論 文

Nanotechnology : Key to Solving Environmental Problems ～Focus on Automobile Environment Technologies～

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ABSTRACT

The state of nanotechnology in Japan was greatly influenced by the Clinton administration of the United States, and as a result, the government has allotted huge budgets for development purposes since 2001. At present, research activities at both national research institutions and private companies are fervently progressing. On the other hand, in the 3rd Session of the Conference of the Parties to the United Nations Framework Convention on Climate Change (COP3) held in 1997, clear objectives regarding environmental problems were set by each country. Research is continuing towards the resolution of these problems as the enforcement year 2008 draws near. This paper describes the relationships between nanotechnology and the automobile environment technologies that hold the key to the resolution of environmental problems based on our national strategy in science technologies.

1. Nanotechnology

1.1 The size of “nano”

Nanotechnology and nanotech have been heard quite a bit recently. We are aware that the nano “is an extraordinarily small world” but just how small it is, more often than not, is not fully grasped at all. The word “nano” derives from the Greek word “nanos” (which means a dwarf). A nanometer means one billionth of a meter ; that is one millionth of a millimeter. A nanometer would be equivalent to 100,000th of the diameter of a single hair. If one thinks of a dwarf as an expert in magic in the West, the world of the “nano” brings out a clearly magical scent. Let us take a look at Figure 1. The world we live in is expressed on the order of “milli” while the size of a hydrogen atom, used as an example of the smallest object, is expressed in picometers (1nm=1000pm ; a world that is 1/1000 of the nano, although not discussed further in this manuscript). In general, the nano world often refers to 1nm－100nm size ranges, and the range of sizes of the nano is defined the same way in this paper. As an example of recent developments in semiconductor technology, in “MIRAI” (joint research under the Ministry of Economics, Trade and Industry project, between Advanced Semiconductor Research Center of National Institute of Advanced Industrial Science and Technology and Association of Super-advanced Electronics Technologies), research on semiconductor processes is currently ongoing with the thinnest line width of circuits being 65～45nm [2]. Ten nanometers is about the size of a virus while 1 nanometer is about the molecular unit size of protein substances and DNA. Hence, in nanotechnology, molecular and atomic substances are referred to as the basic composition unit where functionality starts to appear and the independent operation of that functionality gives rise to new functions that so far do not existent and which might be taken as the basic technology underlying all fields [3].

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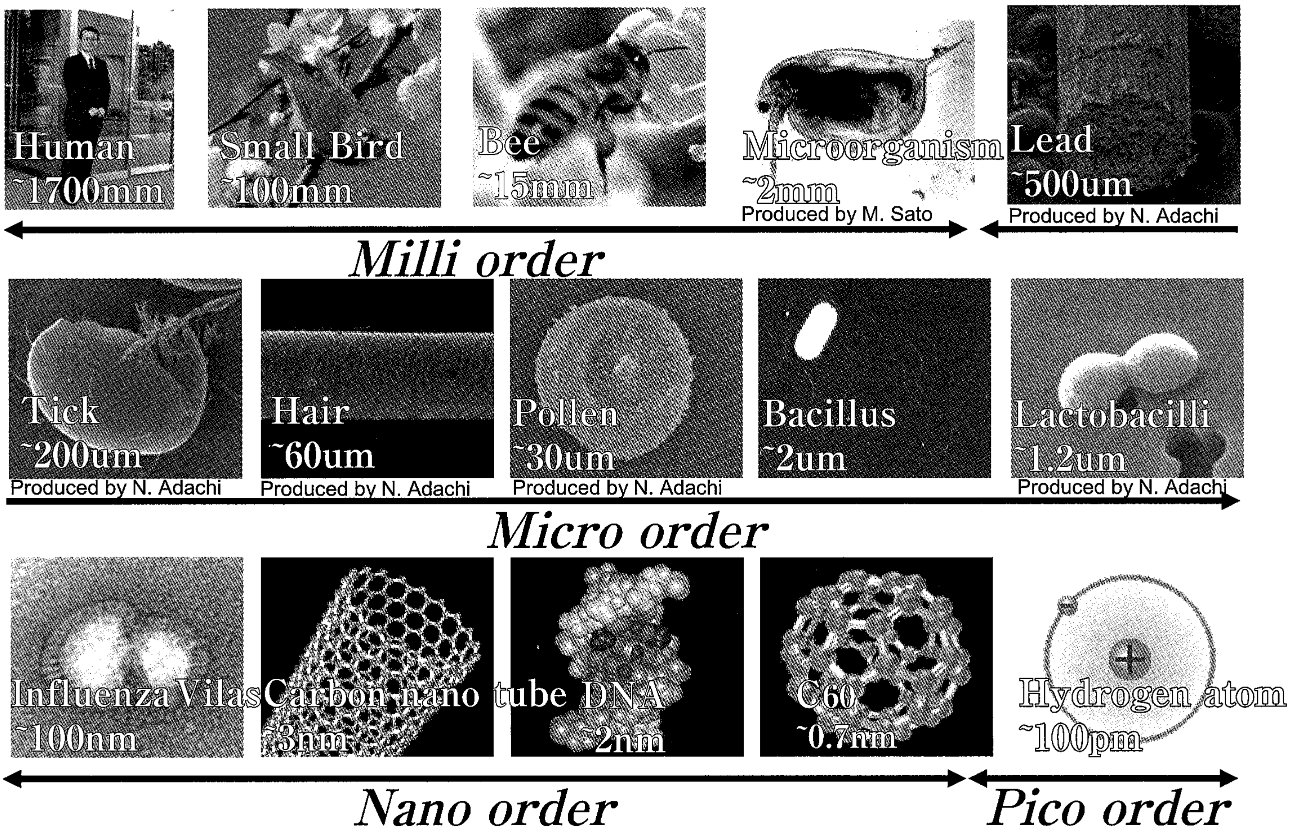

