# NIMS NOW International

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## Department of Materials Infrastructure

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**Prof. Morinobu Endo**

Faculty of Engineering, Shinshu University
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## Concept and Technology for Utilizing "Urban Mines"

In recycling cell phones and personal computers . . .

# Concept and Technology for Utilizing “Urban Mines”

## In recycling cell phones and personal computers . . .

Do you know that your cell phone and personal computer contain precious metals? Depending on the type of metal, the total amount used in various products sometimes greatly exceeds the current underground reserves. Thus, if cell phones and personal computers which are no longer needed can be rationally recovered and the metals they contain can be reused, they are resources as such. In order to use these resources effectively, it is necessary to take up the challenge of technologies based on new concepts and form the social will to make this kind of recycling a reality. At NIMS, our goal is to create technologies which use metal resources to the fullest possible extent and provide backing to ensure smooth functioning of the reuse loop.

## What are “urban mines”?

Although Japan is poor in mineral resources, in fact, this country has huge hidden mines. Starting from the concept of reviewing the nonferrous metals contained in discarded industrial products as resources with the potential for recycling, the term “urban mine” pointing out this fact was first used by Prof. Michio Nanjo of Tohoku University’s Research Institute of Mineral Dressing and Metallurgy (SENKEN) in a paper published in 1988.

Today, 20 years later, when the number of IT devices and AV devices such as large-screen televisions used by individuals has increased so dramatically, it is not difficult to imagine that the accumulation of metals in Japan’s urban mines has also increased greatly. On the other hand, how far have we progressed in recycling and reusing these resources? To begin with, what is the scale of the urban mines in Japan?

Dr. Kohmei Halada, who is Managing Director of the Innovative Materials Engineering Laboratory at NIMS and is involved in ongoing research on life cycle analysis of metal resources and the effect of materials on the global environment, says that “a more inclusive viewpoint of used equipment as a resource is necessary.” Let’s look at the background behind this comment in more detail.

Data already exist estimating the world’s reserves of metals and calculating the total amount of metals extracted and used as a percentage of those reserves (**Fig. 1**). This study was published in 1993 by Prof. Takashi Nishiyama of Kyoto University. According to Prof. Nishiyama, 80% of the world’s mercury, 75% of silver, tin, and lead, 70% of gold and zinc, and 50% of copper and manganese have already been used aboveground. In other words, at the end of the 20th century, the amount of several key metals which had already been extracted was larger than the reserves remaining in underground mines. These numbers are a convincing argument that we cannot simply rely on limited underground resources, but must utilize close-at-hand urban mines and make active efforts to reuse metals.

**Dr. Komei Halada**
Managing Director,
Innovative Materials Engineering Laboratory
Managing Director,
Strategic Use of Elements,
Interdisciplinary Cluster

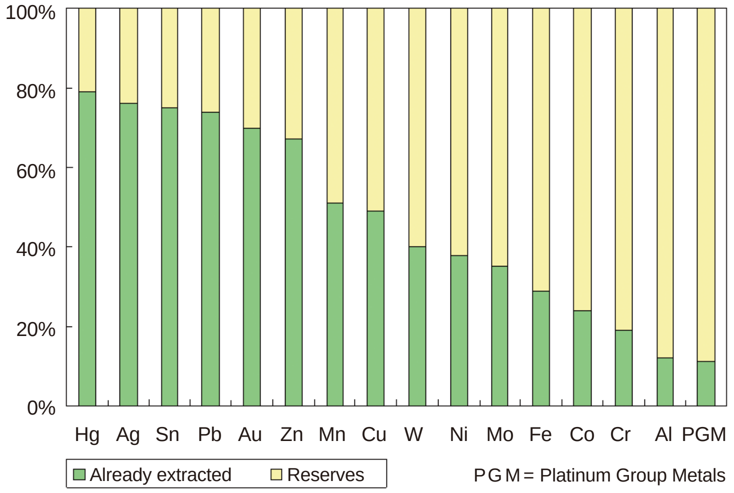

Fig.1 Comparison of metals already extracted and reserves (source: Takashi Nishiyama, “Recommendations on Resource Economics,” Chukoshinsho, 1993)

## Japan’s urban mines are among the world’s largest resources

Many consumers replace their cell phones and personal computers when new designs and models with advanced functions appear. Various metals are used in parts for electronic devices (Table 1). For example, a single cell phone contains approximately 6-8mg of gold, mainly in integrated circuits. Because an estimated 21 million cell phones are replaced and are no longer needed in Japan each year, the amount of gold available for recycling can be calculated at as much as 150kg a year in cell phones alone. In actuality, however, many of these used cell phones are thrown out as trash and incinerated or buried in landfills, left in the back of drawer, or kept as a memento. Only about 1/4 are recovered. This means that approximately 100kg of gold is lost without use each year (**Fig. 2**).

So long as a rational recovery and recycling system does not function, urban mines will remain a possibility to be considered in desktop studies, and cannot actually be utilized as resources. Moreover, even if recovered, at present, these resources do not necessarily remain in Japan; it is estimated that a significant quantity is transferred to other countries in the form of used products.

Dr. Halada devised a method of estimating the accumulation of urban mines in Japan from numerous published data and released the results of his study in January, 2008.

Many people were surprised by his findings because the results revealed that the scale of urban mines in Japan is far larger than was previously imagined. In a simple numerical comparison with reserves of world mines (**Fig. 3**), among the metals which are expected to see increasing demand in the future, the accumulations of gold (Au) and silver (Ag) in Japan’s urban mines are equivalent to 16% and 22% of world reserves, respectively. Other metals also have conspicuously high ratios, including indium (30%), antimony (20%), tin (11%), and tantalum (10%). These are all important industrial metals, as indium is used in liquid crystal displays, antimony in flame-retardant plastics, and tin and tantalum in electronic components.

Even when these figures are compared with the reserves of the world’s major natural resource nations, Japan’s urban mines of gold, silver, lead, and indium are comparable to the world’s largest mines, and copper, platinum, and tantalum are of scales that rank 3rd in the world. Although Japan has generally been considered a resource-poor nation, these figures show that, in fact, it is one of the world’s leading latent metal resource nations

Tab.1 Main metals used in products

| Product | Metal applied |
|---|---|
| Plastic products | Sb, Sn |
| Coated and plated steel products | Zn, Sn |
| Integrated circuits | Au |
| Liquid crystal devices | In |
| Electronic parts | Au, In, Ta, Sn |
| Automobiles | Fe, Pt |
| Electronic equipment | Fe, Pt, Ag |

