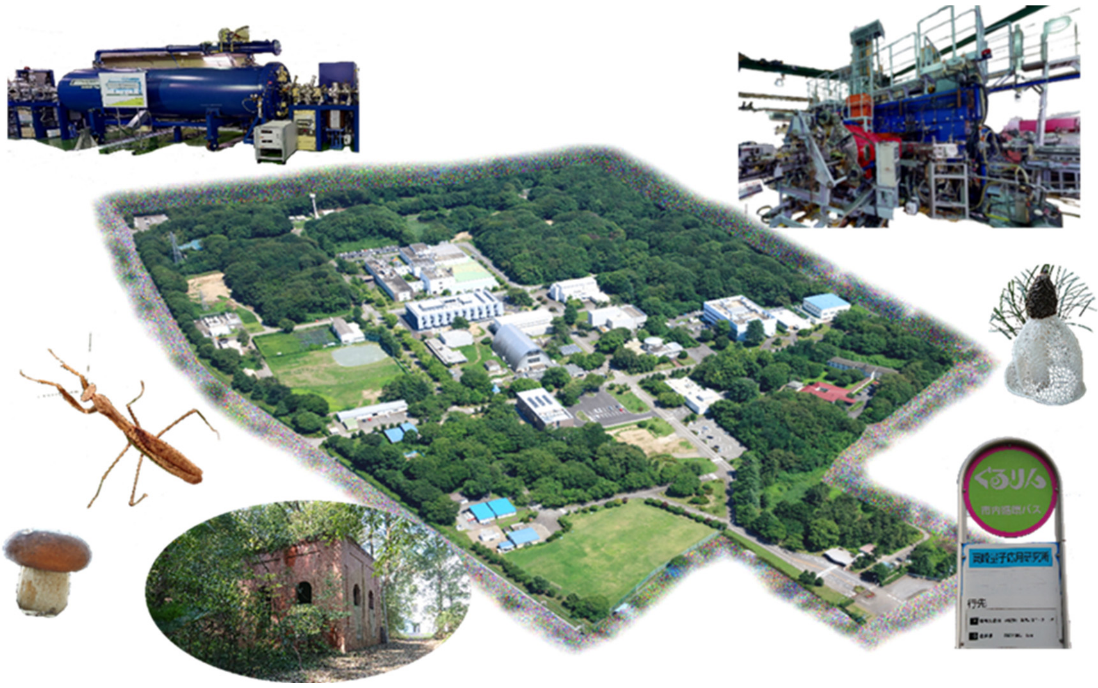
Aiming to Realize the “Society5.0”

Takasaki Institute for Advanced Quantum Science

National Institutes for Quantum Science and Technology



What is “Takasaki Lab” ?

This booklet is a re-edited English version of an article introducing the Takasaki Lab that appeared in the September 2023-February 2024 issue of Gunma Keizai, a monthly magazine published by the Gunma Economic Research Institute, with the Institute's permission.

(June 1, 2024)

1. Overview of Takasaki Lab

Have you ever heard the name "Takasaki Lab"? The official name is Takasaki Institute for Advanced Quantum Science, National Institutes for Quantum Science and Technology.

This booklet introduces the research and development carried out by Takasaki Lab as a national research institute.

What kind of research institute is Takasaki Lab? We will start the introduction with an overview.

Features of Takasaki Lab

Natute x History x Science and Technology

Takasaki Lab is located in the southeast of Takasaki City, occupying part of a lush area between the Karasu-gawa and Ino-gawa rivers. Gunma-no-mori Park is adjacent to the site. And research facilities are located almost in the center of the site, surrounded by large, deep green trees.

It is an area rich in nature, with cherry blossoms in the spring and ginkgo trees leaves in the fall, and a variety of living creatures.

Photo 1-1：Aerial photo of Takasaki Lab

Going back in history, over 1,000 years ago, many ancient tombs were built in this area, including the Kannonyama tomb, and the Futagoyama tomb was built in the area where Takasaki Lab is located. Later, in the Meiji era, the Iwahana Gunpowder Factory was built to manufacture dynamite, and gunpowder production continued until the end of World War II. Remains of brick buildings and earthworks to prevent damage from explosions remain on the premises of Takasaki Lab.