Figure 1 Scale of nano meter size.

1.2 What is nanotechnology?

Nanotechnology operates on a nanoscale where new capabilities and superior properties are brought about by manipulation at will with perfect freedom, and where substances and structures can be formed from two or more completely different types of molecules and atoms. At present, this technology is employed in fields such as materials, chemistry, medicine, electronics, and energy, and cutting edge technologies are being vigorously developed with much intensity. On one hand, it is true that research at the nano scale here would not be possible without the technology needed to observe or analyze them. Generally speaking, analyses at the nano scale use electron microscopy as the main tool. However, even in those analyses, it would not be an exaggeration to say that the development of the Scanning Tunneling Microscope [4] by G. Binnig and H. Rohrer of IBM in 1981 opened the door for nanotechnology [5]. Figure 2 is a simple presentation of the fundamental principles of STM [6].

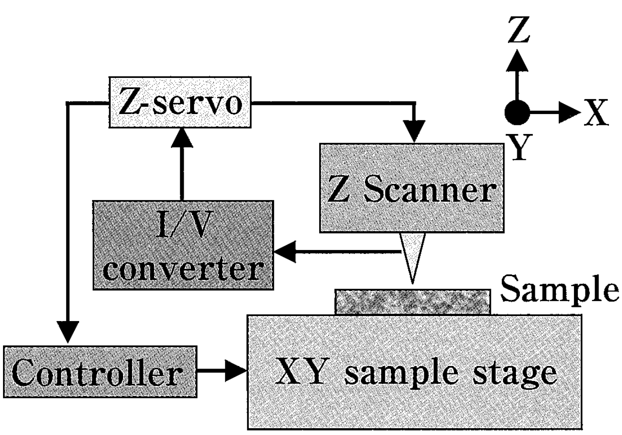

Figure 2 Principle of scanning electron microscope.

First, a probe draws near the test material or specimen and detects microscopic current (tunneling current). Since the strength of tunnel current changes corresponding to the unevenness of the surface of the substrate, the surface information at the atomic level could be obtained by fixing the strength of the tunneling current and letting the probe scan the surface of the specimen. Further, the technology for using the STM probe to operate on the atoms at the surface of the substrate has been developed. In fact, M. Eiger of IBM created the smallest advertisement letters "IBM" using 35 atoms in 1990. (Figure 3)[7][8] In this way, atoms can now be observed and manipulated one at a time.

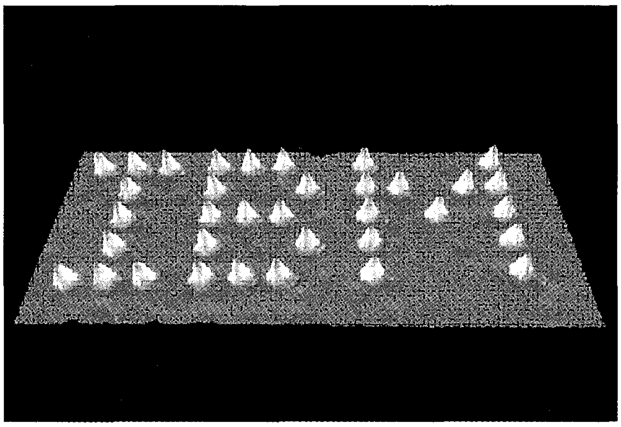

Figure 3 Photograph where minimum advertising character in the world was made with 35 xenon atoms.

2. Background of the national nanotechnology initiative

2.1 Nanotechnology initiatives in Japan and the United States

The establishment of nanotechnology initiative in Japan is deeply linked with developments in the United States. The beginnings can be traced back to January 2000 with the announcement of the NNI (National Nanotechnology Initiative) by then-President Clinton of the United States. The following are paraphrases of excerpts from the pronouncements of former President Clinton on January 21,2000 :

- A new substance having ten times the strength of iron and yet incomparably light,
- A storage device the size of a cube of sugar that can contain all the information in the National Library of Congress,
- Technology that can detect a cancerous tumor at an early stage when the tumor consists of only a group of several cells.

