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Preface for special topic "Green Nanotechnology" Dr. Hiroyuki Akinaga (AIST), NJBulletin Editor ¹

The Fourth Assessment Report of the International Panel on Climate Change (IPCC) and the Working Group I Report "The Physical Science Basis" (2 February 2007 by the Ministry of Education, Culture, Sports, Science, and Technology; Ministry of Economy, Trade, and Industry; Japan Meteorological Agency; and Ministry of the Environment) concluded that global warming and climate change are progressing and that global warming is increased by human-induced greenhouse gas emission. Under such circumstances, applying technology to prevent the disruptive effects of global warming has been seriously discussed. Meanwhile, many policies concerning science and technology have been established, and recycling and energy conservation measures are being actively implemented. The important issues in terms of research and development in Japan, however, remain the securing of resources for mining, manufacturing, energy, food, and water. It has also been pointed out that, when one focuses only on environmental issues, a food crisis may be brought about by the pursuit of the reduction of greenhouse gases and a carbon-neutral economy.

Nanotechnology is the common basis of various scientific technologies, such as information and communication technologies (ICT), biotechnology, environment and energy-related technologies. Therefore, nanotechnology can contribute to solving environment, resource, energy and food-related problems in diverse ways. With this background, NJB will regularly introduce examples throughout the coming year of nanotechnology being applied to solve environment, energy and food-related problems as a special topic entitled "Green Nanotechnology".

[↑](#)

Green Nanotechnology: Special Topic 1. Direct methanol fuel cell (DMFC) as a potential mobile power source --- Interview with Dr. Fumio Ueno, Chief Engineer of Micro Fuel Cell Development Center (Toshiba Corporation) ¹

Miniaturized fuel cells have been attracting attention as power sources for use in the ubiquitous society. By applying nanotechnology, Toshiba Corporation has developed a small direct methanol fuel cell (DMFC) which features long operation time and can use methanol at a concentration as high as 99.5%. In addition, carbon dioxide emission can be completely avoided using bio-methanol. We interviewed the developer of the DMFC, Dr. Fumio Ueno, Chief Engineer of the Micro Fuel Cell Development Center (Display Devices and Components Control Center, Toshiba Corporation).



Contribution of nanotechnology to environment and energy-related problems [†]

For DMFCs, zero carbon dioxide emission is possible when plant-based methanol is used. The DMFCs were realized by developing an electrolyte membrane with nanometer scaled materials having a high density of catalyst particles of 2-3 nm size placed at certain positions. Therefore, the DMFC is considered a good example of nanotechnology contributing to solving environment and energy-related problems.



Significant improvement of DMFC usability while focusing on safety [†]

Dr. Ueno demonstrated a telephone call using a DMFC cellular phone. Figure 1 shows the cellular phone. The DMFC replaces the conventional rechargeable battery and generates electricity when it is filled with fuel. Dr. Ueno emphasized that the incorporation of the fuel cell, which serves as a generator, into small electronic devices such as cellular phones, will revolutionize the user-friendliness of devices.

Below is an outline of the cellular phone, having similar functions to a conventional cellular phone.

- The conventional lithium-ion battery of approximately 3 Watt hour is replaced with a DMFC.
- The exterior dimensions of the cellular phone are 113 x 54 x 17.5 mm³. The thickness is slightly greater than that of a conventional cellular phone because the fuel cell is embedded in the bottom surface.
- One milliliter of methanol can produce approximately 1 Wh of electricity. The operating time of the cellular phone after filling the DMFC with fuel is approximately two times that of a phone with a conventional lithium-ion battery.

The significant feature of the new cellular phone is how the fuel is supplied, which is quite different from conventional electrical charging.

- A 99.5% methanol fuel is supplied using a dedicated cartridge with an inner volume of 50 ml, as shown in Fig. 1. A limiter is attached as a safety measure to control the force applied to the cartridge. Fifty milliliters of methanol is equivalent to approximately 15 charges of a lithium-ion battery. One filling of the DMFC will last at least one month under typical conditions.
- The shape of the methanol inlet is standardized. Thus a fuel cartridge can be used with different DMFC-compatible cellular phones.
- The orientation during operation and storage is not restricted. Fuel can be supplied even during operation.

Safety was thoroughly considered during the development of the new system. In particular, various features have been incorporated in the mechanism of the fuel cartridge, its cap, and the inlet on the cellular phone in consideration of unexpected handling and accidents:

- The cartridge satisfies the safety standards of the International Electrotechnical Commission (IEC) The cartridge will not break even when subjected to a force of 100 kg or dropped from a height of 1 m.
- When the cartridge is connected to the cellular phone, as shown in Fig. 1, the valve on the fuel-tank side of the cellular phone opens first, followed by the valve on the cartridge side. The methanol is supplied from the cartridge only after the two valves open, and the cellular phone is fully connected with the cartridge. Furthermore,
- there is no danger of accidents such as ignition and explosion due to overcharging or over-discharging.
- The combined use of a DMFC and a capacitor, for example, is also possible for electronic devices requiring high peak power.
- The most significant advantages of the DMFC for mobile devices are that an AC adapter is unnecessary and that one never runs out of batteries.

The DMFC has numerous excellent features. In addition, it gives us the feeling of having a device full of patented technology.



Figure 1 Cellular phone with DMFC (figure provided by Toshiba Corporation). Methanol can be supplied to the fuel tank in the cellular phone from a fuel cartridge while the cellular phone is in operation.

Methanol fuel suitable for mobile devices --- Zero carbon dioxide emission is possible when plant-based methanol is used. Dr. Ueno explained the motive behind selecting the DMFC among the various types of fuel cells as follows: the output of hydrogen-based fuel cells is the highest and only water is released. However, hydrogen cells have the following disadvantages.

- It is necessary to store compressed hydrogen in a high-pressure tank or a hydrogen-storage alloy to enable mobile use because hydrogen is gaseous.
- A high-pressure tank takes large space, is heavy, and is inappropriate for use in small mobile devices. Similarly, a large mass of alloy is required to store a sufficient amount of hydrogen because of the low level of the maximum hydrogen storage capacity which is only 4 wt%. Furthermore, measures against alloy degradation are difficult to implement.
- Refilling hydrogen is complicated.

Methanol is inferior to hydrogen in terms of power generation. For example, it is difficult to induce the electrochemical reaction and carbon dioxide gas is emitted. However, methanol has the following advantages:

- Methanol is a liquid at room temperature and the energy density per volume is high for a fuel.
- Methanol is easily handled and refilled.
- The total energy efficiency is approximately 25%, which is almost equivalent to that of a commercial electric power outlet.
- Zero carbon dioxide emission can be achieved when plant-based methanol is used.

Operation mechanism and characteristics of DMFC DMFC has the structure of an electrolyte membrane sandwiched by two electrodes, i.e., an anode (fuel-supply side) and a cathode (air-supply side). This structure is called the membrane electrode assembly (MEA, Fig. 2(b)). Carbon dioxide (CO_2), electrons (e^-), and hydrogen ions (H^+) are generated from methanol (CH_3OH) and water (H_2O) at the anode. The electrons travel to the external circuit. The hydrogen ions pass through the electrolyte membrane and reach the cathode, where they react with the oxygen (O_2) in air, and the electrons travel the external circuit to generate water. The electrons traveling the external circuit drive the electronic device.

The methanol used has a purity of 99.5%. The remaining 0.5% is water that cannot be removed by distillation. This water plays an important role in the anode reaction. The operating mechanism of a polymer electrolyte fuel cell (PEFC) using hydrogen as a fuel is also shown for comparison in Fig. 2(a).

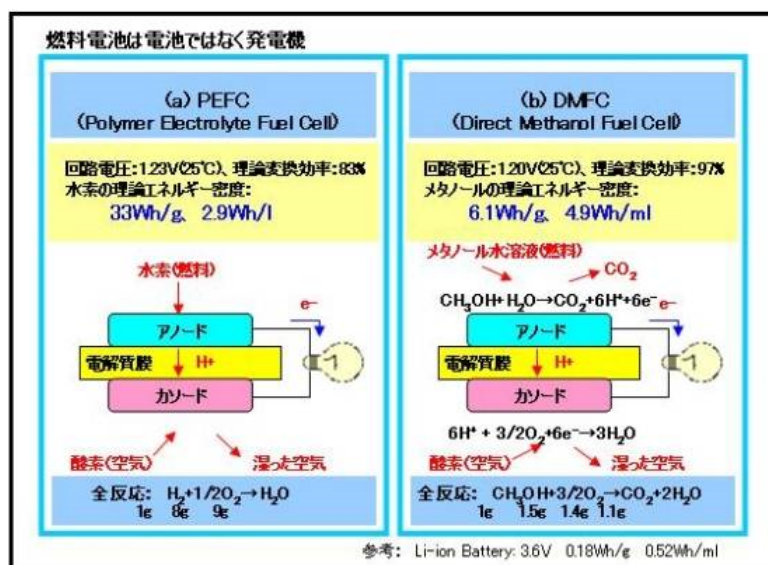
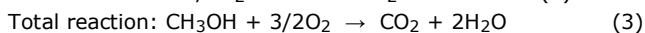
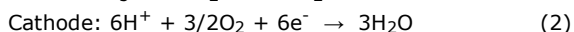
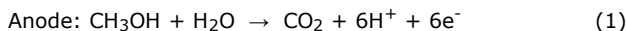


Figure 2 Operating mechanisms of (a) PEFC and (b) DMFC (figure provided by Toshiba Corporation). A fuel cell is a generator rather than a battery. (a) 1. Circuit voltage, theoretical conversion efficiency, theoretical energy density of hydrogen, 2. Hydrogen (fuel), 3.

Anode, 4. Electrolyte membrane, 5. Cathode, 6. Oxygen (air), 7. Moist air, 8. Total reaction. (b) 1. Circuit voltage, theoretical conversion efficiency, theoretical energy density of methanol, 2. Aqueous methanol solution (fuel), 3. Anode, 4. Electrolyte membrane, 5. Cathode, 6. Oxygen (air), 7. Moist air, 8. Total reaction



In the total reaction (3), the change in enthalpy ΔH° is -726 kJ/mol, and that in free energy ΔG° is -702 kJ/mol. Therefore, the theoretical energy efficiency under the equilibrium condition is $\eta = \Delta G^\circ/\Delta H^\circ = 96.7\%$. The standard electromotive force is $E = 1.20\text{ V}$. Figure 3 shows the relationship between current and voltage under cell operating conditions. The voltage decreases when the output current increases as a result of diffusion polarization, resistance polarization, and activation polarization. The voltage drop due to activation polarization is high. The magnitude of activation polarization depends on the performance of the electrode catalyst, and improvement of catalyst performance is an important issue in DMFCs.

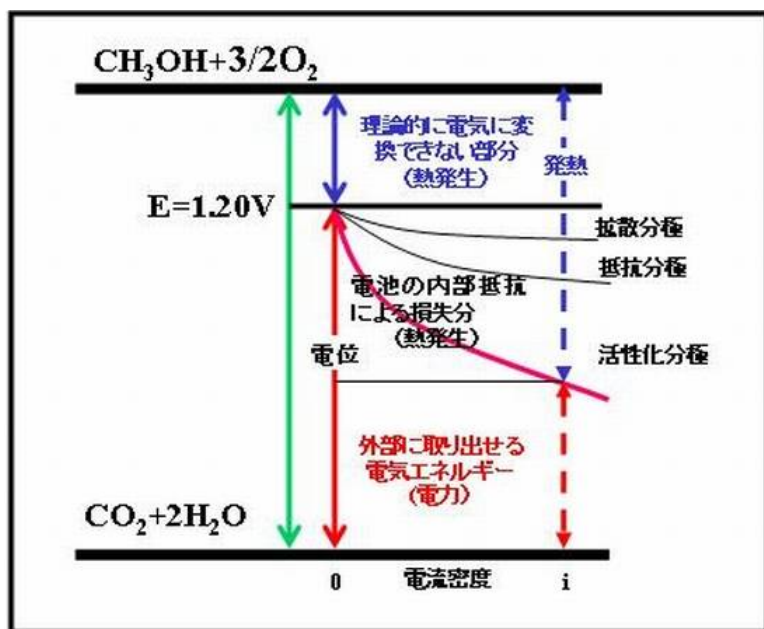


Figure 3 Polarization of DMFC (diffusion polarization, resistance polarization, activation polarization, and the output energy) 1. Energy that cannot be theoretically converted into electricity (heat generation), 2. Heat generation, 3. Diffusion polarization, 4. Resistance polarization, 5. Activation polarization, 6. Loss due to internal resistance of the cell (heat generation), 7. Potential, 8. Output electrical energy (electric power), 9. Current density

Realization of practical application of DMFC by nanotechnology --- Fabrication of catalyst nanoparticles 2-3 nm in size and technology enabling their high-density placement at precise positions platinum-ruthenium (Pt-Ru) and Pt are used as catalysts at the anode and cathode, respectively. Toshiba Corporation uses nanoparticles (2-3 nm) as catalysts and has introduced a technology to position such catalyst particles precisely at a high density to improve the performance of the DMFC.