We are engaged in research and development in a place where nature and history blend together, aiming to realize a prosperous and bright future through science and technology.

Research carried out by Takasaki Lab

From radiation processing to quantum beam science

Takasaki Lab was established in 1963 as a research institute for the purpose of researching the industrial use of radiation, and has contributed to the practical application of materials and products that are useful in everyday life by utilizing the reactions that occur when materials are irradiated with electron beam or gamma ray. These include highly durable and high-quality radial tires, electrolyte membranes for button batteries with excellent ion permeability and stability, and heat-resistant wire coating materials. In addition to the industrial field, Takasaki Lab has also developed technologies used in the agricultural field to improve crop varieties, prevent potatoes from sprouting, and exterminate a pest called the melon fly, and in the medical field to sterilize medical instruments.

In 1991, Takasaki Research Institute established the Ion Beam Research Facility (TIARA) with four ion accelerators to develop the use of ion beams, in which various atoms are electrically accelerated at high speed in a vacuum, for use in various fields of research.

Using ion beams, we developed ultra-thin film evaluation technology for damage caused when cosmic rays (high-energy ions) hit space semiconductors and solar cells. We are developing new fields of research and new technologies that could not be achieved using other methods, such as technology to uniformly create holes over a large area through which one ion can pass through, and ion beam breeding technology to create mutant varieties of crops and microorganisms that have never existed before. We have been exploring and developing.

We pioneered and developed new research fields and new technologies that would not otherwise be possible. For example, technology to evaluate damage caused by cosmic rays (high-energy ions) hitting space semiconductors and solar cells, technology to uniformly create large-area perforations in ultra-thin films through which a single ion can pass, and ion beam breeding technology that creates mutant varieties of crops and microorganisms, so on.

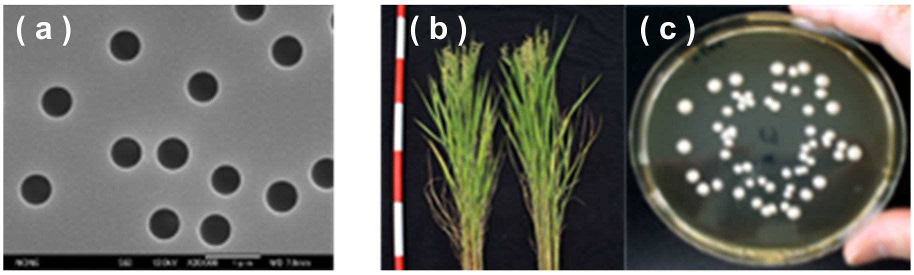


Photo 1-2: Examples of R&D using ion beams.

(a) Perforated membrane made by uniform distribution irradiation of ion beams. Pore diameter is about 6/10,000 mm and homogeneous.
(b) Cadmium-low accumulation rice developed by ion beam breeding (right)
(c) Sake yeast with excellent ginjo aroma.

Becoming a center for quantum technology research

Supply of high-quality quantum materials through industry-academia-government collaboration

In "Society5.0," which is the result of advancing the digitalization of society (DX: Digital Transformation), quantum computers and quantum cryptography will be used, and people will work in a metaverse space where real space and virtual space are fused. The key to achieving this is technology that allows for the instantaneous exchange of vast amounts of information and information processing technology that derives appropriate answers from vast amounts of information. It is known that these technologies cannot be realized in principle with the materials currently used in computers and communication equipment. A breakthrough will require "quantum functional materials" that can utilize quantum properties as material functions.

At Takasaki Lab, we are advancing leading quantum functional material research by leveraging our strength in quantum beams, centered on the Quantum Function Creation Research Center, which was established in 2022.

As a national science and technology policy, aiming to realize a super smart society, the quantum strategy consists of the “Quantum Technology Innovation Strategy (2021)”, “Quantum Future Society Vision (2022)”, and “Quantum Future Industry Creation Strategy (2023)" has been established. Under the strategy, Takasaki Lab is responsible for the research, develope and supply of quantum materials, and has been designated as a quantum technology infrastructure base that promotes research and development and industrialization support for quantum functional materials.

