/automag/material/01-2002/). But up to now, that is all.

Top-down, i.e. starting from the system requirements, we will present further investigated and envisaged nanotechnologies for cars. Our focus is on aspects for conservation of resources. An analysis predicts [1] that a 30% improvement of roll-resistance, air-resistance, car-

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[1] Note that web-sites can move, the given URL can therefore change. Please refer then to the homepage of the institution and search from there.

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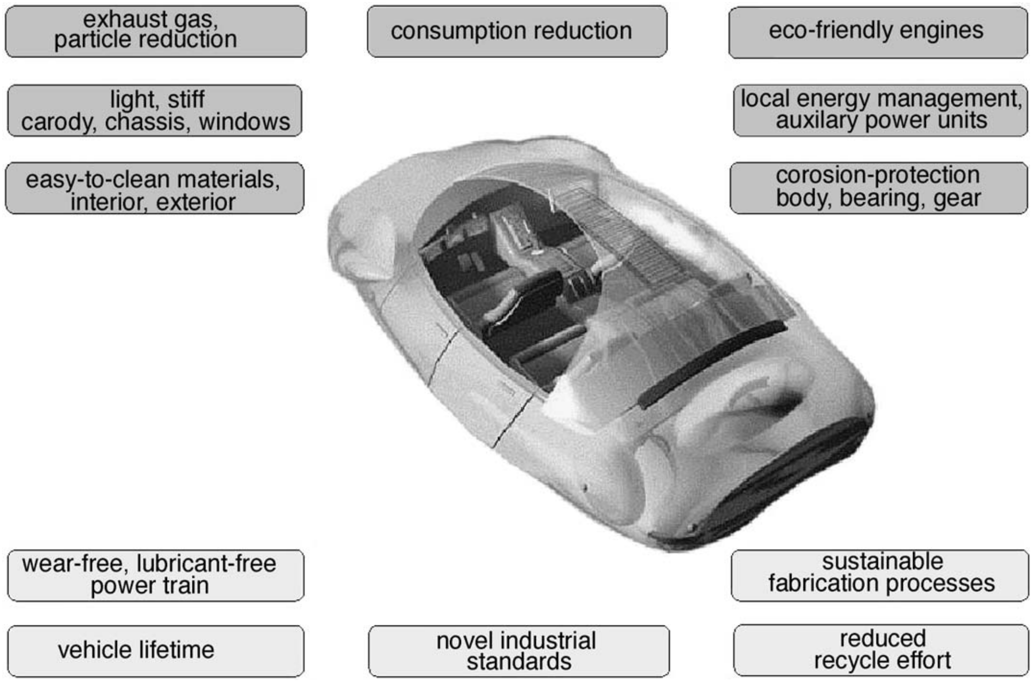

Fig. 1. Potential areas where nanotechnology can contribute to satisfy society demands in the automotive industry.

weight or of power train might reduce the fossil fuel consumption by 4%, 6%, 15%, or 28%. Every tenth of a litre fuel saving counts. Correspondingly, the CO_2 and particle emission will decrease. That estimation does not take into account the huge fuel saving when the car industry introduces energy conversion and alternative engines.

2. Components for power train

The VDA (association of the German automotive industry) and also the respective organisations in other countries agree to lower the CO_2-fleet consumption by about 20% in the following years. Furthermore, the EURO-norm restricts the NO_x- and particle-emission. Up to the

