

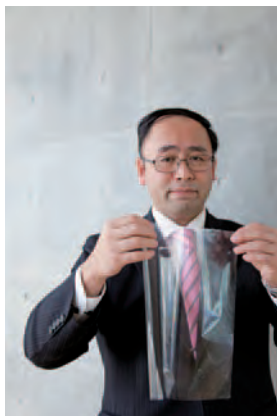


National Institute of
Advanced Industrial Science
and Technology
AIST

From **AIST** to the Innovative World

2014 | AIST Stories No. 2

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

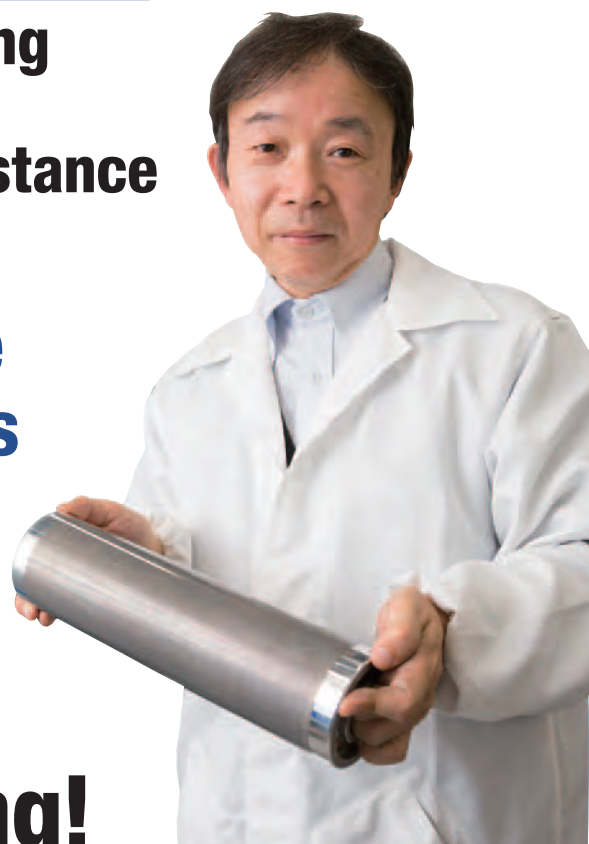


Claist: a high-performance clay-based thin film

**A clay-based film boasting
astounding gas barrier
properties and heat resistance**

**The AD method: an innovative
coating technology that defies
conventional wisdom**

**A robust ceramic film
realized without firing;
merely through spraying!**



Growing GM strawberries in a completely closed system plant factory

**A World First! A Canine Medicine Derived from
GM Plants Comes onto the Market**

Sherbet-like brackish ice for preserving freshness of seafood

**Freshness is vital!
AIST technology delivers delicious fish to the table**



From
AIST
to the Innovative World

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

AIST Stories 2014 No.2

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Just what is AIST? Many of you may have this very question. You might have heard of the organization but you have no idea what it actually does. This might apply to many of you. From AIST to the Innovative World is published with the intent of answering such questions for you. We want to communicate the fact that technologies developed by AIST are actually playing roles in your day-to-day activities. Further, the strenuous efforts of AIST researchers to support people's lives and create a better future for everyone are presented.



AIST in present day living!

A compact personal dosimeter

Reliably Measuring Invisible Radiation so Residents can Return Home without Fear

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A personal dosimeter with a sense of mobility that feels like a charm. Delivering peace of mind with accurate measurement, contributing to recovery support.

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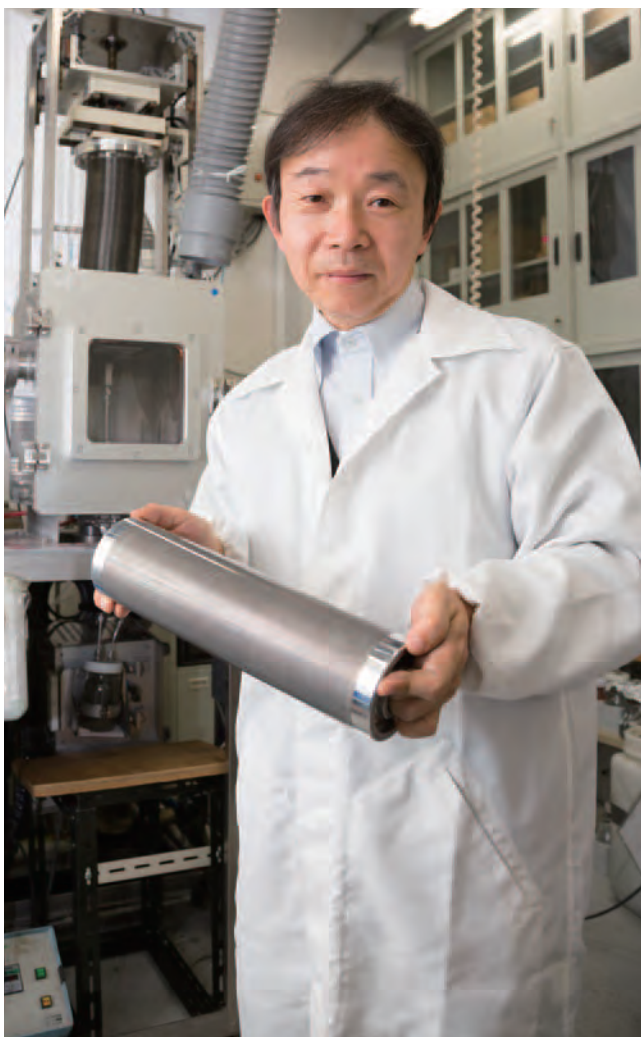
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The AD method: an innovative coating technology that defies conventional wisdom

A robust ceramic film can be realized without firing, merely through spraying!

Playing an active role in a diversity of fields, from semiconductor fabrication equipment to solar cell

Our life and society will change in this way!



Prime Senior Researcher,
Advanced Manufacturing Research Institute

Jun Akedo

The Aerosol Deposition (AD) method is a technology that can be utilized to fabricate thick ceramic films without the need for firing. Films fabricated using this method have high hardness and density, and smooth surfaces. They are already being deployed as plasma-resistant components (coating materials) in semiconductor fabrication factories where they are contributing to dramatic improvements in productivity. Application is also currently advancing in the energy field in products such as solid-state lithium ion batteries and thin film dye-sensitized solar cells. On this account, these films are certain to play key roles in next-generation energy technologies, fuel resource conservation, and cost reduction.

A mysterious coating born of an accident

Ceramics are normally considered as materials made through firing. Fabricating a ceramic without firing was inconceivable; until several years ago, this was global conventional wisdom. Jun Akedo, Prime Senior Researcher at the Advanced Manufacturing Research Institute is the person who overturned conventional wisdom.

Akedo inadvertently discovered a method for producing ceramic thin film without the need for firing. After several years of trial and error, he elucidated the mechanism of this phenomenon and established the basic technology. Currently it is a technology that is becoming indispensable for improving the production efficiency of semiconductor chip manufacturing equipment.

This method was born around 1994. At the time, Akedo was engaged in the R&D of microdevices at the Agency of Industrial Science and Technology's Mechanical Engineering Laboratory (one of the predecessors of AIST). As part of this effort, he started to research a coating method for forming thick ceramic films on substrates in an attempt to fabricate piezoelectric film-type microactuators^{*1}. The research was funded by the national



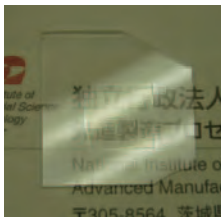
- Apparel
- Household goods
- Information technology
- Eco products



- Environment, resources, energy
- IT and telecommunications
- Electronics
- Motor vehicles
- Materials
- Medical welfare such as a denture and an artificial bone



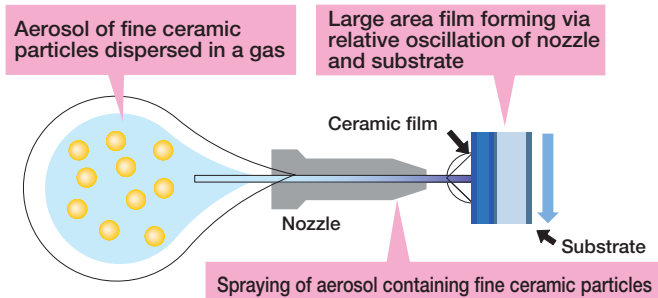
- ▲ The film that forms on the substrate does not peel off even when scraped with sharp tweezers.
- ▶ Transparent ceramic films can be fabricated at ambient temperature. This is an α -alumina (sapphire) film.



Terminology at a glance

Aerosol deposition method

In this technology, fine ceramic particles are mixed with gas and sprayed from a nozzle under reduced pressure. The resulting aerosol jet collides with the substrate and forms a film. Utilizing the room temperature impact consolidation phenomenon, dense, highly adhesive, and moreover hard ceramic films can be formed at room temperature on various substrate materials, including metal, glass and plastic. The rate of film formation is more than several tens of times faster than conventional thin film formation technology.



budget and started from a need for such technology but there was also interest from Akedo himself, a graduate in applied physics, who engaged in the development of a unique method for film-forming that entailed the layering of fine particles.

Akedo tried a method that melted the fine particles and sprayed them in order to layer the fine metal oxide particles that form the ceramic material onto a substrate. In order for the fine particles to form a film on the substrate, they were deposited and sintered on a red-hot substrate or fused via heat from a plasma^{*2}. However, the results weren't quite as anticipated: the films peeled off or crumbled.

Then one day during this time of trial and error, Akedo was cooling a substrate after an experiment and shutting down his apparatus when he mistakenly sprayed fine particles onto the substrate. "When I took a look, I saw some blackened residue had adhered to the edges of the substrate. It was dry and hard and wouldn't crack even when I scraped it with sharp tweezers. This didn't look like just residue. So what exactly was it? I felt that something just didn't quite add up."

This was a trifling phenomenon that would have been so easy to overlook. Previously, Akedo had noted that a similar phenomenon had occurred occasionally but he hadn't paid much attention to it. However, at the time he was coming to a dead end with his experiments so he decided to investigate what it was.

If an organic substance had adhered, it should have melted at high temperature. However even after heating at 500–600°C overnight, the residue remained adhered to the substrate.

"This certainly implied that ceramic particles had hardened

at ambient temperature. I had a hunch that this was an important phenomenon and was in fact quite startled." Akedo straight away used the same method to spray various ceramic particles onto substrates. He subsequently observed that other materials adhered to substrates at ambient temperature, forming hard films. This was the birth of an all-new coating technology called the Aerosol Deposition (AD) method for making ceramic films through the impact of collisions from spraying a mix of fine particles and gas.

Does a ceramic solidify at room temperature? A groundbreaking discovery that confounds conventional wisdom

Still, why do ceramic particles solidify in such a dense manner at room temperature? "I initially thought that the heat resulting from the collisions of fine particles with the substrate was enough to melt them. This is a common-sense explanation that can be derived from physics. Just like when cosmic dust is pulled by gravity to form planets, the energy from high-speed particle impacts heats up the particle surfaces and results in fusing. However, when I actually carried out measurements, in no way could I detect temperatures high enough to melt fine particles on the substrate surface. Whatever was happening, was happening at room temperature. Moreover, by raising the spraying velocity in order to raise the kinetic energy with the aim of

*1 **Piezoelectric thin film microactuator:** A compact drive device that employs a piezoelectric material whose shape changes upon application of a voltage.

*2 **Plasma:** Formed through electrical discharge in a gas, a gaseous state particle group that is comprised of positively charged particles (ions) and negatively charged electrons present in approximately the same ratio (electrically neutral) in ionized states.

achieving even denser adhesion, the opposite happened: the substrate was abraded.”

Subsequently, a new method was developed for measuring the particle impact velocity: after direct measurement of these impact velocities, we found that the velocity that could form films ranged at most between 200 and 300 m/s. According to simulations, at such impact velocities, the surface temperature of the fine particles would not reach that required for sintering ($>1000^{\circ}\text{C}$). In other words, some change occurring when the particles collided was transforming kinetic energy into binding energy, but it could not be explained with a traditional theory of melting and densification. Akedo believed that it must involve some unknown mechanism. Akedo decided to develop a hypothesis that could explain how particles could form a dense, hard film without undergoing melting.

“When collisions occur between ceramic particles and they break into even finer particles, they reach an unstable “active state” with the stable electron bonds between atoms slipping and detaching. When they return to a stable state, minute broken particles immediately adjacent to each other adhere together and densify. This was the essence of my

AD coating experimental setup

▼ Substrate sprayed with fine particles at reduced pressure.



hypothesis.”

This is, so to speak, just like a steamed bun impacting and solidifying. When the steamed bun impacts, its skin is ripped apart and its contents, red bean paste, are discharged. Then, this red bean paste forms bonds between adjacent steamed buns. Is this hypothesis really correct? In order to see whether the particle fragmentation phenomenon was occurring as predicted by his hypothesis, Akedo went about forming dense films by spraying mixtures of different particles and observing the fine structures of their cross-sections. The results indicated that particles that had collided with the substrate were fragmented at the nano-level and were deformed.

This proved that Akedo’s hypothesis was correct. At this time, a phenomenon of sparks flying during collisions could be observed just like sparks being emitted from flint. An alternative hypothesis was thus “Was the impacted surface temperature rising to the point where sparks were emitted?” However, the cause of the sparks was found to be dependent on the type of gas that accelerated and carried the particles; it was not because of a high temperature but rather, electrons being discharged physically from the surfaces when particles collided and this caused the surrounding gas to emit light.

Akedo called this phenomenon the room temperature impact consolidation phenomenon and the method derived from it the Aerosol Deposition (AD) method.

Solving the mechanism to target application development

Compared with films fabricated by traditional methods, the mechanical properties of films fabricated using the AD method are extremely good and the films form much faster. On account of the dense solidification, materials such as alumina^{*3} can be formed into transparent films, whereas such transparency is not easily achieved with the traditional sintering method. Besides microdevices, application was thought to be possible in a wide variety of fields; however, even when presentations were made at academic meetings, reactions were muted because people found it hard to believe in a method that overturned existing conventional wisdom by solidifying ceramic particles at room temperature.

Thereupon, Akedo modified his strategy, prototyping an actuator that used this film and comparing the film’s performance with those fabricated using other methods. Through this, from around 1999, companies started to show interest.

However, several companies that wished to carry out joint research raised concerns, saying “Even if film forming is

^{*3} Alumina: Aluminum oxide. Sapphire is a high purity singlecrystalline form.



Photograph: TOTO

▲ Plasma erosion-resistant components for TOTO's semiconductor fabrication equipment (yttria coating)

reproducible, we can't proceed with R&D directed at commercialization unless we understand the guidelines for discovering the optimum parameters."

"After all, I found that AIST was being asked to clarify the mechanism. Thereupon, based on the previous theory of film formation through particle fragmentation, I believed that the key to understanding was the mechanical fracture properties due to particle collisions more than the velocity of particles sprayed onto the substrate; I thus focused my efforts on determining the relationship between film formation properties and the optimum size, mechanical properties, and pretreatment conditions required for the raw material particles.

