Innovative Nano Composite Materials and Applications in Automobiles

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Abstract

Need of mobility all across the world is increasing exponentially. This is also an important prerequisite for the progress of modern society. In the past, automobile has played a crucial role and shall continue to play a dominant role in the progress of society. The demand of automobiles is increasing rapidly especially in the countries like China, India, Brazil and Korea. The rising economies of these countries will further increase the demand of automobiles. In order to achieve safety, comfort and environment friendliness, automobile companies are investing heavily in research and development. In this context, nanotechnologies are likely to play an important role. Nanotechnology is opening new doors for innovative products and imaginative applications in automobile sector. This paper focuses on the recent trends and future innovative nanotechnology applications in automobile industry.

Keywords-Nanotechnology, Nanomaterials,Automobile

Introduction

Nanotechnology is one of the most significant research areas to emerge in the past two decades or so. It is based on the concept of creating applications based on components built at the very small scale.

Nanotechnology is the engineering of materials on the scale of 1 nanometre (nm) to 100 nm, a nanometre being 1 billionth of a meter. At this level, the basic physical laws governing macro objects undergo a drastic change. A macro particle is a cluster of atoms arranged together in random order. The formation of the structure is left to nature, and control over the properties of the material is difficult. Nanotechnology, on the other hand, is a bottom-up approach where materials are created by placing individual atoms together. This decreases the randomness in the structural formation, enabling significant control over the properties of the material. Mechanical properties such as strength, ductility, and resilience can all be incorporated into one material.

Nanotechnology is the understanding and control of matter at dimensions of roughly 1-100 nm, where unique phenomena enable novel applications. A nanometer is 10-9 of a meter; a sheet of paper is about 100,000 nm thick. Encompassing nanoscale science, engineering and technology, nanotechnology involves imaging, measuring, modeling, and manipulating matter at this length scale. At this level, the physical, chemical and biological properties of materials differ in fundamental and valuable ways from both the properties of individual atoms and molecules or bulk matter.

Nanotechnology offers many benefits to various aspects of entire spectrum of industry. The automotive industry is also not untouched by the brewing nanotechnology revolution. Nanotechnology enhanced materials have already started beginning to improve the performance and cost-effectiveness of automobiles, and in coming years it will further become more and more viable as stronger, lighter and harder nonmaterial are commercially available. Although, a large number of nano-structures have been investigated till now, however, the most significant among them are synthesized from single atomistic layers of carbon. These structures include hollow ball shaped “Bucky balls” (Fullerene-C60), Carbon nano tubes (CNTs) and grapheme sheets which have a very interesting range of mechanical, thermal and electrical properties [1]. A large number of nanomaterials such as metal nanoparticles, nano-powder, nano-adhesives, nano coatings, are being increasingly used in automotive applications.

Nano-composites

A nanocomposite is defined as a solid matrix (usually polymers) that contains a nanoscale filler, called a nano-object (for example nanoparticles, nanotubes, nanofibres, etc.). The main characteristics of nano-objects are increased surface area (contact between the particle and its environment): this gives increased interaction between the particle and the surrounding matrix, resulting in improved mechanical, chemical, and thermal properties (1 g of particles of 25 nm has a surface area of 20 m2); and 2) transparency: when the particle diameter is lower than 30 nm, the reflection of visible light is negligible.

Nano-composites are a mixture of a conventional material with a nano-scale material. In the case of Polymer-Clay Nano-composites, the clay particles act as the nano-material. Nano-composite materials combine bulk properties of conventional materials with the size-dependent properties of nano-scale materials to create composite materials with novel properties. The range of potential nano-composite materials is infinite. These characteristics are the drivers for the development of nano-objects. Thus, there is a wide range of nano-objects available on the market or under development today. Although nanotechnology is considered as a recent science, some of these nano-objects have been sold for decades, even in millions of tons per year. Examples of these are primarily nanoparticles: carbon black, precipitate and fumed silica, etc. Relatively new nano-objects have already found commercial applications, showing real added value when compared to older particles. These nano-objects are (see Figure 1) [2]