All these technologies require long-term initiatives with high levels of difficulty and that the government to play a crucial role in the research and development efforts. Japan identified the four major areas of life science, information, environment and nanotechnology through the Second Basic Plan for Science and Technology for the five years starting FY2001. This is a response to the basic policy set by the Council for Science and Technology Policy of the Cabinet Office, which emphasizes the importance of the research and development in Japan [9]. Table 1 [10] shows the trends in the budgetary allotment of major countries for research and development as reported in the NNI of the United States. The United States had the biggest budgetary allotment until 2000. However, influenced by the Clinton policies, Japan expanded its investment in 2001 to about twice that of the previous year to stand side by side with the United States. In 2002, Japan had the biggest budgetary allotment. The total budgetary allotment to nanotechnology by the governments of all countries in the world amounts to$4.1 billion. This amount indicates an eight-fold or more increase in budgetary allocations of the countries of the world in the period spanning 1997 to 2005. Especially evident in the table is the rapid increases in budgetary allocations in the years following 2000 [9].

(a unit, $ 1 million)

Area	1997	1998	1999	2000	2001	2002	2003	2004	2005
EU	126	151	179	200	~225	~400	~650	~950	~1050
Japan	120	135	157	245	~465	~720	~800	~900	~950
U.S.A	116	190	255	270	465	697	862	989	1081
others	70	83	96	110	~380	~550	~800	~900	1000
total	432	559	687	825	~1535	~2350	~3100	~3700	~4100

Source; Made out by Washington Core based on The National Nanotechnology Initiative at Five years

Table.1 Cross country comparison of amount of government investment to nanotechnology R&D (1997-2005, presumption).

2.2 Nanotechnology and environmental problems

As previously mentioned, the four major fields considered by Japan are nanotechnology, life sciences, information and the environment. One can say that nanotechnology, one of the four major fields in the government's policy declaration, serves as the foundation technology of all fields, starting with the other three major fields in this declaration. Figure 4 shows a schematic outline of the fields that nanotechnology covers [11].