We found that to obtain a dense film, raw material particles of a certain diameter range were required. Although dependent on the material and its internal structure, films are formed only from particles with diameters of around 0.1–1 μm (micrometer, μ: 10⁻⁶). If the particles are smaller, they do not bond but end up forming a compacted powder, whereas if they are larger, deformation and bonding do not occur even after collisions and the fragments scatter and end up abrading the substrate in a manner akin to sand blasting. This became an important guideline in transforming this film forming method into a practical technology."

If the mechanism can be understood, the research route will then become clear. From around this time, significant progress was made in research in the form of a large-scale national project called "Nanostructure Forming for Advanced Ceramic Integration Technology" (2002, NEDO) that was completed in 2006. Subsequently, joint research was carried out with a number of companies starting with TOTO towards development of numerous applications, their practical application, and commercial-scale production. "Through this research, one major result achieved jointly with these private sector-companies was the firming up of strategic patents at an international level."

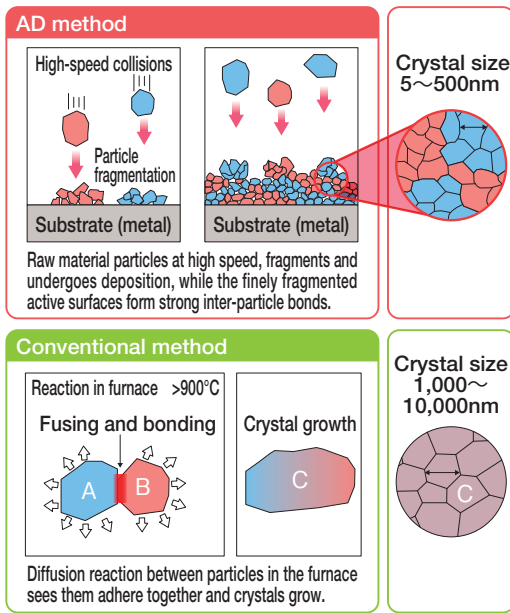
Application in semiconductor fabrication equipment; exploiting a hardness that cannot be abraded even by plasma

Terminology at a glance

Room temperature impact consolidation phenomenon

A phenomenon whereby impacting a substrate with high velocity fine ceramic particles results in the crystalline particles fragmenting on impact, then once again bonding together. Through this action, a robust film can be formed at room temperature. The discovery of this phenomenon resulted in the birth of the AD method.

Film-forming mechanisms: AD method versus conventional method



In 2007, TOTO commercialized a coating technology based on the AD method for semiconductor fabrication equipment. This coating technology, which employs ceramic yttria with hardness on par with sapphire, has become indispensable for next-generation semiconductor fabrication equipment.

A semiconductor chip is fabricated by forming a thin film on a silicon wafer and etching it to create fine patterns that form circuits. Currently, patterns as fine as the order of 20 nm (nanometer; n: 10⁻⁹) in width have been attained. Fabrication with conventional equipment is fast reaching its limits because the etching process entails generating a plasma inside the equipment to abrade the wafer; in doing so, the plasma also abrades the inner walls of the equipment. This in turn leads to the formation of abrasion residue. If this abrasion residue falls onto the chip, unintended patterns can end up forming: the finer the patterning, the more apparent the effects of the abrasion residue become, leading to a fall-off in yield.

"Fabs want to reduce their production costs by raising chip yields and one way of doing so is to prevent formation of this abrasion residue by coating the inner walls of the equipment. Yttria coatings applied using the AD method are an answer to such a need. These coatings are extremely

inert towards chemical reaction and by densely coating metal and glass components with yttria, which is highly resistant to plasma abrasion, chip yields are improved dramatically.”

Previously, thermal spraying*4 was used to coat yttria; although the resulting film was quite rough, it was still more effective than no coating at all. However, coating using the AD method results in a high density film with a nano-level crystalline structure that is an order of magnitude finer, with a four-fold increase in performance as well. Having said so, it has only been over the last one to two years that interest has actually increased. The needs of the times have finally caught up with this technology one might say. Currently, TOTO is expanding its factory and driving production. Through the marketing prowess and efforts of this joint development partner, superior performance and favorable coating cost have been simultaneously achieved, utilizing the potential of the current AD method; this can be said to be a case study of

using technology to increase competitiveness.



Will this become a key technology for deploying next-generation energy?!

Solidification at room temperature means that despite no large-scale equipment being required, the AD method being able to realize low-cost yet high-quality coatings. In 2004, a high transparency ceramic thick film measuring 60 cm by 60 cm was fabricated and at present, roll-to-roll manufacturing is possible. In what areas is this technology likely to be applied going forward?

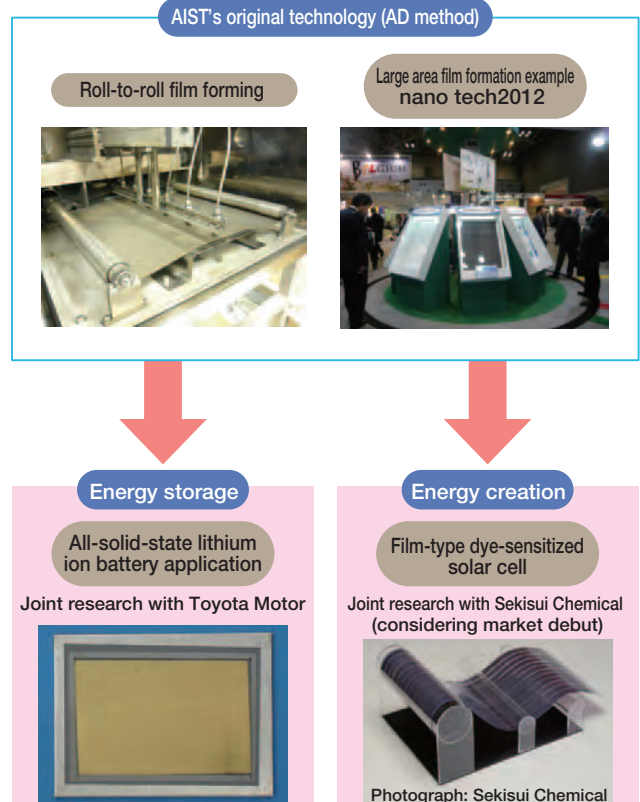
“Initially, application is likely in energy-related components, including lithium ion batteries. Research is underway to fabricate thin sheet batteries by solidifying the normally liquid electrolyte using this technology. In addition, light and flexible dye-sensitized solar cells (DSC) may be commercialized in the next one to two years.”

Toyota Motor is developing all-solid-state lithium ion batteries. The issue of fuel holds an important key to market penetration of hybrid vehicles and electric vehicles; Toyota Motor is conducting R&D on revolutionary next-generation batteries whose performance exceeds that of

Development history

1994	A phenomenon whereby ceramic particles can form a dense, solid film at room temperature is accidentally discovered.
Ca. 1999	The phenomenon (room temperature impact consolidation phenomenon) is verified.
Ca. 2001	The fact that a solidified body of ceramic particles becomes transparent is verified (successful fabrication of large high transparency film in 2004)
Ca. 2002	A large-scale national project (in Japan Nano-technology program) is promoted with the objective of application development for this technology jointly with six private-sector companies
Ca. 2006	Fundamentals of the mechanism of the room temperature impact consolidation phenomenon are elucidated, and basic rules are established leading to commercial-scale production technology
2007	TOTO commercializes coating technology for semiconductor fabrication equipment using the AD method  Photograph: TOTO
Present	Energy technologies such as lithium ion batteries (Toyota Motor Co.) and dye-sensitized solar cells (Sekisui Chemical CO.,LTD) are being developed. Furthermore, application is planned in fashion and design fields. 

AD method for large area film formation and application in the energy sector



▲ Examples of AD method application. Application is advancing for all-solid-state lithium ion batteries and film-type dye-sensitized solar cells.

*4 **Thermal spraying:** Heating and transforming a thermal spraying material into a molten or close to molten state using a gas flame or electrical energy as a heat source, and spraying it onto a substrate to form a thick film.

conventional lithium ion batteries. The AD method has come into focus as an enabling technology for next-generation batteries.

Further, the dye-sensitized solar cell is a type of thin film cell that is expected to be a next-generation, low-cost solar cell. If solar cells can be produced as lightweight films, these could be attached to walls and other surfaces. Sekisui Chemical is engaged in their development and it has adopted the AD method for forming the ceramic film that functions as the semiconductor layer in dye-sensitized solar cells. Because sintering is not required as part of the film forming process, the company has been able to achieve the world's highest power generation efficiency for a dye-sensitized solar cell employing a thin film substrate^{*5}, at 9.2% for a glass substrate and 8.0% for a plastic film substrate. If low-cost solar cells can be commercialized using this method, solar cells are likely to come into general usage.

Pursuing cost reductions with the aim of expanding application inroads into paints

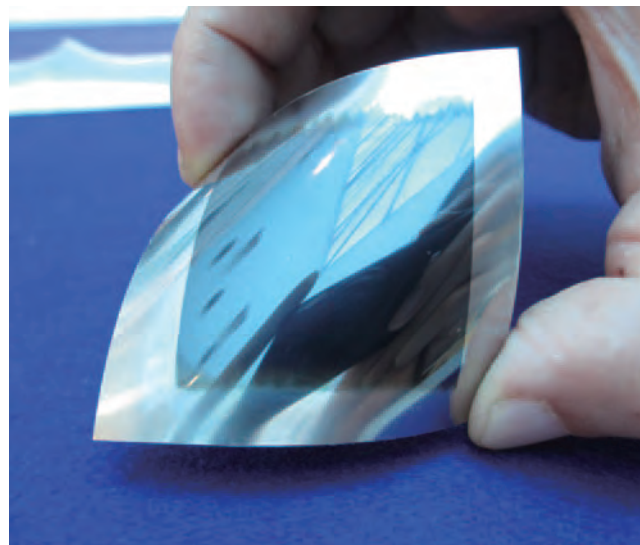
“Furthermore, I am positioning the AD method as an alternative technology to replace traditional coating.” From cellular telephone housings to automobile bodies, there is a literal mountain of technologies in this world that require painting. Through the AD method, Akedo plans to enable the painting of such devices. In fact, efforts are underway to coat cellphone housings and spectacle temples (eyeglass arms) through application of the AD method and in doing so, improve scratch resistance and moreover enable detailed designs.

“The key to widespread adoption is most certainly to what extent costs can be reduced. At present, the AD method has a lower cost than the vacuum coating method used for forming the recorded layer in CDs and DVDs but my aim is to reduce the cost by an additional one to two orders of magnitude and bring it to a level that is not much different from standard painting.”

Once this level is attained, application will then become possible for the painting of industrial parts with large surface areas, such as automobile bodies. Through this, automobiles would not be scratched by slight scrapes, while cellphones would emerge capable of retaining their color even after extended use.

“In order for this to happen, I plan to get back to the basics and push forward with research to elucidate the forming mechanism for finer films and based on this, improve film forming efficiency, establish precise powder material control technology, and verify its reproducibility.”

^{*5} **World's highest power generation efficiency:** Parameters are 4-mm square and AM1.5 100 mW/cm². Data based on Sekisui Chemical measurements.



▲ Flexible components with scratch resistance on a par with ceramics could be applied in coatings on cellular telephones and other devices.

Aerosol Deposition method A vision of the future

To me, there is no boundary between basic research and application development. Until now you had the science that was basic research, and what followed was the engineering or application development; but in practice, such a linear model does not apply. As one carries out application development, it becomes clear what basic research is significant; when one returns to basic research, the areas where efforts should be focused become apparent. By traversing between basic research and application development, it becomes possible to commercialize basic research in an efficient manner and through the advancement of technology, new science also progresses.

My wish is that such an exchange of science and technology will lead to a more affluent world, and that the AD method, born of such an exchange, will be used even 50 or 100 years from now and develop into a technology that is even more useful to society.



Claist: a high-performance clay-based thin film

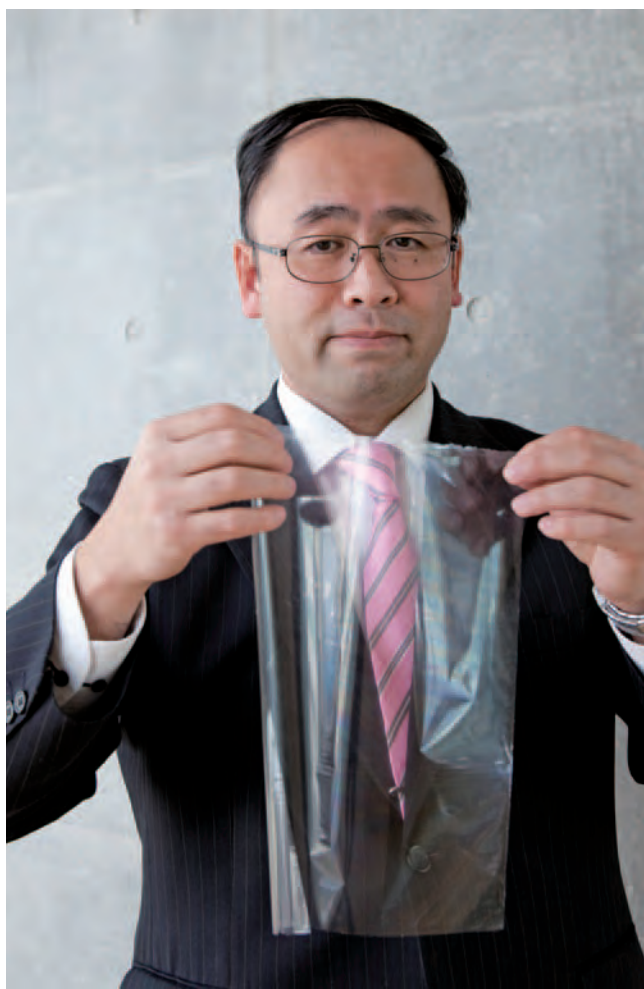
A clay-based film with astounding gas barrier properties and heat resistance

Various applications are being deployed, from chemical plants to packaging materials

Our life and society will change in this way!



Easy to mold and has high heat resistance but has low strength and breaks easily— Claist flexible clay film overturned this image of clay. Developed by AIST, Claist is comprised of 1 nm (nanometer; $n: 10^{-9}$) thick clay crystals; it has extremely high barrier properties for hydrogen and water vapor. It is already widely used as a sealant to prevent gas leakage in chemical plants. Moving forward, this clay film is expected to contribute to the realization of a safe, secure and moreover comfortable society through adoption in applications such as fuel cell vehicle hydrogen fuel tanks and OLED display substrates.



Prime Senior Researcher, Team Leader
Advanced Functional Materials Team, Research Center for Compact Chemical System

Takeo Ebina

The thinner the film, the greater the barrier properties?!

Clay materials are weak in water and soft unless fired, but once fired, they become brittle and break easily. As such, they tend to present an image of exhibiting high plasticity^{*1} coupled with low strength. In fact, this fragility meant that it was difficult to form thin ceramic films. However, in 2004, AIST defied conventional wisdom by successfully fabricating a flexible film from ceramic that was as thin as paper. The gas barrier properties^{*2} and heat resistance of this film were found to be extremely high. The name for the film, Claist, was derived from the words “Clay” and “AIST.” Currently, applications and commercialization are advancing in various industrial sectors.