Figure 4 shows a schematic of the area of the catalytic reaction. On the anode side, liquid methanol (CH_3OH) and water (H_2O) react on the solid catalyst to produce gaseous carbon dioxide (CO_2). Here, a conductive solid should be used to introduce the hydrogen ions (H^+) to the electrolyte membrane and the generated electrons (e^-) to the external circuit. This reaction occurs at the three-phase interface where solid, liquid, and gaseous phases coexist. Particles of the catalyst, the most expensive items among the constituent materials of the DMFC, are expected to be selectively placed at such a three-phase interface.

On the other hand, hydrogen ions (H^+) passing through the electrolyte membrane, gaseous oxygen (O_2), and electrons (e^-) traveling the external circuit react on the catalyst (solid phase) to produce liquid water (H_2O) on the cathode side; the generated water should be discharged from the cell system. Therefore, the catalyst particles are selectively placed at precise positions, similar to the anode case.

The amount of expensive catalyst can be reduced if the selective placement of catalyst particles is achieved, leading to cost reduction. However, in reality, the catalyst often penetrates into the catalyst carrier losing catalytic effect. Toshiba Corporation solved this problem by using nano-size catalyst particles and developing a technology of high-density deposition of these particles at certain locations.

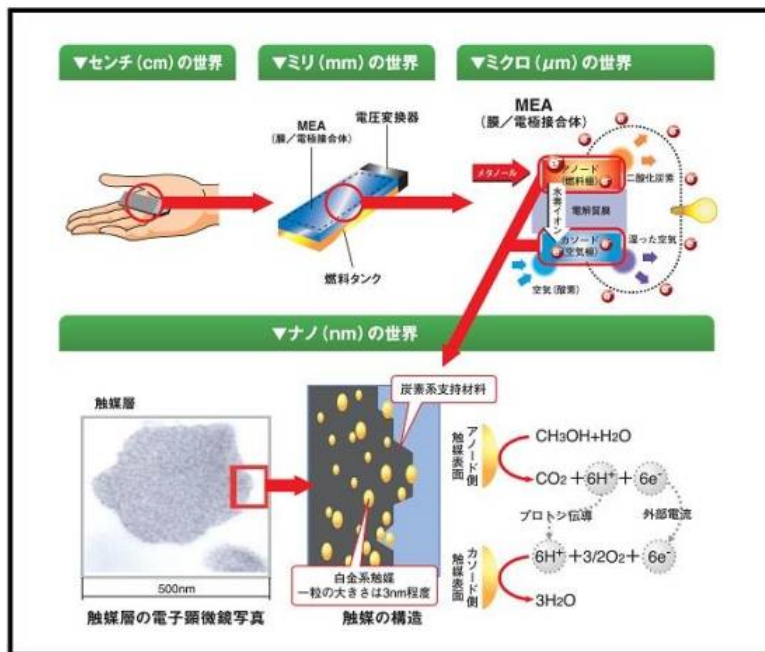


Figure 4 DMFC and electrode catalyst (figure provided by Toshiba Corporation). 1. cm-scale, 2. mm-scale, 3. Voltage converter, 4. Membrane-electrode assembly (MEA), 5. Fuel tank, 6. mm-scale, 7. Membrane-electrode assembly (MEA), 8. Methanol, 9. Anode (fuel side), carbon dioxide, hydrogen ions, electrolyte membrane, cathode (air side), moist air, air (oxygen), 10. nm-scale, 11. Catalyst layer, 12. Electron-microscope image of catalyst layer, 13. Carbon support material, 14. Platinum catalyst with particle size of approximately 3 nm, 15. Structure of catalyst, 16. Anode side, catalyst surface, 17. Cathode side, catalyst surface, 18. Proton conduction, 19. External current

Improving discharge voltage and realizing cell life of 2000-3000 hours Toshiba Corporation has manufactured several prototype cells to satisfy the specifications required for various applications and has evaluated their performance. The market trends will be carefully examined and product commercialization will proceed for the most promising field.

This interview suggests that more environmentally friendly fuel cells will soon be applied in small mobile devices. It accentuates nanotechnology as the key to realizing this goal. Although Dr. Ueno commented that he cannot disclose the release date, we expect that fuel cells will appear on the market at the earliest time possible after the required conditions, including cost, are carefully considered.

References:

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- [2] F. Ueno: Latest trend of development of micro fuel cells, Journal of Institute of the Electrical Engineers of Japan Vol. 126 (2006), No. 2, p. 76.
- [3] H. Ikeda: All About Fuel Cells, p. 216, Nippon Jitsugyo Publishing (2001).



Green Nanotechnology: Special Topic 2. Permanent Magnets that Effectively Use Limited Resources --- Interview with Satoshi Hirosawa, Chief Engineer (NEOMAX Company, Hitachi Metals, Ltd.) ¹

Cars account for 20% of the world's energy consumption and exhaust noxious gases such as NO_x. As countermeasures against energy-related and environmental problems, there are high expectations for hybrid, electrical, and fuel-battery cars, all of which use motors as their power source. Motors that employ permanent magnets are widely used for electric and electronic equipment, home electric appliances, mobile phones, etc. Therefore, permanent magnets are essential materials in the society. Because high-performance permanent magnets require rare elements, such as rare-earth elements, the excessive use of these magnets will consequently lead to resource depletion problems as a result of energy-related and environmental problems.



Dr. Satoshi Hirose (left in the photo) is a chief engineer of Magnetic Materials Research Laboratory, NEOMAX Company, Hitachi Metals, Ltd., which aims to reduce the use of rare-earth elements by developing nanocomposite magnetic powders. In his laboratory in Shimamoto-cho, Osaka Prefecture, near the historical sites of Yamazaki no Gassen (the battle of Yamazaki in 1582) and Kusunoki-ko Sakurai no Wakare (the farewell of the samurai Kusunoki to his son in 1336), we interviewed him in the presence of Dr. Hirokazu Kanekiyo, a manager of the Development Project Division (right in the photo), on the developmental progress.



Application of permanent magnets and rare-earth elements ¹

Permanent magnets are used in the motors of hybrid cars. I saw cross-sectional models of motors that use the NEOMAX magnets displayed in an exhibition room. In medicine, permanent magnets are used for magnetic resonance imaging (MRI), and the intensity of the magnetic field determines the imaging performance. They are also used in IT equipment, such as mobile phones and hard disc drives (HDDs); household appliances, such as air conditioners, washing machines, and refrigerators; and many electric and electronic automobile parts, such as power windows, wiper motors, and crank sensors. Permanent magnets are indispensable fundamental materials.

The two main performance indicators of permanent magnets are the saturation magnetization B_r , which determines the strength of the magnet, and the coercivity H_c , which determines the stability of the magnetization. The maximum product of the magnetization and the magnetic field of the magnetization curve $(BH)_{\max}$ determines the overall performance of permanent magnets. The coercivity also governs the thermal resistance of the magnets, which is necessary for motors that operate at high temperatures.

The performance of permanent magnets was markedly improved when a samarium cobalt (SmCo) magnet was developed in the 1970s. In 1984, Dr. Masato Sagawa of Sumitomo Special Metals, the predecessor of NEOMAX Company, invented a neodymium (Nd) magnet [1]. Most Nd magnets have the composition of $Nd_2Fe_{14}B$, but some have a higher Nd/Fe ratio. Reported theoretical values are $(BH)_{\max}=200 \text{ kJ/m}^3$ for SmCo magnets and $(BH)_{\max}=474 \text{ kJ/m}^3$ ($B_r=1.555 \text{ T}$, $H_{CJ}=653 \text{ kA/m}$) for recently developed Nd magnets [2].

Sm and Nd are rare-earth elements. Dy, another rare-earth element, is added to Nd magnets to increase the thermal resistance. Rare-earth elements are mainly mined in China, and light and heavy rare-earth elements are mined in West Mongolia and Yunnan near Vietnam, respectively. The Nd content of Nd magnets with the basic composition of $Nd_2Fe_{14}B$ is as high as 11.8 at.% and 30.7 wt.%. The crustal abundance (weight) and atomic masses of the related elements are summarized in Table 1. When the crustal abundance is expressed in terms of the number of atoms, the abundance of the heavier rare-earth elements decreases.

Table 1 Crustal abundance (weight, parts per million) and atomic masses of elements in magnet materials

Element	Nd	Sm	Dy	Fe	Co	Ti	C	B
Abundance (ppm)	28	6.0	4.8	50000	25	4400	200	10
Atomic mass	144.2	150.4	162.5	55.8	58.9	47.9	12	10.8

In general, the higher the percentage of rare-earth elements, the higher the performance of the permanent magnet. Therefore, it is necessary to take resource-saving measures to improve the performance of permanent magnets. The price of rare-earth elements is affected by the political and market conditions of the producing countries. The price of Nd was US\$10/kg after 2005, sharply increased to US\$30/kg by mid-2006 and to US\$50/kg by April 2007, and has now settled at US\$40/kg. The price of Dy rose continuously from US\$50/kg from the beginning of 2005 to US\$130/kg at the end of 2007. The mining of rare resources with low abundances generates heavy environmental burden because of the large amount of industrial waste. From these economic and environmental viewpoints, it is essential to effectively use these limited resources in as small quantities as possible while improving the performance of permanent magnets.



Reduction of amount of rare-earth elements in permanent magnets [↑]

Nd magnets are used in motors, such as car motors. Nd, Fe, and B are the main components of the magnets, and Dy is added to increase the thermal resistance. The higher the thermal resistance required, the more Dy is added. However, the magnetic properties deteriorate upon Dy addition. Previously, Dy was added to a molten mixture of Fe, Nd, and B. Now Dy is added by grain boundary diffusion, in which Dy is deposited onto a mold fabricated with a reduced amount of Dy during the melting process. In this method, Dy remains at the grain boundaries rather than inside of the Nd-Fe-B grains. Thus, the thermal resistance was successfully increased, together with the suppression of the decrease in the magnetic force and reduction of the amount of Dy used.

Using this technology, the thermal resistance of conventional Nd magnets has been increased from 180 C to 220 C while the amount of Dy reduced by 20% compared to conventional Nd magnets. It is possible to increase H_c by 320 kA/m or more while maintaining the same value of B_r and to increase B_r by 40 mT or more for the same value of H_c . The research achievement of Hitachi Metals, Ltd., of reducing the amount of rare-earth elements in permanent magnets was reported in detail in the June 26, 2008 issue of "Nikkei Business Daily".

[↑]

Development of nanocomposite magnets [↑]

Nanocomposite magnets are effective for suppressing the amount of rare-earth elements. In the nanocomposite structure, two nanometer-scale metallic phases are mixed (Fig. 1). The nanocomposite magnets are manufactured by mixing and structuring soft-magnetic nanocrystals of Fe_3B or α -Fe with a hard magnet $Nd_2Fe_{14}B$, the constituent of Nd magnets.

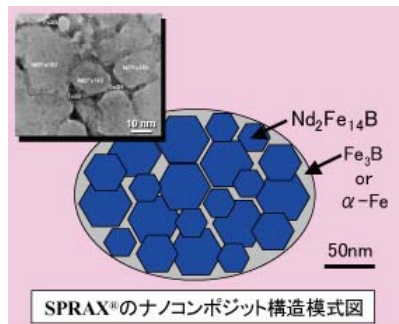


Figure 1 Schematic of SPRAX nanocomposite structure and an electron microscopy image (provided by Hitachi Metals).

A ternary diagram is shown in Fig. 2 for Fe, Nd, and B, which are the main constituents of Nd and nanocomposite magnets.

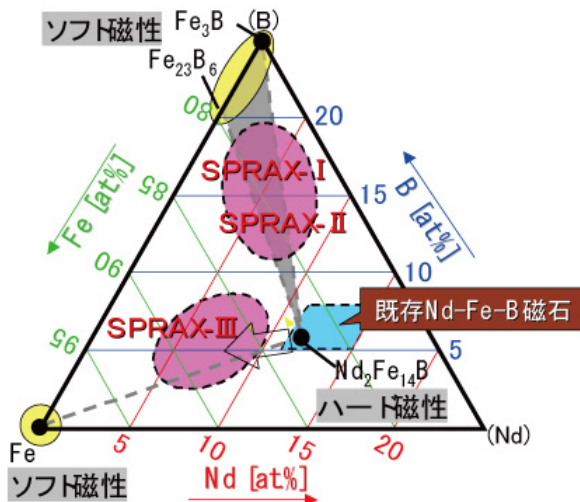


Figure 2 Nd-Fe-B ternary diagram (provided by Hitachi Metals). Captions inside: soft magnetism, existing Nd-Fe-B magnet, hard magnetism.