It is evident that nanotechnology covers a

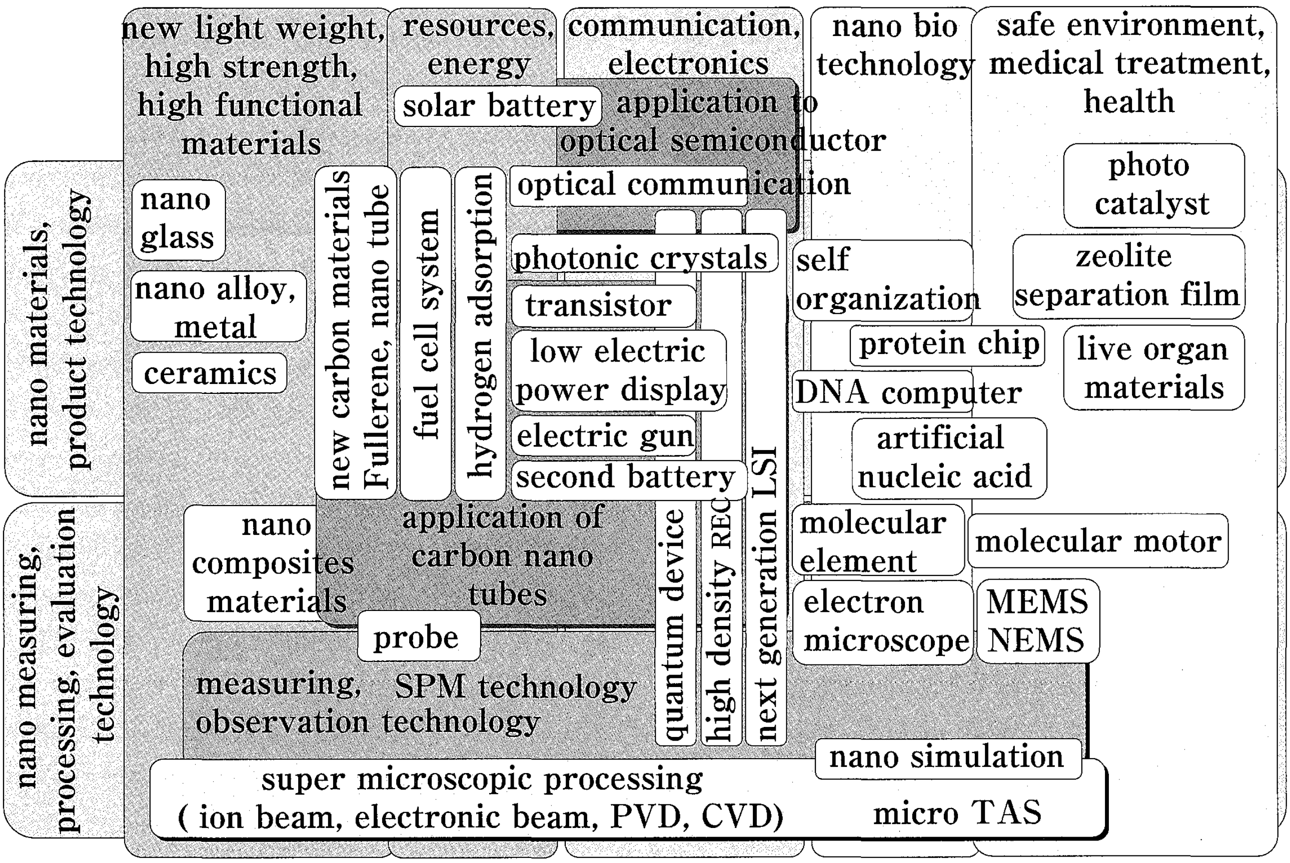

Figure 4 [Application of Nano Technology] Overhead view of the entire technology.

broad range including materials, energy, communication, electronics, biotechnology, environment and safety, and many more. This paper discusses, in detail, the environment of nanotechnology ; i.e., the applications to new materials and energy resources from the point of view of automobile environment technology. The "Kyoto Protocol" adopted by the 3rd Session of the Conference of the Parties to the United Nations Framework Convention on Climate Change in 1997 obligates all advanced countries to, within the specified timeperiod, reduce green house gas emissions, including those of carbon dioxide, methane, zinc nitrides, HFCs, PFCs and sulfur hexafluoride, which is one of the major contributory factors to global warming. (Levels set for the period 2008～2012 are as follows : Japan, 6% ; United States, 7% ; EU, 8%). Chapter 4 describes in detail how nanotechnology could make significant contributions to the resolution of global problems, firstly, by addressing the exhaust emission problems of automobiles.

3. Environmental problems attributable to automobiles

3.1 Global warming (CO_2) problem

Global warming due to greenhouse gases was first mentioned by a Nobel Laureate in Physics, S. A. Arrhenius (1859-1927) and was first recognized as a problem by the United Nations around the mid-1960s. A major problem recognized was the remarkable climatic aberrations that could result from global warming where high-altitude glaciers, and those at north and south poles, melt causing seawater levels to rise ; this was the subject of much discussion in the 1980s. The results of investigations on the relationship between atmospheric temperatures and the past CO_2 concentrations extracted from core samples of ice sheets in the Antarctic showed the interactive relationship between the two [12]. With the increased activities in the production, transportation and other fields, and continuing increases in CO_2 levels, it was predicted in 1955 that the atmospheric temperature in the year 2100 would rise by 1.0-3.5℃ (Intergovernmental Panel Climate Change : IPCC). This was corrected in 2000 to 1.4-5.8℃. An increase of 2℃ would raise the sea water level by 50cm. This would entail huge expenses needed to address the problem of water submersion in lowlying countries in the Pacific and Indian oceans, and countries such as Holland, which have large areas lying below sea level. This has led to talk of moving from the islands in the Pacific to Australia and there is concern about the impact on the ecosystem. The cause of greenhouse gas problem has been attributed mainly to CO_2 emissions from fossil fuels combustion, which has continued to increase since the industrial revolution and which of late has dramatically increased due to dramatic increases in production and transportation, and which, when compared with the other greenhouse gases, is clearly high (Figure 5). [13] [14]

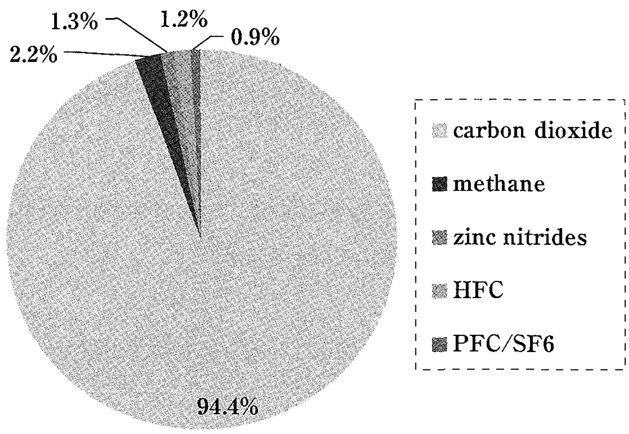

Figure 5 Direct influences of Global warming due to greenhouse gases in Japan (1993).

