Integration for Innovation

National Institute of
Advanced Industrial Science
and Technology
AIST

From AIST to the Innovative World

Supporting, changing, and creating the future of life and society

2013 | AIST Stories No. 1

Humidity-regulating tiles: Spotlight on an eco-construction material

Potential as a construction material that regulates humidity as if it were breathing

Spintronics technology
IT Appliances with Zero Standby Power: Is the Dream Close to Reality?

The leading organization in Japan for metrological technology

Correct metrology is quite common nowadays
The people and technology behind this

Carbon fiber development

From fishing rods to aircraft
Carbon fiber development process

On the publication of “From AIST to the Innovative World”

The word “research” may bring to mind the image of a researcher in a white coat shaking a test tube or a physicist solving a challenging numerical formula. Researchers like those do exist in AIST but if their efforts ended up as mere “research,” the mission of AIST would not be achieved. AIST practices activities that link “Technology to Society”. In other words, we carry out full research whereby the knowledge and findings obtained through fundamental research and practical research are transferred to corporations and reach as far as familiar community life.

As you will see when you read this edition of From AIST to the Innovative World, it is not merely a collection of academic papers. How are the research findings disseminated by AIST linked to society? What discoveries and challenges were there in the R&D process? And what potential do we think is hidden in these research findings? This publication attempts to convey these marvelous AIST findings by getting researchers involved in development including those currently engaged in R&D to talk directly about them.

AIST’s research findings are not only related to science and technology in the distant future. Findings that are already utilized in familiar places, and those for which technology transfer will become possible with a little more effort, also exist. Through this publication, we hope that readers who are not specialist researchers will become interested in AIST, and also feel close to AIST. Moreover, taking this opportunity, we hope that you will come and take a look at our research facilities and thereby form a real bond with AIST.

Ryoji Chubachi
President
National Institute of Advanced Industrial
Science and Technology (AIST)

What is AIST ?

The National Institute of Advanced Industrial Science and Technology (AIST) was established in 2001 as one of the Japan's largest public research institutions. The 15 national research institutes and the Weights and Measures Training Institute under the Ministry of Economy, Trade and Industry that had functioned to strengthen Japan's industrial competitiveness, secure resources, and as the pivot of weights and measures since the Meiji era were brought together as one, and the new entity was inaugurated as an independent administrative corporation.

AIST takes an integrated approach spanning fundamental research through practical research with the aim of "realizing a sustainable society." Currently, its primary two missions are "solving 21st Century issues" and "strengthening the open innovation hub function." AIST is also promoting "green technology to realize an abundant and environmentally friendly society" and "life technology to realize healthy and safe lifestyles."

Through the mission of "strengthening the open innovation hub function," AIST strives to directly link R&D with innovation, offer access to its research facilities to the industrial sector, and contribute to the acceleration of innovation by industry and academic societies. AIST is also promoting efforts to respond to the situation the world finds itself in today. For example, the Fukushima Renewable Energy Institute was established in fiscal 2013 to conduct international R&D and evaluation tests. In this manner, AIST is attaching importance to links with society.

In addition, R&D that forms the basis of everyday life is an important aspect of AIST's work. This includes measurement standards and calibration for scales, as well as underground resources surveys and geological surveys to investigate the state of the earth's surface.

At AIST, we carry out basic research based on science and technology through to full research that generates research findings for the industrial sector. Up to now and in the future, we have and will carry out our daily activities in order that research findings can be used in everyday life.

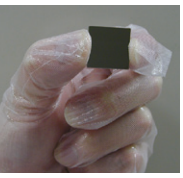
From AIST to the Innovative World

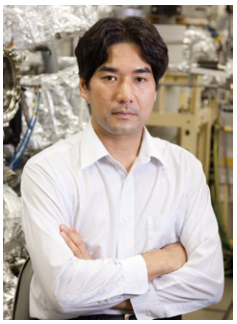
Supporting, changing, and creating the future of life and society

AIST Stories 2013 No.1

Contents

Leading the way AIST!





Spintronics: A fusion of electronics and magnetics

Shinji Yuasa

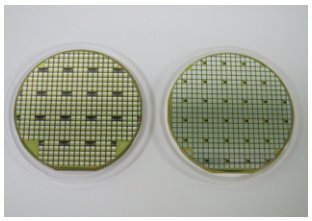
The quest for next-generation PCs equipped with large capacity/zero standby electricity non-volatile memory, equipped through “Spintronics.” Contributing to society through energy-conserving electronic devices.

Humidity-regulating tiles: Spotlight on an eco-construction material

Masaki Maeda

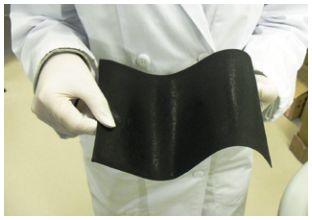
A humidity-regulating construction material that can maintain room humidity at a comfortable level without the need for power.
A gentle environment for households and their occupants; with reduced air-conditioner usage

Into the future AIST!



Semiconductor Silicon Carbide (SiC)

Modern society would break down without electricity.
Reducing waste and living smartly with SiC power devices that effectively utilize electricity.



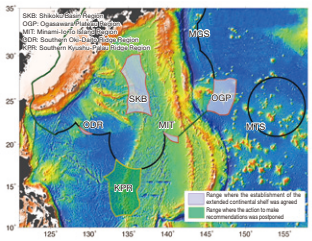
Development of commercial-scale production technology for single-wall carbon nanotubes

The same carbon as soot, but becoming a treasure via a slight change in form
Carbon nanotubes. A dream material of lightness and strength opens up the future.

Personal care robots supporting an ageing society

Helpful in reducing the burden of care giving, carrying out housework, and maintaining/promoting health
Personal care robots: from future technology to familiar technology.

AIST in present day living!



Extention of Japan's continental shelf

Investigating the geology of the seabed through the power of science;
A new "Japanese continental shelf" was discovered there.
Great expectations for Japan's natural resources.

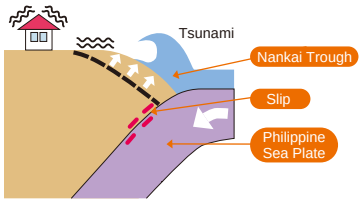
Environmental survey of the Fukushima Daiichi Nuclear Plant by high-access survey robot

Development of a high-access survey robot that can reliably return to its starting point.
Understanding the situation in Fukushima Daiichi Nuclear Power Station buildings; contributing to reactor decommissioning.

AIST supporting livelihoods!

The leading organization in Japan for metrological technology

Maintaining correct metrology; a foundation of safe, secure and reliable life.
Aiming for the same accuracy in measurement; anytime, anywhere, anybody.



Observation network for the Mega-earthquakes in the Nankai Trough

Accumulation and sharing of precise "slow slip" observation data.
Targeting prediction of mega-earthquakes to realize a safe society.

Another success at AIST!

Carbon fiber development

AIST developed manufacturing technology for carbon fiber 60 years ago.
The material blossomed greatly in Japanese industry and transformed into a material used globally.

Leading the way AIST!

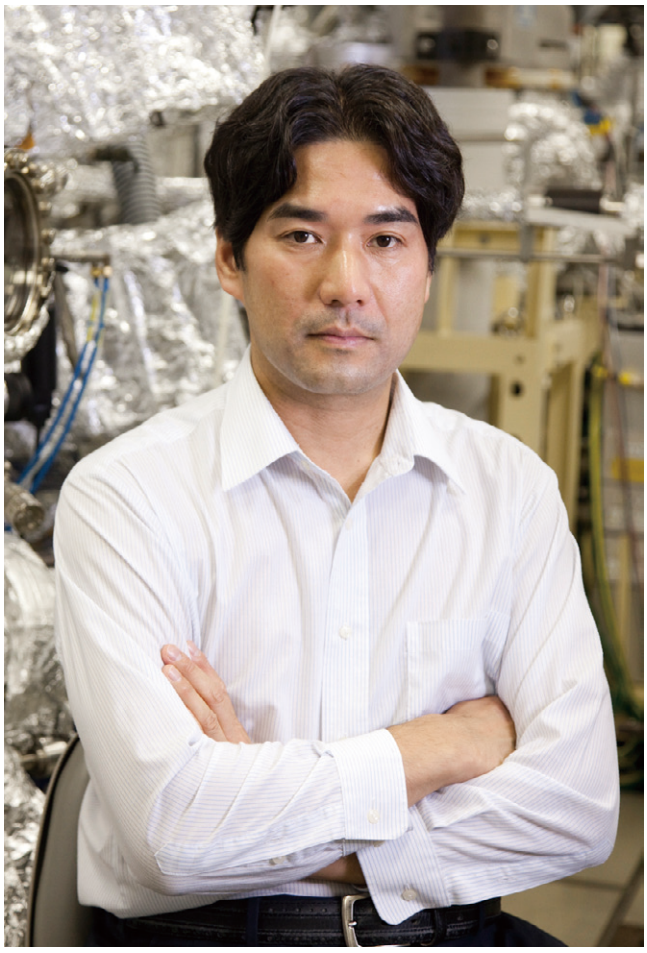
Spintronics: a fusion of electronics and magnetics

IT Appliances with Zero Standby Power: Is the Dream Close to Reality?

A technology that the whole world has been waiting for is being developed from AIST's fundamental research.

Our life and society will change in this way!

Hard disk drive (HDD) magnetic heads based on spintronics were commercialized in 2007 and have greatly contributed to the reduction in the power consumption of computer systems. If we can now use the technology to develop high performance non-volatile memory, we will be able to realize "normally-off computers" that have large memory capacities but do not require any standby power at all. This will further improve the energy efficiency of electronic appliances. The new technologies will contribute to the environmental conservation, and at the same time will reduce the inconvenience of powering and recharging devices.



Director, Spintronics Research Center
Shinji Yuasa

A market share of 100% for revolutionary HDD read heads

The technologies of electronics are the basis of electronic devices such as computers and mobile phones and are an essential part of our modern lifestyles, but they consume large amounts of electrical power. The use of computers and other IT devices will continue to grow in the future, which will naturally lead to increasing levels of power consumption. Suppressing power consumption by electronic devices, which contributes to the global problem of climate change, is a very important issue.

For example, in personal computers, servers and data centers, there are two major factors that increase power consumption. One is that the power consumption of data storage (mainly HDD) is large. The other is that memory devices are volatile, which means that any stored data is

lost when the power supply is turned off. Therefore, the power must always be kept turned on while the memory is being used, so large amounts of electricity are required.

Shinji Yuasa, Director of our Spintronics Research Center and a globally renowned leader in spintronics research, says: “As information processing is moved into the cloud, many people are storing their data over the Internet in data centers. As a result, the power consumption of data centers, which have large numbers of HDDs, is rapidly increasing. Data centers are said to account for 2% of all electricity consumption in developed countries. If we can reduce the power consumption of HDDs, we can achieve a very substantial energy saving.”

Electronics makes use only of the electric charge of electrons, whereas spintronics uses not only the electric charge but also the magnetic nature of electrons, which is called “spin”. Spintronics, which could also be referred to as “future electronics”, has a broad range of applications, increasing the capacities and reducing the power consumption of HDDs, and also contributing to improvements in non-volatile memory. Low-power HDD magnetic heads[*1] that take advantage of the effects of spintronics have already been commercialized and have achieved a global market share of 100%. That is, they are used in all of the HDDs being manufactured now!

Non-volatile memory that retains data even when the power is turned off (such as magnetoresistive random access memory (MRAM)) has been developed but there is still much room for improvement in its capabilities. The development of a second generation of non-volatile memory with higher capabilities (including spin-transfer torque technology (STT-MRAM)) is now proceeding.

Combining the technologies of magnetism with electronics What is spintronics?

Research into two properties of an electron, electric charge and spin, has traditionally been divided between two fields: electronics, which is based on electric charge, and magnetics, which is based on spin.

The achievements of electronics include transistors and large-scale integrated circuit (LSI) chips. Electronics is excellent for computing but has the disadvantage of volatility. From magnetics, magnetic recording technologies are used in HDDs. Magnetics is inappropriate for computing but has the advantage of enabling non-volatility. With the understanding that taking advantage of the two properties together would provide new devices suitable for fast computing and excellent in energy efficiency, the two fields were combined into spintronics, to develop new, high-performance devices.

The most important aspect of spintronics is magnetoresistance effect[*2]. This is a phenomenon in which a current flowing in a ferromagnetic[*3] material or a solid-state device is changed, meaning that the electric resistance is changed, by a change in magnetization or a magnetic field. The phenomenon was discovered long ago, in 1857, when Lord Kelvin discovered anisotropic magnetoresistance (AMR) effect.

The history of magnetoresistance effect is effectively the history of spintronics. Here, the progress of the technology is reviewed.

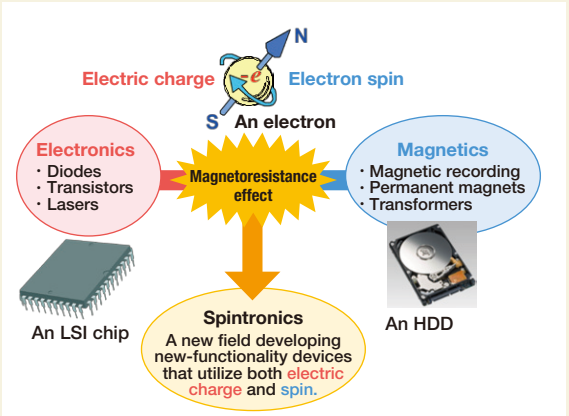
This discovery by Lord Kelvin in the 19th century was not put to use for about 130 years, because the changes in current and resistance caused by AMR (the MR ratio[*4]) were only 1–2% at room temperature. Because the changes were tiny, practical application was difficult.

The next breakthrough was the discovery of giant

Terminology at a glance

Spintronics

A field of research that uses both the electric charge and magnetism (spin) of the electrons in a solid. Typical devices utilizing spintronics include hard disc drive (HDD) magnetic heads and magnetoresistive random access memories (MRAM).