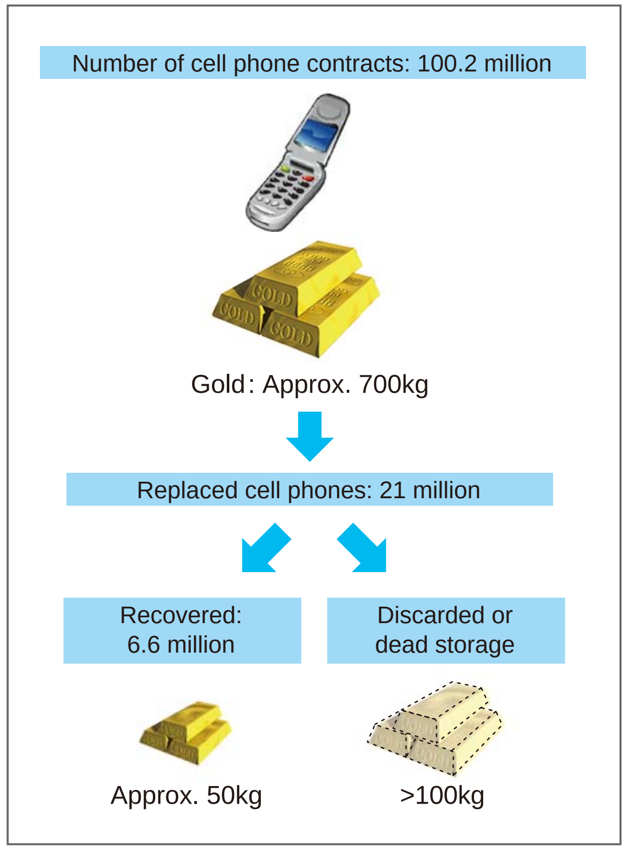

Fig.2 Condition of reuse of gold from cell phones

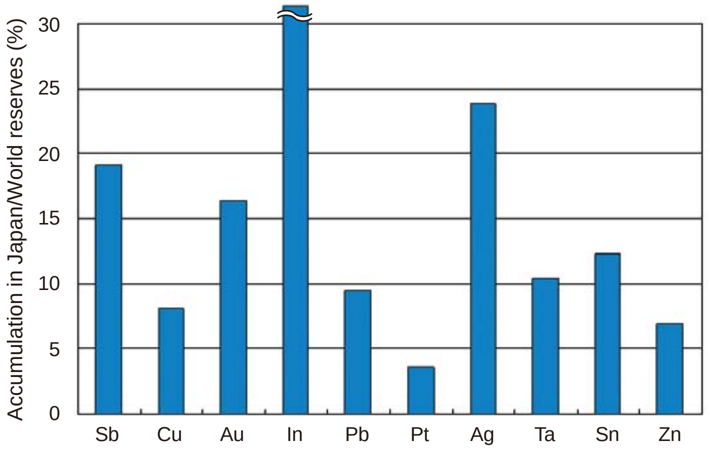

Fig.3 Percentage of accumulation of urban mines in Japan relative to world reserves

## Recycling still has enormous potential

Dr. Halada points out the following: “Recovery and recycling of metal resources in Japan are the most advanced in the world. In the development of urban mines, there have been experiments like Tohoku University’s RtoS (Reserve to Stock).* Nevertheless, at present, many people view recycling as a problem to be promoted as a business by individual companies. Today, when the risk of resource shortages is frequently pointed out, it is necessary to consider what steps we should take in the future based on an assessment of the total condition, and to take the necessary measures, from the viewpoint of effective utilization of resources.”

Since the enforcement of Japan’s Appliance Recycling Law, recycling from electrical appliances has certainly progressed. However, virtually all of the metals recovered and recycling in this process are still limited to steel, copper, and aluminum. There is little recycling of other metals, and in particular, the recycling route still does not extend to the rare metals, even though there is concern about depletion and unstable supplies of these resources due to their scarcity. The rare metals are indispensable in realizing various functions in electronic parts, but because they are used in only tiny quantities in a single product, recycling requires much time and effort, technology, and energy.

Let’s consider the case of the gold in cell phones, which was mentioned previously as an example. As the concept of urban mines becomes more widely known, a gradual increase in the recovery rate of used cell phones is expected. However, at present, a route for sorting phones which are to be reused and those which are to be processed for metals does not necessarily exist in the recovery stage. A single used cell phone weighs around 100g, and the gold it contains is on the order of several mg. Most of the weight of the phone is plastic waste. No efficient technology has yet been established for extracting and sorting only the parts which contain metals from the boards of these devices. At present, recovered used cell phones are received whole by large refiners, and the metals are recovered by melting treatment of the product in a furnace, including the object metals. Because this also includes a large quantity of unnecessary substances, the number of refiners who are capable of performing large-scale processing with technology that does not impact the environment is definitely not large, even in Japan.

On the other hand, the route of exporting unneeded electronic equipment and household appliances to other countries has become active in recent years. It is thought that a large part of the used products which are exported from Japan are utilized in metal recycling processes. Processing in countries where soldering can be removed by hand and environmental costs are comparatively low is perhaps rational as a business under the present circumstances.

However, if this kind of route is established, and the used products which should become resources in Japan’s urban mines are shipped to other countries due to high environmental costs in this country, this is a serious loss for Japan. No small number of persons have misgivings about this.

In actuality, the volume of exports of this type is increasing rapidly. Taking personal computers as an example, a survey conducted by National Institute for Environmental Studies in 2008 found that, 7.8% of 4,880 recovered used personal computers in 2001 were exported, but this rose to 26.4% of 7,470 computers in 2004.

## The overlooked importance of concentrates

Where do we begin in actively developing urban mines? The following will introduce a proposal presented by Dr. Halada in March 2008, namely “In developing urban mines, first, create ‘urban ore’.”

Here, we should briefly review the process by which metals are produced from natural ores. The low-purity ore extracted from a mine is called crude ore. Before shipment, it is normally processed into concentrates by processes at the mine site which increase the purity of the object metal. When concentrates shipped from a resource-producing country arrive in Japan, a refiner produces a product of the specified purity by treating the concentrate in a furnace to extract and separate the object metal.

In urban mines, used products correspond to crude ore. However, in comparison with the process described above, in the present urban mines, there is a strong tendency to export used products as-is and have extraction and separation of the object metals and treatment of the unnecessary plastic waste performed overseas. Thus, a process for producing concentrates, which is a basic condition in the case of natural ores, is also indispensable in developing urban mines. Because the downstream refining technology is one of Japan’s great technical strengths, if these used products are once processed into enriched ore concentrates, in other words, “urban ores,” it is possible to produce recycled resources by performing various processes in Japan, utilizing this country’s outstanding refining technologies. The key point in Dr. Halada’s proposal for urban ores is to increase the current “recovery → extraction” process by one step, to “recovery → enrichment → extraction.” It is necessary to build new urban ore plants for enrichment in this route (**Fig. 4**). If these plants can be sited near major metropolitan areas, where used products are recovered in large quantities, and the products can be processed into urban ores, these resources can be transported to extraction plants in various areas for recycling back into metals.

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* The objective of RtoS is planned recycling to secure a certain amount of resources of a specified quality using a system for collecting used electronic equipment and storing the separated metal resources as artificial ore deposits. This was proposed by Prof. Takashi Nakamura of the Institute of Multidisciplinary Research for Advanced Materials, Tohoku University, and is currently being carried out on an experimental basis by Odate City in Akita Prefecture and elsewhere.