3.2 Trends in CO_2 emissions from automobiles

Although the breakdown in CO_2 emission from transportation indicates that emissions from domestic shipping transportation is 5.6%, railway transportation is 2.7%, and air transportations is 4.0%, for a total 12.3% (1998 figures), about 90% of the total emission from all transportation is accounted for by automobiles. The share of contribution from automobiles is clearly large (Figure 6), and most of the CO_2 from automobiles comes from the combustion of fuels by gasoline and diesel engines. Hence, as a countermeasure. To the global warming phenomena, either the fuel consumption of automobiles should be improved or a shift must occur to low-CO_2 emission automobiles or to clean energy automobiles that do not emit CO_2 [13].

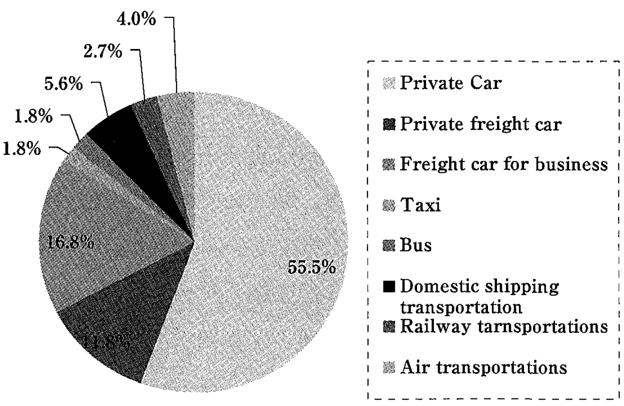

Figure 6 The share of contribution from automobiles in CO2 emission.

4. Nanotechnology to transform automobile technology affecting the environment

4.1 Applications in automobile technology affecting the environment

Technologies to eliminate CO_2 emissions in this age of awareness for environmental problems hold the key to the survival of the automobile industry. Fuel development for the purpose of replacing gasoline or diesel oil with next generation energy sources such as natural gas or fuel cells, or materials development for replacing steel parts with lighter aluminum or plastic plays a very crucial role in the solution of serious environmental problems. Automobile manufacturing aims, as a major prerequisite, to deliver the three functions of running, turning, and stopping automobiles efficiently and safely. However, elimination of gasoline and the use of lighter materials are disadvantageous to the mobility and safety of automobiles. Meanwhile, nanotechnological approaches on how to overcome those problems are now ongoing at a brisk pace at national research institutions and private automobile manufacturing firms, and have become an important development strategy in automobile production technology.

4.2 Fuel cell vehicle (engine / drive system)

Research and development on hydrogen as the ultimate clean fuel is proceeding briskly. One area in this field of fuel research is the Fuel Cell Vehicle which has been the focus of much attention as the next generation low polluting automobile and driven by the electrical energy which results from the chemical reaction between hydrogen and oxygen as shown in Equation (1).

$$H_2 + 1/2\,O_2 \rightarrow H_2O + \text{Energy} \quad (1)$$

The fundamental principles of the Fuel Cell (FC), or Brennstoffzelle (BZ) in German, was discovered by the Englishman H. Davy in 1801 [15]. The first public experiment was conducted by another Englishman, W.R. Grove, in 1839, 20 years before L.G. Plante invented the lead battery. Why it took so long to develop practical applications despite the fact that the fundamental principle is simple can be attributed partly to the difficulties met in increasing the power generation per unit weight or per unit volume, extending the period of generation, and providing the fuel cell at lower cost. The fuel cell consists of catalysts, electrodes, and an ion transmission membrane (Figure 7).

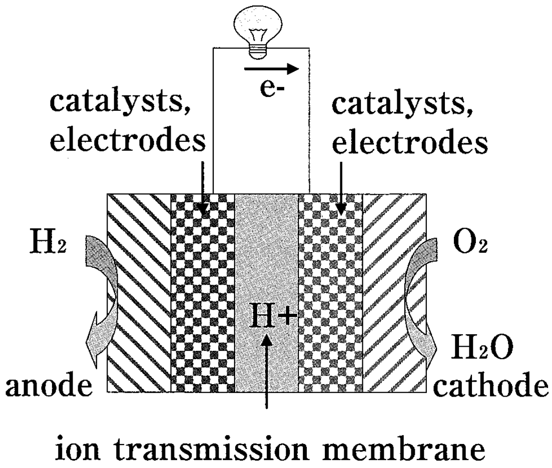

Figure 7 Principle of solid polymer type fuel cell.

One electrode has a catalyst that separates the hydrogen molecule into its component electron and hydrogen ion. The other electrode has a catalyst to generate water by reacting hydrogen ions with oxygen in the air. The electrodes are separated by a membrane, which allows hydrogen ions to pass through. To improve the efficiency of the catalytic reaction, noble metal particles are dispersed in on the order of nanometers (Figure 8)[16].