AIST’s Research Center for Compact Chemical System is located in the east of the city of Sendai. Here, Prime Senior Researcher Takeo Ebina is the “father” of Claist. Ebina’s original specialty was waste treatment for environmental protection and he was researching methods to utilize clays as barrier materials for preventing leakage of organic



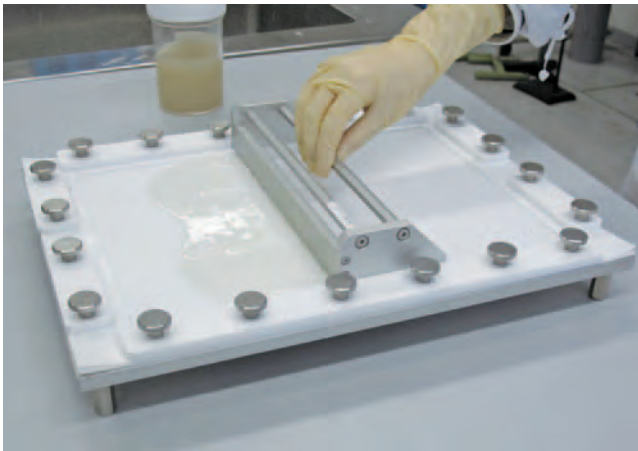
- Food
- Residential
- Information technology
- Eco products
- Medical treatment, welfare, caregiving



- Electronics
- Motor vehicles
- Aerospace
- Building & construction
- Materials
- Medical treatment, chemistry, biotechnology
- Food products

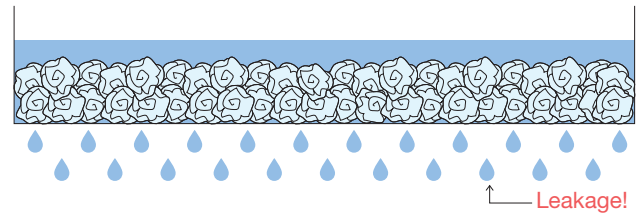
Claist manufacturing process

▼ In the solvent cast method, a clay dispersion is poured into a flat vessel to form a dry film. In principle, the process is the same as paper making.

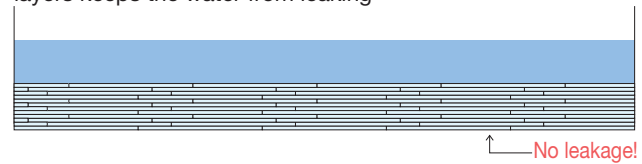


Principle of Claist

Crumpling up paper and spreading it over a deep colander results in water leaking.



Precisely and neatly spreading the paper to form multiple layers keeps the water from leaking



substances from waste treatment facilities.

Various types of clays exist. Clays widely produced in Japan's Tohoku region possess better water retention properties compared to clays from Aichi Prefecture that are commonly employed in pottery^{*3}. These Tohoku clays are commonly employed in the reinforcement of foundations at construction sites, soil improvement in agricultural land, and water-impermeable layers at the base of dams. In 2003, Ebina started investigating this clay property of not readily allowing water to pass through; in other words focusing on the water permeability of clay in an attempt to apply water barrier characteristics in barrier materials for toxic substances.

Ebina formed a layer of clay and poured water on it. However, the water did not seep through the clay layer. This meant that the clay was suitable as a barrier material but as the water did not seep through, actual data could not be collected. Thereupon, Ebina decided to gradually reduce the thickness of the clay layer and measure the time required for water to seep through. Here, an unexpected fact became clear.

“The thinner the clay layer, the slower the rate that water passed through it. In other words, barrier properties improved the thinner the layer was: the thinnest film actually possessed the highest barrier properties.”

20,000 stacked crystals prevent leakage of water and gas

How does such a thing occur? Air and water are present in the gaps between individual clay particles. If the air and water are removed, clay crystals normally sediment randomly. Under these conditions, gaps exist between individual crystals and water is able to permeate through. However, it was found that the thinner the clay layer, the

easier it was for all the individual crystals to become oriented in a single direction. Furthermore, clay that is usually brittle becomes flexible when fabricated into a film and it can be folded and bent.

A material with such high barrier properties that is also flexible and moreover, possesses the high heat resistance of clay surely must have some uses. The first practical use idea that came to mind was the potential for high performance sealing materials in chemical plants.

“When the gas barrier properties and heat resistance of this thin film were tested, a high heat resistance of 600°C was discovered as well as compression properties that could respond to variations in the joint gap between piping that results from temperature variations in metals. In other words, the film performs extremely well as a sealant.”

In fact, it has been known for some time that gas barrier properties increase dramatically when a small quantity of clay is added to plastic. Adding 5% clay results in a three-fold increase in gas barrier properties compared with a material that does not incorporate clay. In the case of Claist, if conversely clay constitutes 95% and the additive 5%, gas barrier properties are calculated to increase 2,400-fold. In fact, there are cases where this improvement reaches more than 10,000-fold. This is a key property of Claist.

*1 **Plasticity:** The property whereby applying force to an object results in its deformation and the object does not return to its original shape even if the force is removed.

*2 **Gas barrier properties:** A gas-shielding property. Particularly important when the objective is retaining quality, preventing oxidative degradation, retaining flavor, and preventing gas leakage in fields such as food and pharmaceutical packaging, electronic materials, and gas sealing material.

*3 **Firing clay:** The humidity-regulating tiles introduced in AIST Stories 2013 No.1 were developed by R&D on firing clay produced in Aichi Prefecture.



▲ Clay synthesis. Clay synthesized in a pressure vessel is used to fabricate a transparent film.

Hugely successful in chemical plants as an alternative material to asbestos

Since 2004, AIST has applied for numerous basic and applications patents based on this research as well as disseminating press releases about this heat-resistant barrier material based on clay film. Around 500 technical inquiries from Japanese and overseas parties have also been addressed and Ebina thereby came to realize the extent of related needs.

In actual fact, a diversity of technology fields can utilize the high barrier properties of Claist. As previously mentioned, high-performance, high-durability sealants are indispensable in ensuring the safety of chemical plants.

“For example, Teflon^{*4} used as a sealant softens at temperatures greater than 260°C and sealing properties are degraded. However, there are no such problems with Claist even at high temperatures of more than 300°C. Furthermore, traditional sealant sheets known as gaskets (employed at the joints between pipes) used asbestos^{*5}, but its use has now been prohibited on account of adverse health effects. For this reason, development of an alternative material to asbestos was prioritized.”

Use of asbestos, with its accompanying high durability and heat resistance, was no longer possible; the graphite used in its place was somewhat difficult to handle. In this situation, Claist, a material with good barrier properties and moreover easy to handle, was born. AIST and Japan Matex commenced joint development of an asbestos alternative gasket: in 2007, they completed a gasket with the highest performance among those utilized in Japan. This product

was welcomed by industry and currently, it has been widely introduced in fields such as thermal power stations, nuclear power stations, paper making plants, chemical plants, and petrochemical plants.

Subsequently, new products have been developed almost on an annual basis; starting with the development of a hydrogen gas barrier composite material in 2008 and including a self-healing gas barrier film and a heat-resistant electrically-insulating film.

Expanding applications, even in fuel cell vehicle hydrogen tanks

The water vapor and gas barrier properties, and superior heat resistance of Claist are highly sought after for many applications.

One such application is the barrier material in hydrogen tanks fitted to fuel cell vehicles. Amid an advancing global transformation from a carbon society to a hydrogen society, the spread of fuel cell vehicles is forecast to accelerate, with their fuel being none other than hydrogen. Hydrogen molecules are the smallest among gases; they easily leak through the minutest of gaps. Further, leakages can potentially lead to explosions.

The key requirements for fuel tanks used in fuel cell vehicles, which drive around with such a burnable fuel on

*4 **Teflon**: A type of fluororesin and trademark of U.S. company DuPont. The polymer exhibits excellent heat resistance, chemical resistance, flame retardance, and non-stick properties.

*5 **Asbestos**: A fibrous mineral with excellent heat resistance, heat-retention properties, fire-retardance, sound-proofing, and wear resistance properties. Usage is currently prohibited on account of the high risk of lung cancer and mesothelioma among those exposed.

Japan Matex's Clear Matex gasket



High electrical resistance; also suppresses formation of rust due to electric corrosion.

Model of hydrogen tank used in a fuel cell vehicle



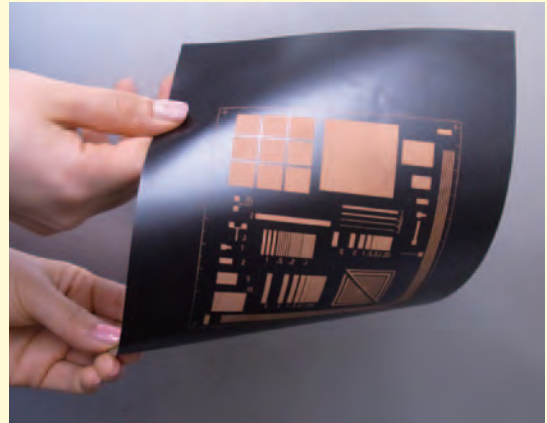
Contributing to reduced fuel consumption and improved energy conservation through tank lightweighting and preventing gas leakage.

Daiwa Can's Laclain high gas barrier food packaging material



Gas barrier performance barely degrades even if crumpled due to its self healing properties.

Sumitomo Seika Chemicals' Toughclai performance film



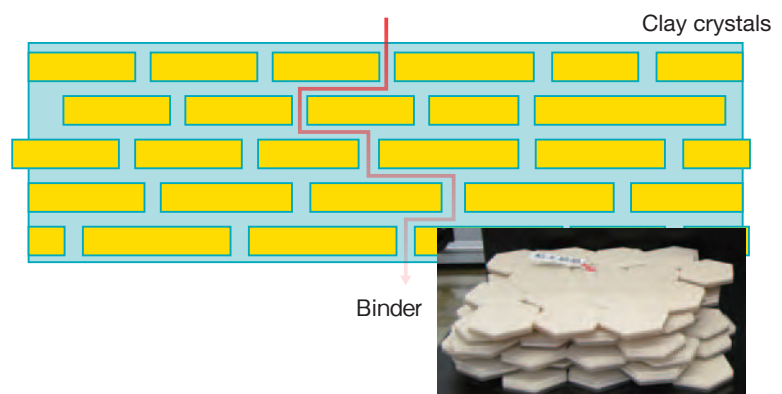
Contributing to improved productivity of printed substrates and sensors, and ensuring safety of electrical equipment.

Terminology at a glance

Claist's gas barrier properties

Clay crystals are platelets measuring around 1 nm in thickness. If 20,000 of these platelets are stacked in parallel in many layers, for molecules to pass through Claist, they must collide with walls 20,000 times and change their path. As a consequence of this "maze effect" which results in molecules getting lost and having trouble escaping to the other side, there are effectively no through holes and this manifests as a high barrier effect.

Manifestation mechanism of gas barrier properties through "maze effect"



board, are low permeation of fuel through the tank walls as well as safety. Currently, a search can be said to be underway for a new barrier material for tanks that features a high degree of safety.

“Maruhachi and Chugoku Kogyo are, independently and jointly with AIST, prototyping lightweight fuel tanks whose inner surfaces are coated with Claist and conducting performance testing. The arrival of a hydrogen society looks like becoming a perfect opportunity for Claist to spread throughout the world. I do not want to miss this golden opportunity. I plan to publicize Claist on a global basis and in several years’ time, proceed through to standardization.”

Furthermore, in addition to its gas barrier properties, transparency and flexibility are properties that one can anticipate to be applicable in the electronics field headed by smartphones. This is on account of the increased number of models of electronic equipment using organic electronics (OLED)*6 in their displays. High transparency, heat resistance, solvent resistance, and gas barrier properties

that shield oxygen and water vapor are required of plastic substrates used in OLEDs but water vapor molecules are small and cannot be shielded easily.

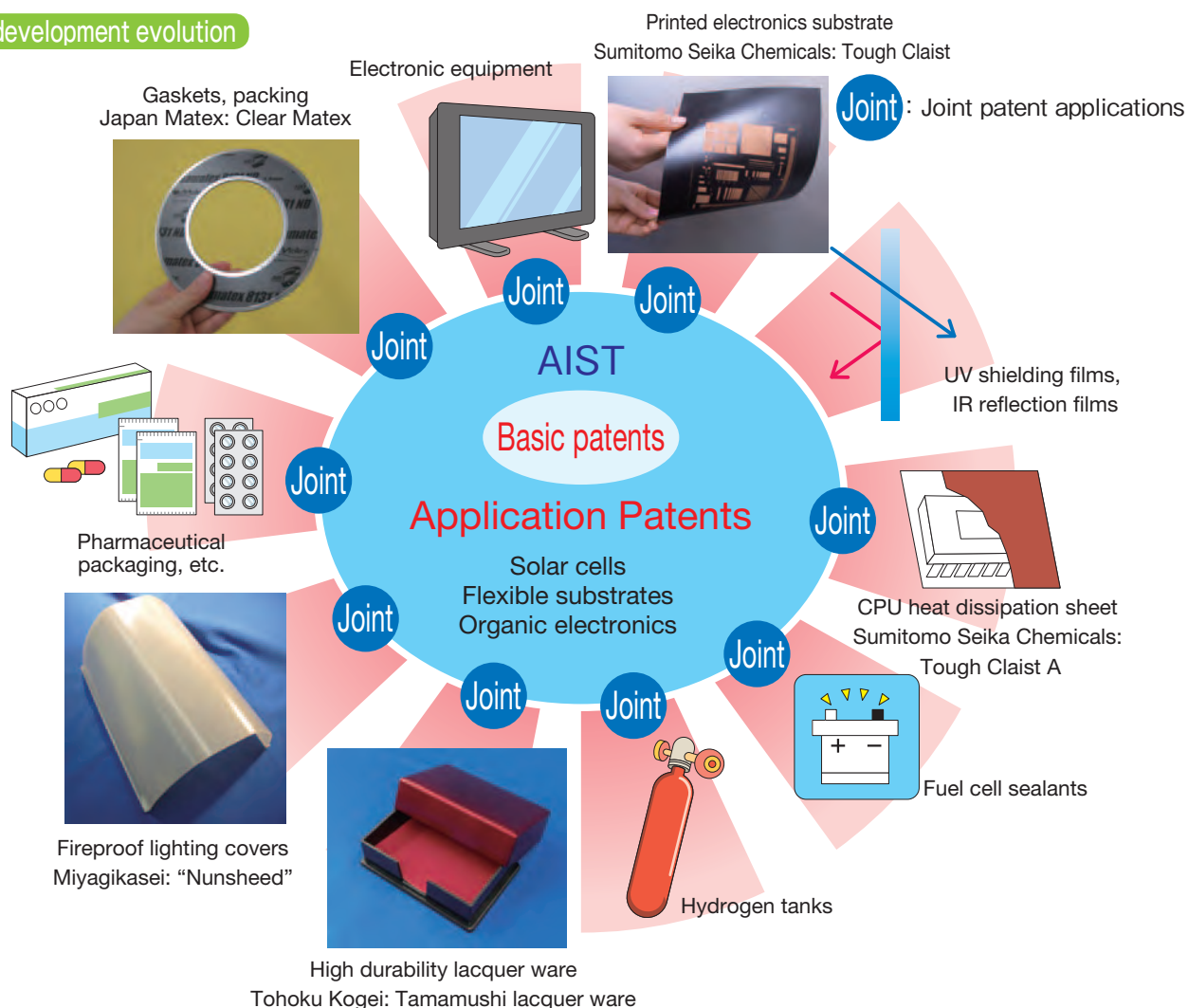
“The ideal plastic that satisfies all of these properties does not yet exist. However, Claist has the potential to satisfy all of these requirements. Using a synthetic clay results in high transparency and it is thought that this can realize the “viewability” that is important for displays.”