The atomic percentage of Nd is 12% for $Nd_2Fe_{14}B$ and 13-15% for current Nd magnets, i.e., the conventional Nd-Fe-B sintered magnets. However, for nanocomposite magnets (denoted as Nd-Fe-B magnets in this article or SPRAXTM (ellipses indicated by arrows in Fig. 2)), the Nd atomic percentage can be reduced to 5% or less either by adding Fe_3B to shift the composition towards the B side or by adding α -Fe to shift the composition towards the Fe side. The weight percentage of the rare-earth elements in the nanocomposite

magnets is ~2/3 of existing Sm or Nd magnets.

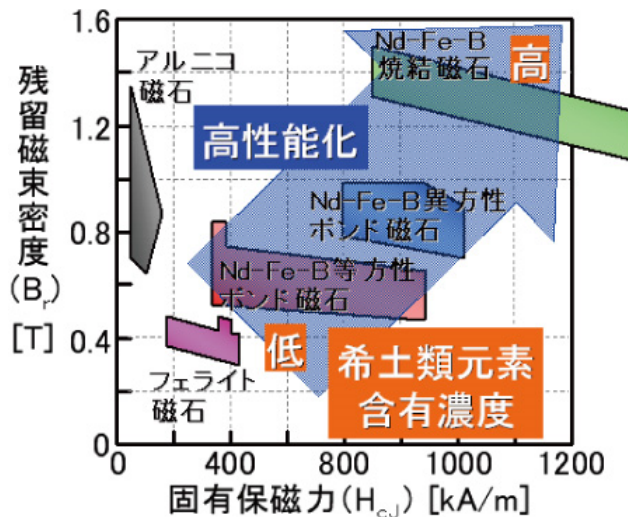


Figure 3 Magnetic properties of permanent magnets (provided by Hitachi Metals). Captions (1) Residual field, (2) Alnico magnet, (3) Nd-Fe-B sintered magnet, (4) High, (5) Advances in performance, (6) Nd-Fe-B anisotropic bond magnet, (7) Nd-Fe-B isotropic bond magnet, (8) Ferrite magnet, (9) Low, (10) Percentage of rare-earth elements, (11) Coercivity

Figure 3 shows the magnetic properties of permanent magnets. As indicated by "high" and "low" in the figure, permanent magnets with a high percentage of rare-earth elements have a high B_r and H_{cJ} , and perform well, as indicated by the large arrow. However, for practical applications it is important to balance all factors, including manufacturing ability and high $(BH)_{max}$, B_r , and H_{cJ} . The nanocomposite magnets have excellent weather resistance and small permanent demagnetization. Permanent magnets of complex shapes can be easily produced through mixing a nanocomposite magnetic powder and a resin.

An important feature of nanocomposite magnets is noise reduction. Because the isotropic orientation of nanocrystals, the magnetization direction can be arbitrarily selected, e.g. by sinusoidal-wave magnetization. This feature is used to reduce the noise in motors. Therefore, nanocomposite magnets are frequently applied to IT equipment, which is sensitive to vibration and noise. The spindle motors of optical disc drives (ODDs) and HDDs almost always contain nanocomposite magnets. Small-diameter multipolar stepping motors, which are used in digital cameras and mobile phones, also frequently contain nanocomposite magnets. Sintered ferrite magnets and Nd-group sintered magnets are widely used in household appliances, and the usage of nanocomposite magnets in washing machines and fan motors is being examined because of their low noise and arbitrary shapes. In automobiles, nanocomposite magnets are mainly used in power windows, seatbelt sensors, engine periphery, rudder-angle sensors, etc. However, those magnets can not be used yet at high-temperature sites of the engine periphery because their thermal resistance is limited by the bonding resin.



History of nanocomposite magnets ¹

The manufacture of nanocomposite magnets via heat treatment of homogeneous amorphous magnetic materials was launched by Dr. Coehoorn of Royal Philips Electronics in the Netherlands in 1988 [3]. Sumitomo Special Metals developed the first-generation nanocomposite magnet (SPRAX-I) by controlling the crystallized structure of $Nd_{4.5}Fe_{77}B_{18.5}$ amorphous alloy. Later, it succeeded in finding additives controlling the fine metallic structure and developed the second-generation nanocomposite magnet (SPRAX-II) by adding Ti-C to $Nd_2Fe_{14}B$ and Fe_3B [4]. In SPRAX-I, Fe_3B was deposited prior to the crystallization of $Nd_2Fe_{14}B$. No natural coercivity was obtained at the practical level because of the impossibility of increasing the volume percentage of Nd-Fe-B. Therefore, Ti-C was added to SPRAX-II such that $Nd_2Fe_{14}B$ was preferentially crystallized prior to the Fe-B phase. As a result, the volume percentage of Fe-Nd-B increased and a high coercivity was achieved. In the internal structure, $Nd_2Fe_{14}B$ is surrounded by Fe_3B crystals (Fig. 4, top-right).

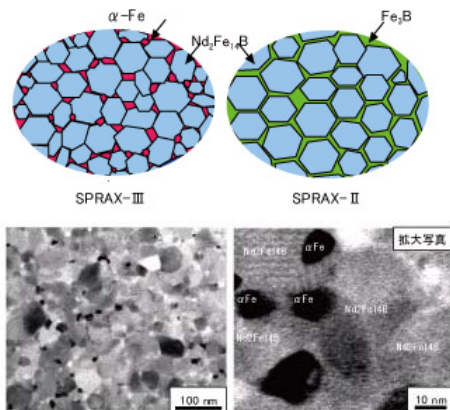


Figure 4 Structure of nanocomposite magnet (provided by Hitachi Metals). (a) Schematic. (b) Electron microscopy images.

The essence of fabricating nanocomposite magnets is to realize nanocrystal structures that are as uniform as possible. Each crystal has its own optimal size, and the coercivity is maximum for a size of 10-20 nm. For the crystal size of 50 nm or more, both the residual magnetization and maximum energy product decrease, resulting in a low-quality permanent magnet. Therefore, it is important to reduce the variation of the crystal size and to limit the average crystal size to ~20 nm. Nanocrystals are obtained by annealing the amorphous or nanocrystallized alloys followed by quenching of the melt.

Fe₃B in SPRAX-II was replaced with α-Fe, which has a higher residual field, resulting in the third-generation nanocomposite magnet SPRAX-III. However, the coercivity would be unsatisfactory if Fe₃B was merely replaced with α-Fe. When the nanocomposite structure was controlled by adding Ti, a homogeneous fine structure containing fine α-Fe crystals was obtained, whereas the abundance of Nd₂Fe₁₄B, which determines the coercivity, was increased. As shown in Fig. 4 (top-left), fine α-Fe crystals are present around the triple grain boundaries of Nd₂Fe₁₄B [5]. Consequently, isotropic magnets have achieved both a residual field of >1 T and a coercivity sufficient for use as permanent magnets.

As shown in the ternary composition map in Fig. 2, the amount of Nd in the alloy composition of the nanocomposite magnets SPRAX is smaller than that in the stoichiometric composition of Nd₂Fe₁₄B. The difference between SPRAX-II and SPRAX-III is that their composition is biased towards Fe₃B or Fe on the ternary composition map, respectively. This difference appears in their magnetic properties, namely, SPRAX-II and SPRAX-III can achieve a high coercivity and a high residual field, respectively (Fig. 5). Magnets with high residual field are suitable for small-diameter multipolar motors. Moreover, thermal resistance and magnetization of magnetic powder are improved to balance the cost and magnetic properties, as represented by UH in Fig. 5. Such magnets are being increasingly incorporated into various sensors and motors, including stepping motors.

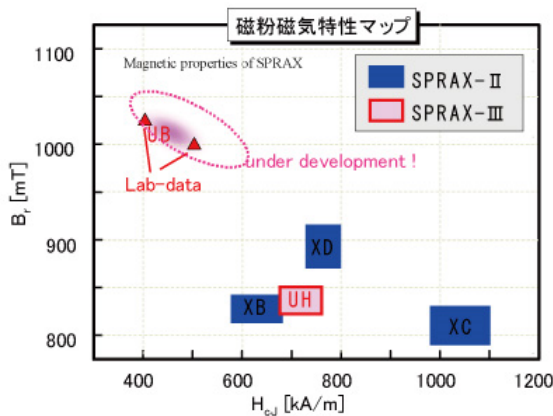


Figure 5 Magnetic properties of nanocomposite magnets (provided by Hitachi Metals).



Characteristics of nanocomposite magnets †

The basic design concept of nanocomposite magnets is to arrange hard and soft magnetic phases alternately at the nanometer level such that the magnetization reversal of the soft magnetic phase owing to a demagnetization field is suppressed by the hard magnetic phase, which has a strong coercivity. Applying this concept, high saturation magnetization and high coercivity are simultaneously achieved (Fig. 6).

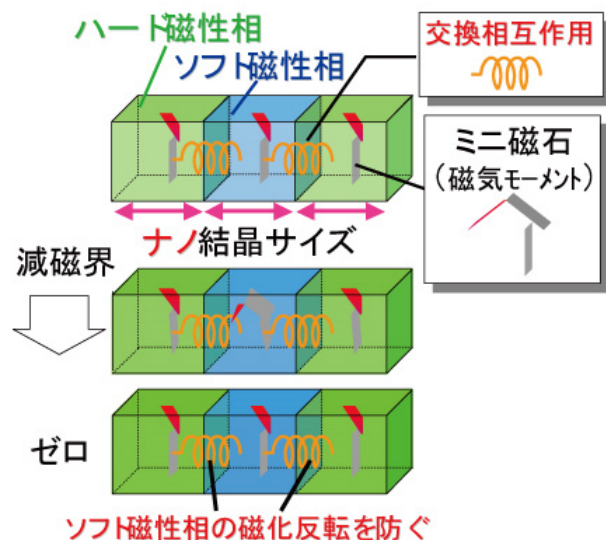


Figure 6 Mechanism of action of nanocomposite magnet (provided by Hitachi Metals). Captions (1) Hard magnetic phase, (2) Soft magnetic phase, (3) Exchange interaction, (4) Magnetic domain, (5) Nanocrystal size, (6) Demagnetization, (7) Zero, (8) Prevention of magnetization reversal of soft magnetic phase

The SPRAX nanocomposite magnetic powders have excellent weather resistance because they contain only a small amount of rare-earth elements that are easily oxidized. The oxidation enhancement at 80 C in the atmosphere with a relative humidity of 90% depends on the percentage of Nd (Fig. 7(a)). Also, the rate of change in the demagnetizing factor with time of the SPRAX magnetic powders is slower than that of Nd-Fe-B magnetic powders created to have a composition close to the stoichiometric composition of Nd₂Fe₁₄B (Fig. 7(b)). The reduced use of rare metals in magnets contributes to the improvement of their stability.

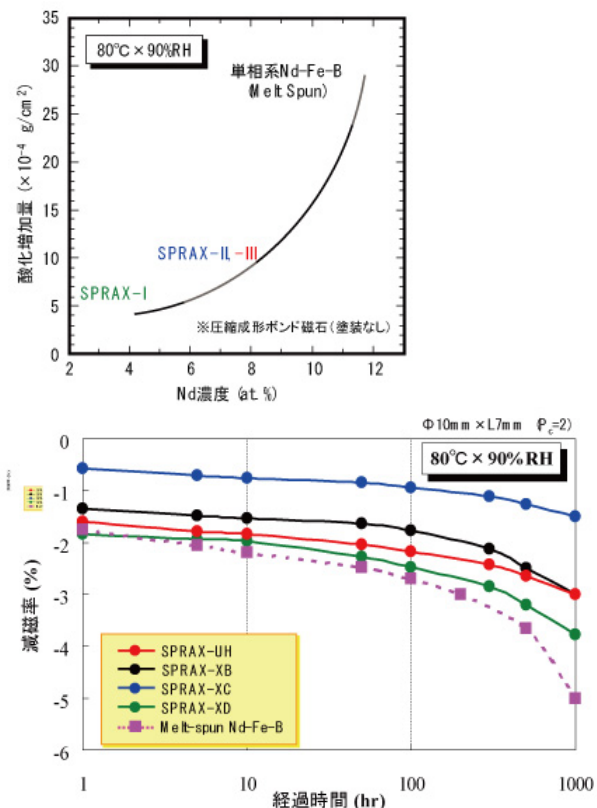


Figure 7 Stability of nanocomposite magnet (provided by Hitachi Metals). (a) Oxidation increment (elapsed time of 200 h), Captions (1) Single-phase Nd-Fe-B, (2) Oxidation increment, (3) *Compression-molded bond magnet (without coating), (4) Nd percentage. (b) Change over time, (1) Demagnetizing factor, (2) Elapsed time.