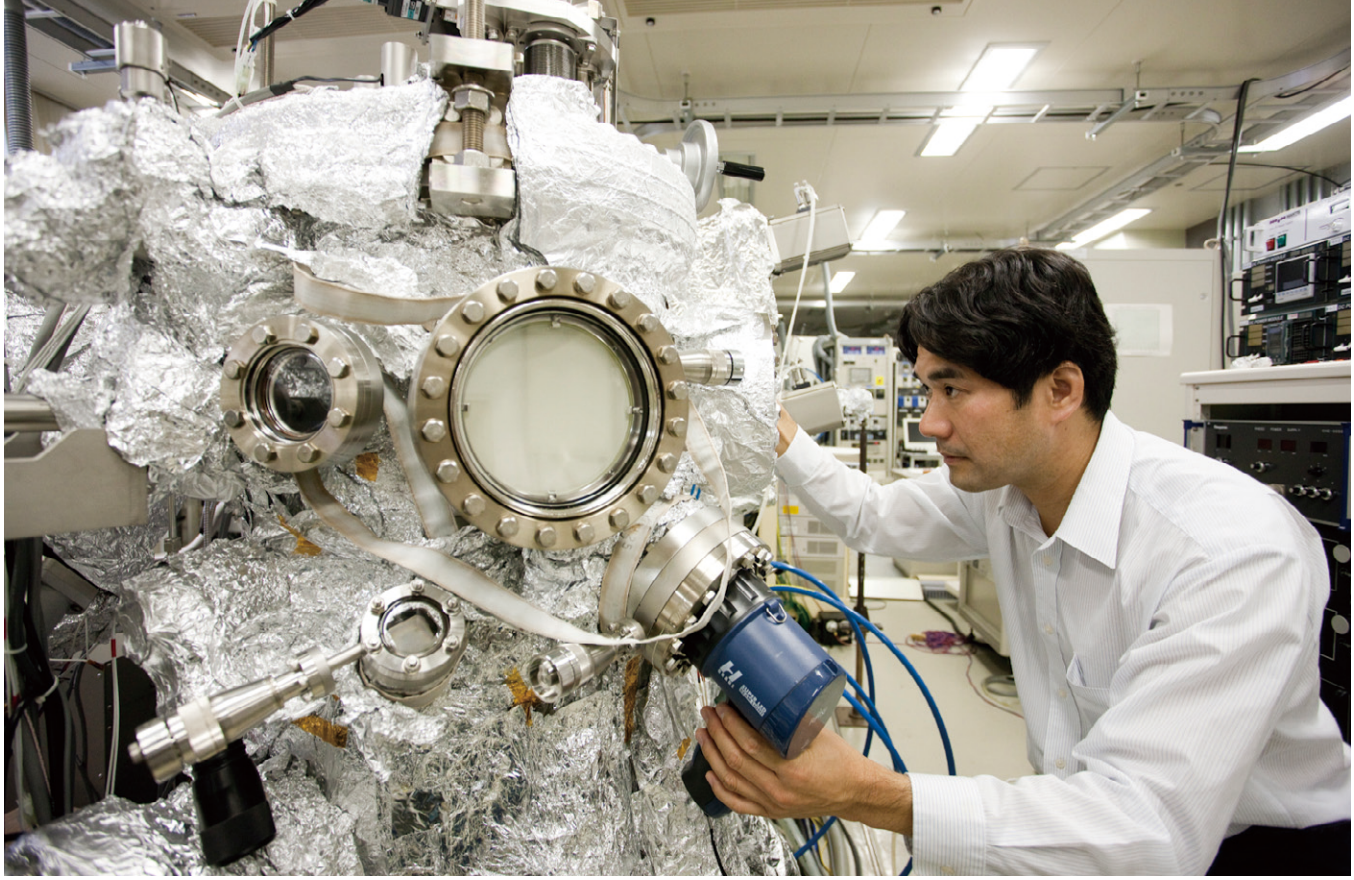
Large-capacity HDDs, magnetic sensors, non-volatile memories, ...

*1 **Magnetic head**: A component, incorporated in a storage device such as an HDD, that magnetizes a material to write data and uses magnetic field changes to read data.

*2 **Magnetoresistance effect**: A phenomenon in which electrical resistance changes in accordance with external magnetic fields.

*3 **Ferromagnetism**: The property of being attracted by magnets. Materials with this property are said to be “ferromagnetic”. In large ferromagnetic bodies, there are often many different “magnetic domains”, regions within which north and south poles are aligned in the same direction. In an HDD, these magnetic domains are used for recording data.

*4 **MR ratio**: A value representing the size of a magnetoresistance effect. The difference in resistance between two states of magnetization is divided by the resistance in one of the states. MR ratio is a performance index for various device applications.



▲A laboratory tool that produces thin films with magnesium oxide. It started operation in 2003 and is still in use. The aluminum foil wrapped round the apparatus is a measure to prevent uneven baking when the apparatus heats up to 200°C and an ultra-high vacuum is created inside the chamber.

magnetoresistance (GMR) effect[*5] in 1988 by Albert Fert of France and Peter Grünberg of Germany. The MR ratio in GMR has values of 5–15%, sufficient for practical applications. The high MR ratio means that the sensitivity when reading magnetic signals is high, so when GMR is employed in a magnetic head that reads data in an HDD, the density of data recording in the HDD can be raised. The development of devices using GMR was pursued internationally, and GMR heads capable of greatly increasing the recording density were commercialized in 1997. Fert and Grünberg were awarded the Nobel Prize in Physics in 2007.

In 1995, Terunobu Miyazaki of Tohoku University and Jagadeesh Moodera of Massachusetts Institute of Technology separately discovered tunnel magnetoresistance (TMR) effect, which gives a high MR ratio, 20–70% at room temperature, by the use of a magnetic tunnel junction (MTJ)[*6] in which an ultrathin layer of amorphous[*7] aluminum oxide is used as an insulator (a tunnel barrier). This revolutionary achievement enabled further miniaturization of recording components, and in 2004 ultra-high density HDD magnetic heads (TMR heads) were commercialized. These increased the recording density of HDDs, leading to reductions in power consumption by greatly improving energy efficiency. This achievement also led to the realization of the world's first non-volatile working memory (MRAM).

World-beating results from individual research

Upon joining the Electrotechnical Laboratory (now AIST) in 1996, Shinji Yuasa was involved in the research and development of HDD magnetic heads and second-generation non-volatile memory using aluminum oxide (Al-O)-based MTJs. He soon felt that the Al-O-based MTJs had reached their limits.

"At that time, the spread of information technology into society was progressing rapidly and there was a need for MTJs with higher MR ratios, and particularly for MR ratios of well over 100%. I thought that it would probably be impossible to achieve these by further development of conventional methods, and that using crystals rather than amorphous materials would be better."

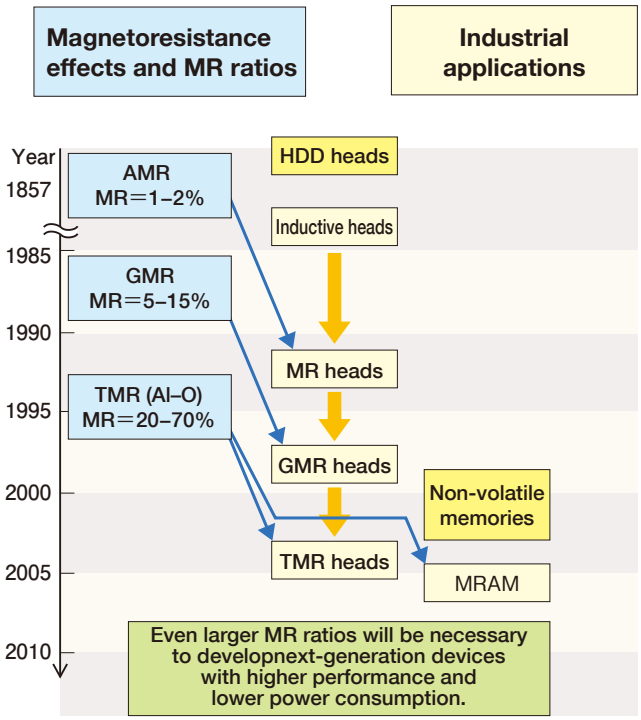
In 2002, he applied to the "Sakigake" (PRESTO) program[*8] of the Japan Science and Technology Agency (JST), a relatively small program that supports individual research. His proposal that stated a clear end product, achieving an

*5 **Giant magnetoresistance (GMR) effect**: A phenomenon in which, when a current flows in a multilayer film of a ferromagnetic metal and a non-magnetic metal, the electrical resistance falls if the spins in the ferromagnetic layers are arranged in parallel, or increases if the spins are arranged in anti-parallel.

*6 **Magnetic tunnel junction (MTJ)**: A component that exhibits tunnel magnetoresistance (TMR) effect. An insulating layer (a tunnel barrier) with a thickness of no more than a few nm (1 nm=10^{-9} m) is sandwiched between two ferromagnetic metal layers.

*7 **Amorphous**: An arrangement of the atoms or molecules structuring a

A history of magnetoresistance effect discoveries and its industrial applications



MR ratio of 150% at room temperature, was highly praised and he won a research grant.

He investigated a number of ways to achieve very high MR ratios, and diligently pursued the research by himself. One of the ways he considered was using crystalline magnesium oxide (MgO).

"This method was theoretically posited by researchers in the US and Europe in 2001, but experiments did not go well so it was almost abandoned. However, I felt it had potential and I decided to take a chance on magnesium oxide crystal."

The first year on Sakigake funded the construction of an apparatus for thin film deposition and ended without producing any results. The apparatus was not finished until near the end of 2003.

"When I finally completed it, I rushed to start my experiments. The first MTJ samples I produced went straight to an MR ratio of 88% at room temperature, which was the highest value in the world at the time. At only the third try, the MR ratio reached 180%. I was amazed by this virtually instant success."

At the time, he had a feeling that magnesium oxide was a material with "an excellent nature." In fact, as the research has progressed, the MR ratio has reached 600%.

material that is not regular and is not a crystalline structure.

*8 **Sakigake (PRESTO)**: A program run by the JST to promote goal-oriented basic research directed toward strategic objectives set by the government of Japan. It is focused on individual research, to cultivate the seeds of future innovation.

Thanks to collaboration with industry, a smooth path through "the valley of death" of development

Now his basic research had provided magnificent results, but he had only been producing MTJ films on small, specialized substrates, at a rate of one per day. There was still a huge barrier to overcome for industrial application: developing the technology for mass production.

"My MTJs using magnesium oxide have a crystal structure with four-fold rotational symmetry in a film plane. However, for use in an HDD head or a non-volatile memory, the crystal structure must be grown on a base structure that has three-fold rotational symmetry in a film plane. Everybody knew that this is impossible."

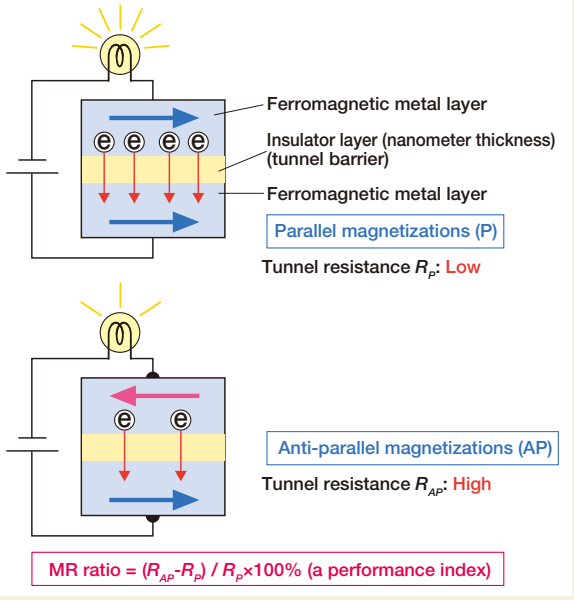
For comparison, this is like having to pile marbles in a square pattern on top of other marbles arranged in a triangular pattern. However, a researcher is not the kind of person to accept that something is impossible just because it is unknown.

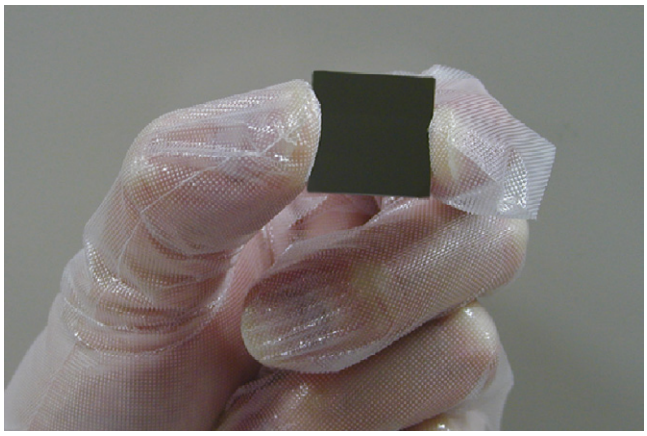
With the goal of mass production, he started collaborative

Terminology at a glance

Tunnel magnetoresistance effect/TMR effect

A phenomenon in which a tiny tunnel current flows through an insulator layer when a voltage is applied to the two sides of a magnetic tunnel junction, and the resistance value (how easily this current flows) changes in accordance with magnetic fields. In general, the resistance is lower when the magnetizations of the ferromagnetic layers are parallel in the same direction and the resistance is higher when the magnetizations are parallel but opposite (anti-parallel).





▲An MTJ film using magnesium oxide. The films were produced on special small substrates at a rate of about one a day.

Development history

2001
A giant TMR effect in an MTJ using a crystal of magnesium oxide (an MgO–MTJ) was theoretically predicted (in the USA and the UK). Major research institutions in Europe and America try to realize the effect, with no success at all.

2003
The giant TMR effect is realized at AIST.

2004
Development in collaboration with CANON ANELVA begins.

2005
Technologies for mass production of MgO–MTJs are developed.

The New Energy and Industrial Technology Development Organization (NEDO) starts its Nanotechnology Challenge Project.

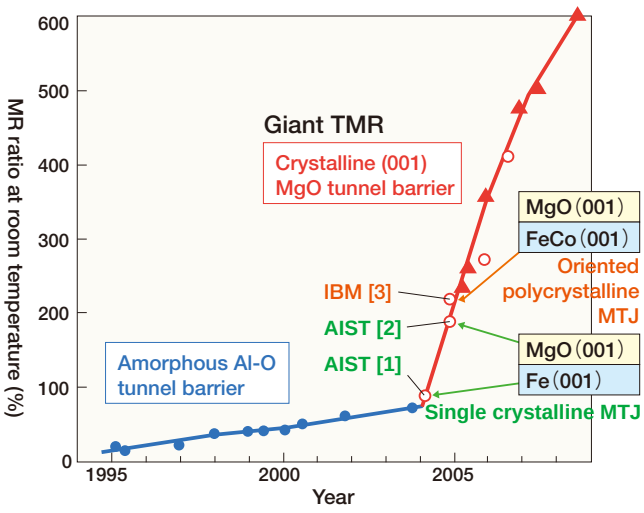
2006
NEDO starts its Spintronics Non-volatile Devices Project

2007
MgO-TMR heads are commercialized (Fujitsu, AIST, CANON ANELVA)

2009-2010
Circuit board technology for large-capacity MRAMs is developed by Toshiba and AIST.

2014
Toshiba is expected to start shipping engineering samples of large-capacity MRAMs.

Tunnel magnetoresistance effect gets bigger and bigger



[1] Yuasa, Jpn. J. Appl. Phys. 43, L558 (2004). [2] Yuasa, Nature Mater. 3, 868 (2004). [3] Parkin, Nature Mater. 3, 862 (2004).

development with CANON ANELVA Corporation (known as ANELVA at the time), a manufacturer of equipment for producing components for HDD magnetic recording heads. He asked them to develop a base structure that would make "the unknown" possible.

"However, they came back with a counter-proposal to develop a method for growing my crystal on a conventional base structure. So I decided to work on that."

The process of development was blessed with several strokes of luck, and before long he had discovered a revolutionary solution. He found that adding boron (B) to a cobalt–iron (CoFe) alloy, the standard material for ferromagnetic electrodes, made it possible to form an amorphous thin film of a CoFeB alloy, and the crystalline layer of magnesium oxide could be grown on that film. In the example of the marbles, this is like being able to form a layer of soft clay on the marbles arranged in the triangular pattern and then stack marbles in the square pattern on that layer.