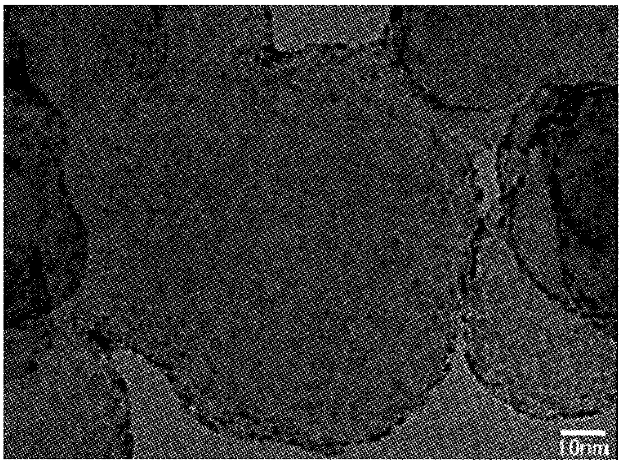

Figure 8 Electron microscope image Of Platinum Ruthenium phosphorus (PtRuP) Catalyst.

4.3 Natural gas automobile (engine / drive system)

Methane gas is a major component of natural gas and is the focus of attention for use as the next generation automobile energy source. The problem is that at room temperatures, it exists as a supercritical gas, making storage and physical adsorption difficult under normal conditions. However, it was discovered in recent years that porous bodies with pore sizes ranging from 0.5～2.0nm could absorb large amounts of methane [17](Figure 9). Expectations run high regarding the development of fuel tanks using nano spaces.

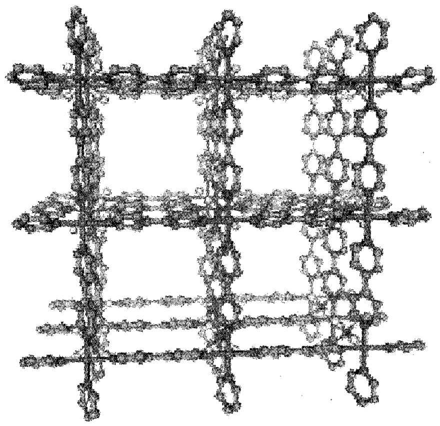

Figure 9 A New Methane Adsorbent Model by Porous Coordination Polymer.

4.4 NANO high-tension ultra-light suspension (materials)

Iron is an element which we meet in our daily lives in its alloy form with carbon, called steel. Steel plate is steel that is hot rolled. This steel plate, when enhanced by the use of nanotechnology, is called NANO High Tension. NANO is the acronym for "New Application of Nano Obstacles for dislocation movement". High tension means "strong steel". The Nano High Tension introduced this time developed for use in automobile suspensions with a plate thickness of 3～5mm [18](Figure 10). Strengthening steel through the rapid cooling of high-temperature steel to precipitate microscopic crystals in the steel structure has been known for years (precipitation hardening). To produce much tougher steel, the size and dispersion state of the precipitates should be as small as possible and as uniformly ordered as possible. This material in which the precipitates have been controlled at the nano level is called Nano High Tension (Figure11)[19]. Actually, the size of precipitates produced compared with the 10nm precipitates that have been produced in the past is about 1 nm, resulting in a threefold increase in strength from what had been produced in the past.

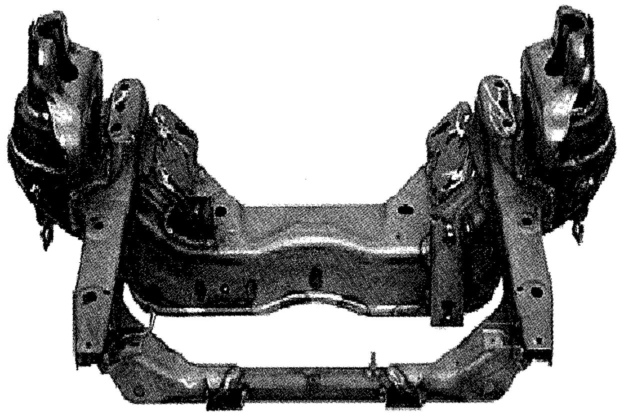

Figure 10 Automobile suspensions (wide=1080mm, height=430mm, length=660mm, weight=36kg).

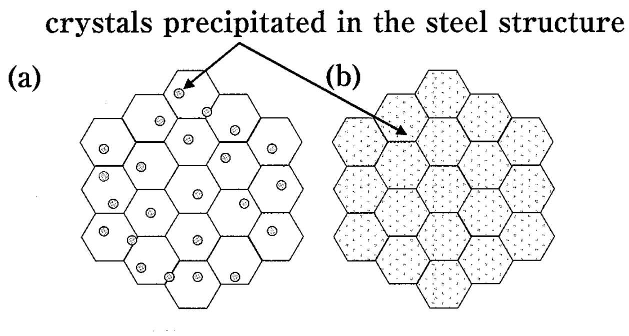

Figure 11 The size and dispersion state of the precipitates, (a) the precipitates of traditional steel are big and no uniform, (d) small and uniform.