The problem is that at present, the mechanical strength of Claist is not yet that high. AIST is proceeding with further R&D directed at realizing both flexibility and resistance to breakage.

Consortium inaugurated: alliances directed at diverse application development

Claist can be utilized in the most familiar of fields, for example, food and pharmaceutical packaging materials. Adopting a three-layer film structure with the outer layer comprised of PET film, the middle layer Claist, and the

Claist development evolution



▲ The scale of industry based on Claist is estimated at approximately JPY300 billion. If progress is made in application development, this will surely lead to revitalization of the economy in the Tohoku region.

inner layer polypropylene film can prevent the permeation of oxygen and extend the preservation of freshness as well as prevent changes in the ingredients from occurring. At present, pricing is higher than conventional packaging materials but if a cost reduction of more than half can be achieved, the potential is high for significant inroads to be made in this application.

Application is seen as possible in areas such as sealants to prevent the leakage of refrigerant gas from heating and air-conditioning units and furthermore, coating materials that prevent rusting, and flame-retardant interior materials for buildings and vehicles. Currently, joint research and development is underway with companies in these various fields.

The respective technology transfer situations vary depending on the product, from those in the planning stage through to those that are just prior to commercialization.

AIST inaugurated a consortium known as the Clayteam^{*7} in 2010 in order to organically link these joint projects and promote R&D. Under the chairmanship of Ebina, approximately 50 corporations and associations are engaged in comprehensive research that gathers together manufacturing expertise.

“What technologies should we bring together and in what manner in order to efficiently develop what we are targeting? AIST is tasked with major role as coordinator in this comprehensive development.”

Moving forward, cost reductions will be pursued for clay raw materials, raw material pastes for films, and commodity films, and usage in a broader range of industries is anticipated for this new material that has emerged from the Tohoku region, headed by electronics and automotive and including, aerospace and power electronics.

Development history

2003

Gas barrier properties of clay film discovered

2004

Transparent clay film invented

2006

Water-resistant clay film invented

2007

Asbestos alternative gasket commercialized



2010

Clay for film applications commercialized



Raw material clay for Kunimine Industries' Kunipia M performance film

2011年

Self-healing gas barrier film developed
Continuous production of thick films enabled

Claist

A vision of the future

“By making slight modifications to a clay that exists in the natural world we came up with Claist, a “natural blessing” as it were. Because it’s merely earth, there are no associated environmental impacts during its manufacture, nor its disposal. By manufacturing practical products from this material born of a region’s natural environment that are of use to society, we can evolve businesses whereby the region’s raw material does not end up merely at the local product level. Through this, I feel that we can bring about a regional economic effect, as well as furnish workplaces for the region. I will continue to leverage the benefits of not only clay but various other natural materials such as minerals and wood, advance “blessed product creation” in new industries, and carry out product creation leading to true sustainability.”



*6 **Organic electronics:** Electronics based on organic semiconductors made by deposition or coating of organic substances on plastic substrates.

*7 **Clayteam:** A consortium with AIST at its core established as a forum for collaboration from various fields and industries in product creation through material development leveraging clay films and inorganic nanomaterials.

Growing GM strawberries in a completely closed system plant factory

A World First! A Canine Medicine Derived from GM Plants Comes onto the Market

Promoting the plant biotechnology industry and contributing to medicine

Plant Molecular Technology Research Group, Bioproduction Research Institute

Our life and society will change in this way!



AIST, Hokusan Co., Ltd. and the Kitasato Institute have developed and started to sell a medicine for dogs. The source of this medicine is strawberries that, thanks to genetic modification, produce a canine interferon. Genetically modified (GM) plants can be used as a raw material source for plant-derived medicines. Production processes for new pharmaceuticals can be developed, and the raw materials for herbal medicines and such can be cultivated. These will help to stabilize supplies and increase concentrations of active ingredients.



▲ Inside the plant factory



▶ GM strawberries and Interberry alpha



Reliable production of useful substances

Plant-derived proteins are often used as raw materials for pharmaceuticals, but plants do not always reliably produce the desired substances. Wouldn't it be better if plants could be genetically modified to express the appropriate genes in large quantities? On this basis, R&D into pharmaceuticals sourced from GM plants is being pushed forward in many countries.

However, matters are not that simple. Gene silencing^{*1} mechanisms operate in plants, inactivating foreign genes that are introduced. AIST's Hokkaido Center has investigated this problem and in 2010 developed a technology to cause the desired substances to be produced in large amounts, using RNA^{*2} derived from a plant virus that suppresses the silencing mechanism. Finally, in 2013, AIST succeeded in commercializing a medicine using the fruit of a GM plant as the drug substance. This medicine is a drug that suppresses inflammation of the gums in dogs, sourced from strawberries that express a canine interferon^{*3}; it went on the market in March 2014.

R&D into using GM technology to create high value-added substances such as raw materials for medicine in plants is being conducted in various institutes and countries. AIST, however, is the first in the world to use GM plants as sources for medicine and achieve a commercial product without extraction and refining processes. As the result of a decade of research, AIST has pioneered a new pharmaceutical production process that uses production by GM plants.

Developing a plant factory for manufacturing medicine

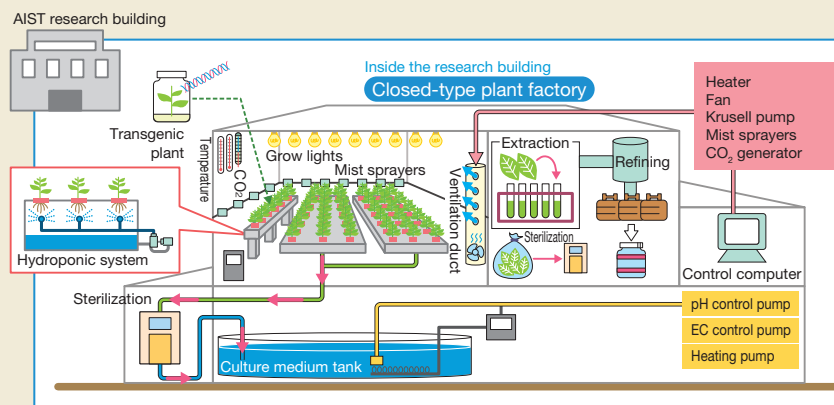
The reason a canine medicine was selected to be the first product is that the approval process of medicines for animals is quicker than that for humans. It was also significant that many dogs suffer from gingivitis and there are few on the market that suppress gum inflammation. As to why strawberries were selected as the source plants,



Terminology at a glance

Plant factory

AIST's plant factory is equipped with artificial environment functions, so temperature, humidity, CO₂ level, wind speed and airflows in the cultivation room can be precisely controlled as desired, and almost any kind of plant can be grown. It is also equipped with dispersal prevention systems complying with the Cartagena Protocol on Biosafety. The factory is divided into a cultivation area and a production area, so the final product can be manufactured from the plant within the one building.



Group Leader Takeshi Matsumura explains: "Firstly, the range of plants that can be genetically modified is limited. For canine interferon, potatoes actually provide a greater yield than strawberries, but potato sprouts contain toxins; so, an additional process to remove the toxins is required. In addition, strawberries do not need to be heated before consumption, which is advantageous for a substance like interferon that is heat sensitive.

The genetic modification itself was not particularly difficult for the expert Matsumura, but there were great difficulties to overcome in developing the plant factory. AIST started on the new development of the plant factory in 2007. In contrast to ordinary plant factories that grow vegetables for consumption, this plant factory was constructed to cultivate a GM plant. Therefore, it had to be a special-purpose space completely sealed so that genetic material would not spread to the outside. It also needed to guarantee reliable production and quality. Developing a factory with these features involved a succession of trials and errors.

Matsumura expands: "For example, when the artificial lighting was set up to provide daylight brightness levels, the room temperature rose to 80°C and the plants withered. Then, when air conditioning was used to suppress this temperature rise, very cold air was being circulated at high speeds, and that too made the plants wither. All kinds of expertise had went into balancing the contradictory requirements."

Since completion, the plant factory has provided some surprising discoveries. For example, in an environment without a day–night cycle, the strawberries can be harvested sooner but the plant lifetimes become shorter. It was also found that potatoes can be cultivated hydroponically, which was previously thought to be difficult.

Can the ingredients for traditional Chinese medicine be harvested in Japan?

This R&D has accomplished more than just the reliable

production of a plant-derived medicine. It will contribute to the development of new forms of industry—the production of raw pharmaceutical materials from GM plants and the production of substances using plant factories. AIST is pushing forward with research into the cultivation of rice, soy, potatoes, tobacco, herbal plants that provide the ingredients of traditional Chinese medicine, and so forth, which have as yet published little about the results of hydroponic cultivation in the plant factory.

Matsumura says: "Many of these herbs are currently harvested only in certain regions in China and elsewhere, and many of them cannot be artificially grown. Perhaps we can artificially grow them if we can reproduce the conditions of those regions within a factory; we may be able to produce herbs that are many times more medicinally potent. We will work to improve the capabilities of the plant factory. We aim to stimulate the plant biotechnology industry, help people and animals with medical treatments, and contribute to the promotion of local industry near our research base in Hokkaido."

Partner's Voice

(Noriko Tabayashi, Hokusan Co., Ltd.)

Thanks to AIST's wide-ranging support, from the initial research phase to actual production, we have managed to achieve a commercial product. Hokusan, AIST and the Kitasato Institute have successfully combined to pursue common goals with great sensitivity to the needs of society and the market. We are looking forward to further cooperative research into practical applications.

*1 **Gene silencing**: When foreign genes are introduced into GM plants, they are often recognized by the plants as being alien to those plants and are prevented from expressing.

*2 **RNA**: Ribonucleic acid, a molecule involved in gene activity.

*3 **Interferon**: Substances that protect the body in many ways: suppressing viruses, preventing cancer, triggering the immune system, and such. They are used in the treatment of patients with viruses such as B-type and C-type hepatitis, and malignant tumors including renal cell carcinoma and leukemia.

Communication aid by brain waves: the Neurocommunicator

Understanding the Wishes of Patients with severe motor deficits by decoding the brain waves

Supporting the daily lives of patients with a safe and easy-to-use brain-machine interface

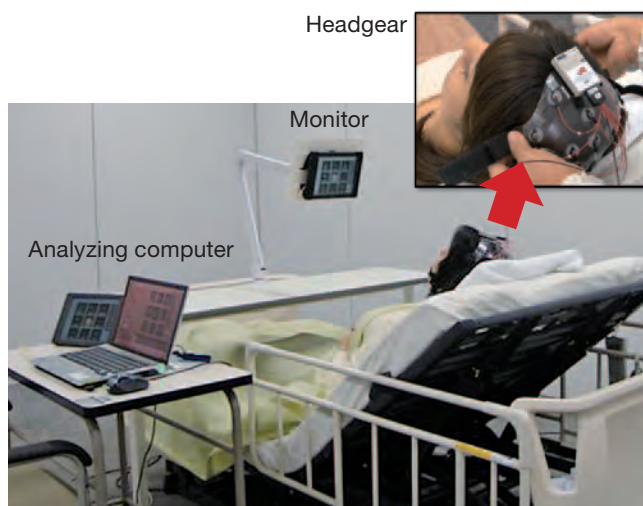
Neurotechnology Research Group, Human Technology Research Institute

Our life and society will change in this way!



Some patients cannot express their wishes because, even though their minds are working, disease or injury of the brain prevent them from talking or writing. When it is difficult for a patient to express their wishes, there is an extra burden on the patient and on caregivers. If a small and easy-to-use brain-machine interface—the Neurocommunicator—can be realized and becomes common in care venues, remarkably unhindered communication will be possible and the quality of life of patients will be greatly improved.

Neurocommunicator Equipment



▲ The patient wears the brain wave-measuring headgear and a small monitor screen is positioned in front of the patient. Brain wave data from the headgear is collected and analyzed by a computer beside the bed.

A compact device that can accurately express intentions

Can a machine be directly connected to the brain to decode the thoughts in a person's head and control external equipment? The brain-machine Interface (BMI)^{*1} is like a technology from a science fiction story, but progress is accelerating in Japan and other countries to make it a reality. It is already a commercial product in some areas in fields such as welfare services, sports and toys.

In the field of welfare services, we anticipate that it will be introduced to venues for the care of patients who, due to incurable diseases such as amyotrophic lateral sclerosis, the consequences of accidents, and suchlike, cannot move their bodies or talk and cannot express their wishes to those around them. Excluding those patients whose cognitive capabilities are greatly reduced, it is very stressful both for a patient and for their caregivers if the patient has no way to share their thoughts when they have feelings and needs that they wish to express.

There are already BMIs that are useful for the expression of these wishes but they have many practical problems, such as the size and cost of the equipment and difficulty of operation. Moreover, to measure the tiny electric currents inside the brain, some types require that electrodes be implanted by surgery. These devices cannot really be considered convenient and safe. Now, though, we have the Neurocommunicator, a BMI that non-invasively measures brain waves. It is superior to other BMIs on the following aspects: the compact size of the apparatus, the speed and accuracy of decoding brain waves, and the range of ideas that can be expressed. The Neurocommunicator was press-released in 2010 by a leader of Neurotechnology Research Group, Dr. Ryohei P. Hasegawa.

"I was originally involved in basic research in brain science. Around 2008, I came to know patients in the 'totally locked-in state', for whom the expression of their wishes is extremely difficult, and I decided that I would try to make a contribution to society by developing more convenient devices to support the daily lives of these patients."