"Then, not only did we solve the problem of growing the MTJ films on a foundation with a different symmetry, but we succeeded in mass-producing them using CANON ANELVA's production equipment. My basic research was suddenly transformed into a mass production technology."

That was the moment that the technology the world had been waiting for was launched. Through CANON ANELVA, transfer of the technology to the industrial world progressed smoothly, and HDD magnetic heads capable of reading at recording densities several times greater than previously were commercialized as soon as 2007. As mentioned above, their global market share is now 100%.

"Between basic research and commercialization, there is a

stage that is difficult to pass through, known as 'the valley of death'. This technology managed to get through this stage quite easily. What's more, because HDDs are a very large market worth three trillion yen per year, of which magnetic heads alone account for 500 billion yen, this success has had a huge impact."

The secret of success is constant consideration of practical application

As mentioned at the beginning of this article, as well as an increase in the recording density of HDD magnetic heads, spintronics is expected to enable the development of high-performance second-generation non-volatile memory (STT-MRAM). Consider computers: a computer is in standby mode for most of the time from one key input to the next key input. Therefore, if we install non-volatile working memory that can store data even when the power is turned off, then the power need be turned on only at the moments when keys are being pressed and can be turned off during the standby times.

If this "normally-off computer" that does not require standby power can be realized, power savings of up to around 80% can be expected for ordinary personal computers.

In 2006, the NEDO Spintronics Non-volatile Devices Project was started by AIST and Toshiba, with the objective of commercializing an STT-MRAM. Combining AIST's magnesium oxide barrier technology with a perpendicular magnetization system proposed by Toshiba, we developed a "perpendicularly magnetized MTJ". Using this MTJ for a new writing technology called "spin-transfer torque (STT) writing"[*9,10], we raised the efficiency of writing to memory and achieved an increase in capacity to the gigabit level (1 Gbit=10^9 bits). Shipping of engineering samples will start in 2014 and we think entry into the market is basically only a matter of time.

So what does Shinji Yuasa think is the secret of producing such a series of great successes in such a short time?

"I am interested in both ideas and needs, and I keep both basic technology and applied technology in mind. Research into ideas that leaves needs unmet is not very effective. However, if you know what is needed, you can specifically describe your goals, you can easily understand the technology that is required, and it is clear what you need to do."

Even when working on basic research as a university student, Yuasa was always aware of how it related to practical applications. Now, when he finds that something is missing in applied research and the gap cannot be filled from previous studies, he will work on research to rectify the deficiency himself. He hopes to be useful to society by linking fundamental research with practical applications. This simple yet powerful idea is the ground on which this world leader in spintronics research stands.

*9 **Spin-transfer torque(STT)**: When a current flows in a ferromagnetic material (a ferromagnet), the spins of electrons flow along with the electric charges and "spin angular momentum" is transferred from the electrons to spins in the ferromagnet. "Spin-transfer torque" is the rotary force (torque) that acts on the spins in the ferromagnet.

*10 **Spin-transfer torque writing**: A technology for writing data by using spin-transfer torque acting on storage layers of MTJs and reverse the magnetizations of the storage layers.

Spintronics A vision of the future

"The field of solid state physics, unlike space research and robotics, lacks the straightforwardness that would make it possible for anyone to keep a simple vision in mind. However, I think that practical application of the results of my work can help other people to hold their own visions.

It looks as if the next generation of large-capacity non-volatile memory (STT-MRAM) will come onto the market around 2018. As previous memory technologies are replaced by STT-MRAM, the dream of computers that need little standby power will at last be a reality. Meanwhile, it will be possible for the mobile devices of the future to go without charging for a month. This technology will improve the energy efficiency of electronic devices and contribute to addressing the global environmental and energy use problems.

Spintronics can also be applied to a whole range of other applications, such as magnetic sensors, microwave oscillators and "spin dice" (random number generators for encryption), and it may make our lives more pleasant, safer and less damaging to the environment. Using spintronics to build such a future: That is my vision."

Leading the way AIST!

Humidity-controlling tiles: Spotlight on an eco-construction material

Potential as a construction material that controls humidity as if it were breathing

The traditional wisdom of a Japanese house is recreated using AIST technology!

Our life and society will change in this way!

Rooms could be maintained at an optimum humidity if humidity-controlling materials come to be widely utilized in residential construction. In summer, the air in the room would not be moisture-laden and sticky, and air-conditioner use could be reduced. In winter, on the other hand, an appropriate level of moisture could be maintained, which would be good for health and beauty. One can anticipate very substantial energy savings no matter what type of residence the material is used in.

Chief Senior Researcher, Materials Research Institute for Sustainable Development, AIST Chubu Center

Masaki Maeda

Realizing a comfortable living space without using electricity

Many of you may have experienced the chilly sensation of entering the main hall of a wooden temple or a storehouse with mud walls even in summer. Buildings such as houses were originally built to conform with the climate in a region in order that they were pleasant to live in or appropriate to store goods in. In Japan with its high humidity, various techniques have traditionally been implemented in order that people could endure hot and humid summers in a cooler manner. These included improving the ventilation by adopting a wooden structure or using mud walls to block off the sunlight.

However, almost all of the structures of today are highly airtight, modern houses. Be it a household or an office, with living spaces being sealed by aluminum sashes, our lives are led while temperature and humidity are controlled using air-conditioners.

In addition to climate change that has become a significant issue over the past 20 years, energy conservation and power saving have also become important issues since the occurrence of the nuclear accident that accompanied the

2011 Great East Japan Earthquake. Having said so, it is quite difficult to forgo comfort once it has been obtained. There are probably many individuals who use air-conditioners while struggling to come to terms with a compromise between comfort and energy conservation.

"Well, what if we could maintain a room at a comfortable humidity without using electricity?"

AIST Chubu Center's Masaki Maeda asked that very question. A 15% drop in indoor humidity is said to result in a 1°C decline in sensible temperature. If humidity can be regulated without consuming electricity, the period for which air-conditioner use is not required can be extended and comfort can be preserved. Even when the air-conditioner is being used, it can be set at a higher temperature.

"Since 1994, I have been engaged in R&D on humidity-controlling materials with porous ceramics[*1]. These are highly functional and can maintain a room at a comfortable humidity without using electricity. The assumption is that they are applied in the form of construction materials such as humidity-controlling tiles and walls. With the intense heat experienced of late in Japan, there was no end to the number of people who succumbed to heat stroke, but if humidity-controlling construction materials were to come into widespread usage and maintaining appropriate room humidity was to become common, I believe that we could reduce such tragedies."

Leading sanitary ware and construction tile manufacturer INAX (currently LIXIL) commercialized humidity-controlling construction materials based on the research of Maeda and his team in 1998. Backed by energy conservation- and health-oriented consumers, sales of these products have continued to increase.

Further, among the numerous technologies possessed by AIST, patents related to these humidity-controlling construction materials have held the number one position in terms of patent revenue for the past seven years.

Targeting a "storehouse with earthen walls" Traditional wisdom matching the climate

Research on humidity-controlling construction materials employing porous ceramics commenced in 1992. This resulted from a request from INAX, which was engaged in the development of new functional construction materials. At the time, ecological awareness was starting to permeate through the general public on account of a rising sense of crisis regarding climate change and an era was emerging with new senses of value. Maeda thought that construction materials and humidity-controlling tiles that could maintain comfort without using electricity would be an attractive proposition as new products for such an era.

Historically speaking, awareness of energy conservation in Japan did not start from this time. The oil shock of the 1970s resulted in efforts being made throughout the country directed at energy conservation and a switch was made from wooden houses that readily let in drafts to houses made from concrete and aluminum sashes that boasted excellent airtightness and thermal insulation properties. While the energy conservation effect was raised greatly by modern houses, another problem gradually started to emerge.

"The higher the airtightness, the fewer routes for steam from cooking and baths, for example, to escape and this meant that condensation readily occurred on windows and

AIST Chubu Center

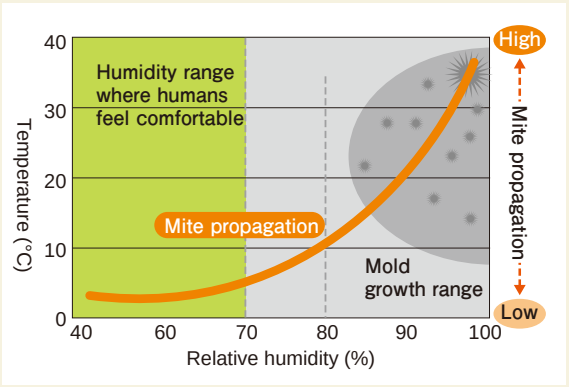
In 1952, the Nagoya Branch of the Mechanical Laboratory, the Nagoya Branch of the Tokyo Industrial Research Institute, and the Kyoto-based Research Institute for Ceramics were merged to form the Nagoya Industrial Research Institute. The Research Institute for Ceramics formed the basis of the current Sustainable Materials Research Division.

Terminology at a glance

Comfortable humidity

A relative humidity of 50–60% is a level at which people can live comfortably. At a temperature of 20–30°C, mites tend to emerge at a humidity of higher than 60% while mold readily occurs at a humidity exceeding 80%. Furthermore, a humidity of less than 40% results in dry skin and mucous membranes. This not only affects beauty, but dry mucous membranes are weakened and become susceptible to infection by viruses, among other health-related effects that are more likely to occur.

● Mold/mite propagation and humidity



Source: LIXIL

*1 **Porous ceramic**: Ceramic that possesses numerous pores in its interior (materials such as pottery and porcelain that are made by sintering clay). They boast excellent electrical resistance and thermal resistance, and are used in applications such as adsorbents and thermal insulation materials. The extent of adsorption and thermal insulation is dependent on the sizes and shapes of the pores.

▲An automated measuring device for testing the moisture-adsorption characteristics of nanoporous ceramics. Without such a device, testing alone would take two to three months.

walls. As a result, occurrences of mold and mites became more common. Not only are buildings damaged more easily by humidity: this humidity also started to affect health."

At the time, Maeda's superior and Ceramic Applications Department Material Technology Section head Yasuo Shibasaki believed that the method for solving these problems lay in traditional construction methods for Japanese houses and materials; therefore, traditional technology was reconsidered. At exactly that time, related parties came to learn of a storehouse built during the Edo period that was to be dismantled. Further, during the dismantling process, a precious mud wall sample was obtained.

"Storehouses have high thermal insulation properties and are superior in their humidity characteristics. In order to understand the reasons for this, the structure of a mud wall of thickness 10-plus cm was investigated: it was discovered that the wall had a multi-layer structure with several layers. The mechanisms of the surface and inner layers differ and this was related to the moisture-adsorption characteristics for adsorption of moisture in the air and the extent of moisture retention in the wall interior. In other words, it became clear that fine holes (pores) of differing sizes in the respective layers capture the moisture from the air, and this moisture accumulates in the interior. When it becomes dry, the moisture is released.

"The mud wall was in fact respiring and controlling the humidity. It was the moment where lost ancient wisdom came to the rescue," recalled Maeda with a grin on his face.

In search of a material to make walls that can breathe!

With the mud wall mechanism was elucidated, the next problem was exactly how to reproduce it using current technology. Even if it was to be reproduced, the solution was by no means to actually fabricate a mud wall: rather, it was to develop an all-new ceramic that could control humidity as if it were actually respiring itself.

While humidity-controlling construction materials existed at the time, their applications were extremely limited, including such areas as storage facilities for cultural assets. Storage areas for cultural assets are closed spaces whose doors rarely open and close and as such, one only need consider restricting fluctuations in moisture levels over a long time span. However, the new approach being attempted was for general residential applications, which involved totally different conditions.

"In the case of a residence, the door is opened several times per day and the amount of moisture indoors varies over short time spans. Humidity rises rapidly even when water is boiled or when other cooking takes place. For this reason, our first task was to search for what type of material to use

*2 **Zeolite**: A typical porous crystalline material in which pores approximately a nanometer across are uniformly arranged. Many zeolites comprise porous structures formed by bonding of silicon, aluminum, oxygen or phosphorus. They are utilized in a wide variety of applications including separation, adsorbents, shape-selective solid catalysts, ion exchange agents, chromatography column packing, chemical reaction sites, humidity agents, and construction materials.

*3 **Diatomaceous earth**: A porous substance formed by the sedimentation and fossilization of the frustules of diatoms, a type of phytoplankton. Currently they are widely used as construction materials

in order to control humidity over durations of several minutes to several hours."

Maeda and his team investigated natural clay-based materials. They considered what type of material would possess the specific pore size to draw in moisture and simultaneously transfer this moisture in a manner similar to the suction effect of a fiber in order that it accumulate. For example, in the case of a zeolite[*2], moisture rapidly reaches a saturated level because of the small size of the pores. Conversely, diatomaceous earth[*3] possesses pores that are slightly too large and on this account, adsorption of moisture is difficult unless the humidity is high. Whereas this material is effective for preventing condensation, it was not a suitable material for maintaining a comfortable humidity. Just what type of material has a large pore volume and could adsorb sufficient moisture, but at the same time retain this moisture without immediately releasing it?

"The first thing we looked for in a material was whether it could autonomously maintain a humidity of around 50–60%, which is considered comfortable for people. The next point was whether it could respond immediately to fluctuations in moisture levels over a short time span. In addition, even for a material that satisfied this balance, based on the presumption of commercialization, we had to consider options that excluded any materials where the cost was high."

Focusing on the moisture condensation phenomenon, a material that adsorbs vast quantities of moisture was discovered.

The research team decided on a natural material called allophane[*4], which is weathered volcanic ash soil. Around 1975, allophane had been used in the development of an adsorbent for toxic volatile organic compounds (VOCs) and its properties were well understood. However, while large quantities of allophane are found in a soil for gardening called Kanuma pumice, it causes plant root rot and for this reason, it is treated as industrial waste and disposed of. On this account, it received high marks as a low-cost material that could be reliably procured.

"We originally used allophane as a raw material for research of synthesis of synthetic clay[*5]. In this research process, we found that the pores in allophane of less than five nanometers condensed moisture; moisture adsorption in allophane was high compared with that in diatomaceous earth. From these facts, we believed that we could obtain a material with a high humidity-controlling effect by utilizing the nanopores remaining after low temperature firing of allophane."

Several research findings from the 1970s led to a single idea and joint development of a new material with INAX leading the way towards realization. Further, it was the manufacturer INAX that concretely cleared the practical obstacles that stood in front of commercialization one by one; AIST (at the time the Nagoya Industrial Research Institute) was involved in the research from the standpoint of technology guidance.

How does one achieve both moisture-adsorption properties and strength? Days of trial and error

Just what challenges did INAX face on the path to commercialization? Maeda explains as follows:

"Ceramics are fired to obtain their final form but this firing process results in shrinkage with the porous structure thereby being lost. Vitrifying and densifying at high temperature is effective for raising strength but this results in the nanopores shrinking and this in turn reduces the quantity of moisture that can be adsorbed. Conversely speaking, strength ends up declining if the nanopores are retained in order to raise the adsorption of moisture. I think the toughest challenge that we faced was to satisfy the dual requirements of possessing a porous structure together with high strength."