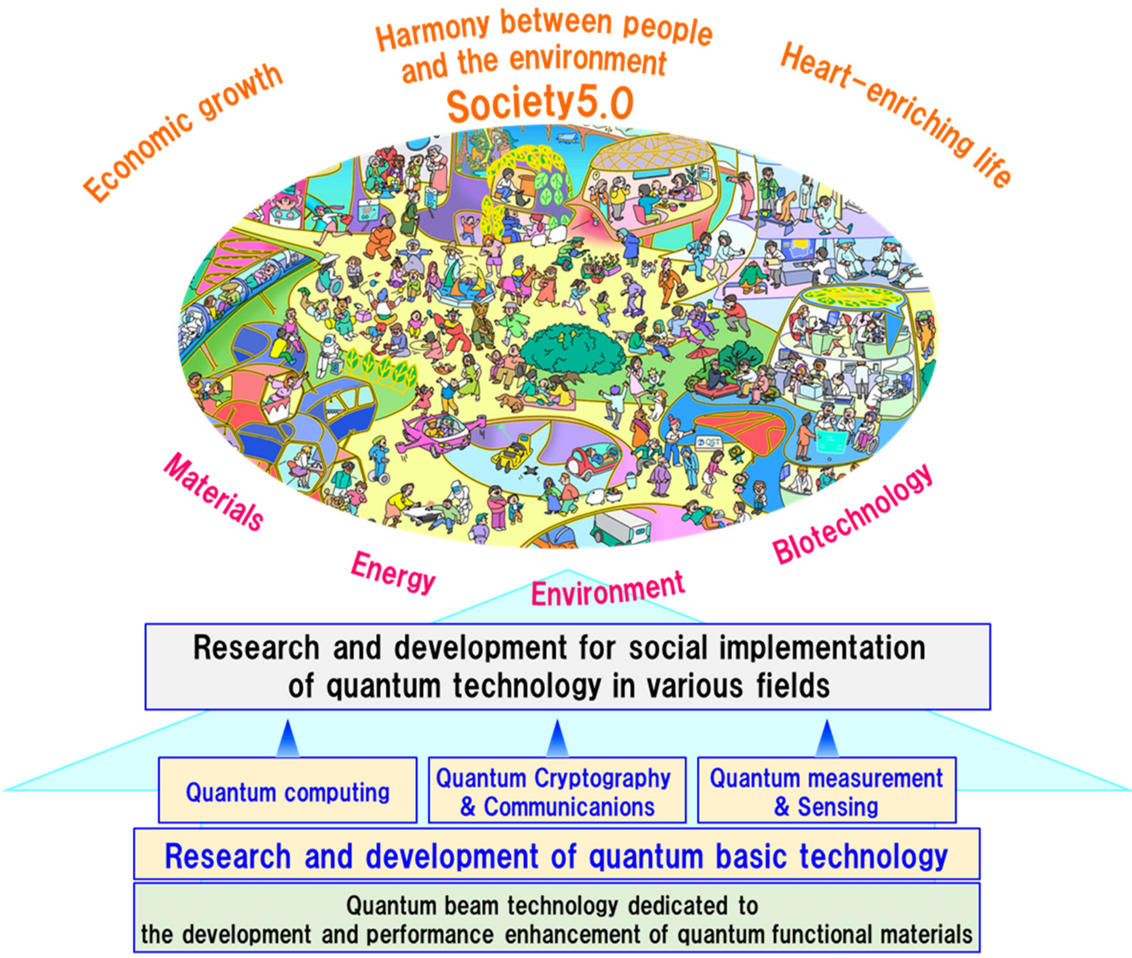


Figure 1-3. Takasaki Lab's approach towards realizing Society5.0.

Using quantum beam technology specialized for development and performance enhancement of quantum functional materials , advance research and development of quantum materials and quantum devices, and aim to realize quantum computers, quantum cryptography, quantum sensors, etc. Further, we will also advance research and development to socially implement these in various fields such as materials, energy, environment, and biotechnology.

2. Quantum Function Creation Research

Quantum technology utilizes quantum behavior that cannot be explained using common sense to achieve high performance in communications, calculations, sensing, etc. In this chapter, we will introduce the development of quantum materials and quantum devices that Takasaki Lab is pursuing as quantum function creation research.

NV center quantum bit

Ultra-high sensitivity sensing using diamond

Diamonds are used as jewelry and industrial materials, but in quantum technology, they are used as the material for making quantum bits (quantum materials). At Takasaki Lab, we are conducting research to create quantum bits in diamond.