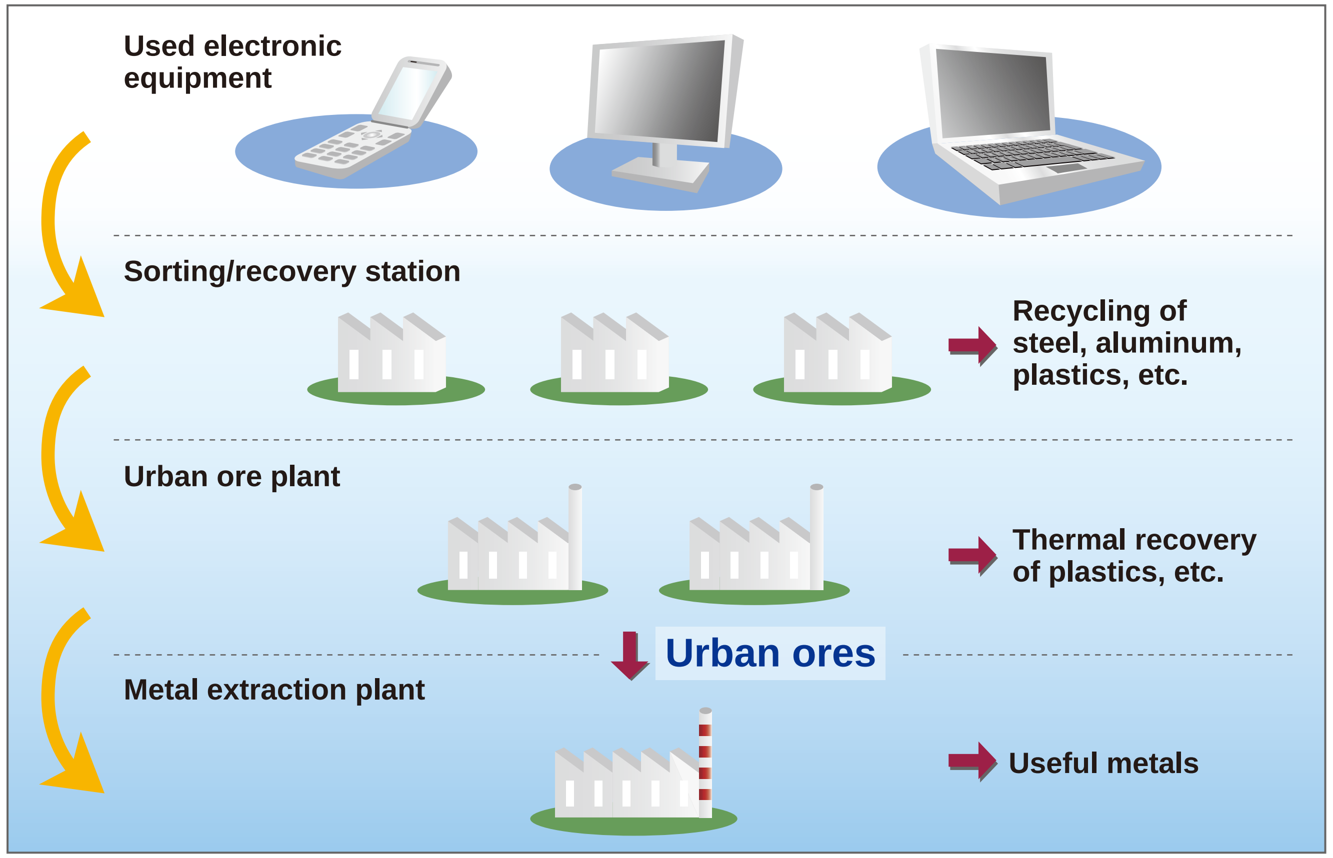


Fig.4 Chain of recovery → urban ore → extraction of metals from used products

Dr. Halada notes, “The conventional metal recycling technology used to date is a process which is suitable for steel, aluminum, and other metals that can be recovered in large quantity and simply melted as-is. However, in recovering precious metals which are used in small quantities, beginning with the rare metals, a new concept and technology suited to their manner of use is necessary.” In addition to this, one point which Dr. Halada stresses is the increased values of enriched urban ores. At present, Japan exports used products, which correspond to crude ore. Because urban ores correspond to ore concentrates, export in this form would increase their value as a product. It is also likely that “scrap containing rare metals” produced from used personal computers would find more desirable purchasers as an international product.

## Creating a metal recycling chain

In fact, the ultimate solution exists in the sustainable use of resources and energy. Depletion of energy resources ceases to be a problem if solar energy is used exclusively. Similarly, because virtually infinite quantities of aluminum, silicon, calcium, iron, and oxygen exist on earth, there is also no need to fear exhaustion of these resources.

From this viewpoint, it can be said that the ultimate resource strategy is to realize the required functions using only this limited range of elements. The development of technologies which substitute rare metals and other scarce resources with these abundant elements is a crucial challenge for the future. However, simultaneously with this, it is also important to create technologies which enable the fullest possible use of the metals that have already been extracted and used until this ultimate solution can be achieved.

The development of enrichment technologies, which is the key to producing urban ores, is one topic for the future. Among technologies which are now under development, several have this potential. One example is a pinpoint separation technology being developed by NIMS. This is a technology which can be used when removing chips from boards and in similar applications. If a liquid of a substance that promotes delamination, which was developed independently by NIMS, is coated on soldered parts, the solder can be removed without applying heat. The accumulation of technical innovations of this type will make it possible to promote sorting and production of urban ores.

Simultaneously with the development of technologies, the creation of a circulating chain of metal reuse is also important. As Dr. Halada says, “If we fail to create a long-term strategy, thinking that some company that wants to make a profit will take care of the problem if we leave it to take care of itself, sustainable use of resources will definitely not be realized.” What Dr. Halada is warning about here is the easy idea that reuse of metals will progress if simply left to short-term economic principles. Dr. Halada has presented a policy which embodies a dream, while looking ahead to the long-term future, and intends to make every effort to realize this with the understanding of consumers and businesses, the national government, and municipalities.

# Materials Database Station

The Materials Database Station disseminates the world's largest materials database over the internet. (http://mits.nims.go.jp ; see **figure**). The name of the NIMS Materials Database is MatNavi. MatNavi consists of online versions of the datasheets on creep, fatigue, corrosion, and space use materials strength published by the Materials Data Sheet Station (PDF), and useful numerical data on polymers, basic data on crystal structures, diffusion data, and data on pressure vessel materials collected from the published scientific literature and incorporated in databases, and an application system for these (see next page). MatNavi not only supports the foundations of materials science education in basic knowledge on crystals, phase diagrams, but also provides support for the development of new materials for building a safe and secure society and the selection and use of the optimum materials to researchers and engineers in private companies. In addition, MatNavi is useful as a tool for prediction of material properties, comparison of material properties, and identification of materials (dictionary function).

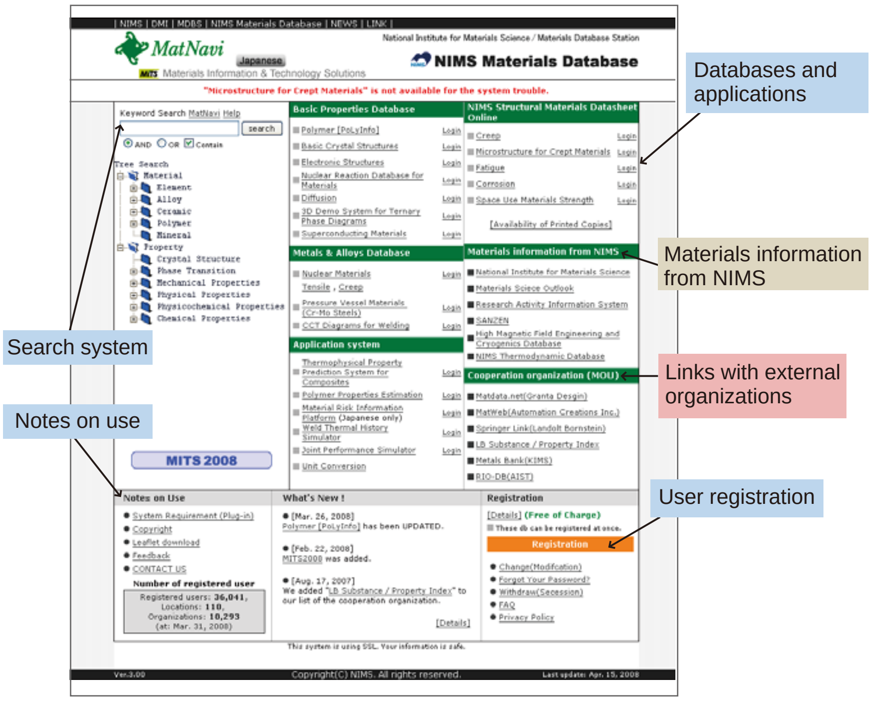
With the motto, "the value of a database is in its use," our aim is to develop a "user-friendly database system," we developed a horizontal search system that makes possible to search the necessary materials information for users with the minimal possible transaction. This system enables horizontal searches over eight types databases by material or by property using categories and keywords (upper left in **figure**).