Manufacturing of nanocomposite magnets †

Figure 8 shows the process of manufacturing nanocomposite magnetic powder. Raw materials are fused into an alloy, which is poured onto a cooling roller to obtain an amorphous or nanocrystallized strip. The strip is ground into particles with an average diameter of 0.4 μm and heated to form a nanocomposite metallic structure that can provide the optimal magnetic properties. Finally, the particle size is adjusted to meet customer requirements and the magnets are delivered. The high-productivity strip cast method was effectively used because the production capability of the amorphous structure was enhanced by decreasing the content of rare-earth elements while increasing that of boron. Here, the production of the two nanocrystal phases that constitute the nanocomposite magnet is controlled by a heat treatment devised at NEOMAX.

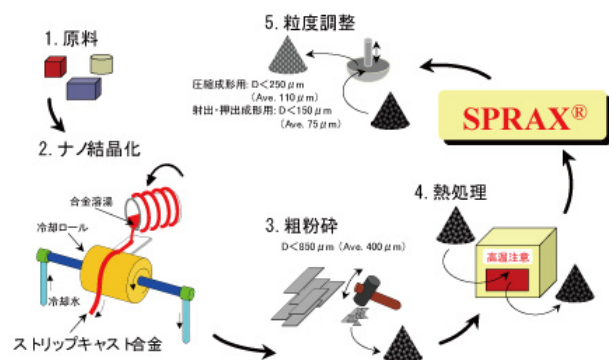


Figure 8 Manufacturing of nanocomposite magnetic powders (provided by Hitachi Metals). Captions (1) Raw materials, (2) Manufacturing of amorphous alloy, (i) Molten metal alloy, (ii) Cooling roller, (iii) Cooling water, (iv) Strip cast alloy, (3) Rough grinding, (4) Annealing, (5) Adjustment of particle size, (i) For compression molding, (ii) For ejection/extrusion molding.

The developed nanocomposite magnet powders have less adverse effect on the global environment. Their features are summarized below.

- (1) High residual field, which translates into higher performance and efficiency of motors.
- (2) As bond magnets with excellent design freedom, they contribute to the simplification of manufacturing processes and the reduction of motor noise.
- (3) Excellent weather resistance and reliability and high tolerance to environmental changes.

Nanocomposite magnet powders are used for manufacturing bond magnets, which are obtained by molding and solidifying magnetic powders using a resin. Bond magnets have a high degree of shape freedom and can be produced with high spatial accuracy. Compression, ejection, and sheet molding can be used to shape bond magnets (Fig. 9). Because of the above features, bond magnets are widely used in fields related to IT equipment.

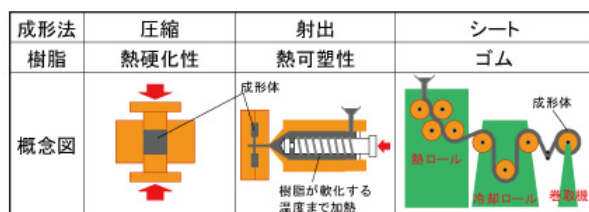


Figure 9 Manufacturing method of bond magnet (provided by Hitachi Metals). (1) Molding method, (2) Compression, (3) Ejection, (4) Sheet method, (5) Resin, (6) Thermosetting, (7) Thermoplastic, (8) Rubber, (9) Schematic, (10) Molded product, (11) Heating to the temperature at which the resin softens, (12) Heating roller, (13) Cooling roller, (14) Winder.

Progress in the research on nanocomposite magnets [†]

The characteristics of nanocomposite magnets are intermediate between those of sintered ferrite magnets and sintered Nd-Fe-B magnets (Nd magnets), as shown in Fig. 3. They consist of clusters of crystal grains having random orientations and no specific magnetization direction, namely, they are isotropic. There is current trend of creating anisotropic nanocomposite magnets to achieve high magnetic performances equivalent to those of sintered Nd magnets [6].

Creation of high-performance isotropic magnets by combining the optimization of the exchange bonding between different phases and realization of bulk magnets owing to the development of molding technologies can improve the performance of magnets while maintaining their isotropy. When magnetic powders are molded and sintered without resin, binderless magnets are obtained having high B_r , thermal resistance, shape accuracy, and resin-independent density. Furthermore, increasing the mold density to the true density of magnetic-powder alloys by using hot-pressing technology enables us to realize isotropic magnets that have magnetic properties equivalent to those of Nd-Fe-B anisotropic bond magnets.

The magnetic properties of anisotropic nanocomposite magnets, which are regarded as next-generation high-performance permanent magnets, can be strengthened by arranging the orientation of their hard magnetic phases. It has long been considered that the performance of magnets can be improved by optimizing the domain orientation. The magnetization direction of the SPRAX magnets cannot be arranged because of its isotropy. The magnetization orientation of the micron-sized crystal grains in sintered magnets can be arranged. However, it is difficult to create anisotropic nanocrystals. Therefore, the performance of base materials is improved by combining fine crystals and strongly magnetic substances.

Anisotropy can be induced using multilayer film nanocomposites. A multilayer Cu-doped film was employed and a $(BH)_{\max}$ of 255 kJ/m³ was achieved for SmCo, which exceeds the theoretical limit of SmCo₅ single-phase magnets of 230 kJ/m³ [7]. It is also possible to apply this method to Nd-Fe-B, whose magnetic properties are superior to those of Sm-Co.

Hitachi Metals participated in the Project of the Strategy for Rare Elements by the Ministry of Education, Culture, Sports, Science and Technology with the research theme of "Nanocomposite bulk materials using anisotropic high-magnetic-force fine particles" aiming to develop anisotropic nanocomposite magnets. They are now engaged in the project "Development of high-performance anisotropic nanocomposite magnets containing small amounts of rare-earth elements" in collaboration with Nagoya Institute of Technology, National Institute for Materials Science, and Kyushu Institute of Technology.

Anisotropic nanocomposite magnets are manufactured by hydrogenation decomposition and decomposition recombination (HDDR) as follows. $\text{Nd}_2\text{Fe}_{14}\text{B}$ is hydrogenated and dehydrogenated to form anisotropic, highly coercive magnetic powders, in which 10 nm Fe particles are dispersed. The thus obtained Fe-coated anisotropic particles with high coercivity and magnetic flux density are shaped into bulk anisotropic nanocomposite magnets (Fig. 10). After the crystals decomposed by hydrogenation are dehydrogenated, they are recrystallized into particles.

異方性ナノコンポジット磁石作製プロセス

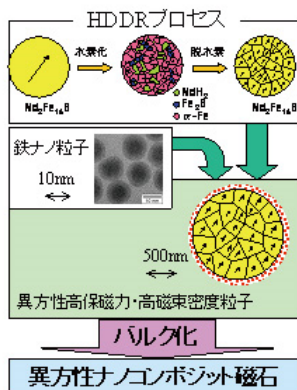


Figure 10 Approach to fabrication of anisotropic nanocomposite magnet (provided by Hitachi Metals). (1) Manufacturing process of anisotropic nanocomposite magnet, (2) HDDR process, (3) Hydrogenation, (4) Dehydrogenation, (5) Fe nanoparticles, (6) Anisotropic high-coercivity high-flux-density particles, (7) Forming into bulk, (8) Anisotropic nanocomposite magnet.

In this project, importance is placed on principles. Analyses are mainly carried out on ultrafast freezing, phase formation, and the structures of magnets. The mechanisms underlying the improvement of performance upon the addition of small amounts of various elements are also examined.



Final remarks ¹

Application of motors in cars is promoted to reduce the energy consumption and the emission of exhaust gases. Because motors are widely used for electric and electronic automobile parts, information appliances, and household appliances, the permanent magnets used in motors are essential fundamental materials. High-performance permanent magnets require rare-earth elements, the supply of which is limited; therefore, the wide utilization and performance improvement of permanent magnets will change the issue of energy-related and environmental problems into that of resource depletion. Hitachi Metals and other institutions are tackling these problems by promoting the effective use of these limited resources.

In high-performance permanent magnets, the improvement of magnetic properties and of thermal resistance was achieved, while the amount of Dy added was reduced. The amount of rare-earth elements used in the base substance, the Nd magnet, was successfully reduced by employing a nanocomposite structure. Development of nanocomposite magnets is based on exchange interaction between hard and soft magnetic phases, material technologies used in manufacturing nanocrystals, and the control of their composition by the addition of Ti or other elements. The study of mechanism of coercive forces and the development of materials and technologies to realize anisotropy are ongoing. There are high expectations that environmental and energy-related problems can be solved by the effective use of limited resources.

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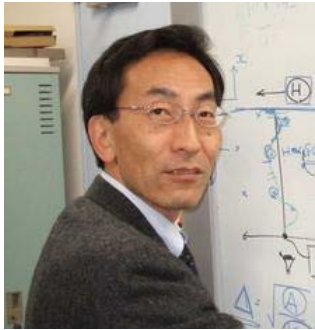
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Frontiers of spintronics. Part 1: Metal-based spintronics looks beyond logic-in memory toward universal memory --- Interview with Professor Hideo Ohno (Tohoku University) [†]

Electronics using electric charge and spin is called spintronics. This area is divided into semiconductor spintronics, which uses the spins in semiconductors, and metal-based spintronics, which uses magnetic metals or magnetic metal/semiconductor hybrid structures. Hideo Ohno, a professor at the Research Institute of Electrical Communication of Tohoku University. He shared his thoughts on semiconductor and metal spintronics with Nanotech Japan. Semiconductor spintronics will be featured in the next issue, and metal spintronics, the industrialization of which is in sight, is introduced here.



Magnetic Random-Access Memory [†]

As our society becomes increasingly ubiquitous, demand increases for a high-speed memory that can be rewritten an unlimited number of times, is nonvolatile (data is maintained even if the power is turned off), and has large capacity. Such an ultimate memory, "universal memory", has not been achieved yet; however, magnetic random-access memory (MRAM) is the most promising candidate.

In MRAM, data are recorded using magnetization, just like in a hard disk. Therefore, MRAM can maintain data without regular data writing (nonvolatile). This is necessary for a semiconductor DRAM, and requires only low power consumption. An MRAM cell has the basic structure of a tunnel junction, in which a tunnel insulating film is sandwiched by two ferromagnetic electrodes, as shown in Fig. 1. When the magnetization direction of one electrode is fixed and that of another is varied, their parallel and antiparallel configurations correspond to binary values of 0 and 1, respectively. (The magnetization of the electrode is fixed by stacking it on an antiferromagnetic layer.) Data are read by measuring the tunneling resistance. The value obtained by dividing the difference in the resistance by the lower resistance is called the magnetoresistance ratio. As shown in Fig. 2, this ratio was as low as 70% in early magnetic tunnel junctions, which used an Al oxide barrier, and is far below the practical level required for highly integrated MRAM.

The magnetoresistance ratio, which is expressed in terms of the spin polarization P of the electrode as $2P^2/(1-P^2)$, should be infinitely large if the electrode is 100% spin polarized. Because ordinary ferromagnetic materials, such as Fe and Co, have a P value of 0.5 at most, the maximum magnetoresistance ratio was estimated as 70%. However, a breakthrough has been achieved by theoretists.