4.5 Nano aluminum super light body (materials)

Aluminum alloys are light and have good fabrication properties. Further, they are highly recyclable materials. Hence, they have been the focus of attention as a superior environmental material. The problem is that their strength limits the range of their application. For that reason, how to increase the strength of aluminum alloys has been an ongoing discussion. Metals are almost all crystalline, formed by the agglomeration of 1 mm or less crystals. As the sizes of these crystals become smaller, the strength increases. (Hall Petch's law) (Equation 2)

$$\sigma = \sigma_0 + kD^{-1/2} \quad (2)$$

σ : yield stress ; σ_0, k : material constant ; D : particle diameter

However, recent research showed that at a particular size, reducing the size further leads to the reverse where the strength decreases (Figure 12)[20]. At the National Institute of Advanced Industrial Science and Technology (AIST), research is being conducted on how to control crystal grains in the nano order particularly at the point where the relationship between the mechanical strength of aluminum alloys and crystal grain size reverses. Further, the ductility and formability of metals are greatly affected by the crystal grain boundary (where crystals meet) structural formation in addition to the crystal grain itself. Hence, a new concept, nano multi structured alloy, was developed for aluminum, where nano precipitates are dispersed within the crystal grain, but where a precipitate-free zone is created near the grain boundary, resulting in an ideal complex structure that is undergoing further research [21] [22] [23]. Aluminum alloys have been used for various parts in the automobile industry beginning with the body itself. If what seem to be contradictory properties, lightness and rigidity, could be brought about through nanotechnology, then automobiles would be made lighter to a large extent and contribute greatly to the preservation of the environment. (Figure 13)