In databases, comprehensiveness of the data in the field is generally required. However, due to budget and staff restrictions, there are limits on the reliable data that can be collected by one organization or institution. Therefore, in addition to the materials databases and applications developed in research projects at NIMS (nuclear power materials, phase diagrams), other materials databases in Japan and internationally are linked with MatNavi in cooperation with the institutions providing those databases. This makes it possible to access databases in Korea, Europe, and the United States from MatNavi.

As of the end of January 2008, the NIMS Materials Database had a total of 34,722 registered users (Japan: 25,543, other countries: 9,179) from 10,293 organizations in 110 countries and was being accessed more than 1 million times a month. Approximately 2,000 persons login and use the database an average of 3-4 times each month.

In the future, the Materials Database Station will continue to expand the data in MatNavi, and will implement a user-friendly system for disseminating useful information for material developers and users.

Fig.



| NIMS | DMI | MDBS | NIMS Materials Database | NEWS | LINK |

MatNavi Japanese
MITS Materials Information & Technology Solutions
National Institute for Materials Science / Materials Database Station
NIMS Materials Database

"Microstructure for Crept Materials" is not available for the system trouble.

Keyword Search MatNavi Help
search
● AND ○ OR ☑ Contain

Tree Search
- Material
  - Element
  - Alloy
  - Ceramic
  - Polymer
  - Mineral
- Property
  - Crystal Structure
  - Phase Transition
  - Mechanical Properties
  - Physical Properties
  - Physicochemical Properties
  - Chemical Properties

MITS 2008

Basic Properties Database
- Polymer [PoLyInfo] Login
- Basic Crystal Structures Login
- Electronic Structures Login
- Nuclear Reaction Database for Materials Login
- Diffusion Login
- 3D Demo System for Ternary Phase Diagrams Login
- Superconducting Materials Login

Metals & Alloys Database
- Nuclear Materials Login
  Tensile , Creep
- Pressure Vessel Materials (Cr-Mo Steels) Login
- CCT Diagrams for Welding Login

Application system
- Thermophysical Property Prediction System for Composites Login
- Polymer Properties Estimation Login
- Material Risk Information Platform (Japanese only) Login
- Weld Thermal History Simulator Login
- Joint Performance Simulator Login
- Unit Conversion

NIMS Structural Materials Datasheet Online
- Creep Login
- Microstructure for Crept Materials Login
- Fatigue Login
- Corrosion Login
- Space Use Materials Strength Login

[Availability of Printed Copies]

Materials information from NIMS
- National Institute for Materials Science
- Materials Sciece Outlook
- Research Activity Information System
- SANZEN
- High Magnetic Field Engineering and Cryogenics Database
- NIMS Thermodynamic Database

Cooperation organization (MOU)
- Matdata.net(Granta Desgin)
- MatWeb(Automation Creations Inc.)
- Springer Link(Landolt Bornstein)
- LB Substance / Property Index
- Metals Bank(KIMS)
- RIO-DB(AIST)

Notes on Use
- System Requirement (Plug-in)
- Copyright
- Leaflet download
- Feedback
- CONTACT US

Number of registered user
Registered users: 36,041,
Locations: 110,
Organizations: 10,293
(at: Mar. 31, 2008)

What's New !
- [Mar. 26, 2008]
  Polymer [PoLyInfo] has been UPDATED.
- [Feb. 22, 2008]
  MITS2008 was added.
- [Aug. 17, 2007]
  We added "LB Substance / Property Index" to our list of the cooperation organization.

[Details]

Registration
[Details] (Free of Charge)
These db can be registered at once.
Registration
- Change(Modifcation)
- Forgot Your Password?
- Withdraw(Secession)
- FAQ
- Privacy Policy

This system is using SSL. Your information is safe.

Ver.3.00 Copyright(C) NIMS. All rights reserved. Last update: Apr. 15, 2008

Top page of the NIMS Materials Database
(http://mits.nims.go.jp/db_top_eng.htm)

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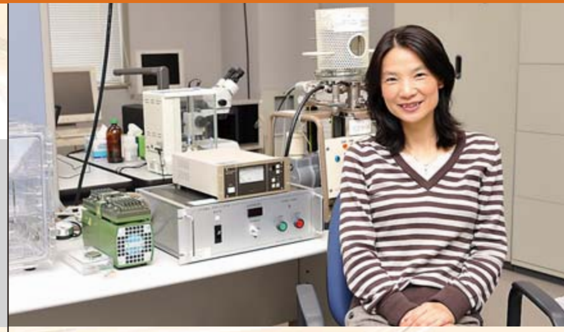
# Predicting the Properties of New Materials Using the Materials Database



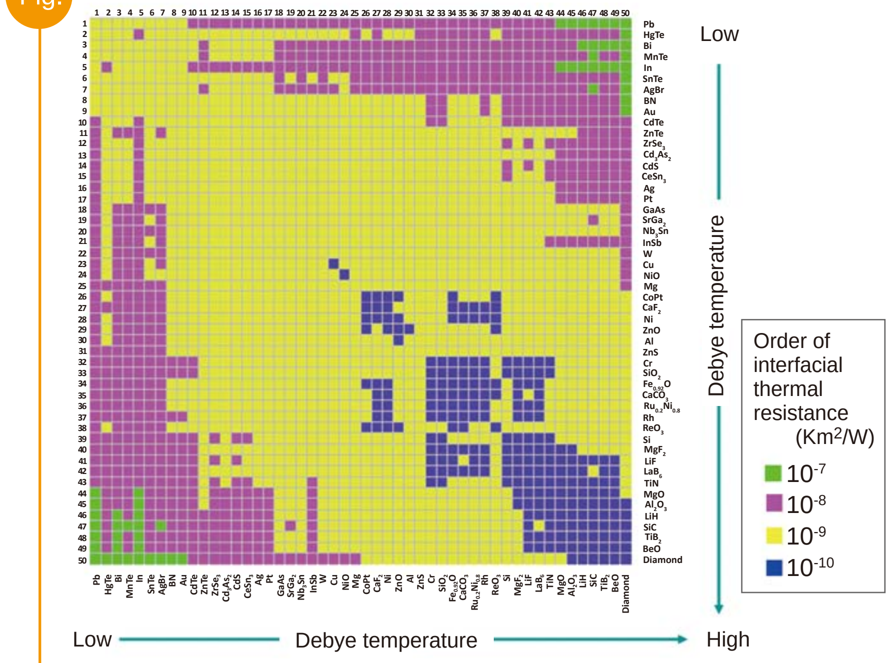
Yibin Xu

The properties of composite materials and other material systems comprising multiple materials are strongly dependent on the individual properties of their component materials. Therefore, it is possible to predict the properties of new materials systems using property data on each component material. In turn, the knowledge obtained in this process becomes an important guideline for the development of new materials. We developed a property prediction tool for new materials based on existing material data and verified its validity by comparison with actual experimental data.