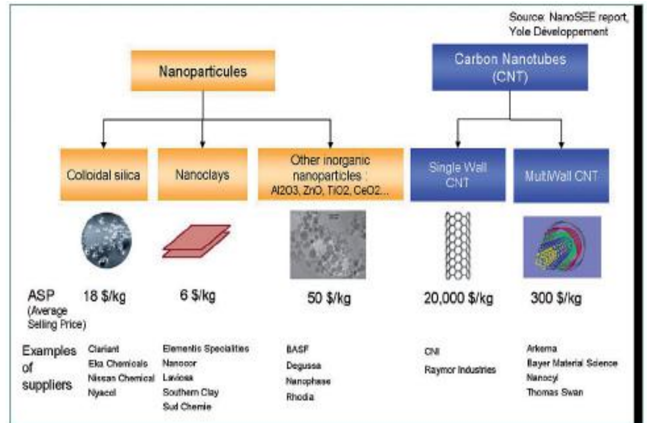

Fig. 1: Nano-objects : nanoparticles and carbon nanotubes.

The automotive industry is one of many fields of applications that have seen the growing impact of nanomaterials. Nanomaterial products are finding uses in the automotive industry for a variety of functions. Examples are:

- fuel-borne catalysts for soot prevention in particulate filters,
- tires reinforced with nanoparticles for better abrasion resistance and improved gas permeability,
- car coatings exhibiting greater scratch resistance and improved gloss,
- anti-fog coatings for headlight and windshield that are highly hydrophilic, forming water films instead of droplets,
- Structural plastic parts combining higher mechanical performance with reduced weight.

General Motors showed the first commercial use of nanoclays in cars in 2002, with the Chevrolet Astro and GMC Safari vans. The step-assist was made of thermoplastic olefin filled with 3% nanoclays. It was much lighter, stiffer, and less brittle at cold temperatures than those made with the conventional talc filler. Although this application drew large media coverage, it has since been terminated. In 2004-2005, GM released the Chevrolet Impala with a body side trim made of nanoclays. A weight savings of 3 to 25% was achieved on the redesigned parts, but their performance is questioned. In 2005, GM's Hummer H2 SUT cargo bed trim contained 3 kg of nanoclays per car Other car manufacturers commercialising nanoclay-filled parts include Maserati, Daimler Chrysler and Audi. Maserati engine bay covers are made of Ube nylon-6 nanocomposites, containing 2% nanoclays by weight.

Key Benefits and Challenges:-

The advantage of nanocomposites over conventional composites is that their mechanical, electrical, thermal, barrier and chemical properties such as increased tensile strength, improved heat deflection temperature, flame retardancy, etc. can be achieved with typically 3-5 wt. % loading of the nanomaterials such as clays, nanotubes and nanofibers while the latter require a high content of the inorganic fillers from 10 wt. % to as much as 50 wt. % in general, to impart the desired properties.

Another advantage of nanocomposites is that the strength, shrinkage, war page, viscosity and optical properties of the polymer matrix are not significantly affected. The enhanced properties are attributed to the structure and morphology of the nanocomposite, as they (clays/polymer) contain organically treated clays such as hectolitre, montmorillonite, and synthetic mica as well as nanotubes (carbon nanotubes, halloysite nanotubes). These nanomaterials have a large aspect ratio (1000:1) and each one is approximately 1 nm thick and hundreds or thousands of these layers are stacked together with weak Van der Waals forces to form a clay particle, resulting in subsequent exfoliation in which the individual layers are peeled apart and then dispersed throughout the polymer matrix. The excellent degree of exfoliation, which results in smaller particle sizes and provides the greater surface area to interact with the host polymer, results in improved performance. CNTs-enabled nanocomposites are also receiving attention as a mechanical reinforcement and electrically conductive additive for automotive fuel system components requiring electrical conductivity. However, there are still many limitations and challenges for nanocomposites production. These include:

- **Processing**: Compatibility, dispersion and exfoliation between nanomaterials and polymer matrices. Only a limited number of plastic matrices (mostly thermoplastics) are compatible with nanoclays/nanotubes/nanofibers as intercalation of clays with the precursor of a polymer can change the functionality of the polymer and inhibit its properties.