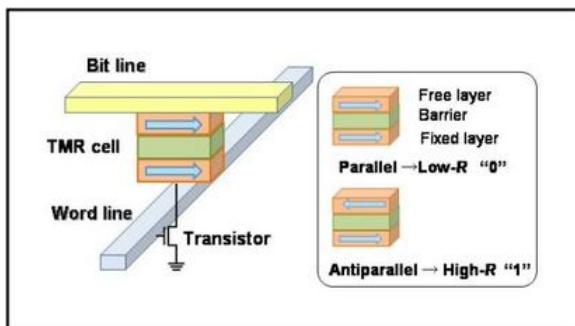


Figure 1

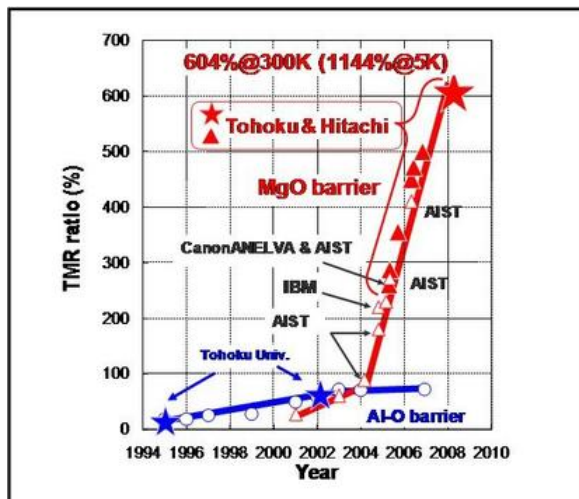


Figure 2

In Fe and Co, which have body-centered cubic (bcc) structure, two electronic bands are located at the Fermi level; band that is completely spin polarized, which accommodates only electrons of specific spin direction and a partially spin polarized band. In 2001, theory groups in the UK and USA independently predicted that, if a tunnel junction structure were prepared, in which a (001)-oriented magnesium oxide (MgO) insulating film is sandwiched by (001)-oriented Fe or Co layers, then P would effectively approach a value of 1 because only electrons in the completely spin-polarized band would tunnel through the MgO barrier owing to the symmetry of their wave functions. The validity of this prediction was verified by an experiment on a fully epitaxial (001)-oriented Fe/MgO/Fe magnetic tunnel junction conducted at the National Institute of Advanced Industrial Science and Technology (AIST), Japan. Afterwards, changing the electrode to an amorphous alloy, a-FeCoB, had improved the results. The amorphous alloy has smooth surface as well as the preferential (001) orientation of the MgO that is formed on the alloy. As shown in Fig. 2, the Canon-ANELVA-AIST group, Tohoku University (Ohno group), and IBM successively broke the record for the highest magnetoresistance ratio by fabricating an a-FeCoB/MgO/a-FeCoB layer structure and then crystallizing the FeCoB electrode by annealing. The highest value at room temperature is currently 604%, achieved by the Tohoku University - Hitachi group in 2008. It is possible to produce this amorphous-alloy tunnel structure by sputtering, which is an established mass-production technology. This has had a large impact on its application: It has promoted the application of the tunnel structure to MRAM, and writing head for hard disks using the structure have already been commercialized.



Scalability and Spin-Injection Magnetization Reversal [†]

One more problem hampers the realization of MRAM: the conventional data-writing method, in which the magnetic field is generated by passing an electric current in wires, is not scalable; the smaller the device, the stronger the demagnetization field that makes writing difficult. Moreover, it is necessary to increase the coercive force to maintain the thermal stability of MRAM, which exacerbates this problem. This issue represents the most vulnerable point of magnetic memories, including hard disks. However, spin-injection magnetization reversal will solve this problem.

In 1996, IBM researchers predicted theoretically that magnetization would be reversed by injecting a spin-polarized current into a ferromagnet. According to this theory, the current required for magnetization reversal should decrease in proportion to the junction area of the TMR device, which means that the smaller the device, the more advantageous it should be for low power consumption (Fig. 3). This trend is the opposite of the magnetization reversal described above using a current-induced magnetic field. Although many researchers were skeptical of this theory and would not carry out any confirming experiments, a group at Cornell University succeeded in observing clear spin-injection magnetization reversal. "I really think that we should conduct more such experiments. Research cannot be advanced if we accept impossibilities from the start" says Professor Ohno. The structure used by the Cornell group was a giant magnetoresistance (CPP-GMR) device consisting of two magnetic layers with Cu layer inserted between them, with the current passed perpendicularly to the layers. Subsequently, spin-injection magnetization reversal using the MgO-barrier TMR device was demonstrated by researchers at Sony, Tohoku University and Hitachi, AIST, Grandis, and other laboratories.

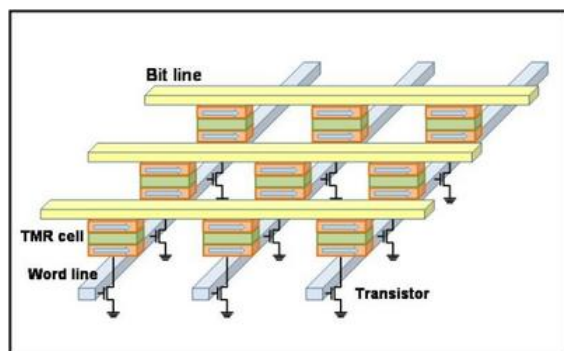


Figure 3



Current Density and Thermal Stability ¹

The use of MgO-barriers has increased the threshold current density to 3×10^6 A/cm², which is required for reversal. This current density must be decreased further by at least a factor of 3 to realize a universal memory; however, thermal stability becomes a problem with the miniaturization of the memory. To prevent errors due to thermal magnetization reversal, an energy barrier is needed. The height of the energy barrier is proportional to the volume, and a barrier height of 60 kT is required for 1 Gb integration. The task at hand is to balance the contradictory demands of high thermal stability and low current density. (To be precise, the pulse width should also be considered because the threshold current density depends on the width of the injected current pulse.)

The conditions required for universal memory (a memory usable for all purposes) are summarized in Table 1. Spin-transfer torque RAM (SPRAM), an MRAM that makes use of spin-injection magnetization writing, has almost achieved the items marked with ○. The remaining items, among which balancing the low current density and high thermal stability is the most important, will be addressed in the future. Professor Ohno says, "We have already established the design principles. We are now tackling engineering tasks to see what today's materials can achieve and at what feature size we need to change to another material."

Table 1

- Large signal (large tunnel resistance ratio)
- Scalable writing
- Nonvolatile
- Nondestructive readout
- Number of repeated writings > 10^{15}
- High-speed writing/reading (<10 ns)
- Compatible with CMOS
- Cell size < $8F^2$ (F: minimum feature size)
- Reliable reading/writing
- Manufacturing ability
- Low cost



Looking Toward Logic-in Memory ¹

At present, SPRAM is the only high-speed non-volatile memory that can be rewritten an unlimited number of times and can be miniaturized to 65 nm or smaller. High-speed unlimited rewriting means the possibility of use in combination with logic elements, similar to DRAM.

In today's semiconductor processors, memories, in particular volatile memories, take up most of the space. Because these memories need current even to maintain data, a serious problem of power consumption arises. In addition, power consumption increases with miniaturization. Moreover, the memories and processing units are arranged on the same plane, which increases the necessary area and thereby increases the delay. On the other hand, the SPRAM can be placed in the wire layer above a processing unit because it is a variable-resistance device. This method could be called intelligent wiring. It is possible to fabricate the SPRAM during the wiring process after the integrated-circuit process, which is convenient for us. As a result, memory-in logic / logic-in memory can be realized for the first time (Fig. 4).

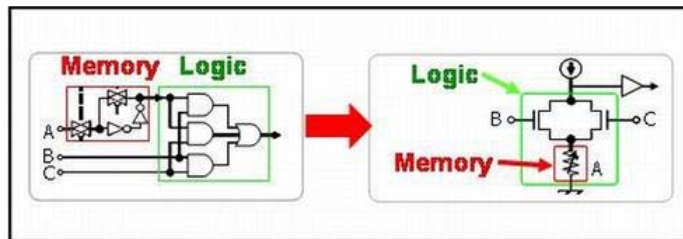


Figure 4

Using such a processor, dynamic reconstruction, data-driven architectures, and even non-von Neumann architectures may be realized; the exploration of new circuit design technologies for such features has already started. "We cannot earn any credit without fabricating real integrated circuits. Simulation alone has no credibility in the IC world" says Professor Ohno. He is attempting to demonstrate this concept by fabricating a SPRAM on a CMOS wafer obtained from a foundry, in collaboration with Hitachi. In February 2007, he developed a bidirectional-current rewritable 2 Mb SPRAM and demonstrated the performance of 100 ns writing time and 40 ns reading time. (Sony released a 4 kb SPRAM in 2005.)

Professor Ohno says, "This trend may not immediately change the entire integrated circuit technology, but it is expected to become the mainstream in some applications." He started a project "High-Performance Low-Power-Consumption Spin Devices and Storage Systems" funded by the "Research and Development for Next-Generation Information Technology" program of the Ministry of Education, Science and Technology in collaboration with seven communication/home-electric-appliance manufacturers in August 2007, and he is now progressing with the demonstration of the spin-injection logic-in memory.

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Venture Capital and Nanotechnology --- Mutsunori Sano (President and CEO, Innovation Engine, Inc.) [↑]

This article is a summary of the talk given by Mr. Sano at the 7th task force meeting of the "Developing Nanotechnologies and Engaging the Public" project (Coordination Program of Science and Technology Projects) held by the Cabinet Office on 7 March 2008.



Contributing to the world through technology [↑]

Japan is currently positioned between emerging countries, the economies of which are expanding, and the U.S., whose economy is in recession. Although Japan's past interests were mostly influenced by the U.S., its future will be affected by developing countries. Therefore, Japan must cooperate with developing countries, some of which have economies growing at 10% per year. As the problems are emerging associated with the large consumption of resources by these countries, Japan can contribute to their solution in two ways. One is to actively promote technology development in the form of miniaturization, by reducing the weight, thickness, length, and size of products, conserving energy and resources, and cleaning the environment. The other is to provide technologies to these countries that will reduce global warming.

Japan's strength is in culture (content or software) and technology. However, if technology is separated from culture, it is merely a matter of time before technology is adopted by other countries. Thus it is beneficial to create products that can contribute to the world by concentrating on the development of technologies that are based on deep-rooted Japanese cultural values.

The traditional Japanese characteristics of saving resources and the concept of dignity (shame) help us to create products in an orderly manner within an organization. In this sense, nanotechnology is a field suited to the Japanese, and Japan is expected to maintain its leading position in the fields of devices, materials, and fundamental technologies in the future.



Current situation and future prospects for the Japanese manufacturing industry ¹

The manufacturing industry has a large role in frontier technology in Japan, but the ideas of "Mission, Vision, and Solution," are missing. Only the initial devices and materials are manufactured in Japan, while most financial profit is gained by European countries and the U.S. - this is the current situation of the Japanese manufacturing industry. It is important to offer high-quality Japanese products overseas by promoting "Mission, Vision, and Solution," including the concept of standardization. I recognize that the profit structures in Japan and the U.S. are different in that the prices of Japanese products are easily beaten because the products are sold individually. Considering the macroeconomics of Japan, it is clear that Japan cannot survive without a manufacturing industry. Although the share of the manufacturing industry itself is only 20% of the Japanese economy, when other peripheral service industries, such as maintenance businesses, are included, the share increases to one-third. Furthermore, when we consider the balance between services and trade, the manufacturing industry makes up most of the trade surplus, which makes it, in effect, the main breadwinner for Japan.

However, we must pay attention to the fact that factories are no longer the center of the manufacturing industry. The capital invested in manufacturing R&D is considered equal to the investment in plants and equipment, and the strong possibility exists that investment in R&D will overtake investment in plants and equipment in the near future. The manufacturing industry has already become an urban industry, and it is actually regarded as an urban R&D industry in developed countries.

The core competence of Japan is science and technology. However, several neighboring countries are becoming manufacturing powerhouses, and we cannot compete with these countries in terms of low-cost mass production. For Japan to be a front runner in manufacturing industries, we should concentrate on manufacturing industries that require no equipment or factories. Such industries may be called R&D industries or laboratory industries. In this way, we can compete with other neighboring countries and easily differentiate ourselves from the countries that have strong information communication technologies.



Complicated and uncertain technology environment ¹

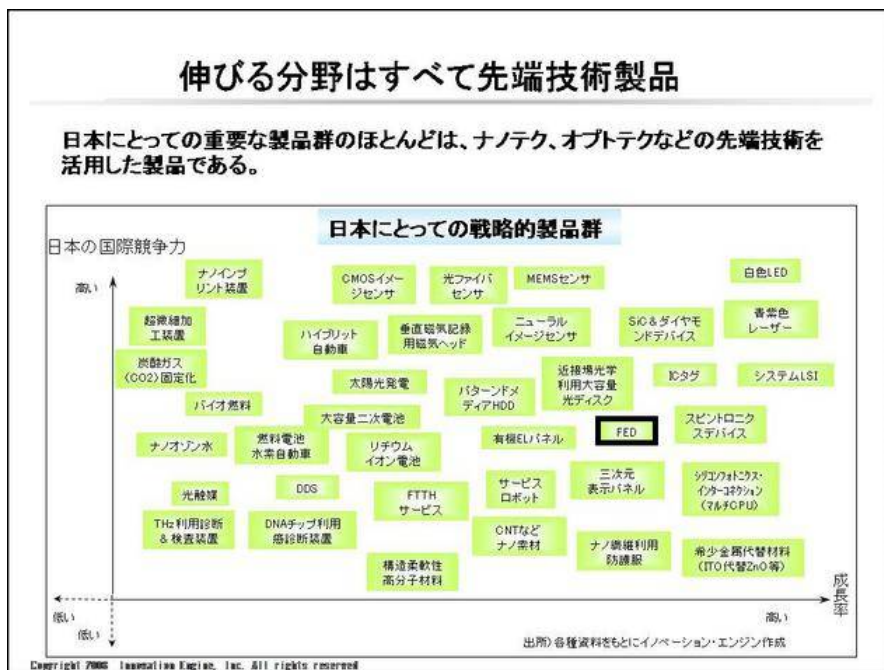
In the past, the fundamental technologies of each industry did not change for 40-50 years. A typical example is displays - we used only CRT displays for several decades. However, in recent years, various alternative display technologies have appeared. Large manufacturers generally specialize in one of these technologies; some have grown rapidly, while others have withdrawn from the market. Storage devices and semiconductors have followed a similar path, and our society is not as simple as it was in the past when, for example, semiconductor technology was developed within a national project.