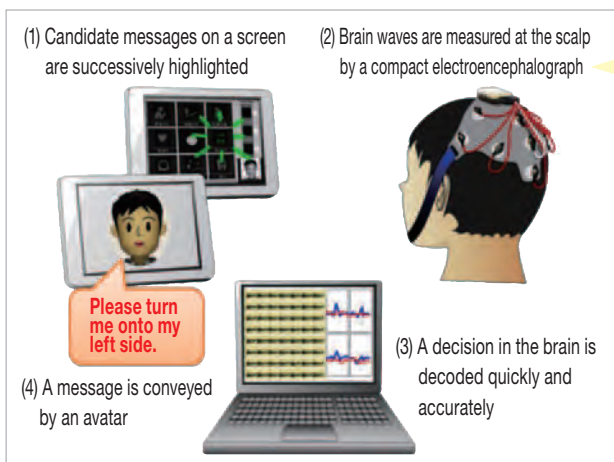


- Food
- Residential
- Information technology
- Medicine, welfare, caregiving
- Services



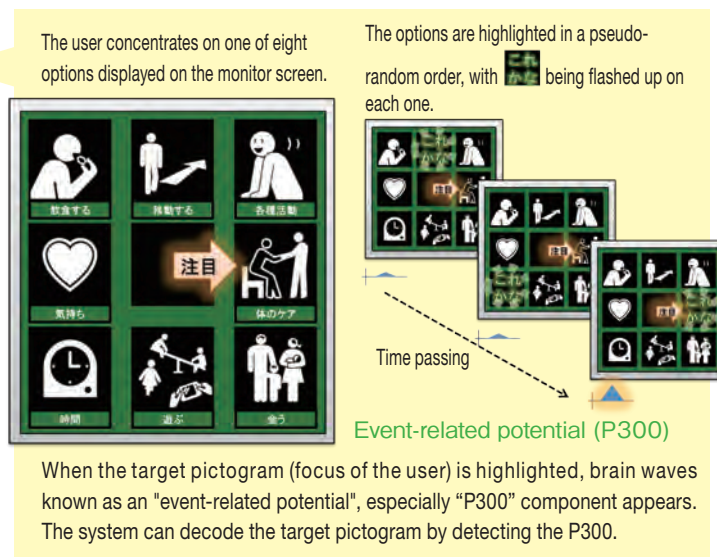
- IT and Telecommunications
- Electronics
- Medicine

How the Neurocommunicator is operated



▲ Brain wave data is decoded while the user wearing the headgear is concentrating on one of the pictograms linked to specific messages on the monitor. From the result of the decoding, the desired message is inferred and is expressed by the avatar.

An example of a thought expression menu



A brain wave is detected and a decision is identified within seconds

The electroencephalogram of the Neurocommunicator is very compact, about half the size of a mobile telephone. Eight channels of brain waves can be measured at the scalp simply by the patient wearing a cap in which the electroencephalograph is incorporated.

The patient selects the idea they want to express from a thought expression menu displayed on a computer screen. An initial display shows pictures and text labels for broad categories of thoughts, such as food/drink, movement, body care, and feelings. When one of these is selected, a menu of more specific items is displayed. By proceeding through the sequence of menus, the patient can express precise requests and feelings.

Dr. Hasegawa explains: "Which item has been selected can be identified by analyzing the brain waves. The candidate items are randomly highlighted, and when the selected candidate is highlighted, the brain responds with a 'Yes!' The change in brain waves that this causes is the key to identification. The brain waves are analyzed with a specific decoding algorithm; this algorithm quickly and accurately infers the patient's decision in the brain."

Many previous developers of communication aid based on brain wave-based BMIs (sometimes called Brain-Computer Interfaces: BCIs) focused on methods of inputting words one character at a time. With these previous technologies, a single selection usually takes ten seconds or more. Moreover, the longer the message that the patient is trying to convey, the longer the time needed for brain wave measurements and the more often erroneous selections are made. In contrast, the Neurocommunicator requires only three to five seconds for one selection (from eight options), regardless of the length of the message. Repeating the process just three times makes it possible to select from 512 (8³) messages. The decoding accuracy is good, at more than

90%.

In addition, the way thoughts are conveyed is user-friendly, with an avatar selected to represent the user appearing on the screen and speaking. This means that more natural communication is possible.

Working toward a practical implementation soon!

The places the Neurocommunicator will be used are ordinary homes and hospital rooms, which are affected by various kinds of electronic interference from air conditioners, refrigerators, etc. It is difficult to measure tiny brain waves in these environments, but Dr. Hasegawa and his staff are devising a unique new electronic shielding system to overcome this problem. Since his initial announcement, he has had a flood of enquiries from the families of incurable patients; clearly, there is a compelling need for this equipment in the fields of caregiving and welfare support. He has now completed a prototype for clinical studies; tests were started with monitor patients with the latest version of the equipment in the spring of 2014.

Dr. Hasegawa says "There has been a greater range of problems than I initially expected and development has been slow, but we are working hard to achieve a practical implementation soon. The Neurocommunicator is still regarded as an 'amazing' technology, but my hope is that some day it will be a familiar thing, simply improving the connections between people."

*1 **Brain-Machine Interface (BMI)**: A general term for devices that directly connect a brain with a machine. These can be broadly divided into invasive types, which use an intracranial implant to record brain activity and/or provide electronic stimuli within the brain, and non-invasive types, which measure neural activity such as brain waves from the scalp. The Neurocommunicator is one of the latter.

A world-leading recycling technology from AIST High-efficiency recovery of a rare metal from “urban mines”

The rare metal tantalum “mined” from electronic devices

Advanced Recycling Technology Research Group, Research Institute for Environmental Management Technology

Our life and society will change in this way!



Rare metals have been discarded along with the electronic devices because there was no way of recycling them. However if AIST technology can be deployed to recover these metals with high efficiency for subsequent reuse, Japan will no longer have to rely entirely on the import of rare metals that are indispensable for electronic devices. Furthermore, if this world-leading technology can be exported, then the result will be not only economic stimulus, but also a contribution to global environmental protection.

How can rare metals be separated from crushed components?

Japan boasts meager natural resources and has been reliant on imports for the vast majority of its requirements. In addition to the emerging possibility that Japan could become a country possessing energy resources on account of the methane hydrates that exist in neighboring waters, there is in fact one more major resource that exists: urban mines.

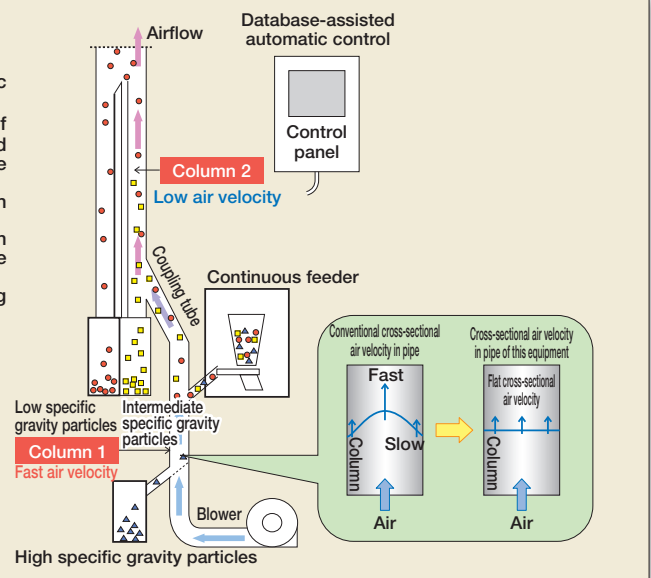
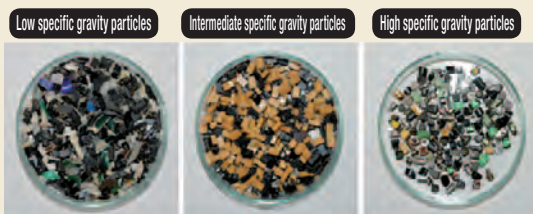
Urban mines are the valuable resources contained in discarded products such as consumer electronic products. One can anticipate an intelligent material cycle if these resources are recovered and reused through recycling. Having said so, “mining” is by no means easy. The target is trace quantities of metal used on the printed circuit boards of discarded consumer electronic products; in contrast to natural mines where resources are concentrated, these resources are spread thinly throughout the whole of Japan. This represents the key challenge. Moreover, to begin with, the majority of rare metals cannot be recovered using standard recycling methods employed in smelters to process copper and other precious metals.

Research Group Leader Tatsuya Oki who handled

Terminology at a glance

Double tube pneumatic separator

- Procedure for separating rare metals using a double tube pneumatic separator
 - (1) Only fragments measuring 2–5 mm are separated from the pieces of crushed components and circuit boards. After sorting in an inclined and low-intensity magnetic shape separator, they are carried to the double tube pneumatic separator.
 - (2) Particles with high specific gravity fall in the No. 1 Column with high air velocity and are recovered.
 - (3) Particles with intermediate specific gravity fall in the No. 2 Column with intermediate air velocity and are recovered and sorted from the floating particles with low specific gravity.
- In this manner, sorting is carried out based on specific gravity by using various airflow velocities.





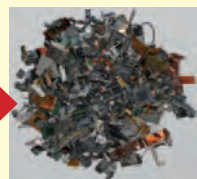
Flow of tantalum capacitors recovery



Printed circuit board

Crushing

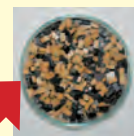
Components stripped from printed circuit board in their original form



Various components comingled

Sorting

Double tube pneumatic separator, inclined and low-intensity magnetic shape separator, etc.



Tantalum capacitor "concentrate"



Tantalum refining

Metal recovery

Refining of various metals

Metal recovery

development of the recycling technology had this to say about the difficulty of recovery.

"In order to carry out recycling, you need to first strip off the electronic components such as tantalum capacitors^{*1} from the printed circuit boards before processing in a smelter. Stripping off electronic components that may measure but a few millimeters while retaining their original form is not easy by any stretch of the imagination. And once they have been stripped off, you are then confronted with a mixture of various component from which rare metals cannot be recycled with any degree of efficiency." Without being able to sort and recover the components containing these important rare metals from this mixture of electronic components, this precious treasure ends up being worthless.

Tantalum components separated and recovered in a world first

AIST was the first organization to develop the equipment required for such new resource development and it now possesses world-leading technology. In 2012, AIST succeeded in developing an advanced sorting system that realized rare metal recycling by recovering electronic components such as tantalum condensers based on their type from discarded printed circuit boards. This system was comprised of a double tube pneumatic separator^{*2} for recovering only specific electronic components such as tantalum capacitors and an inclined and low-intensity magnetic shape separator^{*3} that pre-sorts component such as aluminum electrolytic capacitors and quartz resonators. Through a combination of these two devices, tantalum capacitors can be recovered in high purity from this group of comingled waste electronic components. While infrastructure for recycling rare metals other than tantalum is starting to be established, this is the first system in the world that enables recovery of tantalum capacitors (located at Re-Tem Corporation's Mito Plant).

Currently, development of the second such system is underway. Until now, relatively large printed circuit boards from personal computers and servers have been targeted for recycling but the second system features enhanced performance enabling the separation and recovery of smaller components found in such devices as laptop

computers, cellphones, digital cameras, and smartphones. This is in line with the prevalence of these small domestic appliances and telecommunications devices in the market.

"The number of columns (tubes) has been increased compared with the first unit, and the material types that can be separated has been increased. We also succeeded in downsizing the technology in order to avoid a larger unit size accompanying an increased number of columns."

Leading the world in recycling technology

Tantalum recycling can only be realized if an unbroken cycle can be put in place such that material is recycled and used in subsequent production. To this end, the Strategic Urban Mining Research Base (SURE)^{*4} was established and efforts will start to establish a recycling system jointly with AIST, recycling companies, and equipment manufacturers. This is the first such attempt in the world and if it is realized, it is likely that large-scale and furthermore high purity rare metal recovery will be realized.

"Moving forward, while establishing recycling technology as a proud specialty of Japan, we aim to simultaneously push ahead with comprehensive technology packaging and standardization, and have Japan lead the world as the founding nation of urban mine development. We do hope that our technology will be used throughout the world to achieve global environmental preservation."

*1 **Tantalum capacitor:** Tantalum is a rare metal whose price is exceeded only by those of precious metals. Capacitors using this metal are employed as active components that accumulate and discharge electrical charges in the electrical circuits on printed circuit boards. Compared with other capacitors, they are more compact and have better frequency characteristics.

*2 **Double tube pneumatic separator:** A sorting device that utilizes multiple columns (tubes) employing specific upward airflow rates in order to sort particles based on their specific gravities. Heavier particles fall while lighter particles are suspended (Eriez Magnetics Japan).

*3 **Inclined and low-intensity magnetic shape separator:** A sorting device developed for rough sorting of electronic components based on their shape and magnetic properties (Eriez Magnetics Japan).

*4 **Strategic Urban Mining Research Base (SURE):** An organization to promote the industrialization of urban mine technology with the objective of applying AIST research findings in society.

A compact personal dosimeter Reliably Measuring Invisible Radiation so Residents can Return Home without Fear

Making the most of AIST's miniaturization and energy-conserving technologies

Compact dosimeter development team

Our life and society will change in this way!



Thanks to the development of a compact dosimeter that can continuously monitor radiation levels, people in areas where there is still concern about the effects of radiation can conveniently measure their radiation exposure day by day, identify situations that cause exposure in their daily lives, and avoid unnecessary exposure. It is hoped that people who were evacuated after the Fukushima Daiichi nuclear accident will be able to return to their homes soon. Through use in decontamination plants and robots working in the power station, the dosimeter may lead to real-time measurements of the progress of the clean-up process.

We need a personal dosimeter that we can use easily in our daily lives!

After the accident at the Fukushima Daiichi nuclear power plant that was triggered by the Great East Japan Earthquake in 2011, radioactive material was scattered over a large area, mainly in Fukushima Prefecture. Even outside the evacuation zone, there are many places where there is still concern about radiation exposure in daily life, such as areas with small hotspots of high radioactivity. Therefore, people in such areas have a strong desire to know what radiation doses they are receiving and in what situations, at an individual, day-to-day level. Being able to understand exposure conditions is also very important for evacuated residents who are planning to return home.

What is required in this situation is a radiation dosimeter. However, the dosimeters used by staff who deal with radiation professionally are large and are not designed for use in daily life. Meanwhile, most previous compact dosimeters require frequent battery changes and are not equipped for checking values at arbitrary times or displaying trend data. Because of these and other problems, there are very few products that suit the requirements of personal use.

So what is needed is a dosimeter that can be carried by individuals and can conveniently measure doses day by day over a long period. With such a dosimeter, daily life situations that result in higher doses can be easily understood; with this understanding, unnecessary radiation exposure can be avoided.

To meet these requirements, in 2011 AIST initiated a project for "Developing and applying portable radiation detectors that employ MEMS technology" and gathered together a diverse team of researchers. In 2012, they developed a "compact radiation integration dosimeter" that can be mass produced, record doses for intervals of a specific duration, and give a warning when the radiation level is high.

AIST's comprehensive capabilities enabled low power consumption and a compact design

Even with a battery, a buzzer and an outer case, the weight



A compact dosimeter that can operate with the same battery for over a year (left) and a display unit (right). As well as pockets, the dosimeter can be put into a child's nametag.



- Food
- Disaster prevention
- Safety and security
- Medicine, welfare, caregiving
- Residential



- Environment, resources, energy
- Electronics
- Medicine, chemistry, biotechnology

Computer screen display example

▼ The user can see the day's dose, aggregated dose up to a point in time, and which time period of the day exposure was highest (what the user was doing at that time).

	Since yesterday	Since a week ago	Total measurement period
Dose (μSv)	3.8	17.2	611.8
Number of days	1	7	344.0
Average dose rate (μSv/h)	0.16	0.10	0.074

of the dosimeter is no more than 20 g. The battery is a single 3 V button battery. The dosimeter can work more than a year without changing this battery.