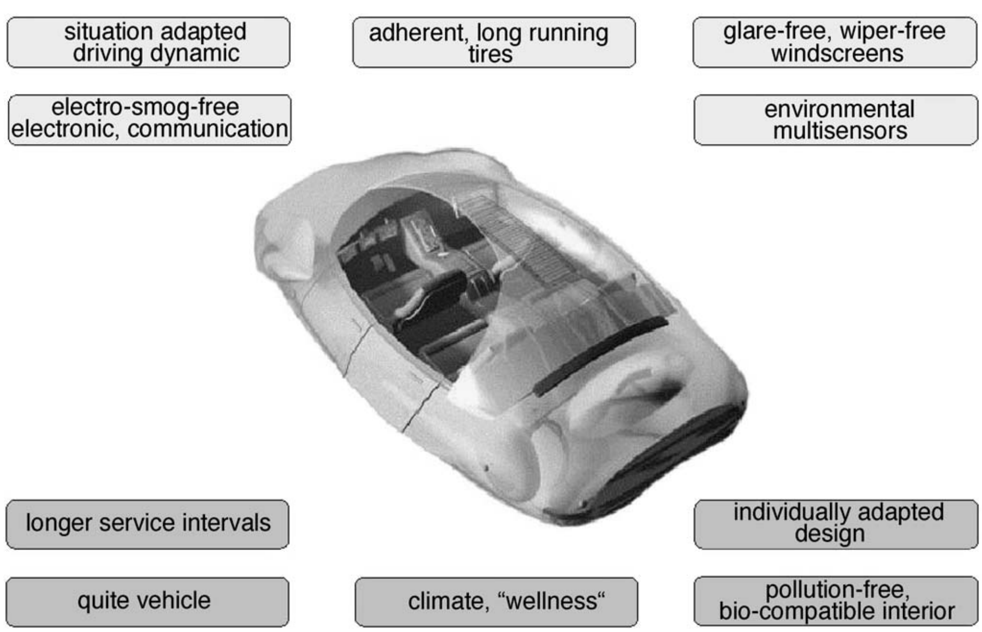

Fig. 2. Customer-specific requirements to future automobiles where nanotechnology has an impact.

year 2008, the NO_x has to be reduced by 50% and the particles by 70%.

Fuel cells are regarded as the engines of the future with the strongest impact on the emission. They will consume either conventional fossil fuel, e.g. methanol that will be converted into hydrogen, or directly hydrogen. Though a first car generation powered by fuel cells will soon be available on the market in a limited number (press release http://www.autointell-news.com/news-2001/december-2001/december-2001-3/december-19-01-p8.htm), many components still require further improvement. Nanotechnology can contribute to hydrocarbon (gasoline, methanol) injection and reforming, to hydrogen storage, to the cell electrodes and to the proton exchange membrane (PEM).

An efficient aerosol formation in the methanol reformer, but also of fuel in the traditional combustion engine, can be achieved by means of nanojet arrays. High-pressure injection through nanojets lowers losses by surface tension [2]. Nanojets can be patterned by deep anodic etching into various materials (e.g. Si, SiC) [3]. Self-assembled etching partly combined with etching through patterns, yield tubes with diameters of several 100 nm with walls thinner than 100 nm. Similar nanostructures can also be installed within a reformer [4]. A catalytic deposition on the giant inner surface of those nanoporous structures would guarantee efficient conversion.

Porous compounds like foams with irregular nanopores may improve sub-components of the fuel cell. The gas distribution layer (for H_2 and O_2) on both sides of the PEM or the electrodes need large surfaces. Shape, diameter, density are determined by process condition, like HF solution, material composition, anodic bias, and by temperature. Porosities up to 80% are possible to realise. Even sintering of nanopowder can create porous nanocomposites [5], see Fig. 3. A further application of porous nanocomposites is to be used as pollution filters, which mechanically and/or by catalytic reaction suppress emission of soot particles or toxic gases. Furthermore, nanoporous material like silicate with diluted metal oxide can act as gas sensor, e.g. for NO_x (www.nimc.go.jp/overview/v18.html).

A further approach to improve the fuel cells can be the substitution of the traditional Nafion PEM by a polymer-inorganic nanocomposite with improved conductivity, permeability, water management and interfacial resistance to the electrode (www.rpi.edu/locker/48/001248/yesterday/public_html/applications.htm). On the other hand, one can introduce into Nafion a nano-net of silica, that mechanically stabilises the PEM, and reduces its thickness to 10%, which yields a substantially lower resistance [6].

In the long-term, fossil fuel engines have to be substituted by those using hydrogen, either by direct combustion (BMW homepage) or by fuel cells (Toyota, GM and DaimlerChrysler homepages). An efficient storage medium for hydrogen is required in order to reduce the tank volume down to 10% of the present hydrogen pressure tanks. Adsorption to metalhydrides and alanates is presently investigated. However, great hope is directed to carbon nanotubes (Bucky fibers based on C_{60} fullerenes) (R.E. Smalley, American Inst. Chem. Engineers, Houston (1996) and www.cnst.rice.edu/whatwedo.cfm/). Single-wall or multiwall tubes have been predicted to reach a hydrogen capacity above 10%. Unfortunately, that has never been measured so far [7].

Mankind is waiting for a hydrogen infrastructure without fossil fuel, as this would solve all oil-related technical and political problems and also guarantee sustainability. How-