In the past, most industries were supported by just one technology. However, various alternative industries and technologies have recently come into existence at the same time and are now competing with each other for survival. Therefore, even large companies face uncertainty.



Growing industry and strategy for development ¹

The figure shows the growing industries that Innovation Engine Inc. expects to be attractive areas of investment. The abscissa represents the product groups with the potential for growth in the future, and the ordinate represents the industrial groups that are strong in Japan. These industries will be increasingly combined with each other in the future. Various industries, including those involving batteries, displays, and materials, are flourishing and have a bright future, and many areas of their business will grow. In the past, large companies captured their market by having a large share in specific core products. However, we have now reached a stage where it is very difficult to specify the area on which to focus and the strategies to adopt for the future.



Words in Figure: The fields expected to grow are all related to frontier-technology products.

Almost all product groups that are important in Japan apply frontier technologies such as nanotechnology and optoelectronic technology.

Protective nanofiber suit

Strategic Japanese product groups

Reference: Prepared by Innovation Engine Inc. using various sources.

In the past, large companies with a top-down and vertical structure earned their profit mainly by simply keeping an eye on the trends, from R&D to industrialization, in European countries and the U.S. However, now is the time to adopt the threefold doctrine of Mission, Vision, and Solution. Namely, we should make use of universities for the study of basic science, and in marketing and development, we must avoid risks through collaborations between venture companies and large companies, or between large companies; otherwise, further progress may be hampered.

Large companies that do not undergo open innovation may find themselves in danger. Even though some companies can develop core businesses by themselves, such businesses are very rare. Furthermore, intermediate technologies, such as niche technologies that are needed between two industries, crossover technologies, and peripheral technologies, may advance very rapidly, but no method has been established for developing such technologies. Basic research institutions advance the R&D of only their core businesses. "Discard all of our own conventional peripheral technologies and instead, collaborate with other companies that have high-quality peripheral technologies." This is the key point of open innovation.

The future mission of R&D institution managers consists of the tasks of fostering human resources within the institution and developing and managing a communication network of people who are carrying out high-quality research outside the institution. The latter will become more important than the management of human resources within the institution.



Large companies and venture businesses ¹

Large companies are superior in terms of their brand value, productivity, and sales capacity. On the other hand, venture companies specialize in specific areas and develop their business at an incredibly high speed while focusing on their specialty. We need to integrate these two kinds of companies. As it is still difficult for venture companies to handle manufacturing, no venture business has yet attempted to develop its business without collaboration with other companies. We must thoroughly consider the matching between several technologies in different industries. Generally speaking, the number of companies that go on the market is decreasing year by year, while the number of frontier manufacturing venture companies is increasing dramatically. This fact is still not well known, but venture companies are gradually creating a sensation behind the scenes. Large companies are gradually allocating less of their core competence to manufacturing and R&D, and R&D is being left to frontier-technology venture companies and universities. However, it is impossible for all R&D to be covered by venture companies alone. They need the cooperation of large companies in terms of marketing power and the ability to respond to customer needs. When it comes to nanotechnology and manufacturing, we often confuse frontier-technology venture companies, which excel at R&D, with manufacturing venture companies, whose strength is manufacturing. This confusion causes us to miss the point of discussions and to fail in cooperative efforts. Therefore, we should distinguish between frontier-technology and manufacturing venture companies.



From R&D to commercialization and industrialization [↑]

Researchers enjoy discovering the laws of science. Engineers create products that contribute to the world. Businessmen compete in the commercialization of products by realizing low-cost mass production, consistent quality, and the observance of delivery deadlines. These three groups of people have different characteristics, and a huge economic gap exists between engineering and business. This has not been problematic up to this point. In the future, however, a problem will arise; when the existing products based on nanotechnology are replaced, the corresponding assets owned by customers will inevitably be replaced. A large gap also exists between commercialization and industrialization. No matter how inexpensive and high in quality a product may be, if competing products are already widespread and people in positions of influence do not want to use a new product, the product cannot be commercialized. Such situations often hamper innovation.

In addition, when we develop new businesses, the standardization of technology is a serious issue, because the compatibility of products and services is very important. Profit-oriented businessmen alone cannot overcome this problem. As this is a key task to be solved by new technologies, people who understand industry-government-academic behavioral principles should be active as mediators of change to alter the culture of these three participants for the technologies to take off.

[↑](#)

What we need for successful nanotechnology venture businesses [↑]

In various senses, the greatest challenge when we nurture a nanotechnology venture business is the problem of "too small, too short." If we spend insufficient amounts of time and money, we will fail. Moreover, a problem arises with the level of technology: if it is too narrow, we can neither attract interest nor feel any joy in the development of the technology. We need to handle global-level technologies. In addition, we should target overseas markets from the beginning because the domestic market is slow to accept new technology. Products that are popular overseas tend to then become popular in Japan.

Regarding the relation to markets, it is often said that university professors in Japan are eager to take center stage in their field and to be involved in the industrialization of their technologies, which is quite different from the situation in Europe and the U.S. It is important for managers to appreciate the feelings of such academics but regulate their roles.

Many cases have arisen of technology developers interfering with the production process. They may overestimate their abilities and mistakenly consider themselves capable of production and thus cause the production process to fail. Developers should hand their technology to managers of production processes because engineers involved in production processes have the appropriate skills. In other words, marketing, administration, engineering, and finance should be skillfully differentiated and left in the hands of the respective competent professionals.

[↑](#)

What we expect of the government [↑]

Although universities are in possession of seeds (i.e., promising technologies), it generally takes 10-15 years to realize final products. If technologies that were in development by large companies for 5-10 years are released to universities, resulting products can be commercialized in 5 years. Such spin-offs from research in large companies are desirable.

I hope to position Japan as a technology hub, such that the seeds of new technologies from overseas countries will bloom in Japan. Fortunately, because Japanese manufacturers have exacting standards, the technologies that become successful in Japan will be acceptable worldwide. In the case of manufacturing, the level of technology as well as the brand value will rise. It is also important to introduce Japanese technologies to the world. In short, the government should support the establishment of Japan's position as a technology hub; this will also enhance the dynamism of Japan.

Government R&D projects have the problem of lacking responsibility for the advancement of projects. It is better to adopt milestones where venture capital will be provided if the designated progress is achieved. Despite this, a schedule-based method is typically adopted at present. It would be ideal to involve some project managers in collaborations with private companies.

Various venture support funds from the government tend to be provided to supporters of venture businesses. Funds are preferentially given to companies who take no risks. However, it is important to fund those who wish to start a venture business. Japanese venture companies will further improve when the government will provide funds to those willing to take action and associated risks.

Finally, Japan effectively has no venture capital companies, banks, or security houses that are strong in technology and business. Europe and the U.S. have both banks and security houses that are completely specialized, for example, venture capital companies with resources allocated exclusively to MEMS and biofuels. It is very important to foster financiers with specialized technological knowledge.

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Shaping the future with materials science - Research environment contributing to researchers making great achievements --- Interview with Koichi Kitazawa (JST) and Sukekatsu Ushioda (NIMS) [↑]

A satisfactory home run, the discovery of a new iron-based high-temperature superconductor in Japan was announced in February 2008. What research environment is desirable to foster great achievements deserving Nobel Prize from researchers? Regarding the future prospects of materials science, Koichi Kitazawa, President of JST, and Sukekatsu Ushioda, Head of NIMS Center for Nanotechnology Network, talked about the above issue. The talk was chaired by Takeshi Inoshita, a member of the editorial board of Nanotech Japan.



Koichi Kitazawa and Sukekatsu Ushioda

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Solid performance of materials science in Japan and expected breakthroughs. ¹

- What do you think of the status of materials science and nanotechnology research in Japan?

KK: The level of nanotechnology and materials science is rather high in Japan. For example, it is expected that new discoveries in materials science, such as high-temperature superconductivity, will be made in Japan or China. Discoveries derived as a corollary of theories are not expected in these countries, but those discoveries are relatively small in number.

SU: It is interesting that Europe and the U.S. would not make such discoveries, isn't it? Is it a systematic or psychological issue?

KK: It is an issue of vitality.

SU: Isn't the research environment of Japan coming close to that of Europe or the United States?

KK: Professor Hideo Hosono (Materials and Structures Laboratory, Tokyo Institute of Technology) wrote: "Young researchers become discouraged, saying that it is not possible for them to make a breakthrough."

SU: How to bolster young people's spirits and set them on the path to science is an issue that needs to be resolved.

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Three consecutive home runs in the life science field ¹

KK: In fact, home runs in both life science and materials science were achieved by Japan. Among them, the iPS cells of Professor Shinya Nakayama (Kyoto University) are the focus of attention, and researchers around the world are building on his achievements. Research on natural immunity by Professor Shizuo Akira (Osaka University) and on a flu vaccine by Professor Yoshihiro Kawaoka (University of Tokyo) are also major achievements. If humans living in a major city such as Tokyo become infected by bird flu, subways will probably be stopped and people will be forced to stay at home. If an infectious virus appears among humans, Professor Kawaoka's research will be effective in shortening the period from the taking of virus samples to the development of a vaccine and its distribution after mass production. Although it had been previously said that the field of life science has been inactive, the above three researchers were awarded the Robert Koch Prize in the period of a few years, which is often a prelude to receiving the Nobel Prize. Professor Yamanaka appeared on daytime TV talk shows and the national 7 o'clock news program, and is currently well known by people on the street. He is also often featured in women's weeklies. Although these commitments make him very busy, I think it is preferable for him to appear in the media as much as he can to inform the public, even if it is at the expense of attending academic conferences.

SU: In addition, he trains students.

KK: In that sense, Professor Yamanaka has achieved greater recognition than the baseball players Ichiro and Matsui in the U.S. Major League. I hear that there are four conditions that have to be met to appear in the women's weeklies, that is,

- 1) being young and good-looking,
- 2) outspokenly criticizing something even in front of a major public figure, such as the Minister of Education, Culture, Sports, Science and Technology,
- 3) being capable of doing an outstanding job, and
- 4) being an excellent speaker with enthusiasm for an issue.

Professor Yamanaka's speeches show his strong desire to provide help for patients as soon as possible, and his way of engaging with the mindset of the general public has increased public awareness of scientific research in Japan. From being previously unknown, Professor Yamanaka has suddenly achieved superstar status as a public face representing the field of science.

SU: Since TV viewers are taxpayers, Professor Yamanaka's visibility is important.

KK: Surveys on the public expectations of new social problems being solved by science and technology are regularly conducted by the

Cabinet Office. The latest survey results showed that 62% of people gave positive answers, a jump from 35% in the survey four years before.

SU: Was this due to the impact of Professor Yamanaka?

KK: The Asahi newspaper says because the news of iPS cells was released just before the survey, it must have affected its results to a great extent. It is a shame that this result is due to popular scientists appearing on daytime TV shows; but nevertheless, there should be stars in science.

SU: I agree with you. What inspired me to go into science was Hideki Yukawa winning the Nobel Prize in 1949. I was an elementary school pupil at that time when the entire Japan was very short of food and it was the only good news then.



Appearance of new high-temperature superconducting material [↑]

There are many people who have gone into science after reading the biographies of scientists such as Hideo Noguchi and Hideki Yukawa. When other heroes were desired, home runs were launched in succession, and meanwhile, another home run, the discovery of a new high-temperature superconductor, was launched by Professor Hosono.

- What is the novelty of Professor Hosono's research?