- **Cost**: The production of nanocomposites on a commercial scale at viable prices, as polymer matrix price depends on crude oil prices and CNTs price is also high.

- **Consistency and reliability in volume production**: It is possible to get consistency and reliability in volume production materials to a great extent. However, particle size distribution and control in volume manufacturing is not so easy.

- **High lead time**: Commercializing the end-use products would take a longer time, mainly due to stringent approval and OEMs acceptance.

- **Oxidative and thermal instability of nanoclays**: Commonly used organoclays are thermally unstable due to exchange of metal cations in clay galleries with organic ammonium salts and can degrade at temperatures as low as 170°C. It is clear that such organoclays are not suitable for most engineering plastics that are fabricated by melt processing technology [3].

Future Development and Directions

It is quite evident from the foregoing discussion that polymer nanocomposites are finding many applications in the automotive industry, and the market for these materials is on the path of growth and expansion. The OEMs/Tier I, Tier II, Tier III, raw materials/nanointermediates manufacturers, researchers and technologists are realizing that other than clays, nanomaterials like grapheme, carbon nanofibers, nanofoams, multiscale hybrid reinforcement and graphene-enabled rubber nanocomposites could drive the market dynamics.

Functional Advantages of Nanotechnology

Nanotechnologies can be utilized in a wide range of industries owing to unique effects and functional properties. Functional advantages which are direct fallout of unique properties of nano materials are described here under.

Mechanical Properties

The demonstrated improved mechanical properties of nanostructure material are higher hardness, increased breaking strength at low temperatures or super elasticity at higher temperatures. The mechanical properties exhibited are due to decrease in grain size resulting in dimensions below which deformation mechanism does not occur in grain itself. These benefits can be translated in terms of lightweight materials, increased durability of components and effective lubricating system.

Geometric Properties

At contact surfaces, a crucial reaction between gaseous or liquid and solid substances takes place at nanoscale. Interaction in different medias therefore requires special physical and chemical properties of the surface of the particles, fibres, pores and the products. With regard to protection function, these demands include resistance against oxidation, corrosion, mechanical abrasions and high temperature .Because of the small size of nanostructures, the extreme surface-to-volume ratio of these materials becomes more important. Therefore, large specific surface and the surface properties of nanostructured materials influence chemical activity Due to pores at nanometer range, materials can exhibit properties which can be used in nanofilters.

Optical Properties

Since nanoparticles are very small as compared to the wavelength of the visible light, no reflection occurs from these particles. Dispersion effect is also demonstrated by nanoparticles which can cause colour effect. By altering the size of the nanoparticles, desired wavelength region can be achieved for intended application. Therefore, the optical property such as light absorption and emission behaviour gets altered. The fact nanoscale features are smaller than the wavelength of visible photons, also impacts light scattering, enabling the design of nanocrystalline ceramics that are as transparent as glass.

Electronic Functionalities

In the nanometer range, quantum effects take place that cannot be observed in larger objects. Charge carriers that can move freely in volume of solid material are strongly influenced in their mobility by nano objects given their small dimensions. The 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 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 turning of the electronic properties[4].

Nano composites drive opportunities in the automotive sector

Nanocomposites are an emerging class of polymeric materials exhibiting excellent mechanical properties, enhanced modulus and dimensional stability, flame retardancy, improved scratch and mar resistance, superior thermal and processing properties, reduced warpage of components and enhanced impact resistance making them suitable to replace metals in automotive and other applications[3]. The key drivers for the use of polymer nanocomposite-enabled parts in the automotive industry are reduction in vehicle's weight, improved engine efficiency (fuel saving), reduction in CO_2 emissions and superior performance (greater safety, increased comfort and better driveability). Fig.2 illustrates the usage of polymer nanocomposites parts.