The Composite Materials Thermophysical Property Prediction System (CompoTherm; http://composite.nims.go.jp/ ) is an online simulation tool for predicting the density, specific heat, thermal conductivity, and thermal diffusivity of composite materials. This tool includes two simulation functions, one being an analytical method which enables rapid calculation based on simple modeling, and the other, a finite element method function which is capable of handling more complex material structures (for example, composite materials including 3 or more component materials and cases in which anisotropy exists in the component materials). CompoTherm contains thermal property data on approximately 1000 materials, including polymers, metals, ceramics, etc., which can be used when selecting materials or inputting calculation conditions. The thermal conductivities of Al alloy composite materials strengthened with SiC whiskers and particles, yttria-stabilized zirconia (YSZ) thermal shield coatings, and other materials were predicted using this tool, confirming that the deviation between the predicted values and experimental values is within 10%.

Another example of prediction of properties using a materials database is prediction of interfacial thermal resistance. In ordinary solid materials, heat is transmitted by lattice vibration (phonons) and electron motion. However, in cases where an interface between two different materials exists, the composite displays thermal resistance due to the reflection or scattering of the phonons and electrons at the interface. Because thermal resistance has a large effect on thermal conductivity and temperature distribution in composite materials and electronic devices, and furthermore, affects heat radiation properties, thermal stress, thermal shock resistance, energy transport/conversion rates, and other properties, this is indispensable data for material development and the design of electronic devices. However, actual measurement of interfacial thermal resistance is extremely difficult, and only a very limited number of data have been reported to date. Therefore, based on an interfacial phonon reflection and scattering model, we developed a program for predicting interfacial thermal resistance using the crystal structure and lattice hardness of the materials on the two sides of the interface and their Debye temperature, Young's modulus, and the speed of sound, which reflect the speed of phonon motion, and predicted the interfacial thermal resistances of approximately 1300 materials using this program (see **figure**). We also measured the thermal resistance at the interfaces of Au/$SiO_2$ and Au/sapphire and confirmed agreement with the predicted values.

Fig.



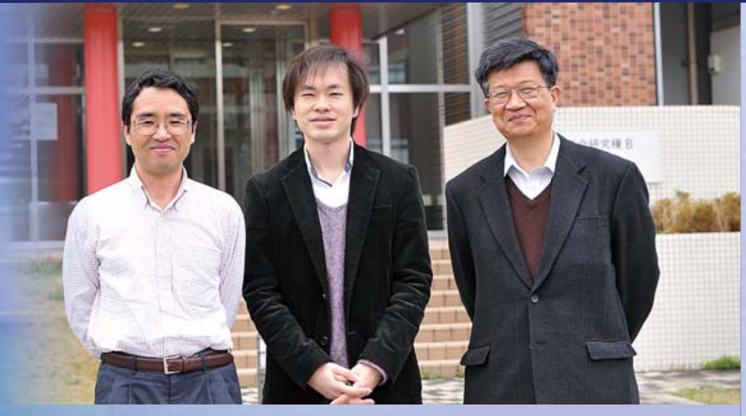
Interfacial thermal resistance map calculated based on a model of interfacial phonon scattering. The x-axis and y-axis show the materials on the two sides of the interface. The colors in the map show the order of interfacial thermal resistance (see box at right).

# Generation of Single Photons from Impurity Atoms in Semiconductor

## - Demonstration of Emission of Single Photons with Identical Energy -

Nano Device Characterization Group,
Advanced Electronic Materials Center, NIMS

Graduate School of Pure and Applied Science,
University of Tsukuba†



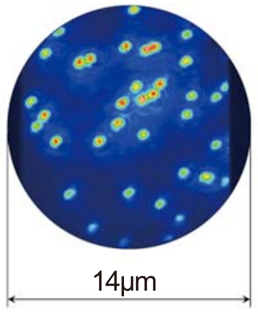
Yoshiki Sakuma, Michio Ikezawa†, Yasuaki Masumoto†

Due to the popularization of computers and the internet, our society has become extremely convenient and affluent. However, with much higher computer processing speed required and information networks also becoming more complex, technological limits of the conventional information processing and telecommunications are becoming apparent. To solve this problem, recent years have seen intense research and development in the new field called "quantum information and communication technologies." This includes the technologies referred to as quantum computing and quantum cryptography. These are ultimate technologies which use the physical laws that govern the worlds of atoms and light, namely, quantum mechanics and quantum optics. If these technologies can be developed, it will be possible to create computers which are far faster than conventional ones and to build secure communication networks which are absolutely free of eavesdropping. Methods that utilize photons are the leading candidates for realizing quantum information and communication technologies. The light that we see is made up of an extremely large number of particles called photons. In quantum information and communication technologies using light, or photons, telecommunication is performed by assigning information to these individual photon particles, and computing is realized by employing the interference between multiple photons. Therefore, it is essential to develop single photon emitting devices which are capable of generating photons one by one, like raindrops.

We are engaged in research on semiconductor materials and devices which efficiently generate single photons. In generating a single photon at will, a semiconductor nanostructure of extremely small size is necessary, in which the electrical and optical properties are just like those in single atoms or molecules. Recently, we have developed a special technique called δ-doping or sheet doping, in which nitrogen impurity atoms of a very low concentration can be accurately incorporated within a two-dimensional layer of a gallium phosphide (GaP) crystal, and have confirmed for the first time in the world that single photons are generated when electrons and holes successively recombine and are extinguished at the energy level formed by nitrogen atom pairs (pairs termed $NN_4$). **Figure 1** shows the result of microscopic observation of a sample where single photons are emitted from the surface. Bright spots can be seen at various locations in the figure. At these points, single photons with the same wavelength, in other words, identical energy, are being generated. Although dilute nitrogen impurities are introduced randomly in a layer of the phosphorus atoms, two nitrogen atoms are arrayed in extremely close proximity with a certain probability, resulting in the formation of an N-N pair, as shown in **Fig. 2**. We discovered that a phenomenon of single photon generation occurs from these pairs. The outstanding feature of this method is that the energies of all of the single photons generated from the different locations in the sample are identical, which cannot be realized with other methods.

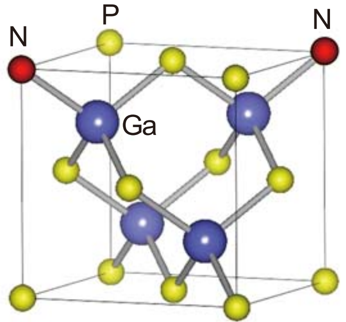
In the next step, we plan to further develop this material technology and carry out basic experiments on quantum information and communication devices.