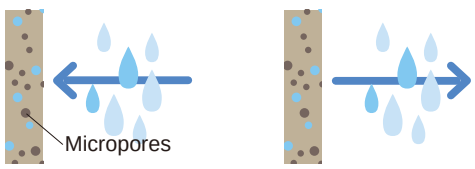
After close to one year of trial and error, the conclusion was reached that firing allophane at a low temperature of around 800°C realized a product with a sufficient quantity of pores remaining as well as sufficient strength for use as a construction material.

The base technologies were completed in 1994 and 1995

Terminology at a glance

Moisture adsorption and release mechanism

When indoor humidity rises, the nanopores in the ceramic adsorb moisture; when the humidity in the room falls, and it dries out, moisture is automatically released.



Source: LIXIL

due to the humidification and deodorization effects of the pores.

*4 **Allophane:** A porous clay mineral present widely in weathered volcanic ash soil. Exhibits high adsorption through moisture condensation in the pores.

*5 **Synthetic clay manufacture**: Japan's Aichi Prefecture, the location of AIST Chubu Center, is a thriving area for ceramics. In the high economic growth era of the 1970s, development of residential areas proceeded rapidly and there were fears that in the future, good quality clays suitable for ceramics would be depleted. Hence, the Nagoya Industrial Research Institute carried out R&D into technology for synthesizing good quality clays. Maeda participated in this project from the start.

and joint patent applications were made with INAX. Several years later in 1998, Ecocarat humidity-controlling tile employing nanoporous ceramics debuted on the market. "Fundamental research on intelligent humidity-controlling materials" was selected under the Private Cooperative Joint Research Program from 1996 to 2000. Furthermore, a ceramic construction material technology research consortium was formed. This organization studied manufacturing methods and as a result, humidity control using materials other than allophane became possible.

Ecocarat humidity-controlling tiles Targeting further market penetration

Amid a social tide of energy conservation awareness and pursuit of comfort and health, sales of Ecocarat are steadily growing and at present, the product varieties have been significantly broadened. Ecocarat has been used in the lobby of the AIST Chubu Center, construction of which started in 2001, as well as the AIST Tsukuba Central Cafeteria, where they are contributing to creating comfortable spaces. And needless to say, they are also used in Maeda's residence.

"In my residence, I feel that the effect of the air-conditioners is better than before. While Nagoya's summer is very hot and humid, the humidity is held at an appropriate level and the rooms often feel dry and pleasant."

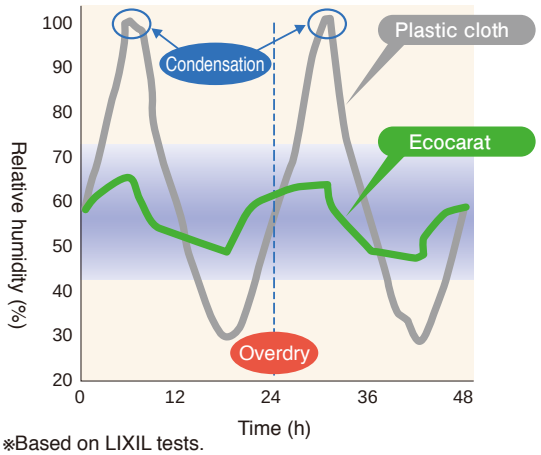
However, no matter how high the functionality of the humidity-controlling construction materials, it's hard to overcome the intense heat of recent summers without using air-conditioners.

"However, if one can set the air-conditioner temperature even 1°C higher through use of humidity-controlling construction materials, this can contribute to energy conservation without losing any degree of comfort. If more households use humidity-controlling construction materials, the energy conservation effect will become even larger. It is a humidity-controlling construction material highly suited to the humid climate of Japan and for this reason, from the perspective of energy conservation, I expect that the product will make further inroads."

The new challenge continues: pursuing energy conserving, comfortable households

To this day, Maeda continues his research with the

Humidity variation suppression of humidity-controlling construction materials



※Based on LIXIL tests.
Differs depending on parameters such as other construction materials, furniture layout, climate, and ventilation.

Source: LIXIL

Development history

Ca. 1975
Development of volatile organic compound (VOC) adsorbent.
In the Nagoya Industrial Technology Institute era, allophane was discovered to be a suitable material for adsorbing VOCs. It was subsequently commercialized.

1988-1992
Inauguration of research association for synthetic clay manufacturing technology.

1994-95
Focus on allophane.
The moisture adsorption and release properties of various natural clay materials were investigated and allophane was selected as a material.

1998
Humidity-controlling construction material commercialization.
INAX commenced marketing of humidity-controlling construction material Ecocarat utilizing allophane.

Photograph: LIXIL

Current
Development of new humidity-controlling materials.
Promoting development of new high functionality ceramics such as HASClay (hydroxyl aluminum silicate).


HASClay: a new humidity-controlling construction material

1975 — 2000

1988
Technology guidance for a leading residential fitting manufacturer.
INAX (as it was known at the time) enquired about improving the performance of porous ceramics, and technology guidance was subsequently given.

1992-93
A storehouse earthen wall from the Edo era was analyzed.
An earthen wall sample was obtained upon dismantling of a storehouse built in the Edo period and its moisture adsorption and release properties were investigated and analyzed. The earthen wall was found to possess a multi-layer structure. Development of a humidity-controlling construction material commenced.

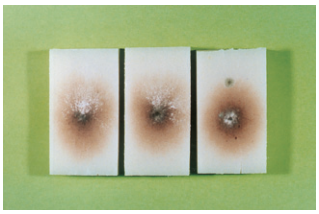
1996-2000
Public-private sector joint research starts.
"Fundamental research of intelligent humidity-controlling materials" was conducted jointly with a private sector company. Synthesis of materials that could autonomously adsorb and release moisture over the range where humans feel comfortable and natural materials that could be used as humidity-controlling materials were investigated.

2000-2004
Inauguration of a research consortium for ceramic construction material technology.

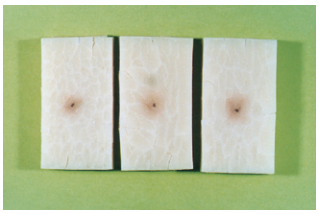
Mold growth tests

When rice cakes were placed in a room with Ecocarat walls and in a conventional room that employed plastic sheet, the room using Ecocarat was found to inhibit mold growth.

*Test results are dependent on room usage parameters, and environmental conditions such as climate and ventilation.



▲Right: Plastic sheet room



▲Left: Ecocarat room

Photographs: LIXIL

objective of developing highly functional porous ceramics. He is primarily developing moisture adsorption and release materials suitable for desiccant air-conditioning[*6], which uses desiccants to soak up moisture in the air and thereby increase the comfort of living spaces. Compared with standard air-conditioners, desiccant air-conditioning systems are expected to be able to conserve energy by reducing electricity consumption. This air-conditioning system has already been incorporated into some residential air-conditioners but there is still scope to improve on the capacity of moisture adsorption and releases by the desiccants that are currently used.

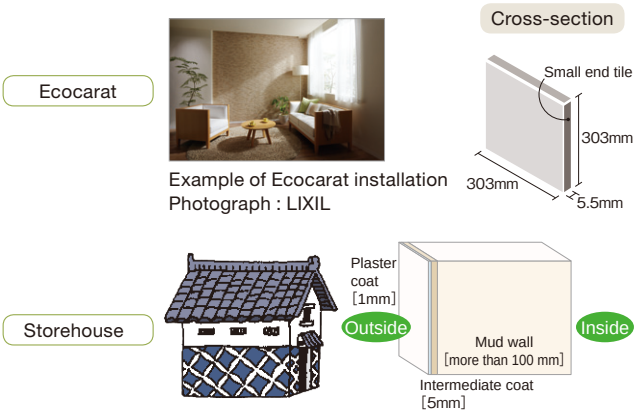
"Many industrial sectors have an aversion to moisture and therefore, one can say that higher functionality of moisture adsorption and release materials is sought for this technology. And so, in 2008 we developed a new high functionality ceramic called HASClay[*7]. It is easy to apply on a practical basis given that it is a low-cost material and currently, industrial material manufacturers are proceeding with its commercialization. In any case, if HASClay is incorporated into a household dehumidifier, an air-conditioning system that realizes both comfort and energy conservation will be the result."

When traditional Japanese wisdom meets cutting-edge technology, new technology suited to the Japanese climate is born. While this itself is a wonderful thing, excellent new technologies should not only contribute to the applications that they initially targeted: they should also generate notable demand through new applications. Today, energy conservation has become a global issue. Nanoporous ceramics are certain to find a useful place in the world.

*6 **Desiccant air-conditioning**: An air-conditioning system in which a desiccant is used to remove moisture in order to make a living space comfortable. Compared with a conventional moisture removal system based on cooling/dew condensation, reheating energy is not required due to prevention of supercooling; low temperature waste heat discharged from an air-conditioner can be used as the heat source for drying and regenerating the desiccant. For this reason, electricity consumption can be reduced. Contribution to energy conservation is expected.

*7 **HASClay**: Developed at AIST, a high performance moisture adsorption/desorption material comprised of a composite of low crystallinity clay and amorphous aluminum silicate (main component is Si (silicon) -Al (aluminum)). The term was coined by combining HAS (Hydroxyl Aluminum Silicate) from the amorphous aluminum silicate component and Clay from the low crystallinity lamellar clay mineral component. HASClay can be used over a wide range of relative humidities, and is expected to be used in next-generation energy-conserving/comfort construction materials.

Comparison of a mud wall and Ecocarat



Photographs & Source: LIXIL

▶ **Humidity-controlling tiles are used in the lobby of the Chubu Center**

A vision of the future

humidity-controlling construction materials

Simultaneously with popularization in Japan, rollout in Asian markets is also anticipated. As opposed to the relatively dry climates of Europe and North America, a hot and humid monsoon season occurs across Southeast Asia. Economic development is expected to continue in Asia and in the near future, demands for energy conservation and comfortable living are likely to rise. For both of these demands, I believe humidity-controlling construction materials can contribute greatly.

We are currently engaged in R&D of "non-fired ceramics" that bring out to the greatest degree possible the features of nanoporous ceramics. In Japan, a history already exists for wet processing methods that knead materials such as plaster and gypsum and then dry them. Plastered walls last for several decades and if they are damaged, they can be repaired by painting over. We feel that coating-type humidity-controlling walls that utilize HASclay have potential.

Food, clothing and shelter are the fundamentals of human life. We plan to continue to actively contribute to industries that improve the shelter component.

Into the future AIST!

Semiconductor silicon carbide (SiC)

A Revolution in Power Electronics Made Possible by Semiconductor Silicon Carbide

Through collaborative research with industry, we are aiming to commercialize SiC and related technologies.

Our life and society will change in this way!

In a society that cannot function without the use of electricity, increasing the efficiency of electricity use is critical. Silicon carbide power devices, which use power efficiently, can raise energy efficiency in electronic devices and the electricity infrastructure to a higher level, and will contribute to the realization of a low-carbon society.

Director, Advanced Power Electronics Research Center
Hajime Okumura

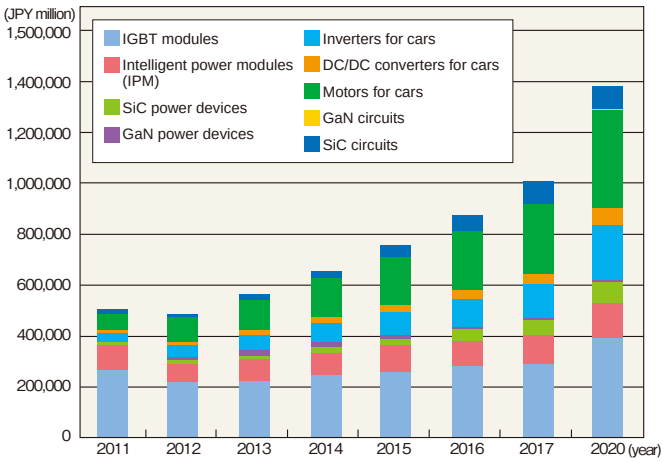
New semiconductor devices that cut power losses to the minimum

Our current lifestyle would not be possible without electricity. We use electricity everywhere, from household equipment such as refrigerators, washing machines and computers to trains, electric cars, and infrastructure such as the water supply and telecommunications. Power electronics, the technologies that quickly and efficiently switch electric power between AC and DC and change frequencies, etc. to suit different applications, are essential for society.

Electric power is converted and controlled by semiconductor devices (power converters). Until now, the main material in these components has been silicon (Si), as it has been for half a century. Research into reducing power losses during power conversions has reached its limits for silicon. Therefore, for the realization of a low-carbon, energy-efficient society, we require development of devices with higher speeds and lower losses to replace silicon power devices.

Through participation in various New Energy and Industrial Technology Develop-ment Organization (NEDO) projects, AIST has been tirelessly working on this challenge since the late 1970s. Silicon carbide (SiC)[*1] is chemically stable and hard, and has excellent heat resistance and high thermal conductivity.

The growing market for power electronics

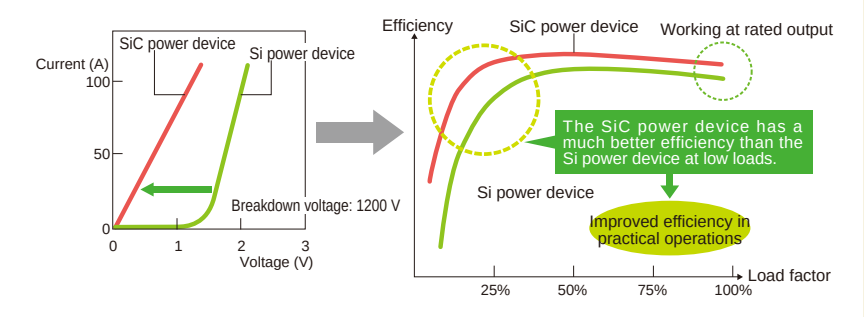


Source: *Potential Materials for Electronics Parts 2013 – Comprehensive Survey* (2012, Fuji Chimera Research Institute, Inc.)

Terminology at a glance

Comparing the efficiency of Si and SiC power devices

Compared to Si power devices, SiC power devices are less wasteful and can utilize power even when generation levels are low. The graph to the right shows that SiC power devices exhibit higher power conversion efficiency than Si power devices in a low load region (the region in which generation levels are low).



Source: *Focus NEDO No. 48* (March 2013, NEDO)

The goal of the development was higher-performance power devices using SiC, and higher-performance electrical equipment incorporating these power devices.

Hajime Okumura, Director of the Advanced Power Electronics Research Center, reflects on those times: "Development in which the semiconductor material was simply replaced with silicon carbide was very difficult. There were many defects in the early silicon carbide wafers and we did not have the technology to produce large-diameter substrates."

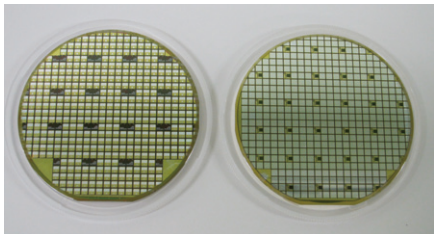
The road to industrial-scale application did not open up until costs were reduced by improved yields of larger wafers. To make the required technologies that had been developed through NEDO projects suitable for mass production, AIST used its own funds to set up an organization for collaborative research with businesses, specifically Fuji Electric Co., Ltd. and ULVAC, Inc.