Figure. 2: Illustration of the usage of polymer nanocomposites parts.

The commercialization of polymer nanocomposites started in 1991 when Toyota Motor Co. first introduced nylon-6/clay nanocomposites in the market to produce timing belt covers as a part of the engine for their Toyota Camry cars, in collaboration with Ube industries in 19912. At about the same period, Unitika Co. of Japan introduced nylon-6 nanocomposite for engine covers on Mitsubishi GDI engines manufactured by injection moulding, the product is said to offer a 20% weight reduction and excellent surface finish. In 2002, General Motors launched a step-assist automotive component made of polyolefin reinforced with 3% nanoclays, in collaboration with Basell (now LyondellBasell Industries) for GM's Safari and Chevrolet Astro vans, followed by the application of these nanocomposites in the doors of Chevrolet Impalas

Nanoclays also offer a reduction in relative heat release, excellent dispersion and exfoliation, excellent flame retardant synergy, and reduced weight. Polyolefin is commonly used as host polymer and thermoplastics such as polyamide (nylon), Polyphenylene Sulphide (PPS), Polyetheretherketone (PEEK), Polyethylene terephthalate (PET), polycarbonate, thermosets such as epoxy, and thermoplastic elastomers such as butadiene-styrene diblock copolymer are also used in more demanding automotive applications. The use of thermoplastics as a matrix material in nanocomposites has been growing steadily, especially in automotive applications, largely due to the material's low cost, high performance, low density, longer shelf life, easy dispersion and processing with nanomaterials, ability to regrind, and recyclability. Thermoplastics also offer enhanced mechanical, thermal, electrical and barrier properties, excellent fracture toughness over thermosets as well as the ability to be easily joined by mechanical joining and welding techniques[5].

The list of specific automotive nanotechnology applications includes at least the following:

- Lightweight structure materials
- Fire-resistant and thermal protection materials
- Strength, hardness and duration improvement
- Functional paint and coating/smart skins
  - Self-cleaning
  - Scratch-resistant
  - Anti-corrosion
  - Color effects
  - Optical performance
  - Programmable materials
  - Other functional materials

Nanotech-based energy generation and storage

- Fuel cells
- Solar cells
- Gasoline catalyst
- Energy storage
- Ultrafine sensing and monitoring
- Motion monitoring
- Pressure monitoring
- Inclination monitoring
- Biometric systems
- Climate sensing
- Nanoelectronics
- Smart-engine management
- Displays and lighting
- High-temperature electronics
- Security controlling
- Long-lasting batteries

Applications of Nanotechnologies in Automobiles

Nanotechnology offers great promises of innovative products and sustainable solutions to entire cross section of industry. Automotive industry is set to get benefited with research and development taking place in nanotechnology. The nanotechnology enabled products have already started showing its presence across automotive industry by way of enhanced performance and cost effectiveness. The industry requirements of increased fuel efficiency, safety and comfort, environmental safety etc are set to be revolutionarised by nanotechnology. As on date, a large number of nanotechnology applications are in use in automobile industry. The areas which are likely to have impact in future are discussed below.

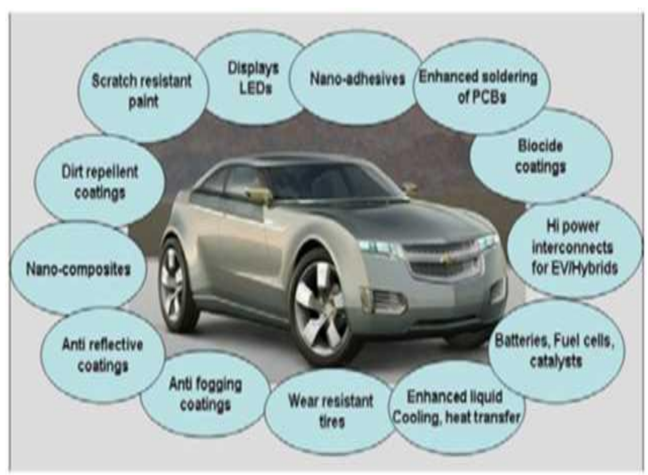

Figure 3 Automotive applications of nanotechnology

The most promising automotive applications of nanotechnology include the following:

- Improved materials with CNTs, grapheme and other nanoparticles/structures
- Improved mechanical, thermal, and appearance properties for plastics
- Coatings & encapsulates for wear and corrosion resistance, permeation barriers, and appearance
- Cooling fluids with improved thermal performance
- Joining interfaces for improved thermal cycle and crack resistance
- Metal alloys with greater mechanical strength
- Metal matrix and ceramics with improved mechanical properties
- Solder materials with crack resistance or lower processing temperature
- Displays with lower cost and higher performance
- Batteries for electric vehicles and fuel cells with improved energy capacity
- Automotive sensors with nano-sensing elements, nanostructures and nanomachines
- Hybrid electric vehicles using electrical interconnects for high-frequency and high power applications
- Electrical switching including CNT transistors, quantum Transistors, nano-electromechanical switches, electron emission amplification, and more efficient solar cells
- Self-assembly using fluid carriers.

Nanotechnology for Car Body

Keeping in mind the safety of the automobile occupant, it is important to develop nano structured materials which can offer high strength to take care of the high intensity impact during crash. Light weight would also lead to reduced fuel consumption and thus economy in operation.

Nano Steel

Crash safety and lightweight are the two major issues which are required to be addressed. A high strength yet light weight material for car body can be produced by using nanotechnologies. It has been reported that embedded nano particles of metallic carbon nitride can effectively increase the strength of steel. In long term loading tiers of up to 10,000 hours, it was observed that a share of 0.002 percent of finely dispersed carbon can increase the stability of the steel significantly. The small size of only five to ten nanometer of carbon nitride is responsible for the outstanding properties.

Figure 4.Nano Steel

PAINT

Automotive paints are already coming into commercial production that use nanotechnology to migrate silicon particles to the outer surface of the coating, creating an extremely thin, hard, glass-like surface three times more scratch-resistant than conventional non-metallic or metallic paints. U.S.-based PPG Industries Inc. has produced a nano-based scratch-free paint.

Figure 5 Nano Car Paint

Corrosion Protection

Another desired characteristic of automotive parts is corrosion protection. Widely used Chrome III (Cr^{3+}) does not offer long term protection. By the use of nanotechnologies it has been made possible to enhance protection by the use of SiO_2 nano particles in the electrolyte. The passivation achieved through galvanization processes consists of a Cr^{3+} enriched layer and a layer containing SiO_2 nano particles in Cr^{3+} matrix.

Nanotechnology for Chassis and exterior

Reduction of the automobile weight is the primary concern of the automobile manufacturer. The reduced weight of the automobile leads to reduced fuel consumption and emission of exhaust fumes.

Nanotechnologies can give rise to lighter and more resistant materials by incorporation of nano particles or by the control of structure at nano scale. It is possible to achieve same mechanical strength with less and lighter material with enhanced performance.

Nano engineered thermoplastic materials allow a weight reduction of up to 40% compared to traditional steel chassis parts. With regard to paints and surface coatings, nanostructured surfaces result in improved paint adhesion and colour 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.

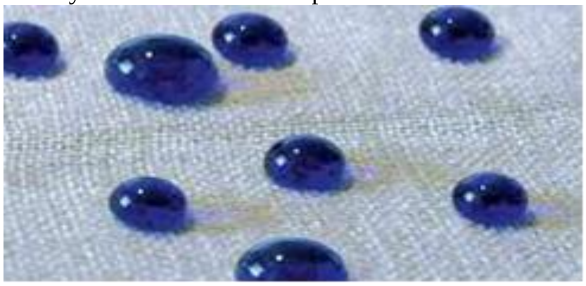

Figure 6 Hydrophobic Effect

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, resistance to initial wear and tear, and tear propagation. There are three products that significantly improve the properties of natural rubber: soot, silica and organosilane. Now being produced in nanoscale form, these particles as well as the crosslinking with the natural rubber molecules play a key role for tire properties.