Fig.1



Microscopic observation of photoluminescence image from nitrogen atom pairs.
At each bright spot, single photons are generated from electrons/holes bound to N atom pairs ($NN_4$), which occupy the 4th neighboring atomic positions of phosphorus (P) sites in GaP, The wavelength of the single photons is 541.5 nm, corresponding to a green color.

Fig.2



Arrangement of one observed nitrogen atom pair ($NN_4$) at the surface of a GaP crystal.
The two N atoms are located at P lattice sites and are separated by a distance of 0.77 nm. This type of pair creates a spatially-localized energy level, which attracts the electrons and holes, and light is emitted. Actually, the N atom pair is embedded in the GaP crystal.

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# Success in Second Harmonic Generation using Ferroelectric Fluoride Single Crystals

Frequency Conversion Group,
Optronic Materials Center, NIMS

Hitachi Chemical Co., Ltd.†

Nachimuthu Senguttuvan†, Masahiro Aoshima†, Keiji Sumiya†
Group Leader
Kiyoshi Shimamura, Encarnación G. Víllora, Andrey Medvedev

Fluoride single crystals are used as lenses in cameras and semiconductor processing devices, as coating materials, as well as in other applications. The most characteristic property of these crystals is their high optical transmittance from the infrared, through the visible, to the vacuum ultraviolet region (VUV, e.g. wavelengths close to 100nm). Taking advantage of the high transparency of fluoride single crystals, our research activities aim at realizing a completely new generation of all-solid-state laser sources emitting in the UV/VUV, in particular at 193nm, as a substitute for the currently used ArF excimer lasers. The applications of the latter are proceeding to the micro-processing of semiconductor integrated circuits, medicine, and micromachining. Our objective is the fabrication of a compact UV/VUV laser source, which is non-toxic and has high reliability and long life.

Second-, third-, and fourth-harmonic generation (SHG*, THG, FHG) are used to fabricate all-solid-state laser sources in the visible and near UV wavelength region. For this purpose, birefringent-phase-matching (BPM) in nonlinear oxide crystals is utilized. In general, fluoride crystals have small birefringence, so BPM is difficult or even impossible. An alternative technique to the BPM-SHG is the quasi-phase-matching (QPM**) technique, which, in contrast to the BPM, is non-critical at any wavelength.

We focused on $BaMgF_4$ (BMF), since this material shows high transparency from the infrared to the VUV wavelength region. Single crystals as large as 2 inches in diameter were grown by the Czochralski technique, as well as by the Bridgman technique (**Fig. 1**), the latter in joint work with Hitachi Chemical Co., Ltd. We have demonstrated the almost ideal ferroelectric hysteresis of this crystal, determined the optical properties of this crystal (refractive indices, etc.), and calculated the grating period as a function of the pumping wavelength.

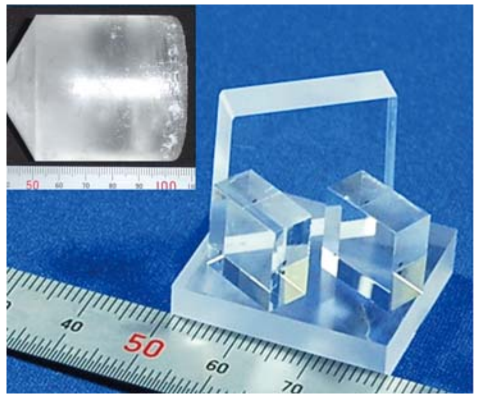
In order to demonstrate for the first time SHG by the QPM-technique using a fluoride crystal, periodically poled structures of different periods were prepared by photolithographical patterning and subsequent polar-axis reversal applying an electric field. We succeeded in doubling the 1064nm emission of a pulsed Nd:YAG laser, i.e. visible light (green, 532 nm) was generated, as seen in **Fig. 2**. Beyond this, a mode-locked Ti:sapphire laser was used as a laser source for frequency doubling in the near UV wavelength region, namely at 415 and 406 nm. By further reducing the grating period of the periodical structure, we aim in the future to obtain emission at 193nm, which cannot be achieved with commercially available oxide crystals.

This work is partially supported by the Industrial Technology Research Grant Program of Japan's New Energy and Industrial Technology Development Organization (NEDO). This work has received the Excellence Award of the Japan Electric Materials Society and the Prize for Excellent Original Paper of the Materials Science Society of Japan.

* Second Harmonic Generation (SHG)
SHG is a nonlinear optical process, in which photons interacting with a nonlinear crystal are effectively "combined" to form new photons with twice the energy, and therefore twice the frequency and half the wavelength, of the initial photons. Traditionally, the birefringent-phase-matching (BPM) technique is used. In this case, a nonlinear crystal is oriented so that the pump and the frequency doubled waves are in phase, i.e. the refractive index at both wavelengths is the same.

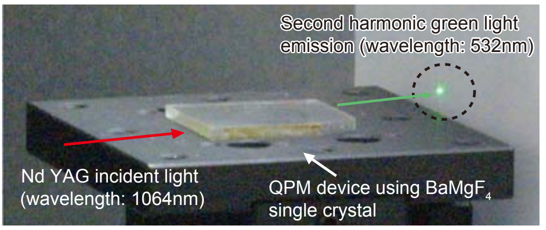
** Quasi-Phase Matching (QPM)
In the case of SHG by this technique, the pump and frequency doubled waves are not in phase. A positive "addition" of the second harmonic waves generated at different parts of the crystal is assured by the periodical reversal of the polar-axis of the ferroelectric crystal. Often it is possible to utilize a larger nonlinear coefficient than is accessible with BPM, and as a result, very efficient devices can be produced.

Fig.1



$BaMgF_4$ single crystals (upper left: 2 inch crystal grown by the Bridgman technique)

Fig.2



Second harmonic generation (532 nm) by the QPM–technique using a periodically poled $BaMgF_4$

# SPECIAL Interview

## Pioneering Research Opening the Road to Practical Application of Carbon Nanotubes

Behind the success of the creative research which realized mass production of multi-walled carbon nanotubes for the first time in the world, there are a number of extremely interesting episodes. Prof. Morinobu Endo of Shinshu University talks about the importance of efforts with an attitude free of preconception that says “See what’s there, not what you want to see.” We heard from Dr. Endo about his experience of serendipity, which gives the true feeling that “Fortune favors the prepared mind.” (L. Pasteur).

**Prof. Morinobu Endo**
Faculty of Engineering, Shinshu University
Director, Shinshu University Institute
of Carbon Science & Technology

### What led you to begin research on carbon fibers?

At the beginning of 1970, when I was still in the Masters course at university, I belonged to a laboratory studying on semiconductors. At the time, semiconductors research were the most popular in electric and electronics field, and everybody in the lab was choosing semiconductor research. Because I wanted to become a world class researcher, even if it meant working in a minor field, I had the ambition to be a “big carp in a little pond, rather than a little fish in a big pond,” so I chose the subject on carbon fibers.