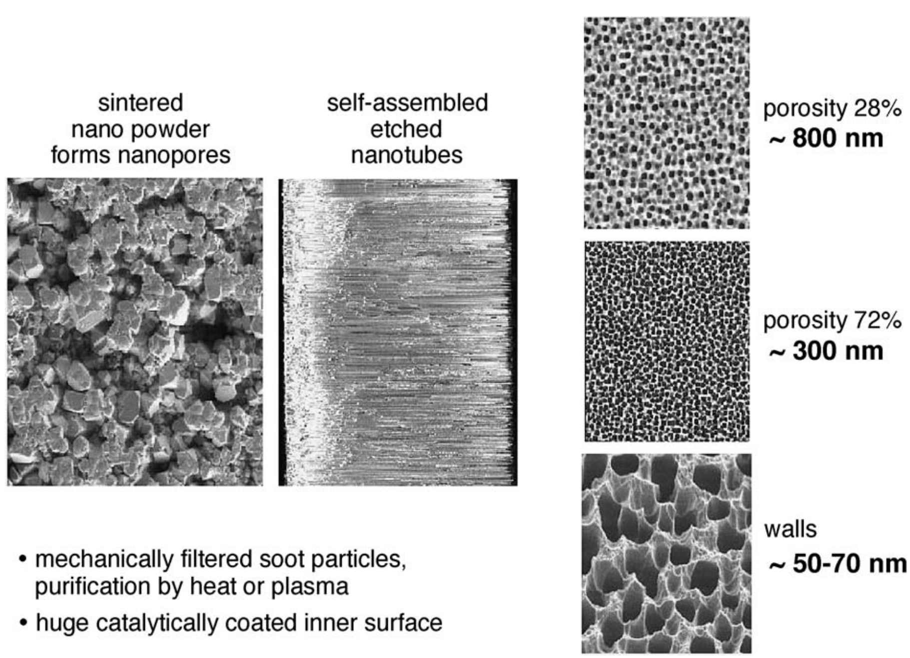

Fig. 3. Porous structures with potential for pollution filters.

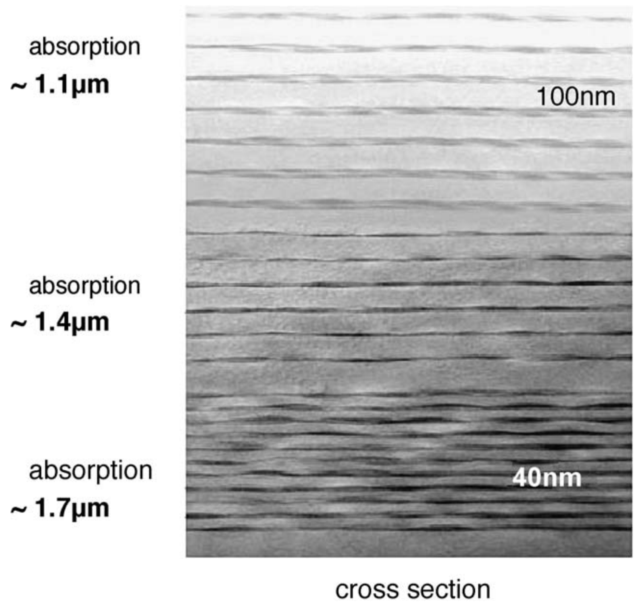

Fig. 4. Si semiconductor composite with multilayered Ge nano-dots for thin film solar cells on the car body.

ever, as long as the expected huge storage capacity of nanotubes for hydrogen is not proven, and as long no sustainable hydrogen formation (e.g. electrolytically with solar energy) and no hydrogen transportation strategy into hubs of conurbations, and no solution for save filling stations are available, this will remain a vision. Fortunately, the automotive industry and the oil-producing industry try to solve this topic in a concerted action.

Improved power train also concerns friction and wear reduction of translatory or rotating parts; in general, it deals with the topic tribology. The largest mechanical losses at high revolution rates come from piston, piston rings and crankshaft gear, at low revolving rates, instead, mainly from the walve train [8]. Novel hard and/or low-friction coatings are necessary. Nanocomposites with SiC, SiO_2, TiO_2, BN_3, C, diamond, even teflon within matrix material such as Ni, Al, Fe, and alloys suppress dislocation gliding and crack formation by pinning at the diluted particles. The Hall-Petch relation represents the improvement in strength when going from micro- to nanoparticles [9]. The improved mechanical stability means less wear, better gliding, thinner coating, less lubricants, longer service intervals and pronounced fuel saving.

3. Components for energy conversion

Solar cells on the car roof are already an option of few car manufacturers [10], in order to provide a ventilation in the interior when the engine is off. However, the extracted power is low due to the low efficiency of standard cells and due to the small area of the covered car roof. Improvements are welcome to apply them, e.g. for more efficient cooling and for charging a back-up battery for emergency cases or after accidents. A nanocomposite with semiconductor nano-dots, e.g. Ge within a semiconductor matrix, e.g. Si may improve absorption, and increase efficiency [11]. Thanks to the nano-dots, a perfect crystalline combination of these different materials can grow. The nano-dots assemble self-organised in layers stacked up to hundreds within the matrix material, with a large freedom in concentration, size, density, layer distance, which can be adjusted by process conditions and surfactant pre-deposition. One can deposit