Figure 7 Nano Tyre

Nanotechnology for Shell of the Car

Nanotechnology offers innovative solution for scratch resistance, dirt repellent and self-healing car paints beside ultrathin coating for mirrors and reflectors applicable for car body shell. Following are some of the recent developments taken place for car body shell applications.

Scratch Resistance

Nano-varnishes are now offering scratch resistance and maintained paint brilliance for a long time. This property is possible due to embedded ceramic particles in the final varnish layer in the nanometer range. Conventional paints consist of binder and cross linking agents while the nano paints consist of organic binder with high elasticity and inorganic nano particles with high strength. The tightly packed nano particles make the paint scratch-resistant.

Ultra-Thin Layers for Mirrors and Reflectors

Nowadays, large amount of glass is processed in a car with major chunk used for windscreen and window panes. Nanotechnology holds great promise in reducing the weight of the glass by the substitution of mineral glass by polymer glass. in order to make polymer glass scratch and impact resistant , it is coated with paints having extremely hard aluminum oxide nano particles placed in the substrate matrix during the hardening process resulting in high abrasive resistance with increased impact strength.

Nanotechnology for Engine and Transmission System

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 cheapbipolar materials using nanocomposites, more efficient non-platinum electro catalysts, 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.

Figure 8 Nano Technology In Reduction Friction Amongst Moving Parts

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 per cent of the fuel consumption is influenced by engine friction due to the friction loss at the moving mechanical parts (piston, crank drive, valve drive). Nano coatings applied to mechanical parts, and nanostructured lubricants, help reduce friction and abrasion and thereby improve fuel efficiency

Improving Fuel Injection

In modern diesel automobiles, direct injection pumps are used to spray the fuel into combustion chamber. By controlling the pressure and precise time of injection, more efficient combustion can be achieved. Piezo ceramic materials are used these days to achieve higher fuel economy, reduced pollution and noise by the use of effect to enable the opening and closing mechanisms of the injection valve. Nanocrystalline piezoelectric materials are used (Lead-Zirkone Titanate) in injectors regulating the distance which is in nanometer range. Nanotechnology enabled piezo injectors can ensure several finely closed injections per combustion cycle in powerful diesel engines at 1600 bar injection pressure.

Reduction in Exhaust Emission

Modern automobiles are able to reduce exhaust emission by the use of catalytic converter which consist of high grade steel housing that include catalytically active materials used for conversion of pollutants to nitrogen , steam and carbon dioxide. Nanotechnology plays an important role during conversion of toxic to non-toxic gases. If the material used for the catalytic function is scaled to nanometer range, the specific surface increases drastically. The composition is designed in such a way that the exhaust gases can optimally interact with catalytic coating thereby increasing the rate of chemical transformation into harmless substances.

Conclusion

The automotive industry will be influenced by the development and implementation nanotechnology. It is our hope to raise the awareness that nanotechnology will positively influence the business of the automotive industry over the next several years. Due to the small size of nano-materials, their physical/ chemical properties (e.g. stability, hardness, conductivity, reactivity, optical sensitivity, melting point, etc.) can be manipulated to improve the overall properties of conventional material.

Automobile industry is set to be influenced by the development taking place in the field of nanotechnology. Due to small size of particles in nano range, their chemical and physical properties can be altered to improve the overall properties of conventional material. Increased surface area of the metal nano particles results in significantly enhanced reactivity in a catalytic converter thereby resulting in reduction of emission. Other fields where nano technology is likely to be employed gainfully are cooling systems for efficient heat transfer and use of nano-magnetic fluids in shock absorbers to increase vibration control efficiency. High efficient nano layers of semiconductor materials provide electronic components and systems with a longer lifetime. Sensors based on nano-layer structures find applications in engine control, airbag, antilock brake and electronic stability program systems. Nanotechnology is therefore likely to influence the auto industry in a great deal and shall deliver features and products which are not scalable today.

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