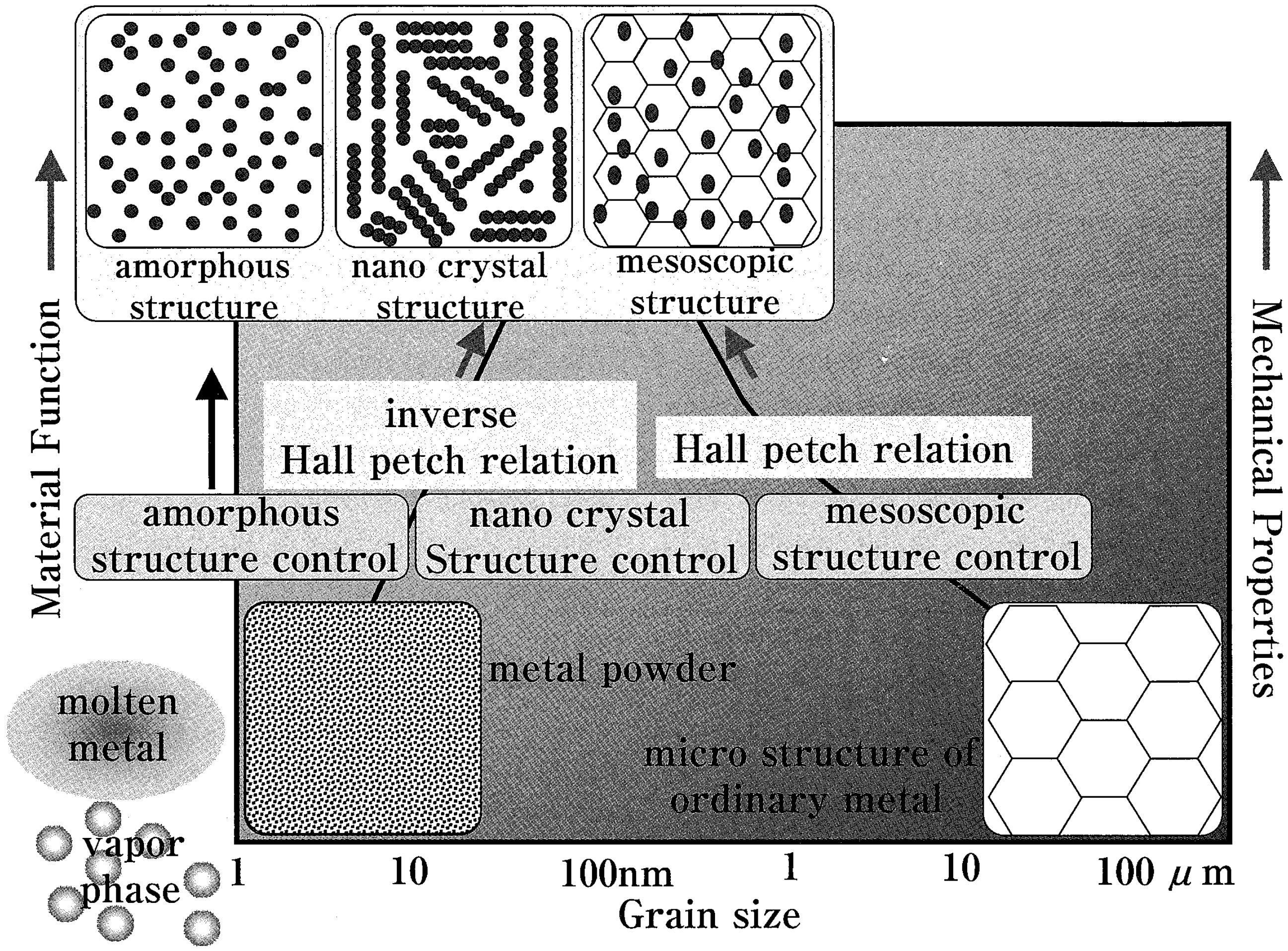

Figure 12 Schematic illustration of development of super metal.

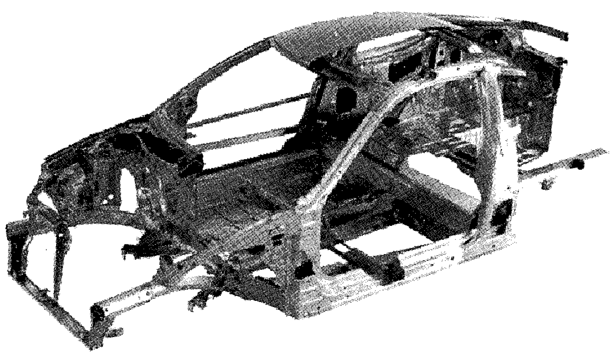

Figure13 Aluminum hybrid body (HONDA INSITE) [24].

4.6 Nanotechnology catalysts for automobiles (catalysts)

Vehicular gas emissions consist not only of carbon dioxide but include carbon monoxide, hydrogen carbide, nitrogen compounds, and other harmful substances. Automobile catalysts are purifying devices that convert these harmful substances into water, nitrogen, and carbon dioxide. Automobile catalysts are made from minute noble metal particles and carriers and co-catalysts that make minute noble metal particles stable, and transform harmful substances into harmless substances. That is, the catalytic effect occurs at the level of the small noble metal particles (Figure 14) [25]. When small noble metal particles of several nm in size are dispersed, the purifying effect remarkably improves. Since the catalysts are exposed to high temperatures and an oxidizing atmosphere when the vehicle runs, how these small noble metal particles of several nm can be kept stable for long periods of time is the issue confronting catalyst development at present. To address these technological issues, research is now underway on the co-catalyst that forms one of the components of catalytic structure capacity for storing and releasing oxygen. For example, several tens of nanometers of cerium-zirconium solid solution that serves as a medium to store and release oxygen is being considered for dispers on alumina particles as a co-catalyst so that, when necessary, it could rip the oxygen off the noble metal. This further preserves the catalyst functionality. It is possible to run over 160,000 kilometers when supported by a highly effective purifying substance to act against harmful substances. [26] [27] [28] [29] [30].

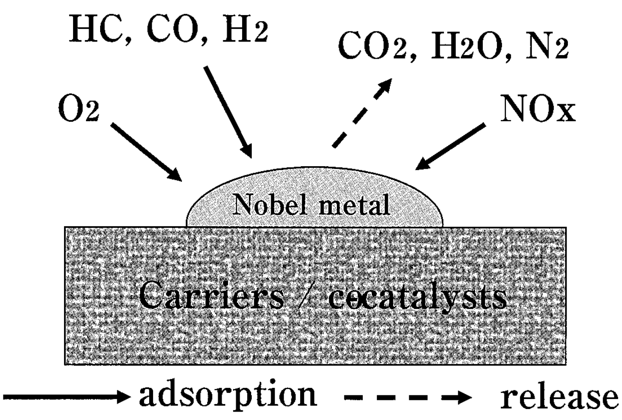

Figure 14 Structure of automobile catalyst and basic mechanism.

In conclusion

Nanotechnology. Of late, this word evokes simply a slightly old image intruding deeply into our lives. However, simply said, the word seems to exist on its own without the correct awareness having been developed. Nanotechnology is not simply making things small. Rather, it involves the control or combination of those small things, and it brings about totally different and new functionalities. In that sense, we can say that the theorems of physics and chemistry textbooks that have been used up to now have become obsolete. How far and firmly this newly developed technology will be established, how much it can contribute to this world, and how this technology will develop in 50 or 100 years from now, form one of the important missions of the university.

Lastly, in conclusion, I would like to express my deep appreciation to the Director of Research Institute of Management and Information Science, Shikoku University, for his deep understanding and cooperation in this paper and to my colleagues in the faculty for their peer review.

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