The goal is efficient use of electricity and strengthening international competitiveness

Establishing production technologies that do not result in defects is critical for mass production. As well as R&D of devices for practical use as power devices, R&D for related technologies at the same time is necessary. Development has been pursued to raise the technical maturity of all aspects.

The key to improving the quality of SiC power devices was in the production of MOSFETs[*2] (metal oxide semiconductor field effect transistors) in 2002, when we developed a device structure, with an ion implantation epitaxial structure[*3] on the carbon surface of silicon carbide wafers; these provided good electron transport characteristics. Using this structure, we managed to produce samples of low-loss power devices with world-beating performance in 2006. Now, being shipped are general-purpose inverters and power conditioners for solar power that are equipped with power semiconductor

Mass production samples of SiC components formed on 3-inch wafers



transistors and diodes for the 1 kV range; this range of devices has the highest sales volumes. We have also achieved a great reduction in the sizes of the inverters.

"As well as replacing previous devices, silicon carbide power devices will be suitable for fields in which power electronics has not previously been used; so, we can expect even more efficient use of electricity and more energy savings. The result will be that Japan's semiconductor industry will become more competitive."

Our research and development is now focused, from the wafer level to the system level, on power devices in the multiple kV range, to be used in railways and other heavy electric equipment.

"In the long term, we aim to develop devices with ultra-high breakdown voltages, of 10 kV and above, to be used in smart grids and the like. To grow the market, high-reliability power transistors to be used in the next generation of cars will be the key target. Energy supplies are a very big issue for Japan in particular. We are working to establish a portfolio of technologies for the new energy electronics."

*1 **Silicon carbide (SiC)**: A compound of equal numbers of carbon and silicon atoms. Also known as carborundum. It has properties between those of diamond and silicon: very hard with excellent chemical stability and thermal conductivity. As well as being used as a semiconductor material, its uses include polishing and grinding, and emergency brakes for mountain railways.
*2 **MOSFET**: Short for "metal oxide semiconductor field effect transistor", a fundamental element of integrated circuits. On a substrate of a semiconductor such as silicon, a gate electrode is formed on an oxide layer and source and drain electrodes are formed at two sides of the gate electrode, thus forming the field effect transistor.
*3 **Epitaxial structure**: A technology for growing thin films of crystal. A number of crystalline films of semiconductor are layered on a semiconductor substrate.

Development of commercial-scale production technology for single-wall carbon nanotubes

Great expectations for a dream material 〈21st Century Industrial Revolution〉

Aiming for commercial-scale production and practical usage through development of the super growth method!

Our life and society will change in this way!

Carbon nanotubes (CNT) outperform many existing materials in terms of their strength, lightness, and thermal conductivity. If they can be practically applied as low-cost materials, there is potential for application in all sorts of industries, including buildings with improved resistance to earthquakes, thin and light electrical wires that do not emit heat, and more compact and high-density semiconductor chips; thus, CNTs will probably bring about a revolutionary transformation across the industrial sector.

Prime Senior Researcher, Nanotube Research Center

Kenji Hata

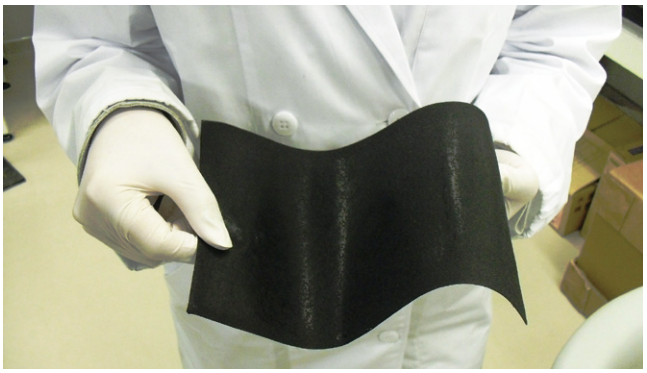
Thousand-fold synthetic efficiency! Breakthrough super growth method

Carbon nanotubes (CNTs) are allotropes of carbon with a cylindrical nanostructure with a diameter around 1 nm[*1] (nanometer) and length of several micrometers (μm) to several millimeters. Single-wall and multi-wall varieties exist, with the walls formed by one-atom-thick sheets of carbon, called graphene (a one-atom thick layer of graphite). Single-wall CNTs are characterized by their dynamic strength of 20-times that of steel, high thermal conductivity on par with diamond, and density half that of aluminum. They are excellent materials in all respects. Application is anticipated in a wide variety of applications where these attributes can be exploited, such as semiconductor elements and electrical wires.

Multi-wall CNTs comprising multiple concentric tubes of single-wall CNTs of different diameters are already being manufactured in commercial-scale plants throughout the world and as progress is made in lowering costs, the field is entering a phase of full-fledged market penetration. However, despite an intense global effort spanning many years, the synthesis efficiency for single-wall CNTs that possess superior properties compared with the multi-wall variety remains extremely low and to date, commercial-scale production as a full-fledged industrial material has not come to fruition.

Prime Senior Researcher Kenji Hata of the Nanotube Research Center is the person who has changed this situation. In 2004, Hata's team developed the revolutionary single-wall CNT synthesis technology known as the super growth method.

"By adding a trace amount of water during the synthesis of single-wall CNTs, we achieved a more than thousand-fold increase in growth efficiency. Single-wall CNTs synthesized using this method were much purer than previous CNTs, and the specific surface area was at the maximum level for a fibrous substance. Further, as a conductive filler (a material added to confer a certain function), single-wall CNTs possess the maximum aspect ratio[*2] (diameter: 3 nm; length: several 100 μm). As such, this material exhibits several excellent features."



▲The thermal conductivity of rubber developed using CNTs is on par with that of titanium, yet is light, thin and flexible. This thermally conductive rubber was developed as a heat dissipation material for LSIs.

By obtaining synthesis efficiency more than a thousand times greater than before, at long last the potential for commercial scale production of single-wall CNTs had arrived.

Practical application is already imminent Targeting creation of new industries

In actual fact, after Hata developed the super growth method, he says that he worried about where to place the research emphasis.

"It was apparent that disciplines with infinite potential were unfolding right before my very eyes. However, I didn't want the super growth method to be a flash in the pan boom: I wanted it to be prominent 10 or 20 years from now, and be a technology that would increasingly blossom."

Thereupon, Hata decided to aim for commercial-scale production of single-wall CNTs on an unprecedented scale. Working jointly with the chemical company Zeon Corp., development of a single-wall CNT commercial-scale production technology commenced. Besides creating a comprehensive vision for the commercial-scale production process, planning research, and setting milestones, Hata guided a synthesis group that included researchers from Zeon.

He successfully guided the research elements one by one, including continuous synthesis, large surface area synthesis, development of a wet catalyst, and development of a metal substrate. A demonstration plant combining these technologies commenced operations in 2012 as an entity that could, for the first time in the world, manufacture single-wall CNTs in units of 100 g and moreover, supply them at a practical cost.

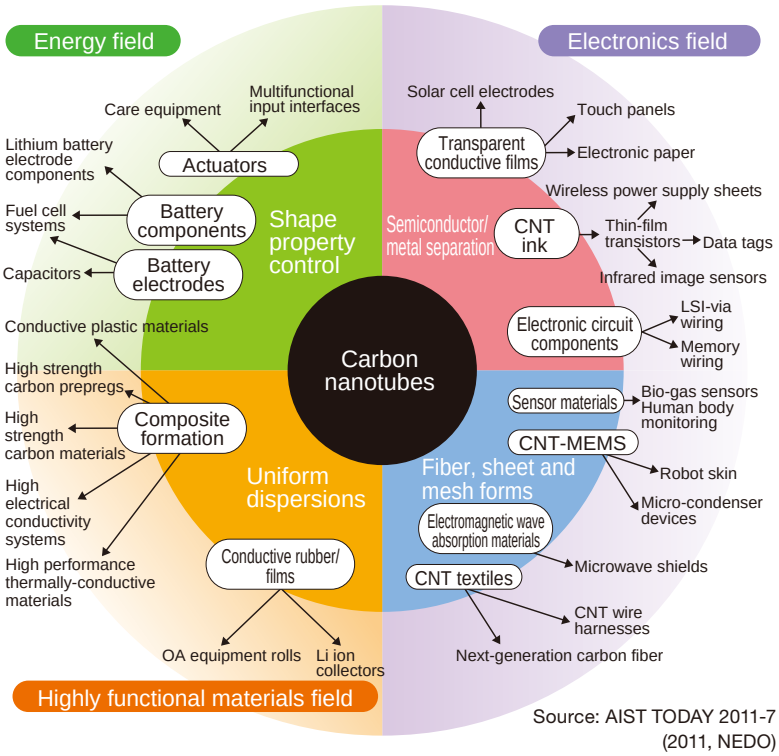
"Currently we are transitioning to applications research, and having developed highly functional CNT-based parts through dispersion/processing/composite production technology, we are now carrying out application development that will lead to creation of industries. Gathering together all of the technologies developed to date, we have come up with a B2B flow between material manufacturers and application manufacturers."

The application scope of single-wall CNTs is diverse, spanning energy, environment, and IT (information technology). Concrete examples of practical applications underway include conductive rubber materials, carbon textiles, conductive plastics, strain gauges, and capacitors*3. AIST is targeting a cost of JPY10,000 per kilogram by 2020, and if commercial-scale production can be achieved through lowering costs, major innovation will surely occur in the industrial sector.

At last, industrial-scale production of single-wall CNTs is set to be achieved in 2015.

"Our objective is for single-wall carbon nanotubes to be utilized 'here, there, and everywhere.' Furthermore, I want to see my mother actually holding a product that contains CNTs when I return home. With this objective, I want to devote my career to CNT R&D."

Diverse application potential for carbon nanotubes



Source: AIST TODAY 2011-7 (2011, NEDO)

*1 **nm (nanometer)**: 1 nm = 0.001 μm = 0.000001 mm

*2 **Aspect ratio**: The vertical to horizontal ratio of an object. In the current R&D, the ratio of the CNT's length to its diameter.

*3 **Capacitor**: An energy storage device, such as an element that possesses the functions of accumulating and emitting electrons (condenser). Used in components for electrical products. In recent years, various types of next-generation capacitors have been developed, such as pseudo-capacitors that enable fast charging and discharge just like traditional capacitors, despite the process being accompanied by a chemical reaction like those seen in rechargeable batteries.

Personal care robots supporting an ageing society

Personal care robots spread out as a "new infrastructure"

AIST promotes the international safety standards on personal care robots!

Our life and society will change in this way!

Amplifying human power to reduce the muscular burden for caregiving, carrying out housework, and furthermore helping with maintaining and promoting human health. By establishing safety evaluation technology and its international safety standards on the personal care robots, practical robot usage will be realized. The day whereby we live together with robots, and appreciate the comfort and convenience is not far off.

Deputy Director, Intelligent Systems Research Institute
Kohtaro Ohba

Robots working in the daily life of people New international safety standards sought

In Japan, decreasing birthrate and aging population have become social issues in recent years. The decline in the population of young people not only impacts the available labor force: there are also fears that there will be insufficient labor available for housework and care giving. One method anticipated to solve this problem is amplifying the power of humans and using personal care robots to substitute for humans in carrying out tasks.

The HAL Robot Suit from CYBERDYNE that amplifies body movements and the Honda Walking Assist Device have already been showcased in the media. While both are in the experimental stage, they are seen as functioning to reduce the muscular burden accompanying care giving. However, their current performance levels are insufficient for use in real life situations. One particular issue is ensuring safety.

As opposed to industrial robots working in factories where they are separated from humans and environments are standardized, personal care robots work in various environments, including residences, welfare facilities, and outdoors. For example, in everyday life, minor unexpected situations often occur, such as something falling down while walking, and signals from cellular telephones that become sources of interference. In response to these changes, robots themselves must ensure that their movements are stable, so as to not threaten the safety of humans. Moreover, those who operate the robots are not experienced engineers; rather they are numerous unspecified individuals. For these reasons, we require another standards that pay more attention to safety than the safety standards on industry robots.

Moving forward, it is indispensable to prepare safety standards that will enable widespread adoption of personal care robots while simultaneously establishing an

CYBERDYNE (Tsukuba City, Ibaraki Prefecture) announced on February 27, 2013 that the HAL Robot Suit for welfare applications that it developed had obtained an international standard certification for personal care robots. The certification by the Japan Quality Assurance Organization (JQA) of the safety in welfare applications of the HAL Robot Suit (right photo/the robot is worn to expand, amplify and support bodily functions) was the first such certification worldwide based on the ISO/DIS 13482: 2011 draft international standard that was published in September 2011.

Photograph: JQA

organization for certification and verification.

Establishing a safety certification method A society where robots can be used with peace-of-mind

AIST is promoting a "Personal Care Robots Project" to address these issues. This encompasses R&D centered on safety technology and safety evaluation methods for four types of personal care robot: (1) manipulation-centric mobile task type; (2) movement-centric mobile task type; (3) wearable type; and (4) ride-on type.

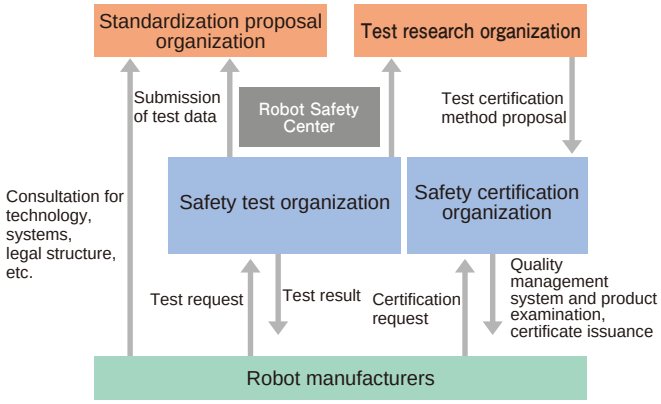
Needless to say, durability and strength similar to that of industrial robots must be ensured, but particular attention needs to be paid to whether the robot can come to a stop when it collides with a person or object, to what extent it harms people when it does collide; that is the important aspects of robots becoming part of the living space of humans. In addition, it is indispensable to study the effects on robots of strong electromagnetic waves that they may be subjected to. We are checking on safety from these various perspectives, while simultaneously developing risk assessment methods and safety test assessment methods that can be applied to the robot field, and conducting R&D of compatibility assessment methods. Currently, efforts remain focused within Japan, but moving forward, reflection in international standards will be targeted.

Reflects Kohtaro Ohba, Deputy Director, Intelligent Systems Research Institute, who is in charge of R&D, "This is the first project globally speaking to develop safety standards for personal care robots. It is not easy work because it is necessary to carry out everything simultaneously, from drawing up international standards to establishing test methods and certification processes."

Safety evaluation on personal care robots developed by various companies and establishing methods for certification will help users in selecting personal care robots and utilizing them with peace of mind. If robots come into widespread usage in households and public facilities and people realize that their lives become more convenient, we can expect the Japanese robot industry to be revitalized. In addition, if Japan's advanced robot technology can be promoted to the world, progress will also be made in terms of technology exchange with various countries, and this should contribute to industrial development.