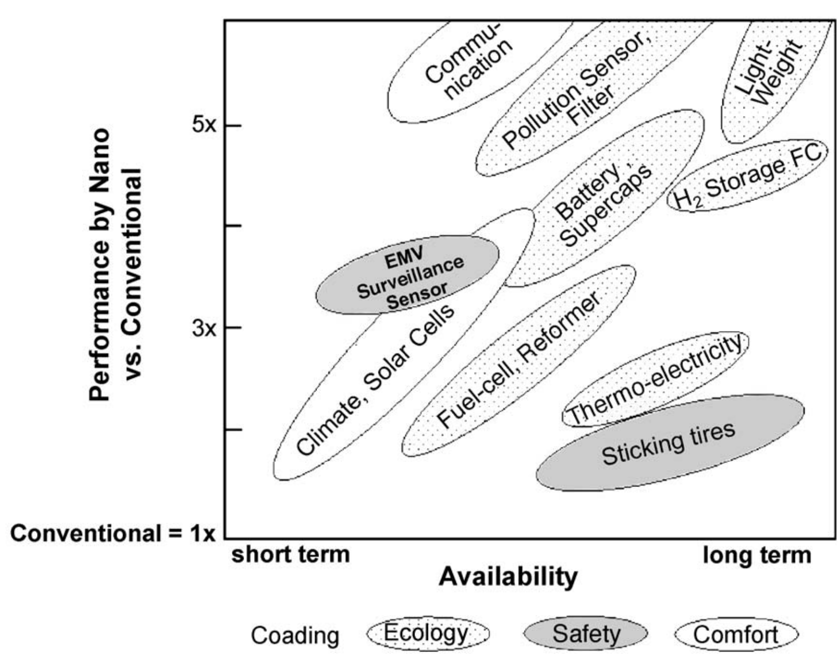

Fig. 5. Performance improvements of car components and functionalities achievable by nanotechnology.

triple cells (see Fig. 4), which can use a wider part of the solar spectrum. The goal is a solar roof of roughly 100 W maximum power output on passenger cars and even 1 kW on trucks and buses.

One idea may be the use of the complete car body as a solar cell (Patent DC-P 801289/DE filed). Various nanocomposites came into the game, e.g. a photovoltaic paint composed of dye-sensitized TiO_2-nanoparticles embedded in an electrolyte [12] or a flexible thin film semiconductor cell with multi-nanolayers, or polymer cells either with carbon bucky balls or with semiconductor nano-rods [13]. Based on an envisaged efficiency of 10%, one can gain around 0.5 kW of electrical power for a limousine, enough to feed into the battery and thus saving power by the accompanying release of the car's generator. However, a lot of open questions wait for a solution, like electrical connections on the car body and scratch resistant coating.

Thermoelectricity is another way of gaining energy. Wafers arranged around hot car modules like engine, exhaust, or catalyst can convert at least some percent of the thermal energy which until now has been wasted. Applicable materials are small-band semiconductors such as InGaAs, GaSb and SiGe. Their thermoelectric efficiency depends on the electrical and thermal conductivity and on the Seebeck-coefficient [14]. A nanocomposite with a diluted second phase precipitate or grains created within the material can lower the thermal conductivity and increase the efficiency. The efficiency reaches at least 4–8%, if the size of inclusions decreases to nanometer dimensions.

4. Light-weight components

Lighter car bodies without compromises to the stiffness and crash resistance means less material and indirectly less fuel consumption. Nanocomposites based on various metal or plastic matrix material strengthened by metal or ceramic nanoparticles or nanoplatelets can improve the strength by 100% [15]. However, a real breakthrough will occur when carbon Bucky fibers will become available in huge quantities. These giant one-dimensional molecule promises a tensile strength of $\sim$150 GPa, about 50 times that of steel with 1/5th of the weight. Even a polymer-nanofiber nanocomposite would yield considerably thinner, stiffer and lighter parts for cars. That opens a huge research field for the next years.

Future round view concepts without the A, B and C pillar of standard automobiles demand for transparent light-weight material, too. Glass may be substituted by polycarbonate windows. However, those have to be coated with harder, scratch resistant layers based on nanocomposites [16], e.g. nanolaminated clay-polymer stacks with aluminosilicates as clay minerals can be used (www.chem.qmul.ac.uk/research/resareas.html). Preferentially the hard-coating should simultaneously guarantee antiglare view and easy-to-clean performance [17].

5. Conclusion

Few topics have been shown above, where nanotechnology, especially nanocomposites have a striking impact on car components, according to the estimated, by factors improved functionalities (see Fig. 5). There are still a number of further examples, like nanocomposites for tires, for the fuel system, for gas separation membranes in fuel cells, for seat textiles and for glues of composite body parts. A study by an independent institute for trend-analysis in Germany has identified much more topics, up to 50.

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