The development team's Ryoichi Suzuki, Prime Senior Researcher of the Research Institute of Instrumentation Frontier, says "Such a small size and low power consumption was previously thought to be very difficult to achieve. However, we managed to do it by applying the development of battery-operated portable X-ray sources^{*1}, AIST's own miniaturization and energy efficiency technologies cultivated in the development of equipment using microelectromechanical systems (MEMS) and wireless technology. This could be described as a crystallization of AIST's comprehensive capabilities."

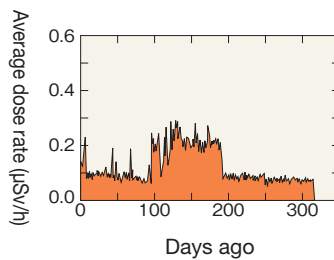
This dosimeter measures gamma ray radiation, which is associated with radionuclides with long half-lives and long-term effects. The lower limit of measurement and display is 0.1 μSv (microsieverts, $\mu = 10^{-6}$)^{*2}. This is about a tenth of the lower limit of detection of the usual dosimeters used by professional staff dealing with radiation. A semiconductor sensor is employed for detection^{*3}. This sensor sometimes misdetects electrical noise caused by physical impacts and the like as radiation. Therefore, an impact sensor is also incorporated and a function for removing noise is employed, further improving the detection accuracy. When a high dose is measured, a warning is given by a LED light and an alarm.

Data from the dosimeter is transferred to a computer or the like without having to be physically connected, by an optical communication adapter or a wireless link. Hence, total amounts of exposure and variations in dose amounts can be checked by day, by hour, or by some other time interval. We anticipate that decontamination work will be conducted on the basis of these records, and that behaviors that avoid exposure will be adopted. Thus, the radiation exposure of residents can be minimized.

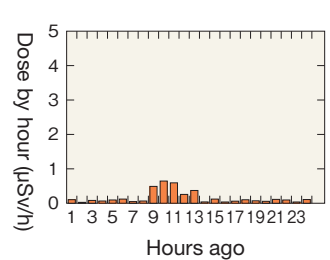
Plans for distribution to returning residents; deployment in decontamination plants

When the development was announced, there were many enquiries both from interested businesses and from local government bodies, NPOs and the general public. Society in general showed great interest and enthusiasm. In partnership with Chiyoda Technol Corporation, a provider of radiation dosimetry services, AIST conducted research

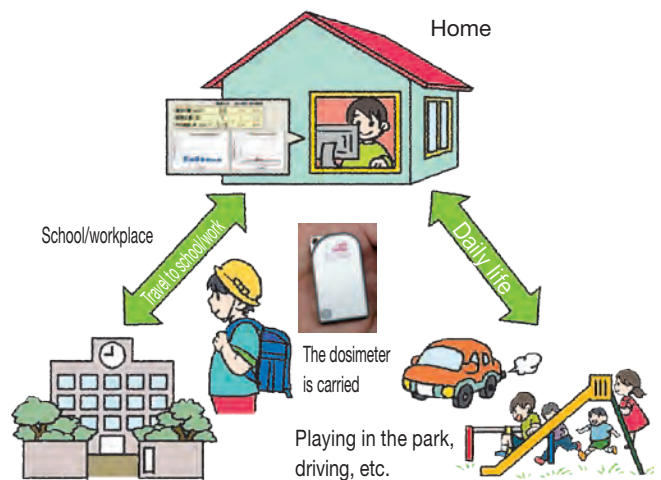
Changes in exposure over the total measurement period



Changes in exposure over the last 24 hours



An illustration of uses of the compact dosimeter



into mass production of the dosimeters. After a demonstration experiment with the residents of Tsukuba City where AIST is located, the technology was transferred to Chiyoda Technol for commercial production. The manufactured dosimeter is the leading candidate for distribution by local governments planning for the return of evacuated residents. The technology is now being considered not only for returning residents, but also for radiation monitoring in decontamination plants and robots working inside nuclear power plants. Suzuki adds that "We are going to improve usability and reliability and expand the range of applications, by increasing data transfer speeds to improve ease of use as well as making it possible to measure low-energy X-rays in clinical locations, and so on."

*1 **Battery-operated portable X-ray source:** AIST developed a practical portable X-ray source in 2009, using a carbon nanostructure cold cathode electron source. Among its other features, the X-ray source can capture over 300 high-precision X-ray transmission images with two AA-size batteries. It does not need to be warmed up, so X-ray examinations can be performed immediately when required. It can even take high-speed images at 1/1000 s.

*2 **Sv (sievert):** A unit representing how much an organism is affected by exposure to radiation.

*3 **Semiconductor sensor:** One method of detecting gamma rays. A tiny current that flows when radiation strikes a semiconductor PN junction is amplified to produce a signal representing the radiation. This enables a radiation detector that is smaller and cheaper than a detector that uses a Geiger-Müller tube (a so-called Geiger counter).

A new energy resource drawing attention

“Fiery ice” laying under the seabed

The promise of methane hydrate

Development given impetus through world-first offshore production test!

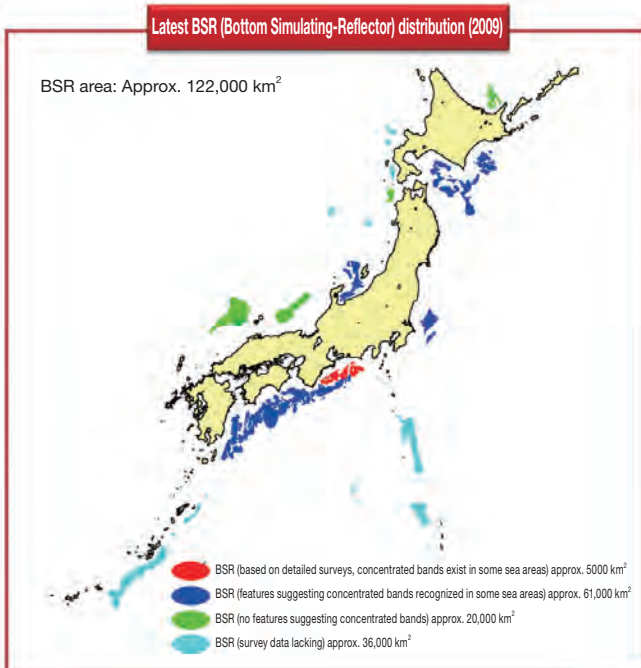
Methane Hydrate Research Center

Our life and society will change in this way!



Vast quantities of methane hydrate are known to exist in sea area surrounding Japan; it is hoped that this substance will be a new energy source for resource-poor Japan. If progress is made in resource development and methane hydrate can be utilized as energy, then the energy situation for Japan will change dramatically. It would also likely lead to increased energy security.

Map of methane hydrate distribution around Japan



▲ Indications of dense concentrations in sea areas adjacent to Japan.
Source: Research Consortium for Methane Hydrate Resources in Japan

Will Japan become an energy resource-rich country?

In March 2013, a marine production test for methane hydrate was conducted for the first time in the world in the area of the Eastern Nankai Trough offshore from Japan’s Atsumi Peninsula and Shima Peninsula. The depressurization method^{*1} developed by AIST was employed and production of 120,000 m³ of natural gas was verified over a six-day period. This indicates the potential for future commercial production. National broadcaster NHK as well as major newspapers and trade publications reported the findings of the test, which also came under the global spotlight. Amid fears of petroleum resources being exhausted, there are great expectations for methane hydrate as a new natural gas resource.

Methane hydrate exists in large quantities in sea areas adjacent to Japan: reserves located in the Eastern Nankai Trough region are estimated to be equivalent to 11 years of natural gas consumption in Japan. This is of major significance for Japan, which is heavily reliant on imports of energy resources. If methane hydrate can be utilized as an energy resource, such a resource could be securely guaranteed for the long term; on this account, not only would it result in lower natural gas prices and improvement in the trade balance, but Japan’s diplomatic stance could also change.

Producing gas from solid methane hydrate

“However, it is not easy to produce natural gas from methane hydrate. As opposed to conventional natural gas, which exists in gaseous form in the earth, methane hydrate does not gush forth even if a well is drilled. There are many issues that remain to be resolved in terms of how efficiently it can be produced from the seabed, thereby enabling commercial production,” says Research Center Director Hideo Narita.

Currently, production technologies are being developed by various countries as national projects. Japan initiated its Methane Hydrates R&D Program under the auspices of the Ministry of Economy, Trade and Industry in 2001. As a



- Residential
- Safety and security



- Environment, resources, energy
- Materials
- Chemistry



◀ Geological sampling at sea.

result, AIST and the Japan Oil, Gas and Metals National Corporation established a research consortium that has been engaged in evaluation and development of technologies to produce natural gas from methane hydrate resources.

To date AIST has studied various methods for stimulating methane hydrate in order to gasify it including, the Hot Water Injection Process^{*2} and the Inhibitor Injection Process^{*3}. AIST has explored efficient methods by developing its own simulator, for example, and as a result it ended up adopting the Depressurization Method. In 2008, it succeeded in producing approximately 2,400 m³/day in an onshore production test in Canada.

Energy security through swift commercialization

The Methane Hydrate Research Center was set up in AIST in 2009. The center has undertaken such work as analysis of sand layers that contain methane hydrate, and synthesis of methane hydrate containing sandy sediment to advance preparations for offshore production test. Subsequently, in 2013, the world's first offshore test was carried out. This test succeeded in producing an average of 20,000 m³ of natural gas per day, which was a much larger quantity than in the test in Canada.

In commercialization as an energy resource, natural gas must be produced in a reliable and long-term manner with an energy content that exceeds that required for production. Regarding production rate, at least several tens of thousands cubic meters is required for the commercial production.

Obstacles to production have been identified at present, such as sand flowing into the well. On this account, AIST is prioritizing development of commercial-scale production technology that is reliable over the long term. Currently, the effectiveness of the newly developed Ultra-depressurization Method^{*4} is being verified. Although

Terminology at a glance

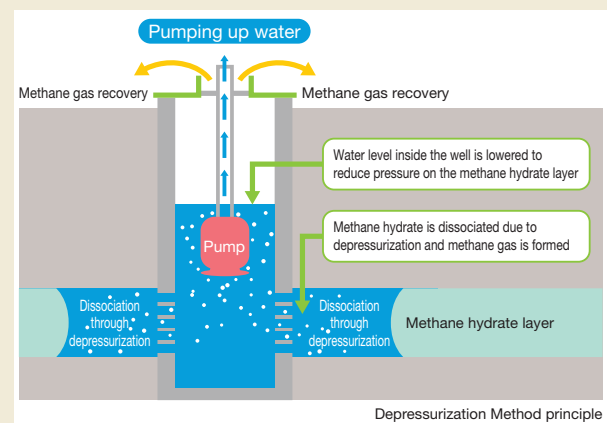
Methane hydrate



An icy substance found in and/or under seabed areas comprised of methane gas, which is the main component of natural gas. Also known as fiery ice because it combusts when lit. It exists in permafrost regions and in seabed areas in continental fringes that are deeper than 500 m. The quantity of methane incorporated is equivalent to approximately 160-times its gaseous volume. Methane hydrate is expected to become a next-generation natural resource; currently, various countries are proceeding with development of methane hydrate resources

Depressurization Method

By drawing up the water in the drilled well and reducing the pressure in the methane hydrate layer, dissociation of methane hydrate is accelerated, the methane gas and seawater that flow into the well are separated, and methane gas is recovered at the surface.



AIST is the sole research institute with all of the required core equipment related to this production technology, the USA, China and South Korea are currently making great strides. Shale gas is another area of note, with development centered on the USA. Rapid commercialization of methane hydrates through corporate participation is an urgent issue for Japan to maintain its advantage.

“If methane hydrates can be developed, Japan will needless to say boost its energy security but further, we also believe that construction of marine pipelines, for example, in the surrounding areas will rejuvenate Japan's maritime industry and create new industries.”

*1 **Depressurization Method:** A method to stimulate solid methane hydrate and thereby gasify it. Refer to Terminology at a glance.

*2 **Hot Water Injection Process:** A method that heats methane hydrate to break it down.

*3 **Inhibitor Injection Process:** A method entailing injection of alcohol to accelerate dissociation.

*4 **Ultra-depressurization Method:** A variation of the Depressurization Method: this method reduces pressure even more, to less than 30 atm, in order to accelerate dissociation. There is a high probability that production quantities can thereby be doubled.

Sherbet-like brackish ice for preserving freshness of seafood

Freshness is vital! AIST technology delivers delicious fish to the table

Applications expected in the medical and food fields

Thermal and Fluid System Group, Energy Technology Research Institute

Our life and society will change in this way!



Manufacturing technology for sherbet-like brackish ice that can retain the freshness of seafood for longer and keep it in better condition. By using this technology, not only can fresh, delicious seafood be delivered to the table, but one can also anticipate that local fisheries and industries could be revitalized through branding of their seafood. Furthermore, the technology could potentially be applied to and contribute to the food (frozen food etc.) and medical (low-temperature surgery etc.) fields.

Development of an ice-making machine for fresher, more delicious fish

An important part of Japanese cuisine is the savoring of raw seafood. The Japanese are very particular about the freshness of seafood; already the control of freshness from the fishing ground to the table is of a high level. However, those in the fisheries industry sought an even more advanced freshness retention technology. Furthermore, there was a desire to deliver to tables throughout the nation fresh, delicious seafood that could be enjoyed by all.

The freshness of fish is greatly influenced by the ability to swiftly disable the fish when it is landed, a process known as “ikejime”¹, before it can flop around; also important is the extent to which temperature can be controlled appropriately. However, it is not easy to execute the ikejime process for a large quantity of fish onboard. In place of this process, a method that employs sherbet-like brackish water ice comprised of fine ice particles has come to be employed. Preserving fish with sherbet-like ice means they end up dying without flopping around: because they are rapidly

cooled, freshness can be retained. Furthermore, fine ice particles do not disfigure the fish.

Hokkaido-based machinery manufacturer Nikko wanted to manufacture a low-cost, higher-performance sherbet-like ice-making machine; hence, they commenced development efforts. Nikko approached AIST for technical advice; in 2010, joint development of an ice-making machine commenced.

Cumulative fundamental research into how to make ice

Takaaki Inada was charged with developing the ice-making machine. Originally, he was a researcher conducting research and development related to sherbet-like ice for air-conditioning.

“In ice thermal storage systems^{*2} used in air-conditioning units, supercooled water is increasingly being used to make sherbet-like ice. This is because this method is superior to others in terms of energy efficiency. However, here we are talking about installing such a system in a fishing boat so we need to consider making it as compact as possible. I thought that a scraping system would be best suited to making a large quantity of sherbet ice as quickly as possible on a fishing boat.”