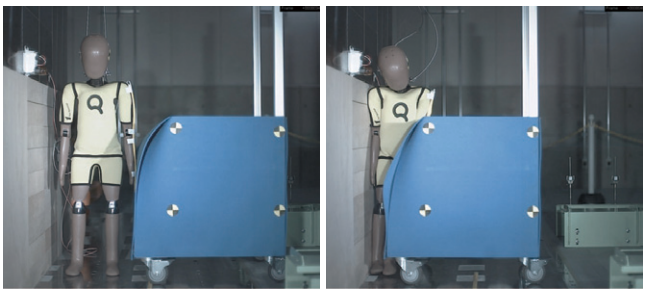
"Moving forward, it is important to clearly define operating systems such as licensing systems and training systems taking into account the usage of robots in various environments. In the future, establishment of a business model that strives to simultaneously minimize risk and maximize merits will likely be called for. I hope that Japan can quickly establish its own safety culture and form the foundations that will support the coming aging society."

Safety testing and certification framework for personal care robots

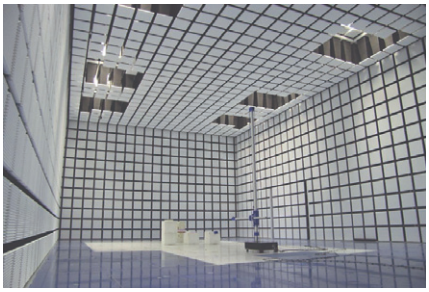


Source: NEDO Personal Care Robot Project pamphlet

Robot safety tests



▲Collision safety test. Verification of safety when a robot collides with a human.



◀EMC test. Verification of variations in robot movement when it is irradiated with strong electromagnetic waves in an anechoic chamber that blocks out other electromagnetic signals, as well as measuring the electromagnetic waves generated by the robot itself.

Extention of Japan's continental shelf

The extended continental shelf: Impetus for a marine resources survey contributing to future society

AIST's unique contribution with its geoscientific discipline to a government project!

Continental Shelf Research project team

Our life and society will change in this way!

Coastal States, including Japan, will have sovereign rights over the extended continental shelf, for the purpose of exploring it and exploiting its natural resources.
This is of great significance for Japan as a resource-poor country, as well as for developing coastal States and small island developing States. In addition to the exploration of expectant marine resources at hand, scientific clarification of the continental shelf through surveys and research is far important by promoting the peaceful use of the seas and oceans, equitable and efficient utilization of their resources, the conservation of marine life, and the protection and preservation of the marine environment as a whole.

The road to recognition of Japan's extended continental shelf (AIST-related)

1994	United Nations Convention on the Law of the Sea enacted
1996	Japanese Government Ratifies Convention on the Law of the Sea
2003	Japanese Government Inaugurates continental shelf assessment/advisory council
March 2004	AIST Inauguration of Continental Shelf Survey Project Team Continental Shelf Survey Study Working Group (review of main points for survey plan)
August 2004	Japanese Government Draws up basic policy for continental shelf submission
November 2004	AIST Inaugurates continental shelf research project
January 2005	Japanese Government Inaugurates task force to prepare submission of information draft to the United Nations
2003–2008	AIST Surveys and analyses
November 2008	Japanese Government Submission to UN of petition to extend continental shelf
2009–	Japanese Government Inaugurates task force to respond to judgment on continental shelf submission and respond to examination of Japan Subcommittee of Commission on the Limits of the Continental Shelf
April 2012	Japanese Government Receipt of the recommendation from United Nations Commission on the Limits of the Continental Shelf

Is Japan's continental shelf extened?

"Japan's continental shelf extended" in April 2012. This news was reported along with expectations towards the future. Moreover, the newly extended area is equivalent to approximately 80% of Japan's land area. So just what is expansion of a continental shelf and why should it be welcomed.

Many will recall from their science and social studies lessons in middle school that "the continental shelf is a flat shallow geographical feature with a water depth reaching to 200 m." From another perspective, "continental shelf" exists as a juridical term in the United Nations' Convention on the Continental Shelf of 1964 as "the coastal State exercises over the continental shelf sovereign rights for the purpose of exploring it and exploiting its natural resources" The continental shelf that has been expanded here is the latter one.

The United Nations Convention on the Law of the Sea, the so-called "marine constitution," was adopted in 1982. This was an historic year and critical juncture in which a strict definition of the continental shelf and the means of determining it was indicated. According to this, besides the exclusive economic zone (EEZ) seabed extending 200 nautical miles from coastal nations, if conditions such as the geographical feature or geology being continuous with the land are satisfied, then a continental shelf that extends beyond 200 nautical miles will be recognized.

Countries may claim development rights for the seabed resources present in sea areas that are recognized as continental shelf. A large area has been recognized as extended continental shelf and this implies that a route has been opened up for development of new natural resources present in the seabed within these confines. This is in reality delightful news for resource-poor Japan.

Exhibiting collective strength as a marine geology specialist group

Needless to say, coastal countries cannot just go about extending their continental shelves unilaterally as long as the conditions are satisfied. In order for a continental shelf to be extended, coastal countries must apply to the United Nations based on provisions in international law and a

scientific basis, and the submission must be reviewed and approved by the Commission on the Limits of the Continental Shelf comprised of experts from various countries in geology, geophysics and hydrography, etc.
Thereupon, in 2004 the Japanese Government commenced an initiative (continental shelf delineation survey) with the objective of compiling a submission to the United Nations based on the findings of a sea area survey. AIST was responsible for the country's geological survey: the Continental Shelf Survey Research Team was formed with the Institute of Geology and Geoinformation as the nucleus. The team was responsible for (1) the sea area survey, (2) analysis and interpretation of the rocks collected, and (3) compiling the submission, thereby contributing to this eight-year project
AIST has an extensive track record of sea area surveys in the vicinity of Japan and incorporating data such as geological data for specific areas into geological maps. In addition to this, it possesses technology of the highest level internationally for marine rock analysis. Thus, it possessed more than sufficient qualifications to be able to contribute in a comprehensive manner to the project as a marine geology specialist group. Nevertheless, the current task of bringing scientific proof to contribute to expansion of territory was a rare event for AIST, even historically speaking.

Transfer of heritage in the hands of future society and citizens is an important point of view

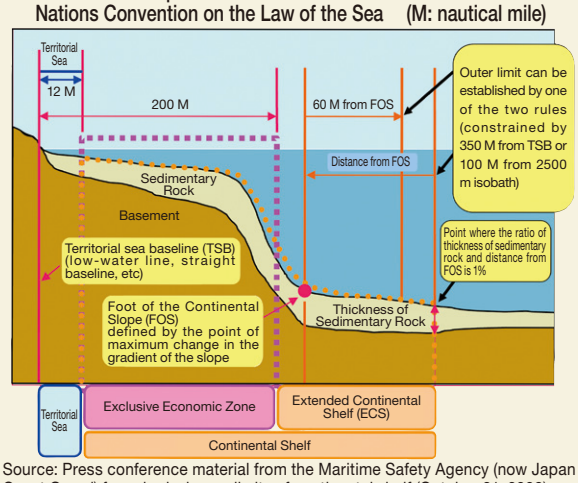
In recent years, it has come to be known that unknown resources may exist in the seabed. It is thought that various seabed resources exist in locations that have been newly recognized as Japan's continental shelf, such as rare metals that are indispensable for manufacturing automobiles and electronic components. The extended continental shelf is expected to give a major impetus to initiatives directed at seabed resource development.
However, there are issues associated with seabed resources development. Specialized technologies and significant cost are required to better utilize these resources and furthermore, scientific assessment of the environmental effects accompanying development are required. As such, considerable time will be required to attain actual commercial project status. This is the very reason why project team participant Kiyoyuki Kisimoto emphasizes the major significance of a Japanese government organization taking time to carry out the survey.
"At this point in time, Japan have taken approximately 30 years to at last complete the first batch of geomorphological /geological survey of an immense sea area and are just now starting on the next steps for a survey of seabed resources in detailed scale. While it is easy for discoveries of resources such as under-the-spotlight rare metals to become news, we expect there exist resources with future value that cannot be assessed with current knowledge and technologies. I believe that such dream resources will emerge serendipitously from steady surveying and research."
To the future, AIST will continue to survey resources in sea areas including the extended continental shelf.

Terminology at a glance

Extended continental shelf

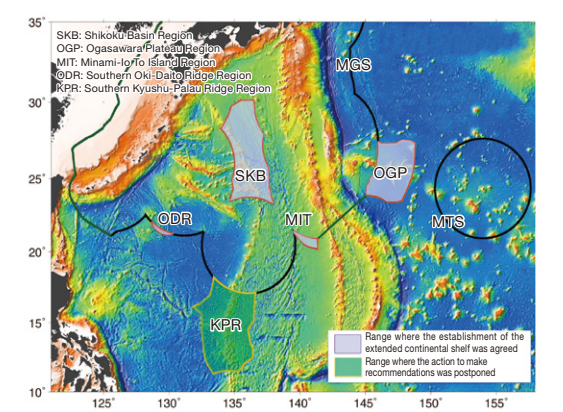
According to the legal definition of continental shelf as prescribed in Article 76 of the United Nations Convention on the Law of the Sea (UNCLOS), a sea area where an extension of sovereign power has been recognized. On April 27, 2012, the Japanese Government received the recommendation in which the UN Commission on the Limits of the Continental Shelf recognized four sea areas in the Pacific Ocean with combined area of approximately 310,000 square kilometers as being part of Japan's extended continental shelf.
The newly recognized extended continental shelf is said to include locations estimated to incorporate cobalt-rich crust as well as potential for the discovery of seabed hydrothermal deposits and substantial quantities of rare metals.

Schematic interpretation of continental shelf formulated in United Nations Convention on the Law of the Sea (M: nautical mile)



Source: Press conference material from the Maritime Safety Agency (now Japan Coast Guard) for submission on limits of continental shelf (October 31, 2008).

Japan's extended continental shelf



Source: Cabinet Secretariat; On the recommendations of the Commission on the Limits of the Continental Shelf related to extension of Japan's continental shelf.

Senior Chief Scientist, Tectonics and Resources Research Group, Institute of Geology and Geoinformation
Kiyoyuki Kisimoto

Environmental survey of Fukushima Daiichi Nuclear Power Station by high-access survey robot

Robot rises to the challenge of surveying an extreme environment unapproachable by humans

Robot developed by AIST and Honda contributes to recovery efforts

Intelligent Systems Research Institute

Our life and society will change in this way!

High-access survey robots that can unfailingly return to their starting point are expected to be able to assess the situation in high locations within the nuclear reactor buildings at Fukushima Daiichi Nuclear Power Station; up to now, adequate surveys of such locations have not been possible, in particular for such aspects as the radiation levels in high locations and the extent and nature of damage. Knowing the situation accurately, and enabling the accident to be addressed has the potential to greatly advance work directed at reactor decommissioning.

High-access survey robot

Dimensions when moving are 0.8 m in width, 1.8 m in height, and 1.8 m in length but when operating in high locations, its height reaches a maximum of 7 m. The arm itself moves with 11 degrees of freedom and its length is 1.7 m; mounted on it are a camera, dosimeter, and laser range finder (LRF). The robot weights 1.1 t, and can operate for approximately five hours on a single battery charge.

AIST and Honda develop robot Survey started at Fukushima Daiichi Nuclear Power Station

More than two years have passed since the accident at the Fukushima Daiichi Nuclear Power Station that resulted from the Great East Japan Earthquake and now in 2013, a complete resolution to the accident remains a long way away.

Work is proceeding at a snail's pace on account of, needless to say, a radioactive contamination zone that makes it dangerous for humans to approach. The annual permitted exposure for a worker has been set at fifty millisieverts; for this reason, if carried out in areas with high levels of radiation, work must be stopped within just 10 to 15 minutes. Workers who have reached the dose standard can no longer enter and a large number of backup workers are thus required. Therefore, robots that can take the place of workers and carry out their tasks are called for.

In this situation, in June 2013, the high-access survey robot, jointly developed by AIST and Honda, started work in the Unit 2 reactor building of the Fukushima Daiichi Nuclear Power Station. Honda took charge of development of the survey arm as it possessed technology capable of simultaneously controlling multiple joints through the development of ASIMO, its humanoid robot. AIST took charge of the high-area accessible crawler type work platform and the remote control technology.

In June 2013, the high-access survey robot carried out work in high locations in the first floor of the building that could not be surveyed previously. Using remote control, the arm was extended into narrow confines and the structure was verified; the robot also identified whether there were any obstacles that would hinder recovery work. Further, onsite radiation levels were measured. This news was reported in national newspapers such as the Asahi Shimbun and the Nihon Keizai Shimbun, as well as specialist newspapers such as the Nikkan Kogyo Shimbun and the Denki Shimbun (Electric Daily News), indicating the scale of expectations.

Aiming for a "robot that is useful onsite" Repeated improvements

There is a good reason why great expectations are held of robots. In task planning at the accident sites, preparations must be made including assigning tasks to specific individuals as well as stipulating the number of minutes that work can be carried out in specific locations. In other words, if radiation levels are not accurately known, plans can neither be made for radiation dose reduction measures, nor repairs. Until now the situation at high locations within building was not sufficiently elucidated; through the current survey, the probability has been raised that future recovery work will make significant progress.

Needless to say, robots developed in Japan and overseas have been deployed in the past, but nuclear plants were designed assuming that people would work in them; thus, carrying out tasks in nuclear plants by using large robots is not that easy. For example, the Japanese rescue robot "Quince" deployed in June 2011 successfully measured radiation and filmed the vicinity of the spent fuel storage pool but because the width of the stairs was narrower than the width of the crawler, the original objective of descending underground to carry out a survey was not possible. In addition, its cables were severed, which meant that it could not return and to this day, it remains stranded onsite.

Based on this precedent, AIST focused on making certain that its robot could reach the target location and moreover be able to return to the starting location. To this end, the vehicle is based on a high performance crawler with remote operation capability. Kazuhito Yokoi, who was involved with the development of this high-access survey robot, explains as follows:

"While referring to previous examples, this robot was completed through repeated improvements in order to be useful onsite. Wireless control is not possible within the building, so communication is via cable, but the robot is also equipped with wireless. This redundancy was adopted because if the cables were severed, it is possible that the robot stranded onsite could communicate with other robots and return from its stranded location. In addition, the cable length is 400 m even the distance to the survey area was less than 200 m and if it got caught on something, the remainder could be drawn out, thus enabling a return to base."

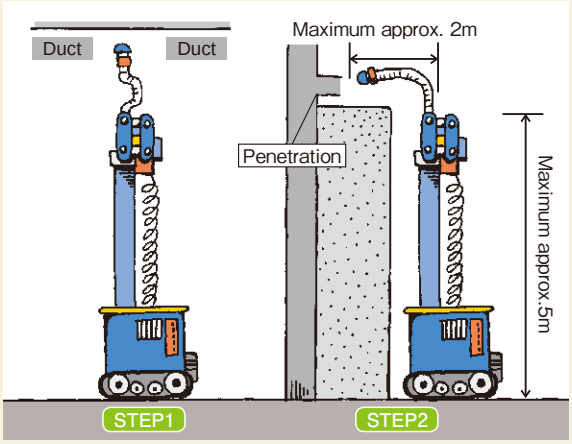
The arm component was designed so that it could work in confined spaces between installed piping.