KK: The material he first discovered was a laminate of alternate layers containing iron and arsenic and ones containing lanthanum and oxygen. Previous high-temperature superconductors were only cuprates. Now it has become possible to create compounds containing copper, iron or oxygen as well as positive metal ions such as rare-earth ions, and group V materials such as nitrogen, phosphorus, arsenic, or antimony, the number of possible superconductors has greatly increased. When I reviewed the development of cuprates, system 214 was first discovered. Later, Hiroshi Maeda from the National Research Institute for Metals (predecessor of NIMS) discovered system 2223, which has a different structure from 214, and a system 123 was also discovered abroad. The development of these compounds for practical application is being advanced. If the material discovered by Professor Hosono is compared with system 214, there is a high probability that system 123 and system 2223 will be found. It is a matter of primary concern who will discover the system first.

SU: Professor Kitazawa, you discovered new superconductor 20 years ago, didn't you.

KK: We were in the vanguard, but many laboratories discovered similar materials from 1986 to 1987. Currently, researchers are slow in discovering other materials.

SU: Indeed, that is the situation in Japan. China has moved ahead of Japan.

KK: I think this situation is undesirable and I have urged researchers to speed up the research process.

- Did the difficulty of making samples contribute to their failure to discover new materials?

KK: That is one reason. Another reason is that if a Japanese scientist is the first to discover something, other Japanese researchers become discouraged, even though Bednorz-Muller first discovered high-temperature superconductivity in 1986.

SU: Discoveries by foreign researchers may be more psychologically acceptable to them.

KK: Nevertheless, who discovers the next high-temperature superconductor is very important. Thanks to Dr. Maeda's discovery of system 2223, Japan is given due respect in the high-temperature superconductivity field. To maintain its high standing, I would like Japanese researchers to discover a high-temperature superconductor equivalent to system 2223. There should be people who want to be engaged in this interesting research.



Physical-chemical cross-pollination leading to achievements [↑]

SU: Dr. Kitazawa, what research did you do at that time ?

KK: I focused on research on unusual superconductivity using oxides and fluorides under the guidance of Professor Shoji Tanaka, University of Tokyo (Incumbent Director, Superconductivity Research Laboratory) starting in 1981. To tell the truth, I should have discovered a new superconductor ahead of everyone else, but I was beaten to it.

SU: Were you aware of the research of Muller et al.?

KK: No, I was not. Their paper was published in Zeitschrift fur Physik, which did not attract much attention for some time until Kazuko Sekizawa, who was at Nihon University, informed me of that publication. The paper was published in April 1986 and I was informed about it in October.

Many odd superconductors such as CuCl, CdS and TiB₂, some of which were claimed to have room-temperature superconductivity, had

been reported previously, but all of them had been false reports. I came from the field of applied chemistry but was invited to the laboratory of physical engineering as an associate professor. The reason was, as commented by Professor Tanaka, physicists are busy studying binary compound systems such as gallium and arsenide and they are thus unable to handle superconductors containing a great variety of elements.

SU: It was an example of the successful cross-pollination of physics and chemistry.

KK: When Bednorz and Muller's paper was published, I had previously seen a lot of false reports on high-temperature superconductivity, so I thought the paper was such a report. When I asked a graduate student to conduct follow-up test, definite indications of superconductivity appeared on the first attempt, and we were astonished at the results.

Bednorz was a chemist and made the first sample by coprecipitation, a very difficult method. Both barium (lanthanum) and copper were precipitated from their solutions and a mixed hydroxide of them was burned to make an oxide. The ratio of barium to copper was clearly specified in the paper, but actually, the metals did not precipitate properly and the ratio was wrong. The graduate student conducted the test by an easy method, that is, taking material powders and mixing them in an agate mortar. Because of this, the obtained material was different from Bednorz's in terms of composition. It had far better properties and was immediately proven to be superconductive.



Combination of senior researchers pursuing their dream and spirited young researchers ¹

SU: Rohrer, who co-invented the scanning tunneling microscope, was Bednorz's supervisor.

KK: It is said that on the very day when Rohrer at IBM Zurich Research Laboratory received the news that he would be awarded the Nobel Prize, Bednorz went to Rohrer to get his approval for contributing his first paper on high-temperature superconductivity. Rohrer signed the document when he was very busy because of the news of the Nobel Prize. The thus-published paper brought the second Nobel Prize to IBM Zurich Research Laboratory.

SU: I was at IBM Almaden Research Laboratory for a period of time. A manager came and said, "The Nobel Prizes were awarded to the researchers at IBM Zurich Research Laboratory, a small laboratory that spends less money than our laboratory. Why hasn't any researcher at this Laboratory won one even though we spend such a large amount of money?" A friend of mine said to him, "Because managers like you keep plaguing us with questions."

Muller was well advanced in years at that time and a willful man. It seems that IBM let him carry out his own research since it did not cost very much. It is a good thing that a few researchers are left unattended.

KK: The Rohrer-Binnig combination that invented the scanning tunneling microscope was also very similar. Research by Rohrer alone and Binnig alone should not be fruitful. However, the combination of a quixotic senior researcher who pursued his dream and a young man who wanted to carry out interesting research produced excellent results.

- Were the areas of research of Binnig and Rohrer the same?

KK: Both Binnig and Rohrer were physicists, although their work was mainly making devices.

SU: A similar combination of BCS theory researchers also had great success. I guess that Bardeen was an elderly researcher, Schrieffer was a graduate student at Illinois, and Cooper was a postdoctoral researcher. If young researchers find an elderly researcher and ask him for work, they may get the Nobel Prize.

KK: Regarding Schrieffer, he was told to make a basic state model of superconductivity by Bardeen. Every time Schrieffer brought a new model, Bardeen glanced over, crumpled it into a ball and threw it away. This caused Schrieffer great distress. He visited the Niels Bohr Laboratory in Denmark for his holidays. Just before returning to America, he fell in love at first sight with a woman, slammed on the brake of the car he was driving at the time and spoke to her. Her parents said to Schrieffer, "If you are still serious after one year, we will then reconsider your proposal to our daughter." Schrieffer completed the BCS theory during that year, which provided the basis of the Nobel Prize, and he married the woman he had fallen in love with.

Since the story was too good to be true, I thought for quite a while that it had been made up by Schrieffer. One day, I directly asked his wife, a beautiful woman who reminded me of Elizabeth Taylor, and found that the story was true. I now advise my students: never miss an opportunity. Be sure to slam on the brakes when necessary. The same is also true with experiments.

SU: Schrieffer wrote his doctoral thesis on the BCS theory.



Young people tackle interesting subjects wherever and whenever they can ¹

- What is the impetus that motivates young people?

KK: With the discovery of high-temperature superconductivity, I am convinced that young people engage themselves in research

without sparing time to sleep and eat. However, this kind of challenge is rarely encountered. In many cases, when a new continent is discovered, young people embark on an adventure there. Since Professor Yamanaka's pioneering work on iPS cells is also similar to the discovery of a new continent, many young people are now doing research in that field.

SU: They all entered the field together.

KK: Research has gone into overdrive in the U.S. and Japan. Japan is at the forefront of high-temperature superconductivity as is shown by Professor Hosono's high-temperature superconductor, but China, Taiwan and France are making rapid progress. It is the Chinese researchers who have entered the field in the U.S.

SU: The most ambitious researchers are the first to enter new fields.

KK: Twenty years ago, students at my laboratory did not go home, so I locked the laboratory during the first three days of the New Year. When I dropped by the laboratory when I paid a visit to a shrine at the beginning of the New Year, four students were sleeping on cardboard spread on the floor.

SU: With such enthusiasm, research achievements are sure to be obtained.

- When the entire field of materials is overviewed, various achievements following Professor Hosono's will appear.

KK: For example, Takayoshi Sasaki at NIMS is conducting research on a new materials synthesis technique by making nanosheets and laying them on top of one another. Previously, only techniques from the field of compound semiconductors could be used to synthesize each layer. Professor Hosono discovered a new materials synthesis technique by laminating pnictide and oxide layers. This technique is appropriate for synthesizing nanosheets. This technique has not been tried very often so far, but will be used more in the future.



Chemists run, while physicists support them [†]

- I feel that collaborations between physicists and chemists will lead to great results.

SU: Since the most important task in nanotechnology is the creation of materials, physicists are of less importance these days and reluctantly play the supporting role of taking measurements.

KK: I think the relationship between chemists and physicists is akin to that of children running at a school sports day with a cheering group around them. Chemists run and physicists support them. A physicist alone will not produce new materials, while a chemist alone will not be motivated in the absence of encouragement.

Professor Hosono is the type of person who increases his motivation by playing the roles of both a physicist and a chemist and repeatedly switching between the two roles. In practice, the laminated superconductive compound is his third home run. His first home run was a transparent oxide semiconductor film with superior electric conductivity even though it was an amorphous semiconductor, and his second was the work of converting cement ($12\text{CaO} \cdot 7\text{Al}_2\text{O}_3$), originally an insulator, to a transparent electric conductor with metallic conductivity. This material has sites with high positive ion density similar to a basket that easily traps negative charge. Physicists have the idea that a regular arrangement of electrons may form a metal. In contrast, chemists think that it is necessary to change the distribution of positive and negative ions to trap electrons locally and think of ideas for that purpose.

SU: Indeed, it would be just like a chemist to think in this way.

KK: The combined technology of physics and chemistry brought about his three home runs. The first home run was not based on a particularly novel idea but on one that people had not thought about much. The second one was based on a principle that people considered to be too good to be true or unfeasible. The third one was high-temperature superconductivity, and involved a lucky guess rather than based on synthetic research.

SU: Nevertheless, Professor Hosono was close to discovering high-temperature superconductivity as you were, Professor Kitazawa.



Discussions sharpen thinking [†]

- Professor Hosono once said, "Discovery gets into a routine. If it hits you once, the probability of it hitting you again will increase. You should be able to advise other people about your experience with this."

KK: It is very important that all researchers discuss issues eagerly. This is the tradition of Professor Hosono's laboratory and AT&T Bell Labs. Professor Kawazoe and Professor Hosono are always arguing about theories behind various issues with researchers around them.

SU: I used to not like taking part in discussions. Professor Burstein, who guided me at graduate school thought: "Discussions produce creative ideas, which enable a new leap forward to a new place." When I said, "I will reflect on this carefully after I go home, and let us discuss it tomorrow." Professor Burstein said, "It is no use unless we discuss it right now." Recently, I have also come to realize that he is correct.

KK: When I visited Bell Labs, researchers took out a piece of paper at lunchtime and made notes. Such sights are less common in Japan.

SU: At Tohoku University, professors have lunch with their own group members, but at California University, I often had lunch with Rowland, an ozone hole researcher, and Reines, a neutrino researcher. Both of them won a Nobel Prize in 1995. I was always intrigued to hear the content of research conducted by researchers in other fields and their discussions. If it is necessary to explain some issue to other people or if a question is given from a different point of view, it will afford you good training in thinking.

KK: Also, if you are criticized, you will arm yourself with knowledge.

SU: When I made presentations at academic conferences after I returned to Japan, no one asked difficult questions. After I stayed in Japan for three years, I attended a seminar in the U.S. and got criticized so much that I felt an urgent need to improve the rigor of my arguments.

KK: I believe that in Japan too high-level physicists have serious discussions.

SU: Professor Ryogo Kubo always asked difficult questions to young researchers without regard to their feelings. I suppose chemists are slightly gentler.

KK: In the field of chemistry, people are friendlier. If you ask "At what temperature did you burn the sample," one researcher answers "I burned it at 1400 C" and another answers "I burned it at 1250 C" and a stimulating conversation follows. This then leads the questioner to think "this time, I will conduct the experiment this way." Physicists have more heated discussions.

SU: If someone says "I burned it at 1450 C" another person will ask a sharp question "Why did you burn at 1450 C?" If you are unable to explain why, you may feel ashamed.

KK: In physics, it is rather difficult to argue about something with researchers in the same field. Discussion may sometimes reveal the level of understanding of the speaker. This may explain the reason why a combination of young researchers and an elderly one is preferable.



Should globalization be advanced or should national research be protected? ¹

- Does the difference between physicists' and chemists' attitudes to discussion lead to the issue of globalization?

SU: With the internationalization of our research environment, when a foreign research group starts an argument about some issue, one cannot help arguing in response to it.

KK: I do not think it is necessary to internationalize all research institutes in Japan without exception and that a thorough distinction should be made between research institutes that are globalized and those that stick to research along national interests. For instance, it may be better to thoroughly globalize some institutes such as NIMS that have already started to move in this direction.

Many European countries have small populations, and universities and research institutes there may have no other option than to globalize themselves. In Japan, if local research institutes accept only local people, they will soon be faced with the difficulty selecting suitable personnel and will want to accept researchers across Japan. This is the scale of these research organizations.