### The episode in which you used sandpaper in an experiment is famous, isn’t it?

We had been forming carbon fibers by thermally decomposing hydrocarbons such as benzene, but these were days of struggle, and things weren’t going very well. In an experiment, I carefully washed a substrate that was covered with soot and carbon film using distilled water, and placed the substrate in an electric furnace. When heated in the air, it returned to a pure white ceramic substrate. The next day, when I set the substrate in the electric furnace and repeated the experiment, I took the shortcut of removing the soot and carbon using sandpaper or emery paper with brown color in order to save time. When I did this, extremely dense carbon fibers with a length of 1-2 cm were grown on the substrate entirely. However, when I changed the black-colored sandpaper, no carbon fibers were grown at all. I discovered the reason 2 years later, by high resolution electron microscopy that I was doing as a Ph. D foreign student in Madame A. Oberlin’s laboratory in France. The carbon tubes which grew at first were the result of nano-sized iron particles, in other words, an extremely small catalyst. The main component of the brown sandpaper that I’d used first consisted of iron, but the black-colored sandpaper I used after that was silicon carbide.

### That was certainly serendipity.

Applying this discovery, I published a “seeding method” that involves spreading ultra-fine particles of iron intentionally on a substrate, and private companies began experiments aiming at mass production. At the time, carbon fiber was highlighted in the field of space exploration, but because this catalytic vapor deposition method was more expensive than other mass production methods such as PAN-based fibers, a more economical and large-scalable production method was required.

One day, I happened to read in a newspaper article in the train to Tokyo that when a person with influenza sneezes, the virus is scattered as far as 15m. Because the size of the influenza virus is on the order of 100nm, and the catalytic particles that I used in experiments were several to 10nm in size, I had the inspiration that it might be possible to form a large quantity of carbon fiber if the catalytic particles could be floated such as floating dust in sunlight. That same evening, I set up an electric furnace in the laboratory and conducted an experiment in which the catalyst was floating by introducing the hydrocarbon and catalyst from the top. When I did this, so-called multi-walled carbon nanotubes were formed at a single stroke. That was also serendipity.

This production method was patented in 1987 as the “floating catalyst method.” Mass production began in 1988, and since that time, this “Endo method” has been used in mass production of multi-walled carbon nanotubes. In the future, if industry wants to increase its current productivity by 2 or 3 times, it can certainly build 2 or 3 new plants using this technology, but I would want to take on the challenge of developing an innovative method that dramatically increases productivity as 10 to 100 times, expecting another, different serendipity.

### In what applications are multi-walled carbon nanotubes used?

They’re used as the effective additive for the anode of lithium ion battery. Recently, they have also been used as an additive for the cathode. Production of lithium ion battery exceeds 1 billion units worldwide, and multi-walled carbon nanotubes are used as key component in many of these. They are now becoming a key material of lithium ion batteries for next-generation automobiles as plug-in electric vehicles, from environmental, energy and natural resource issues. This material has also shown growth in the field of medical technology. When used in composite materials and other open applications, not in a closed application like batteries, a scientific, rational toxicity assessment is indispensable, and related research has been developing widely, with the concept of "Safety for Success". Development of applications to establish a unique position in key fields is underway, while seeking broad-based social agreement based on an understanding of the risks and benefits,

### What is important for researchers?

I treat the words of my own teacher, Prof. Tsuneo Koyama, with great importance. He said, “Researchers must not take their minds off their research topics.” If you keep your research topic in the back of your mind, even when you’re doing something completely different, you’ll have the chance to skillfully pick up information from other fields and can link it to your own research, and this also contributes to everyday inspiration. Of course, for researchers, research by desktop thinking is important, but how much you move your body is one indicator for judging capabilities. Particularly when the actual situation isn’t visible, things become clear while you’re acting.

### What is your dream?

The basic aim of science is to satisfy intellectual requirements, but at the same time, the world wants science to be useful for humankind and society. From this viewpoint, I would serve as a strong bridge in developing science into engineering technologies.

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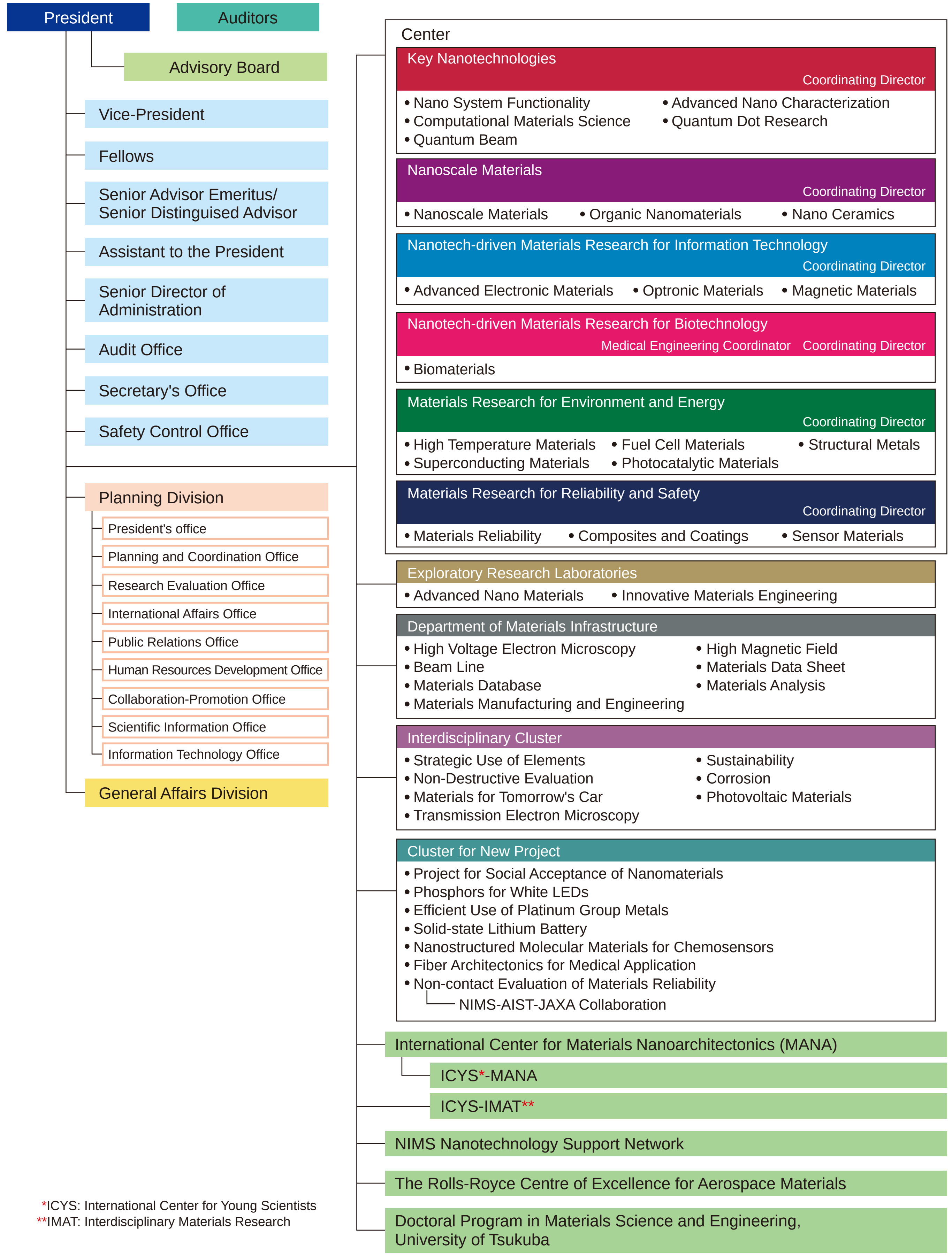
# NIMS NEWS