Developing the equipment was a process of trial and error. Ice cooled to around -15°C would adhere strongly to the cooled solid surfaces. Scraping ice from there sometimes broke the scraper blades. So, an observation apparatus resembling an ice-making machine was built, and the appearance of ice under various conditions inside the ice-making machine was researched. Through these tests, it was determined that the appearance of ice being scraped is classified into two types depending on the salt concentration. By making two types of ice, the salt concentration of the seawater could be adjusted. When the salt concentration was low, the ice crystals were crushed to make ice; when the salt concentration was high, ice was generated via peeling the ice off from the solid surfaces of the inner walls of the cooled ice-making machine. Through



- Food
- Medical treatment, welfare, care giving



- Food products
- Distribution and retailing
- Agriculture and fisheries
- Medical treatment, biotechnology

Sherbet-like ice discharged from ice-making machine



Photograph: Nikko

accumulation of such fundamental research, a prototype of an ice-making machine that could form sherbet-like ice with diameters of just 8 μm (μ: 10⁻⁶) was completed in 2011.

Expectations for QOL enhancement and promotion of local industry

The cooperation of people in the fisheries field was obtained in commercialization of the ice-making machine, which was actually installed in a fishing boat. Numerous field tests were conducted, onsite issues such as the effects of pitching and rolling of the boat on safety and machine reliability were noted, and improvements were made. In addition, whether sherbet-like brackish ice actually improved freshness retention was verified with cooperation from experts from the Hokkaido Industrial Technology Center. The findings proved that there was a substantial freshness retention effect. Then, in 2013, Nikko commercialized its Kaihyo (Sea Ice) Continuous Silk Ice System.

The sherbet-like ice made with this ice-making machine is revolutionary in that it has a soft texture that does not damage the fish, it can cool fish to below the freezing point in one-fifth of the time required by traditional crushed ice and moreover, it can retain this temperature. The ice is made from seawater so there is no need to carry water on board the ship, and the ice-making cost can be lowered significantly.

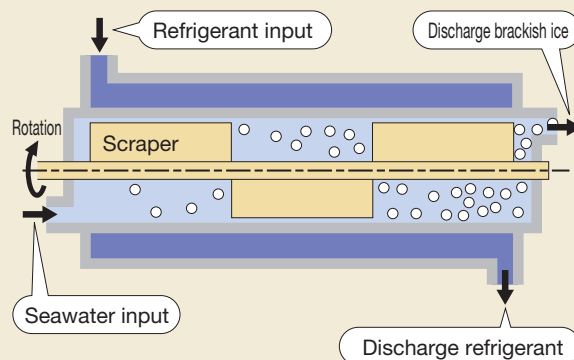
“This technology can also be applied in the medical field in low-temperature surgery and in the food industry in the freezing of food. I think it can contribute to improving QOL (quality of life) in various fields.”

In addition, Nikko anticipates that the technology will lead to the promotion of local industry in Hokkaido, where it is based.

Terminology at a glance

Ice-making machine for sherbet-like brackish ice

First, a refrigerant is fed into the upper left of the ice-making machine to cool its inner wall. Next, seawater flows in (lower left) and the inner wall cool the seawater to form small ice particles. When the scraper is then rotated, sherbet-like brackish ice is continuously formed and by scraping this off, sherbet-like brackish ice is discharged (upper right).



“Kaihyo (Silk Ice)” sherbet-like brackish ice ice-making machine



Photograph: Nikko



◀ Pacific saury stored with sherbet-like brackish ice (bottom) is fresher than the same fish stored using conventional means (top). For this reason, its market price is higher and it can also be beneficial in fish branding and differentiation.

Photograph: Nikko
Hokkaido Industrial Technology Center

*1 **Ikejime**: The process of quickly destroying the motor center of a just-landed fish to prevent it from flopping around.
 *2 **Ice thermal storage system**: Exploiting the fact that electricity tariffs are cheaper at night compared with daylight hours, ice is prepared at night and utilized in the daytime for air-conditioning.
 *3 **Supercooled water**: A state whereby water is cooled to a temperature lower than 0°C while remaining a liquid and not solidifying.

Music-understanding technologies to realize the full potential of digital music

Proposing New Ways to Enjoy Music for Supporting the Digital Content Industry

Engendering a "Content-Symbiotic Society" in which content can be created and published without hesitation

Media Interaction Group, Information Technology Research Institute

Our life and society will change in this way!



Music has been digitized and it is now possible to access a huge number of musical pieces. Technologies by which computers can automatically analyze and understand this vast body of music will make daily appreciation of music more enjoyable and enable anyone to easily create music. This change could lead to a drastic change of the culture around music. AIST's music-understanding technologies will open up new ways to enjoy music in the future and will provide a boost to content industries.

Making computers "understand" music

Masataka Goto, a Prime Senior Researcher of the Information Technology Research Institute, knows that music-understanding technologies are necessary. He explains: "When I was shopping for CDs to encounter unfamiliar but interesting music in my twenties, I would go to a trial-listening corner and repeatedly press the fast-forward button to listen to chorus sections ("hook") of a song. Since then, digital music has become the norm and, realizing that I would not be able to hear everything even if I spent my whole life listening to music, I decided that it would be helpful if computers could do the listening for me." From this point, he started on a quest to work out how computers could be made to understand music in a way that is useful for people.

When humans listen to music, they do things like humming along to the melody, clapping in time with the beat, and instantly identifying the chorus. Although these things are easy for humans, it is difficult to implement automatic understanding of music by a computer if its mechanism is not clear. Since music is one of the most complicated signals with multiple sounds being mixed together, existing

technologies were not enough to overcome the difficulties of understanding music. Toward achieving automatic music-understanding technologies, Goto and his colleagues have been researching and developing a wide range of core technologies for over 20 years and have become world leaders in the field.

A web service "Songle" (launched in 2012) enables anyone to easily try some of such technologies. Songle is distinct from ordinary music players in that a user can view the entire structure of a song as a music map that is visualized by using music-understanding technologies. A user can jump and listen to the chorus with just a push of a button, which is useful not only for trial listening but also for comparison between repeated choruses.

Aggregating the power of the crowd to improve usefulness

Songle has applied music-understanding technologies to over 700,000 songs that have already been open to the public on the Internet, and their results can be enjoyed by everyone in the form of music maps. There are some errors in the music maps, but this is to be expected. The reality is that AIST is conducting an important experiment in how to make imperfect technologies useful for society. Songle is provided with a function that enables anyone who can find and fix errors to contribute by making corrections. In this way, Songle can make use of a synergy between the capabilities of computers with their great processing power but imperfect understanding and humans with their ability to spot and fix errors. In other words, we are studying systems of harmonious cooperation between computers and humans that will be critical to society in the future.

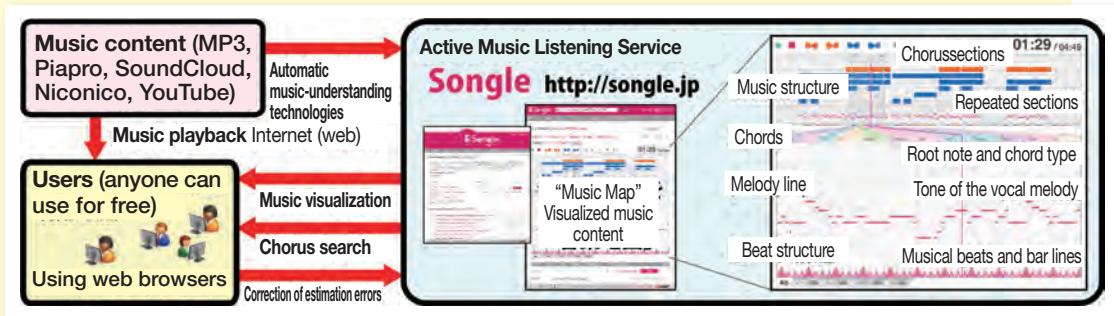
Another web service "Songrium" (launched in 2013) uses the automatic music-understanding results from Songle and enables a user to understand relationships between large numbers of songs from a variety of viewpoints. In Songrium, a user can also skip ahead to the chorus and can easily find songs with similar moods to their favorite songs, videos in which people are singing and dancing along with those favorite songs, and the like. In an era in which new original songs are first released on the Internet, such new

Songle

<http://songle.jp>

▶ The results of automatic understanding of the content of a song on the Internet are visualized as a music map. While viewing the structure of the song, the user may listen only to a rousing chorus or may compare repeated sections.

(From an AIST press release of August 29, 2012)



ways to enjoy music are continuing to open up.

Researching singing synthesis technology for creating music

The advance of technology is bringing about a new culture of music. Singing synthesis technology, which has been attracting attention since 2007, has produced, for the first time in history, a culture that can positively enjoy songs with synthesized voices as main vocals. This innovative culture is an expression of Japan's strengths, and AIST is pursuing research to take this culture further forward. One such singing synthesis technology is called VocaListener ("Bokarisu"). This technology enables the synthesis of singing voices that imitate the way a user sings. The user need only input a sample of their singing into VocaListener, which then controls commercially available singing synthesis software with various voice timbres to naturally synthesize voices that imitate the singing.

In this era of digital music, music-understanding technology is supporting access to the huge body of songs on the Internet, and singing synthesis technology is expanding the scope for enjoyment in creating music. These trends will not be limited to music but will spread to other forms of content, such as videos. Goto adds that "There is a problem of whether, as the digitalization of content produces a society in which nothing is forgotten, the future might be buried under the huge and continually growing body of content from the past. For listeners, selecting music is getting more difficult, and for creators, their creations can easily just disappear into obscurity. In addition, as more and more similar content appears, the risk that a person's creations will be criticized for being too similar to other pieces increases, and there is a danger that we will end up with a society in which people hesitate to create and publish their own content. By continuing with research and development powered by AIST's core technologies, we are aiming for a "Content-Symbiotic Society" in which everyone can enjoy appreciating and creating music without hesitation while paying due respect to older content."

Songrium

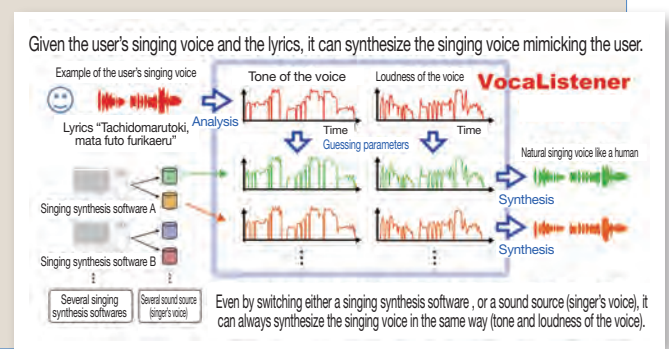
<http://songrium.jp>



▶ Songrium visualizes various musical relations between music videos on video sharing websites. The user can keep encountering new songs and review a history of old songs.
 (From an AIST press release of August 27, 2013)

Toward making singing synthesis more natural

Singing synthesis software, such as Hatsune Miku created by Crypton Future Media, uses VOCALOID, a singing synthesis technology developed by Yamaha. In the past it was difficult to produce natural-sounding singing with this technology but AIST overcame this problem with "VocaListener". Yamaha started to sell a commercial version of VocaListener in 2012.
 (From a Yamaha press release of September 18, 2012)



Natural sweetener manufacturing technology winning over the world

AIST's first patent export dramatically changed the food industry

Realizing the sweetness of fructose from potatoes and corn



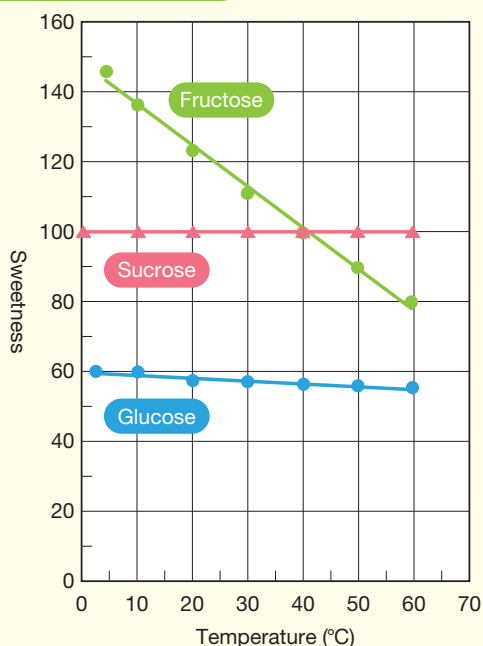
The original natural sweetener sugar is made from sugar cane and sugar beets. However, areas that can cultivate these crops are limited and sugar prices tend to be high. Can't a sweetener like sugar be made from a crop that can be grown cheaply in great quantities? In 1965, AIST solved this challenge by using a technology to convert glucose into fructose by using glucose isomerase. This patent was exported overseas and as the pioneer of natural sweetener manufacturing technology, a low-cost and safe sweetener was supplied to the world.

Sweetness of various sugars

* Sucrose set at 100

Sugar type	Molecular formula	Sweetness
Sucrose (sugar)	$C_{12}H_{22}O_{11}$	100
Glucose	$C_6H_{12}O_6$	60~75
Fructose	$C_6H_{12}O_6$	115~175
Lactose	$C_{12}H_{22}O_{11}$	15~30
Maltose	$C_{12}H_{22}O_{11}$	30~45
Invertose		Sweeter than sugar
Honey		Sweeter than sugar

Sugar sweetness and temperature



▲ Fructose sweetness is significantly impacted by temperature; its sweetness is 1.5-times that of sucrose at approximately 5°C and roughly equivalent at around 40°C.

Making a natural sweetener from low-cost sweet potato

Today one might have a sense of it being somewhat behind the times but in the past, sweetness conveyed the impression of wealth. Japan up until around the 1960s relied on imports for the majority of its sugar, which was high priced. Sweet things were thus considered luxuries. In contrast, during the post-war era Japan faced a food shortage and efforts were focused on the cultivation of sweet potatoes. On this account, a large surplus of sweet potato resulted. Well then, couldn't one reduce imports of costly sugar by producing natural sweetener from sweet potato that could be harvested in mass quantities? In 1962, research and development of natural sweeteners commenced in Japan, with the research institutes of the various government ministries and agencies competing to be the first to succeed.