The high-access survey robot has already been deployed at Fukushima twice to carry out radiation dose measurements and surveys. Yokoi has visited the site and by observing the robot in actual operation, proceeded with further improvements to resolve the issues he came across, as well as add new functions in his efforts to support Tokyo Electric Power Company (TEPCO).

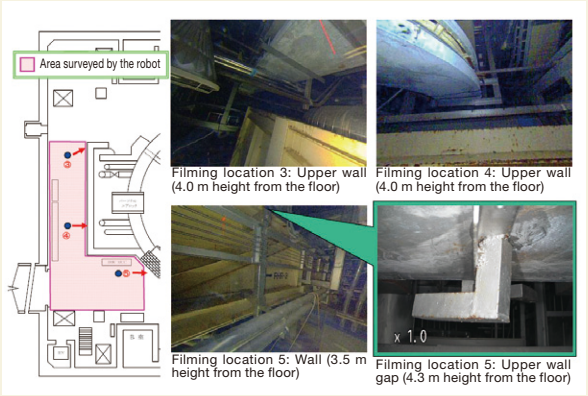
"TEPCO has indicated its desire to use the robot in moving forward. I would like to contribute through development of robots that will in their own small way enable progress in handling of the accident."

Terminology at a glance

Survey of reactor building by high-access survey robot



The first survey (STEP1: June 18, 2013) was of the upper reaches of the building, while the second one (STEP2: July 23, 2013) was in the vicinity of a PCV (Pressure Containment Vessel) penetration in a high location. The photos below show the upper walls of the Fukushima Daiichi Nuclear Power Station Unit 2 reactor building as verified from the findings of the first survey.



Source: Material disclosed on TEPCO website

Deputy Director, Intelligent Systems Research Institute
Kazuhito Yokoi

The leading organization in Japan for metrological technology

The people and technology behind correct measurement, which is quite common nowadays

The role of AIST supporting accurate measurement and the future of measurement

National Metrology Institute of Japan (NMIJ)

Serving our lives and society in this manner!

Our daily lives and economic activity are inseparably bonded with measurement. Daily life would more than likely be thrown into utter confusion if measuring apparatus delivered mistaken results. The National Metrology Institute of Japan (NMIJ), part of AIST, plays an important role in maintaining the accuracy of measurement, which is a foundation of safe and secure life. Advances in metrological technology are called for accompanying changes in society and technology. Technology research and development is underway targeting more accurate metrology.

Various measuring tools

Gas meter

Food service scales

Water meter

Taximeter

Clinical thermometer

Laws for correct measurement The Measurement Act

In our day-to-day lives we are constantly measuring. We shop for things and concern ourselves with how much two-hundred grams of beef will cost, or how much a half liter bottle of milk will cost; when we cook, we measure ingredients with a measuring cup or spoon. When it comes to our health, we measure our blood pressure and we pay our public utility charges for electricity, gas, and water based on usage measured by meters.

We generally have very few complaints regarding the actual amounts that are measured. We use scales* and rulers, and pay for products based on measurements made by other people. Accurate measurement has become a given for us in today's world. And why is this the case? Because measurement standards are prescribed in Japan by a law known as the Measurement Act, and people involved with measuring strive to abide by this act.

There are two primary objectives of the Measurement Act. The first is to establish measurement standards (establish measurement units, etc.). The second is to ensure accurate execution of measurement (mandating of accurate measurement, etc.). Based on this act, measuring apparatus for measurement of weight (kg) and volume (l) are called "specified measuring instruments" and they must be inspected and certified when shipped or prior to use as being able to measure correctly, as well as periodically inspected and certified forthwith. In fact, the scales used by your local butcher must be regularly inspected.

Ensuring traceability through national standards

AIST's National Metrology Institute of Japan (NMIJ) is Japan's leading organization when it comes to the field of metrology. Measuring instruments are calibrated by calibration service providers using accurate (small error)

standard devices. The standard devices are themselves calibrated by standard devices with even higher accuracy. In this way, the pursuit of accurate standard devices allows us to arrive at national standards and this is known as measurement traceability. Within this step by step calibration, AIST calibrates various metrology standards at the highest level.

In addition, AIST is taking part in a mechanism to ensure that specified measuring instruments operating in day-to-day life such as water meters, gas meters, taximeters, blood-pressure meters, and clinical thermometers are functioning correctly. AIST carries out structural inspection and performance tests for specified measuring instruments manufactured by companies, assesses whether they meet technology standards prescribed by the act and confirms conformance. Specified measuring instruments accepted here must be inspected and certified individually by a designated verification body prior to usage. Furthermore, the entity that guarantees the correctness of measurements carried out by these designated verification bodies is AIST, with its national standards through measurement traceability. Then, if specified measuring instruments are used correctly, they can exhibit its accuracy. To this end, AIST is supporting the development of human resources for measurement such as metrology public officials and certified measurers through its Metrology Training Center.

In this way, through multiple processes, which pursue accuracy, specified measuring instruments deliver to society measurements that secure the trust of consumers. The fact that we can live in a society where accurate measurements are a given is due to the appropriate functioning of regulations.

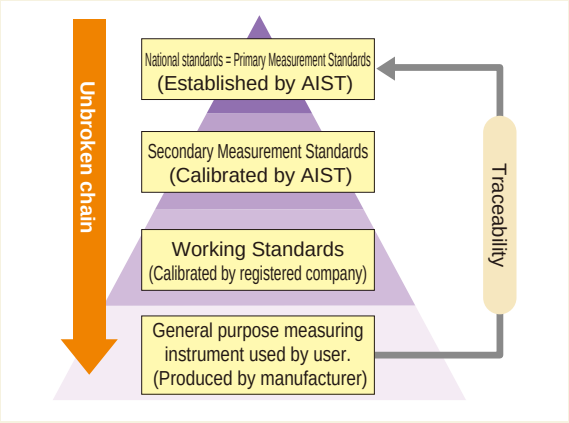
Furthermore, AIST is also conducting research and development that targets an even more accurate standard. Formerly, a meter standard made from an alloy of platinum and indium was used as a length standard. Currently, the definition of one meter is a standard based on the speed of light; Japan's national standard that realizes this is an optical frequency comb that uses the frequency of light. The world has shifted from the international meter standard with its accompanying fear of being lost or damaged and the constant need for comparison with a manmade object to a mechanism based on a fundamental physical constant: namely the speed of light in a vacuum, which can express the meter anywhere. However, when it comes to mass, the kilogram standard is still used. AIST is undertaking research on a method that utilizes atomic mass to determine mass more accurately.

Moving forward, the diffusion of new types of specified measuring instruments and measurement hardware incorporating more software and telecommunications functions is predicted. There are numerous associated issues, however, such as how to protect consumers from software manipulation and how to guarantee reliability. Further advances in metrological technology are called for in order for us to be able to live with peace of mind.

Terminology at a glance

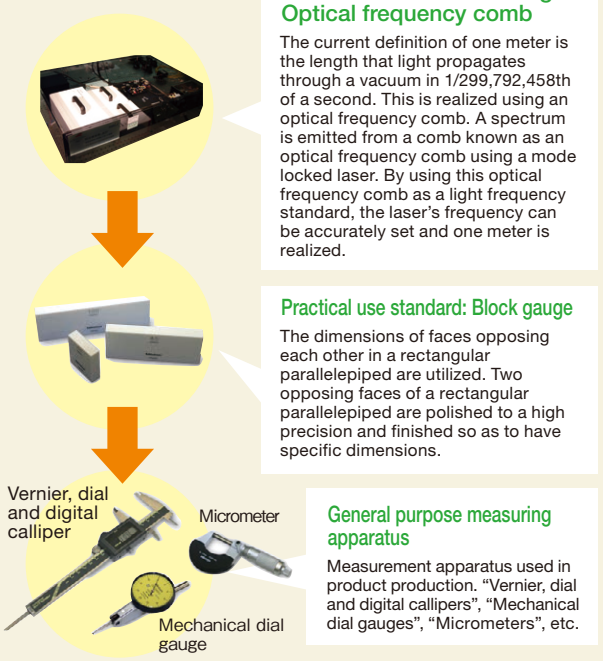
Measurement traceability

Measurement traceability is a mechanism whereby an unbroken chain of measurements back to the national measurement standard is maintained in the order of general purpose measuring instrument → Working standard → Secondary Measurement Standard → National standard. Further, each measurement is calibrated using a standard with precision one level higher in order that calibration of each level is carried out correctly.



Source: Through and Through, Easy Measurement Book (in Japanese; editor-in-chief: Hidesuke Imai) (2007: Nikkan Kogyo Shimbun)

Traceability example: length traceability



*In general, the term "scales" is called "Non-automatic Weighing instruments" in the Measurement Act.

Observation network for the Mega-earthquakes in the Nankai Trough

Precursor phenomena for a mega-earthquake
Fluctuation of slow slips beneath deep under the ground.

Monitoring underground movements: We want to be of use in mega-earthquake prediction and disaster prevention!

Tectono-Hydrology Research Team, Active Fault and Earthquake Research Center

Serving our lives and society in this manner!

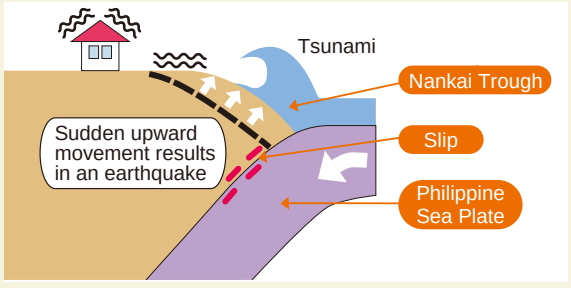
Using highly precise and reliable data, there is an expectation that we may be able to ascertain the probability of an impending mega-earthquakes in the Nankai Trough through the accumulation and sharing of observations of "slow slip" phenomena. If so, then it will be possible to devise the necessary earthquake countermeasures at the household, corporate, or national government level.

Terminology at a glance

Mega-earthquakes in the Nankai Trough

There are fears of a M 8-9 mega-earthquakes along the Nankai Trough occurring in the near future with the hypocentral region being located at the plate boundary along the Nankai Trough. A monitoring program for the Tokai Earthquake, which is one segment of the mega-earthquakes along the Nankai Trough, has been adopted in accordance with the Act on Special Measures Concerning Countermeasures for Large-Scale Earthquakes (enacted in December 1978).

● Mechanism of the mega-earthquake in the Nankai Trough



Earthquake prediction research: picking up the pace through discovery of precursor data for earthquakes

Mega-earthquakes are caused by the massive energy of the earth. Learning from the enormous tsunami of the once in a thousand years Great East Japan Earthquake of 2011, national and local governments are proceeding with reviews of presumption of magnitude of earthquake and tsunami heights and disaster prevention measures.

The Presumption of maximum magnitude of a mega-earthquake occurring in the Nankai Trough has been raised to 9. Meanwhile, a working group convened by the Cabinet Office in 2012 released preliminary calculations indicating large-scale damage including potentially more than 400,000 fatalities in an area centered on the Pacific coast from Shizuoka Prefecture to Kochi Prefecture as the result of a very severe earthquake that shocked various sectors of society.

How should we prepare for an earthquake when we don't know when it will come? We live in a country where a mega-earthquake could come at any time but it will be difficult to maintain a high degree of disaster prevention awareness over generations. However, if we can predict with relative precision to what extent a coming earthquake is impending, then we may be able to devise the necessary earthquake countermeasures without underestimating risk.

Looking back at history, full-scale earthquake prediction research started in Japan in the 1970s. Fearing a Tokai Earthquake on the scale of magnitude 8, the Large-Scale Earthquake Countermeasures Law was enacted in 1978 and earthquake countermeasures were studied. Observation data from governmental and university research organizations was sent to the Meteorological Agency and monitoring was carried out on a 24-hour basis.

In actual fact, the findings of data analysis showed that possible precursor data was observed in the region of the hypocenter during the Great East Japan Earthquake and this fact has accelerated research linked to earthquake prediction.

Impact in the following fields!

Community life
- Living
- Disaster prevention
- Safety and security

Industry
- Environment, resources, energy

The target is “slow slip” Real-time observation with underground sensors

In preparing for the coming mega-earthquake, AIST continues to monitor the Nankai Trough. Mega-earthquakes in the Nankai Trough have occurred repeatedly in the past. In the Nankai Trough, the Philippine Sea Plate is being subducted under the Eurasian Plate at rates of 3–6 cm annually. At the plate boundaries (depths of 10–30 km), which is presumed to the hypocentral region, the bedrock in the upper layer adheres to the subducting plate and normally does not move, but at deeper locations (depths of 30–40 km), a slow slip phenomenon can be observed once every 3–6 months.

This slow slip phenomenon has been known since around 2005 but more recently, it has come to be known that changes may occur prior to major earthquakes, such as increases in frequency, duration, and a mount of slip. In addition, immediately prior to the Great East Japan Earthquake, slow slip over one month was verified to have occurred in the vicinity of the hypocentral region. It is only recently that the relationship between this phenomenon and earthquake occurrences has been pointed out based on computer simulation.

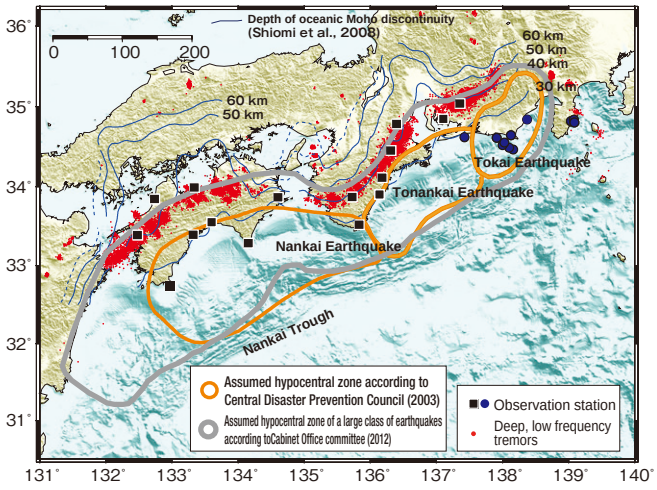
Slow slip, which is the most promising telltale sign of a mega-earthquake, appears in a form that can be visualized through changes in groundwater levels and strain in the earth’s crust. On this account, the Tectono-Hydrology Research Team of the Active Fault and Earthquake Research Center has bored deep wells at 16 locations from the island of Shikoku to the Kii Peninsula from which it carries out measurements using sensors placed deep within the earth. This observation data is furnished in real time to the Meteorological Agency and other organizations, and then publicly released.

▲AIST observation well (A photo during construction. Upon completion, the derrick will be dismantled)

Research into the prediction of mega-earthquakes is still incomplete, but what is supporting this persistent research is the strong feeling of the researchers that one day they will be able to predict earthquakes. Moving forward, Team Leader Norio Matsumoto says that more observation points will be added, while the measuring instruments will be improved so that they can precisely indicate earth crustal movements from measuring the slightest strain, among other activities. While thus striving to improve analytical capabilities, the data accumulated will be used to target prediction of the mega-earthquake in the Nankai Trough.