## New Organization



- President
- Auditors
- Advisory Board
- Vice-President
- Fellows
- Senior Advisor Emeritus/ Senior Distinguised Advisor
- Assistant to the President
- Senior Director of Administration
- Audit Office
- Secretary's Office
- Safety Control Office
- Planning Division
  - President's office
  - Planning and Coordination Office
  - Research Evaluation Office
  - International Affairs Office
  - Public Relations Office
  - Human Resources Development Office
  - Collaboration-Promotion Office
  - Scientific Information Office
  - Information Technology Office
- General Affairs Division
- Center
  - Key Nanotechnologies — Coordinating Director
    - Nano System Functionality
    - Computational Materials Science
    - Quantum Beam
    - Advanced Nano Characterization
    - Quantum Dot Research
  - Nanoscale Materials — Coordinating Director
    - Nanoscale Materials
    - Organic Nanomaterials
    - Nano Ceramics
  - Nanotech-driven Materials Research for Information Technology — Coordinating Director
    - Advanced Electronic Materials
    - Optronic Materials
    - Magnetic Materials
  - Nanotech-driven Materials Research for Biotechnology — Medical Engineering Coordinator, Coordinating Director
    - Biomaterials
  - Materials Research for Environment and Energy — Coordinating Director
    - High Temperature Materials
    - Superconducting Materials
    - Fuel Cell Materials
    - Photocatalytic Materials
    - Structural Metals
  - Materials Research for Reliability and Safety — Coordinating Director
    - Materials Reliability
    - Composites and Coatings
    - Sensor Materials
- Exploratory Research Laboratories
  - Advanced Nano Materials
  - Innovative Materials Engineering
- Department of Materials Infrastructure
  - High Voltage Electron Microscopy
  - Beam Line
  - Materials Database
  - Materials Manufacturing and Engineering
  - High Magnetic Field
  - Materials Data Sheet
  - Materials Analysis
- Interdisciplinary Cluster
  - Strategic Use of Elements
  - Non-Destructive Evaluation
  - Materials for Tomorrow's Car
  - Transmission Electron Microscopy
  - Sustainability
  - Corrosion
  - Photovoltaic Materials
- Cluster for New Project
  - Project for Social Acceptance of Nanomaterials
  - Phosphors for White LEDs
  - Efficient Use of Platinum Group Metals
  - Solid-state Lithium Battery
  - Nanostructured Molecular Materials for Chemosensors
  - Fiber Architectonics for Medical Application
  - Non-contact Evaluation of Materials Reliability
    - NIMS-AIST-JAXA Collaboration
- International Center for Materials Nanoarchitectonics (MANA)
  - ICYS*-MANA
- ICYS-IMAT**
- NIMS Nanotechnology Support Network
- The Rolls-Royce Centre of Excellence for Aerospace Materials
- Doctoral Program in Materials Science and Engineering, University of Tsukuba

*ICYS: International Center for Young Scientists
**IMAT: Interdisciplinary Materials Research

# NIMS NEWS

## New Vice President

### Dr. Yukichi Umakoshi

Completed Master Course of The Graduate School of Engineering, Osaka University (1969). Subsequently worked as a Research Associate at Osaka University, and overseas as a Visiting Scientist at the Max-Planck Institute, Germany (supported by Alexsander von Humboldt Foundation), and Visiting Scientist at the University of Pennsylvania in the US (Long-term Overseas Researcher, Ministry of Education). Returned to Osaka University, where he served as Associate Professor and Professor, member of the Board of Trustees, Dean of the School of Engineering/Graduate School of Engineering, and Vice President. Appointed Vice President of NIMS in April 2008. Dr. Umakoshi holds a Doctorate in Engineering from the same University and is a member of the Science Council of Japan.

### Comments on Appointment as Vice President:

At Osaka University, I was involved in research in cooperation with researchers in a wide range of fields, from elucidation of the mechanism of deformation/destruction of heat resistant intermetallic compounds, the behavior of dislocations in crystals and improvement of mechanical properties by their control, nanocomposite structure control by electron beam induced phase transformation, and evaluation of the reliability of materials utilizing magnetic properties, to diagnosis of bone regeneration and bone disease by engineering techniques.

NIMS is one of the world's top level research institutes in the field of materials, in fact as well as name, as evidenced by the recent selection of its MANA project (International Center for Materials Nanoarchitectonics) as part of the Japanese government's World Premier International Research Center Initiative (WPI). Although there are differences in the organizations of a university and an Independent Administrative Institution like NIMS, they both share a commitment to materials technology and materials research for society and for people. From this viewpoint, I hope to take advantage of my experience in academia up to now to provide fresh ideas that will contribute to the further development of NIMS.

## New Fellow

### Dr. Sukekatsu Ushioda

Graduated from Hibiya High School in Tokyo (1960). Received his A.B. from Dartmouth College (1964), and M.S. (1965) and Ph.D. (1969) from the University of Pennsylvania. Served as Assistant Professor in the Department of Physics, University of California, Irvine (1969), and Associate Professor (1974) and Professor (1978) at the same university. Appointed Professor, Research Institute of Electrical Communication, Tohoku University (1985), and President, Japan Advanced Institute of Science and Technology (2004). Named NIMS Fellow in 2008.

### Comments on Appointment as NIMS Fellow:

I recently became a NIMS Fellow, and was appointed Managing Director of the ICYS/IMAT and Director-General of the NIMS Nanotechnology Support Network. I believe that my main jobs in these posts are to assist in creating an environment in which all researchers can do their work more easily, and to vigorously promote the activities of the Nanotechnology Network at the nationwide level. Using the experience from my time as a Professor at the University of California, I also plan to devote my full efforts to promoting internationalization at NIMS.

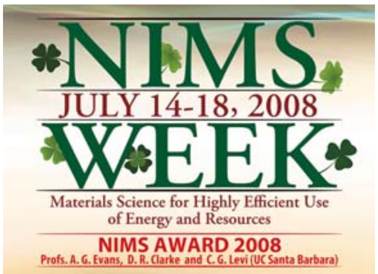
## Announcement of NIMS Week 2008

NIMS Week 2008 will be held at the Epochal Tsukuba International Congress Center (Tsukuba City) over a 5-day period from July 14 to July 18. This year's event will feature the unified theme of "Materials Science for Highly Efficiency Use of Energy and Resources," and will have a full program of activities, including the Award Ceremony for the NIMS Award and special lectures introducing efforts to solve environmental and energy problems by NIMS researchers on the opening day, and nine International Symposia planned by young scientists at NIMS and seven satellite symposia on the second and following days.

The NIMS Award for 2008 will be presented to Prof. A. Evans, Prof. D. Clarke, and Prof. C. Levi of the University of California, Santa Barbara (UCSB) for their outstanding achievements in systematic research on heat shield coating systems. These research achievements were highly evaluated for their contribution to creating a materials infrastructure enabling substantial reduction of $CO_2$ emissions by remarkably improving the thermal efficiency of internal combustion engines, for example by enabling combustion at temperatures exceeding 1700°C in jet engines.

An exhibition about joint use of the large-scale research facilities for joint research at NIMS and some others by cooperative companies will also be held from July 14 to July 16.

Please visit the NIMS website for more details at http://www.nims.go.jp/nimsconf08, on-line registrations will be closed on June 30, 2008.



Date: July 14-18, 2008
Venue: Epochal Tsukuba
Registration fee: Free
On-line registration by June 30
**www.nims.go.jp/nimsconf08**

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