SU: Japanese research organizations are of intermediate size. In countries where research organizations are completely open such as the U.S., it is all right that way. Small countries in Europe have to employ people from around the world.

In addition, the learning system of Japan is such that Japanese teachers are able to carry on with teaching since texts are in Japanese and teaching is also in Japanese, thanks to the great efforts of people in the Meiji Era. Japanese organizations prefer not to invite people from abroad unless they are conscious of globalization.

The International Center for Young Scientists (ICYS) started by NIMS in 2003 was originally based on the idea of Dejima (the artificial island located in Nagasaki designated for importing foreign technology and ideas during the period of national isolation in the 17 - 19th century that played a vital role in the modernization of Japan). I hear that by adopting the concept of Dejima, NIMS aims to set up ICYS on the mainland and reach out to more young scientists. All the staff at the ICYS can speak English, but it is difficult to spread this to reach more young scientists.

KK: The number of bilingual Japanese people has increased substantially in recent years. JST has only clerical workers, but the capability to speak English and Japanese has been set as a requirement of employment for the past six to seven years, thanks to the former director's courageous decision. Since JST invites people of various backgrounds, objective experiments can be conducted in English.

SU: Globalization takes a long time. In Japan, since people cannot be laid off until the retirement age, globalization can only spread gradually.

KK: There is no end to the discussion on whether globalization is appropriate. I would suggest that each organization bases its policy on the view of all employees and, upon deciding, moves in that direction. If human affairs are dealt with following international standards,

excellent human resources will be recruited on the basis of ability from across the world.

SU: If Japan strives only nationally, there is little chance of competing with the U.S., where best people are hired from all over the world. On the other hand, there is an option of only Japanese researchers quietly cooperating.

KK: In that case, the average ability of researchers may not be outstanding, but they will produce the results of research harmoniously and efficiently.

SU: It is difficult to have a policy between pure globalization and restricting research to Japanese nationals.

(Interviewer: Dr. Takeshi Inoshita, National Institute for Materials Science, Japan. Recorded at Tokyo head office of Japan Science and Technology Agency on July 21, 2008)



NANO JAPAN, the United States Japan Student Internship Program --- Interview with Junichiro Kono (Rice University) [↑]



There are various research internship programs available that send students from Japan to abroad or from abroad to Japan, but these programs are mostly for graduate students. [NANO JAPAN](#), which started in the U.S. three years ago, is a unique program for undergraduates, specifically freshmen and sophomores in the nanotechnology field. It sends about ten young American students to Japan every year. The program was highly rated in the United States for its spirit of innovation and won the Andrew Heiskell Award in 2008 from the Institute of International Education. Junichiro Kono, Associate Professor at Rice University (Houston, Texas), who organizes NANO JAPAN, was interviewed.



Could you please first tell us how NANO JAPAN started and give an outline of this program? [↑]

The National Science Foundation (NSF) initiated a program, Partnerships for International Research and Education (PIRE), three years ago. This is a major program focused on international joint research projects and international education. Many grants awarded by the Foundation are spent on education. I formed a group including two physicists from the University of Florida and Texas A&M University, and an international education expert from Tulsa University. I recommended semiconductor researchers from Tokyo Institute of Technology and Osaka Institute of Technology to apply. We applied for PIRE in the first year and fortunately, our application was accepted. Being eager to send American undergraduates to Japan, we initiated NANO JAPAN. Innovative international education is conducted at three levels: university freshmen and sophomores, junior and senior students, and graduate students, and NANO JAPAN is for university freshmen and sophomores.

NANO JAPAN aims to increase the number of students, who go to graduate school to study nanotechnology, and to foster scientists and engineers who have international experience and a global perspective. Since 2006, sixteen promising students, selected from universities and colleges across the U.S., were sent to about ten research institutions in Japan (Hokkaido University, Tohoku University, Tokyo Institute of Technology, the University of Tokyo, Keio University, Shinshu University, Osaka University, Osaka Institute of Technology, National Institute for Materials Science, and RIKEN). All the laboratories acting as hosts are conducting world-class research on the basic properties and applications of semiconductor nanostructures and carbon nanotubes.

Students stay in Japan for 11 weeks in total. An orientation is provided to all the students, which takes place in Tokyo during the first three weeks, then they are sent to the research institutions to begin research under the guidance of the host researchers.



Please describe the implementation of this year's program [↑]

In January 2008, applications were sought and 70 students applied from many universities and colleges across the U.S., including prestigious universities such as Harvard University, Princeton University, and the University of California at Berkeley. Ultimately, 16 students from a diverse range of ethnic backgrounds were selected and sent to Japan. There were particularly many outstanding female students among the applicants this year, and 8 male and 8 female students were selected. They stayed in Japan from May 17 to August 5. The results of their research were presented at a workshop held at Rice University, and the entire program was smoothly completed. Five students are writing papers based on the research they conducted in Japan and will contribute to the Journal of Young Investigators, a peer-reviewed journal for undergraduate students in the U.S.



What is the scale of the grants? [↑]

PIRE has provided funding for a 5-year project and the total grant amounts to approximately 2 million dollars. We allocate about 60% of the grant to research and about 40% to education. NANO JAPAN students receive 3,500 dollars each to cover transportation costs, lodging and food expenses during their stay in Japan. The students also contribute an average of about 2,000 dollars to cover other expenses, although the amount varies between individuals.



Why did you decide that NANO JAPAN should be intended for freshmen and sophomores? [↑]

I wanted to give young Americans an opportunity to gain experience in internationally significant research and to boost their future career prospects. This also corresponds to the view of NSF. In the U.S., most undergraduates are American, whereas foreigners make up the majority of graduate students in the science and engineering majors. NSF wants undergraduates to appreciate the enjoyable aspects of science, leading to an increase in Americans who go to graduate school. A disproportionate number of international programs in the U.S. are for students of humanities. Although there are some American international programs for graduate students majoring in the science and engineering fields, there were virtually none for undergraduates, particularly for university freshmen or sophomores. I believe that, because NANO JAPAN targeted such students, it was evaluated highly by NSF.



How were the students selected? [↑]

Students are evaluated on the basis of three criteria: their academic performance, a letter of recommendation, and essays that they submit with their application. Many students of high scholastic ability applied, some of whom had a GPA of 4.0. Letters of recommendation clearly show the extracurricular activities in which applicants have participated to date. Some university students have already had experience in research even though they are in their first year, and this situation is greatly different from that in Japan. I was particularly impressed by a student among this year's applicants who had already published two papers. The applicants are instructed to write essays on two topics: (i) what they know about nanotechnology and (ii) what aspects of Japan they have an interest in. Most applicants are interested in Japanese animated films and its high technology, but few seemed to have an in-depth knowledge of Japanese culture and history.



Doesn't guiding the freshmen and sophomores keep the Japanese hosts' hands full? [↑]

Indeed. We are extremely grateful to the hosts. However, many hosts told us that it is much easier to guide and teach American freshmen and sophomores than Japanese students of the same age. This stemmed from a difference between the Japanese and American educational systems. In Japan, undergraduate students are assigned to a laboratory for the first time to start research when they are in their final year. Before this, the experiments they carry out are mainly those whose outcomes are known and they have little opportunity to conduct full-scale research. In contrast, in the U.S., many undergraduates enter a laboratory and start acquiring practical experience when they are in their first and second years.

American students, some of whom do not understand quantum mechanics even when they attend graduate school, often do not have the academic ability of students from Asia, but they possess research-ready potential in the laboratory. Also, many first-year American graduate students are familiar with the basics of electronics and vacuum technology experiments. On the contrary, many Japanese and other Asian graduate find first-year classes unattractive and need to be taught everything, even how to use a wrench, when they actually get into a laboratory.



NANO JAPAN supports students in areas other than research, doesn't it? [↑]

The students are given lectures on Japanese, Japanese culture and society, and nanoscience in a three-week orientation provided in Tokyo. Ms. Keiko Packard, a lecturer herself and a member of the America-Japan Society, Inc., has assumed the position of representative from Japan starting this year and has come up with various new projects. One of them was a weekly debate with Japanese students. About 30 students from universities, including the University of Tokyo, Keio University, Waseda University, Hitotsubashi University, Sophia University, and International Christian University, debated with the 16 American students from NANO JAPAN about topics such as the differences in education between America and Japan, the rights and wrongs of ethical education, and global warming. Visits to scientific and technology-related companies were newly incorporated in the program. It thus became possible to provide an orientation made up of a variety of stimulating activities.

The students are required to submit a report once a week during their stay in Japan. I read through each report and give comments on it. I visit all the places where the students stay and hear from them and their hosts alike and provide advice.

After they return to the U.S., the students join the program staff and talk about their experience in Japan. Some students experience reverse culture shock. To prevent this, we lend a sympathetic ear to the students by offering counseling from an expert.

The staff follows up the future activities of the students who completed the program to find out their current occupation and the field they have pursued.



What benefits does NANO JAPAN offer for the students and for Rice University? [↑]

NANO JAPAN allows students to carry out research on cutting-edge nanotechnology at a young age, to experience a three-month stay in Japan, and to learn Japanese culture and broaden their international viewpoint. The benefit of NANO JAPAN for Rice University is that it contributes to increased publicity for the university. At Rice University, nanotechnology has become an active area of research since the discovery of fullerenes by Smalley et al., and the Nanotechnology Research Center was established in the early 90s, but Rice University's reputation is still not as good as that of the prestigious universities on the East Coast. Since the university has a number of excellent researchers in the nanotechnology field, I understand that many Japanese researchers are also familiar with Rice University.



When you look back on the past three years of NANO JAPAN, how do you feel? [↑]

I worked so feverishly during the first and second years that I couldn't keep track of what I was doing. It was not until NANO JAPAN entered its third year that I had the peace of mind to feel that NANO JAPAN was on the right track. NANO JAPAN's receipt of the Andrew Heiskell Award had an unexpectedly large impact. Information on this award was placed on various websites and, as a result, the level of applicants has increased, for which I am grateful.



I understand that NANO JAPAN has had many difficulties in its first three years. [↑]

The greatest issue of the program to be solved is how to strengthen the link between education and research. In an interim assessment recently made by the NSF, it was commented: "NANO JAPAN itself is a great program, but the link between research and education should be further developed. We want NANO JAPAN to link education to the presentation of research papers." Regarding this issue, the recent inclusion of research on carbon nanotubes to the scope of NANO JAPAN, in addition to research on semiconductor nanostructures, has made it easier to strengthen the link. Regarding nanotubes, it is possible to obtain very high quality samples at Rice University. If students bring such samples to Japan and measure their properties with special equipment, it will be possible to write a paper in a relatively short time. There are world-class researchers in Japan who have kindly accepted the students in spite of their heavy workload schedule. This has also been helpful in reducing the gap between education and research.

The program also has a budget problem. The students are paid 3,500 dollars for a round-trip air ticket and accommodation, which is not enough. NSF has given advice about trying to obtain support from Japanese companies. This advice also implies that the students may be able to continue research after the end of the grant period.



Do you have any plan to accept Japanese students to study in the U.S.? [↑]

Japanese students are welcome there since they have a good reputation. Unfortunately, they will not be eligible to receive an NSF grant, and financial support from Japan will be necessary. It would be better to send graduate students rather than undergraduates from Japan in view of their experience and adaptability. Besides, many university laboratories are small in Japan. Faculty members may be reluctant to send a student to the U.S. because it will result in a decrease the capacity of their laboratory. In this regard, I think that the International Relations Program of the Center for Engineering Education Development (CEED), Hokkaido University, makes it possible to send students to the U.S. for duration of few months. My laboratory has previously accepted four students from Hokkaido University through CEED. The program seems to have given all students valuable experience, and has thus become very popular. I hope to continue our efforts to support this program.



Orientation during the NANO JAPAN Program 2008 (Okayama Campus of Tokyo Institute of Technology). Within the Program, Dr. Andrew L. Bement (Director of NSF, third from left in the front row) and Dr. Machi F. Dilworth (Head of the NSF Tokyo office, third from left in the second row) visited Japan to meet and talk with the 16 participating students. Ms. Sarah Phillips (Program Administrator, Rice University) is seated on the left and Dr. Junichiro Kono is second from left in the front row. We thank the NSF Tokyo office for providing the pictures used in this article.

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[Young Researcher Interview --- Supporting a wide range of research in biological and material fields --- Dr. Koji Funaba \(NIMS Nanotechnology Innovation Center\)](#) [†]

[↑](#)

[Young Researcher Interview --- Dealing with various materials leads to discoveries of new interesting phenomena --- Dr. Naoki Ikeda \(NIMS Center for Nanotechnology Network\)](#) [†]

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