“Preparing for a mega-earthquake and tsunami is a critical issue that will affect how Japan can recover from such as event. Exploiting the observation findings for the sake of people’s lives and corporate activity is a major obligation of AIST.”

Observation network of AIST for the megathrust earthquakes in the Nanka Trough



Mega-earthquake in the Nankai Trough, observation network data disclosure destinations, etc.

Besides reporting to the governmental Earthquake Research Committee, which collects and analyzes survey findings from various organizations, and to the Earthquake Assessment Committee for Areas under Intensified Measures against Earthquake Disaster at the Meteorological Agency, data is also available at the Groundwater, Strain and Seismograph Presentation System Well Web (www.gsj.jp/wellweb).

Leader, Tectono-Hydrology Research Team
Norio Matsumoto

Another success at AIST!

Carbon fiber development

From fishing rods to aircraft Carbon fiber development process

Technology to society—the foundation of AIST's innovation model

The Boeing 787 next-generation passenger jet made its maiden commercial flight between Japan's Narita Airport and Hong Kong in October 2011 and the world's attention was drawn toward this new aircraft. This was because of the anticipated improved fuel consumption through adoption of a lightweight airframe. Japanese company Toray's carbon fiber composite material played a part in this light weighting. Carbon fiber composite materials are a strong field for innovative Japanese companies, and Japanese carbon fiber manufacturers command an approximately 70% share of global production. Moreover, this technology was discovered at AIST in the 1950s and as such, it is a technology with history.

Carbon fiber application fields: Examples of application as CFRP

Space and aero-space	Aircraft	・Primary structural material: Main wings, tail wings, fuselages, floor beams ・Secondary structural material: Ailerons, rudders, elevators, fairings ・Interior materials: floor panels, lavatories, seats
	Rockets	Satellite fairings, intermediate stages, motor cases, nozzle throats
	Satellites	Antennae, solar cell panels, tube truss structural materials
	Radio telescopes	Antennae, stays
Sports equipment and daily necessities	Fishing equipment	Fishing rods, reels
	Golf	Shafts, club heads, face plates
	Rackets	Tennis, badminton, squash
	Automobiles	Frames, wheels, steering wheels, cranks
	Maritime	Yachts, cruisers, racing boats, masts
	Other sports	Baseball bats, skis, ski poles, Kendo swords, Japanese archery bows, Western-style bows, radio-controlled cars, table tennis, billiards
	Care giving products	Wheelchairs, portable slopes for wheelchairs, prosthetic legs, walking sticks
	Electrical products	Computer housings, sound speakers
	Other articles of daily life	Umbrellas, helmets, bags, furniture
Industrial	Automobiles	Drive shafts, exterior panels
	Motorcycles	Racing cowlings, muffler covers
	Rolling stock and containers	Railroad vehicle bodies, linear motor car bodies, seats
	Machinery components	Fiber components, leaf springs, robots arm
	High-speed rotating equipment	Centrifuge rotors, uranium enrichment tubes, flywheels Industrial rollers, shafts, rayon spinning pots
	Electric components	Parabola antennae
	Pressure vessels	CNG tanks, hydrogen tanks, firefighting air respirator cylinders
	Chemical equipment	Mixing impellers, pipes, tanks
	Medical devices	Top plates, cassettes, X-ray grids
	Building and construction	Concrete reinforcing materials, cables, rods
	Other	Resin molds Sheet-form heating elements

Source: Compiled based on Industrial Materials 47 (3) (1999, Nikkan Kogyo Shimbun, in Japanese) by Tetsuro Tsunai

Strong, light, and thermally conductive "Top performer" of the materials world

Carbon fiber is obtained by firing an organic fiber and its carbon content is 90% or more. Its origins are said to date from the 19th century, when master inventor Edison carbonized Japanese bamboo by baking it and used it as the filament in incandescent lamps.

The main features of this fiber are its light weight, strength, and hardness. It is one-quarter the weight of steel, yet possesses more than 10 times the strength and seven times the hardness. Furthermore, carbon fiber exhibits high fatigue resistance, corrosion resistance, vibration attenuation properties (vibration stops immediately), X-ray transmissivity, and thermal conductivity. On the other hand, its coefficient of thermal expansion is extremely low, meaning it exhibits excellent dimensional stability (size does not change). In all aspects, carbon fiber is a top performing material.

Carbon fiber R&D gathered pace in the 1950s. Carbon fiber with high heat resistance was necessary for the U.S. space development program and a carbon fiber that employed rayon as a raw material was developed. Hearing of this, Dr. Akio Shindo of the Industrial Research Institute of Osaka, part of the Agency of Industrial Science and Technology under the Ministry of International Trade and Industry (one of the predecessor organizations to AIST) was eager to replicate this effort in Japan by all means; after substantial trial and error, he discovered that a higher performance carbon fiber could be synthesized by using polyacrylonitrile (PAN) fiber. An application was made for a patent for PAN-based carbon fiber in 1959.

The Shindo Model: Cooperation with industry from the development phase
Preparing the foundations for technology development

Initial development of PAN-based carbon fiber assumed

CFRP accounts for 50% of the overall airframe structure mass in the Boeing B787. In addition to improved fuel economy, passenger space has been expanded due to the higher strength of the fuselage structure and comfort has thereby been improved.

Photograph: Boeing

utilization of primarily its thermal and electrical properties. However, American military personnel who came to look at the material pointed out its excellent strength and elasticity. A firm belief in its potential as a structural material thus emerged and the course of research was altered. Through this, the industrial application scope expanded remarkably.

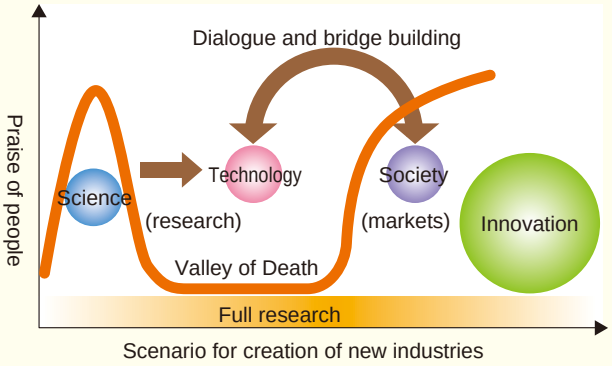
Taking note of Dr. Shindo's research, the number of companies entering into carbon fiber research in Japan increased, and efforts directed at commercialization became energized. In 1962, Nippon Carbon Co., Ltd. established a pilot plant for PAN-based carbon fiber. In 1971, Toray started fully-fledged production of PAN-based high performance carbon fiber based on licensed technology. The company had been conducting R&D for an extended period through an industry-government collaboration.

After inventing PAN-based carbon fiber, Dr. Shindo obtained patents for the manufacturing process, advised close to 30 companies concerning the technology, and coordinated efforts for the standardization of carbon fiber evaluation methods, as part of efforts to form the foundations for carbon fiber technological strength. This methodology that linked invention with commercialization in other fields was called the Shindo Model, and it has become a foundation of AIST R&D today.

Applications continue to expand, from sporting goods to space development

When carbon fiber is used as a structural material, it is not used in its fiber form. Rather, it is primarily used embedded in a resin, for example, as a composite material (a material comprised of two or more base materials, including a matrix material that delivers overall integration and a reinforcing material whose role is to strengthen and fortify). The most common type is a carbon fiber-reinforced plastic (CFRP) that employs a thermosetting resin as the matrix material. Although usually people are not very aware, this material is indispensable for our day-to-day

AIST's approach to promoting innovation



Strengthening efforts directed at promoting innovation

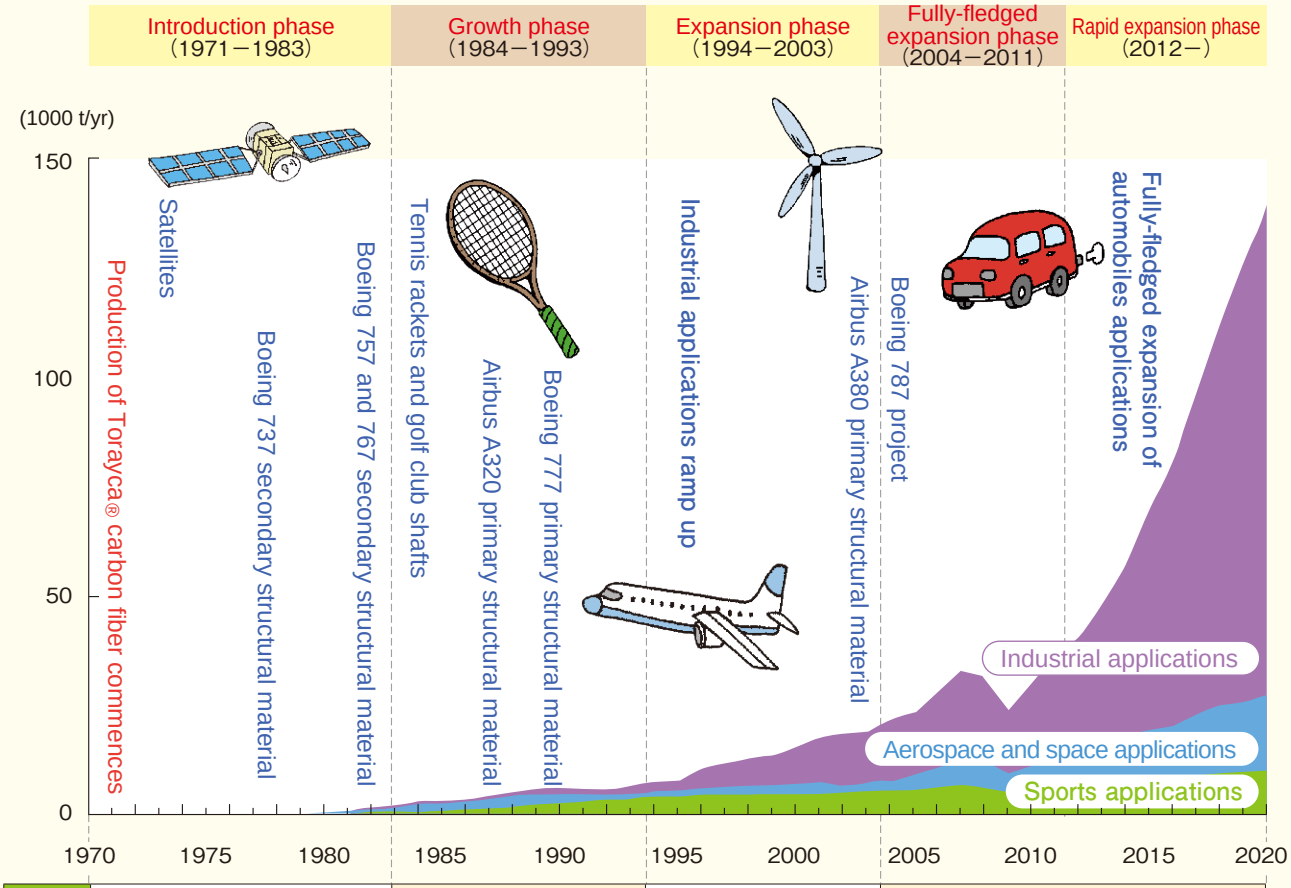
- Shaping a tide of innovation
- Integrated dissemination of research findings
- Precise understanding of society's needs
- Research resource utilization and research support from the viewpoint of promoting practical research

Management leadership-based innovation promotion

▲ Dr. Akio Shindo

▲ Kansai OSL, the industry-academia-government collaborative research wing located at the AIST Kansai Center, the former site of the Industrial Research Institute of Osaka

Carbon fiber market transition



	Introduction phase (1971–1983)	Growth phase (1984–1993)	Expansion phase (1994–2003)	Fully-fledged expansion phase (2004–2011)	Rapid expansion phase (2012–)
Applications	**Limited fields** Fishing rods Aircraft secondary structural material	**Expansion of applications** Tennis rackets Golf club shafts Aircraft primary structural material	**Industrial applications ramp up** Pressure vessels Industrial machinery, ships Civil engineering and construction, repair and reinforcement	**Rapid expansion of aerospace applications, ramping up of automobile applications** Large-scale aerospace programs Wind power generation Automobile applications, deep-sea oilfields	
Comments	High quality	Product type expansion Progress in processing technology	Cost reduction Large structural materials	Diversification of processing techniques Responding to demands for recycling	

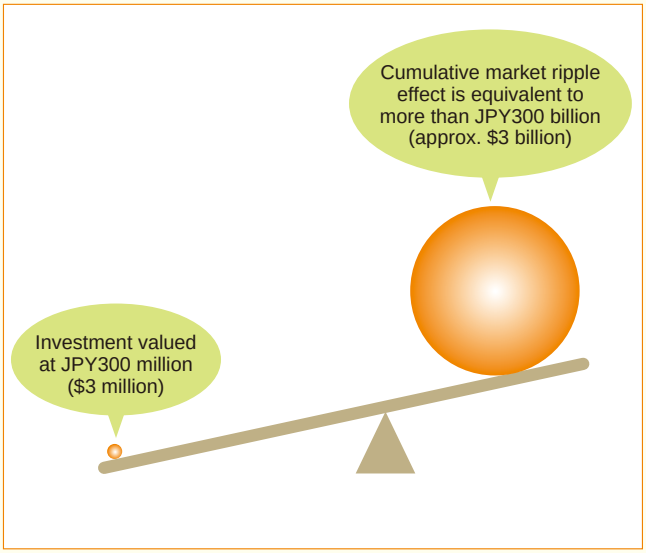
Source: Toray

lives.

Carbon fiber first came to be used in sporting goods in the 1970s, thereby becoming a familiar material to consumers. It was applied in various products, including fishing rods, golf shafts, tennis rackets, and skis, and played a major role in light weighting and performance enhancements. Currently, it is an indispensable material in sporting goods. Utilization in large passenger aircraft fuselages started from the 1980s and its use has since spread to other applications that currently include rollers for printing presses, high-pressure tanks, earthquake-resistance reinforcement, wind turbine blades, building and construction, industrial machinery, and space and aerospace development.

More than half a century has passed since the invention of PAN-based carbon fiber. However, this technology that was born in Japan continues to support the lives of people through the world to this day.

Market ripple effect of carbon fiber research



Index

Keywords that are familiar to us

QR code

AIST HP

http://www.aist.go.jp

AIST Twitter

https://twitter.com/AIST_JP

YouTube AIST CHANNEL

http://www.youtube.com/user/aistchannel

From AIST to the Innovative World Supporting, changing, and creating the future of life and society

AIST Stories 2013 No.1

Editor and Publisher: The National Institute of Advanced Industrial Science and Technology (AIST)
Enquiries: AIST Planning Headquarters, Ministry of Economy, Trade and Industry Building, 1-3-1 Kasumigaseki, Chiyoda-ku, Tokyo 100-8921
www.aist.go.jp

Cover photograph: Boeing (B787)
Contents page photograph JQA (CYBERDYNE HAL robot suit)


National Institute of
Advanced Industrial Science
and Technology
AIST