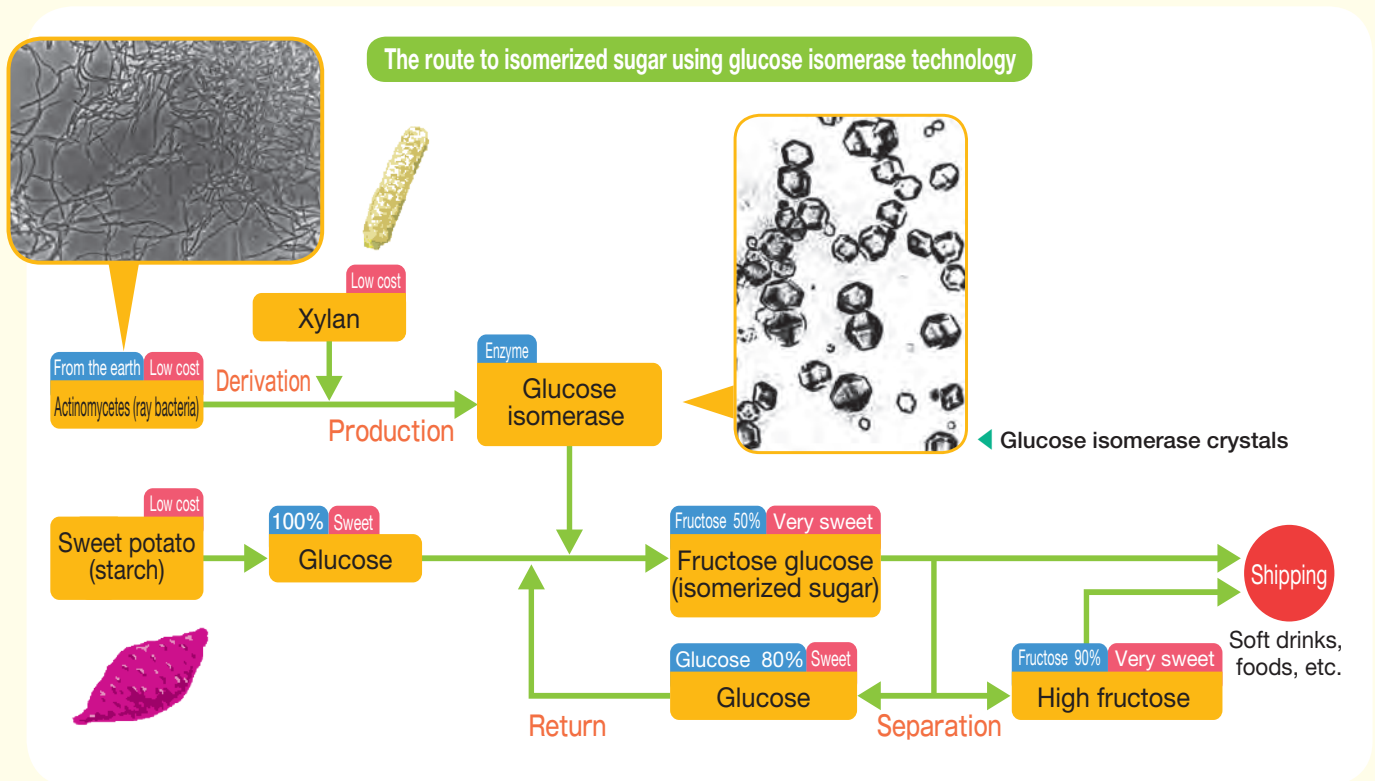
There are in fact various sugars that can be used as natural sweeteners. The main ingredient of table sugar is sucrose, whereas the main component of the Japanese sweetener mizuame is maltose. Further, there is fructose, which is found in fruits and honey, and glucose that is used in intravenous solutions in hospitals. By the 1960s, technology for extracting glucose from sweet potato starch had already been developed. The problem was that glucose is only 60–70% as sweet as table sugar. In contrast, fructose is the sweetest of all natural sugars and at low temperatures in particular, its sweetness is 1.7-times that of table sugar. How could the glucose contained in sweet potato, which could be produced cheaply and in large quantities, be transformed into highly sweet fructose? This was the challenge taken up by Dr. Yoshiyuki Takasaki and his group at AIST (at the time known as the Fermentation



- Food
- Safety and security
- Medical treatment, welfare, caregiving



- Environment, resources, energy
- Medical treatment, chemistry, biotechnology
- Food products
- Agriculture and fisheries



Research Institute); at the time they started developing an appropriate method, they had been engaged in enzyme research. The method that they adopted used the microbial enzyme glucose isomerase.

Discovery of an enzyme to convert glucose into fructose!

Glucose and fructose both possess the molecular formula $C_6H_{12}O_6$. Although they are formed from the same atoms, their molecular structures are different and their properties also differ. Substances like this with the same molecular formula but with different molecular structures are known as isomers. Glucose is an isomer of fructose and vice-versa. Moreover, glucose isomerase is an enzyme that can isomerize glucose into fructose.

A chemical reaction proceeds when glucose isomerase is added to a glucose solution held at 65–70°C and a pH of 6.8–7.2 and 50% of the glucose is converted to fructose. The resulting mixed solution of glucose and fructose is known as isomerized sugar. This sweet solution is used as a natural sweetener. In other words, glucose isomerase is all that is needed in order to directly convert glucose into fructose with high efficiency. Well then, how can large quantities of glucose isomerase be produced?

Dr. Takasaki and his colleagues ascertained that bacteria known as actinomycetes held the key. Actinomycetes are a type of bacteria often used to make antibiotics. They are also known as ray bacteria on account of the manner in which they propagate, like thread stretching. It was found

The enzyme laboratory at the time



that one of the actinomycete groups that was discovered in soil could actively produce glucose isomerase from a substance contained in plants called xylan. Xylan is present in large quantities in the byproducts of cereal production, such as in corn cobs and husks, rice and wheat straw, chaff, and wheat bran. Using this method, raw materials that would normally be discarded and bacteria can be used to produce glucose isomerase cheaply. Furthermore, this glucose isomerase can be used to produce isomerized glucose syrup containing a large quantity of fructose. The glucose isomerase technology developed by AIST gives rise to a valuable sweetness from low-cost ingredients; this is very economical technology for manufacturing natural sweetener.

Taking on the global sweetener market with patent acquisition as a springboard

The product fructose-glucose liquid sugar

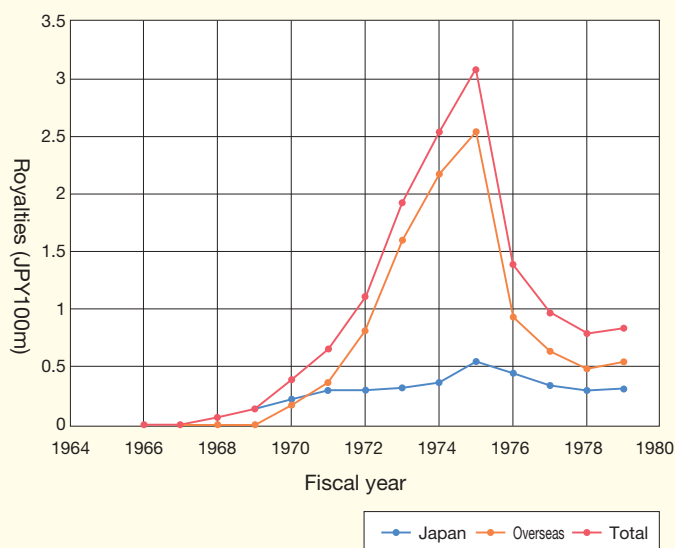


The Institute for Fermentation obtained the patent that formed the basis of the glucose isomerase manufacturing process in 1965. Subsequently, it obtained a total of four patents through 1970 and the basic industrial-scale manufacturing process was established. The reaction of industry to this development was swift, in particular from American companies. At the time, the United States and Cuba were at odds and tensions heightened to the point whereby the two countries almost went to war. The United States blockaded Cuba around this Cuban Missile Crisis. Accompanying this, the United States was unable to import sugar and with international sugar prices skyrocketing, the United States was in search of a substitute for sugar.

Leading US food manufacturer Standard Brands Incorporated (merged with Nabisco in 1981) was the first to show interest and in 1966, it signed a contract with AIST (known as Agency of Industrial Science and Technology at the time). This contract was the first patent export achieved by the then Ministry of International Trade and Industry (MITI). Then in 1968, fellow US company and leading corn starch manufacturer A.E. Staley (currently Staley Continental) acquired a sub-license from Standard Brands. Production of isomerized sugar was started.

Offshore development was not limited to the United States. Contracts were also inked with Indian glucose manufacturer Sayaji Industries in 1970, Germany's Kali-Chemie in 1972, and Finland's Finnsugar in 1985. Isomerized sugar production based on glucose isomerase spread throughout the world with great momentum. A

Patent royalty income from glucose isomerase technology



▲ Approximately 10 years after acquiring patents, patent revenue from overseas grew dramatically. Further, entering the 1980s, major beverage manufacturers adopted isomerized sugar and revenue once again grew significantly.

particularly large impetus was provided by a major soft drink manufacturer that started using isomerized sugar in 1980, with another leading manufacturer following suit in 1984. Use of isomerized sugar grew by leaps and bounds on account of these two companies. Subsequently, technological guidance was provided to China and AIST actively promoted proliferation of the technology on a global basis.

Glucose isomerase spreads throughout the world

While development partner Sanmatsu Kogyo was the only company in Japan to produce isomerized sugar in the 1960s, once word spread of the successes in the United States, various enzyme manufacturers started to utilize glucose isomerase. Nagase & Co. (contract executed in 1971) and Godo Shusei (contract executed in 1977) were among the 15 or 16 companies that were producing isomerized sugar in the second half of the 1970s. With patent utilization spreading in Japan in addition to overseas developments, a total of JPY1.4 billion in patent revenue was generated, peaking around 1975. This was the highest patent revenue ever for AIST.

Nowadays, with the spread of health consciousness, sweeteners containing fewer carbohydrates are one after the other emerging, and one can no longer claim that glucose isomerase plays the leading role in the natural sweetener market.

Newspaper reports at the time

The natural sweetener synthesis technology based on glucose isomerase and tie-ups with foreign companies were big news at the time.

▲ Nikkan Kogyo Shimbun, September 26, 1970

▲ Nikkan Kogyo Shimbun, January 7, 1972

▲ Nikkan Kogyo Shimbun, August 30, 1969

However, the role of isomerized sugar itself has not yet come to an end. According to the Agriculture & Livestock Industries Corporation's Global Starch Product Supply-Demand Forecast (in Japanese), production of isomerized sugar in 2009 was a total of 17.3 million tons. The United States was the leading producer at 7.77 million tons, while North America overall produced 12.38 million tons, Asia 3.37 million tons, and Europe 860,000 tons. In this manner, isomerized sugar continues to be manufactured on a global scale^{*1}. With global sugar production for the 2008/09 harvest year totaling 158 million tons^{*2}, production of isomerized sugar has already grown to more than 10% of sugar production.

Glucose isomerase technology uses the power of bacteria to extract the sweetness of fruit from sweet potatoes and corn. This isomerized sugar production technology pioneered by AIST is indispensable in enriching diets throughout the world to this day. Furthermore, this technology evolved from simply playing a role in the fermentation industry (brewing) into a form of enzyme utilization engineering; furthermore, it became a cornerstone in expanding into biotechnology (regenerative medicine, drug creation, etc.), which is a key 21st century technology.

*1: LMC International report
*2: Sugar: World Production Supply and Distribution (USDA)

Development history

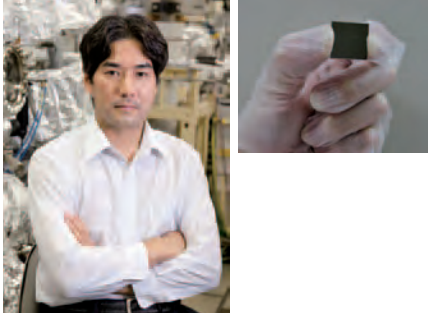
1962	Start of development of fructose production technology as a substitute for costly imported sugar. Researcher Yoshiyuki Takasaki isolates isomerase-producing actinomycetes. Bacteria die when heated to 50°C but enzymes are immobilized on bacterial cells. High concentration isomerized sugar can be produced at low cost at a temperature of 60°C.
1965	Patent application for glucose isomerase manufacturing method. Commercial-scale production start-up at Sanmatsu Kogyo.
1966	Technology exported to a US-based company (first patent export by Ministry of International Trade and Industry). Isomerized sugar made rapid advances in the United States during the era when sugar imports from Cuba were disrupted.
1977	Immobilized enzymes debuted on market (Nagase Biochemical, Ltd.). At this time, leading United States-based beverage manufacturers started to ramp up their use of isomerized sugar.
1980	Isomerized sugar production in the United States surpasses 3 million tons/year
1984	Production in Japan exceeds 700,000 tons/year
1995	Global production passes 8 million tons/year
To the present	Production quantities: Japan: 750,000 tons/yr.; the United States: 8.2 million tons/yr. Production values: Japan; Approximately JPY60 billion; the United States: Approximately JPY656 billion

Leading the way AIST!

**Spintronics: A fusion of electronics and magnetics
IT Appliances with Zero Standby Power:
Is the Dream Close to Reality?**

Shinji Yuasa

4



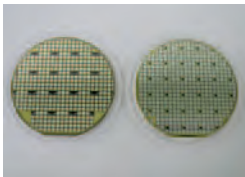
**Humidity-regulating tiles: Spotlight on an eco-construction material
Potential as a construction material that
regulates humidity as if it were breathing**

Masaki Maeda

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Into the future AIST!



**Semiconductor Silicon Carbide (SiC)
A Revolution in Power
Electronics Made Possible by
Semiconductor Silicon Carbide**

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**Development of commercial-scale production
technology for single-wall carbon nanotubes
Great expectations for a dream material
<21st Century Industrial Revolution>**

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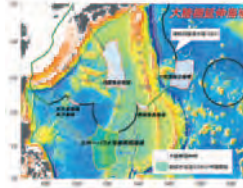


Photograph: JQA

**Personal care robots supporting
an ageing society
Personal care robots
spread out as a "new
infrastructure"**

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AIST in present day living!



**Extention of Japan's continental shelf
The extended continental shelf:
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survey contributing to future society**

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**Environmental survey of the Fukushima Daiichi
Nuclear Plant by high-access survey robot
Robot rises to the challenge of
surveying an extreme environment
unapproachable by humans**

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AIST supporting livelihoods!

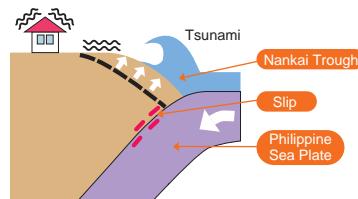
**The leading organization in Japan for metrological technology
The people and technology behind correct
measurement, which is quite common nowadays**

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**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**

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Another success at AIST!



**Carbon fiber development
From fishing rods to aircraft
Carbon fiber development
process**

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Editorial postscript

The birth cry of "From AIST to the Innovative World" came from a word from the top, namely from AIST President Ryoji Chubachi. Happily, our first issue was well received by our readers. The entire staff is filled with a sense of gratitude.

Meanwhile, thanks to guidance, words of encouragement, and advice from our readers, we have been able to publish this second issue.

During the editing process, we came to be aware that the foundations of R&D carried out by AIST were directed at specific themes:

1. Display of collective strength (in this issue: plant factory, neurocommunicator, urban mine, compact dosimeter, methane hydrate);
2. Contributing to the promotion of local industries (Claist, plant factory, methane hydrate, sherbet-like brackish ice);
3. Contributing to small- and medium-scale companies (AD method, Claist, plant factory, urban mine, sherbet-like brackish ice);

4. Structural approach. In this edition, we introduce these trends concretely as outlined below.

- Claist (using clay crystals as is)
- Neurocommunicator menu (using neither the alphabet nor Japanese syllabary)
- Tantalum capacitor urban mine (the capacitor itself is not crushed into pieces)
- Rhythms, melodies and hooks for musical understanding (the musical note level is not used)

The general style of fundamental research is to thoroughly partition the constituent elements of something but not being restricted by this, AIST researchers are practicing full research that freely migrates between basic and applied research objectives in order to achieve swift product commercialization.

We once again came to think that this is the stance of AIST researchers.

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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 2014 No.2

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: Nikko (Pacific saury/ sherbet-like brackish ice)
Contents page photograph: Nikko (sherbet-like brackish ice)

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