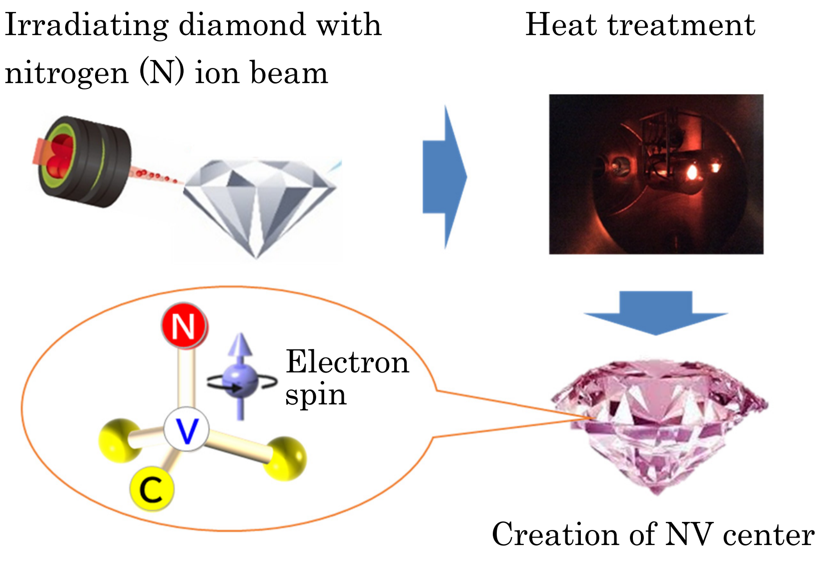


Figure 2-1. Outline of NV center manufacturing method.

When nitrogen atoms (N) are implanted as an ion beam into a diamond crystal made only of carbon atoms (C), it is possible to create NV centers where there is no carbon atom next to the nitrogen atom (vacancies).

The NV center has electron spin (a magnetic property caused by the rotation of electron, which is a quanta), and can be used as a qubit. NV center qubits are extremely sensitive to changes in the surrounding environment, such as magnetic field and temperature. The information is retained for long periods of time even at room temperature, and can be precisely read out by manipulation using microwaves or light.

Takasaki Lab is conducting research to apply the NV center as an ultra-fine and ultra-sensitive quantum sensor (quantum device) to measure temperature and pH in living cells in collaboration with QST's Institute for Quantum Life Science and universities.

Quantum sensors can be used with a single qubit (NV center), but in order to perform quantum calculations, "multiple qubits" are needed, where the qubits are densely packed in positions where they interact with each other. Therefore, we are conducting research to create multiple qubits using technology that controls and irradiates molecules that have multiple nitrogen atoms, such as amino acids, in the same way as a single atom (ion).

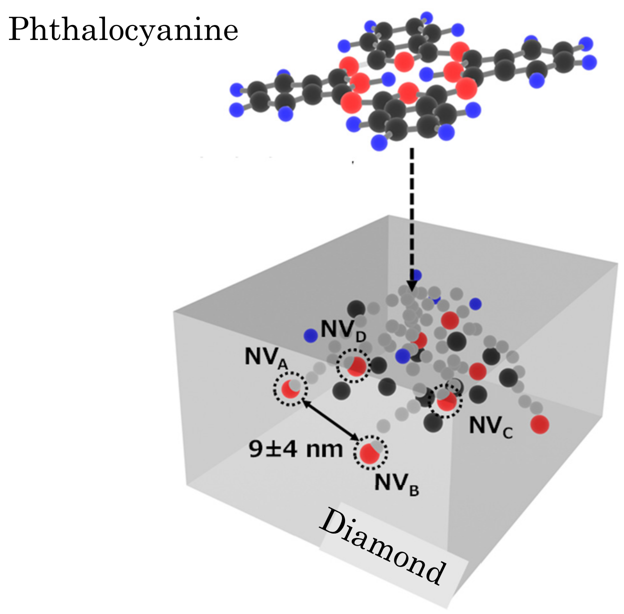


Figure 2-2. Image of multi-quantum bit generation.

Irradiating diamond with phthalocyanine (a pigment with eight nitrogen atoms) increases the probability that multiple NV centers will form densely in positions where they interact with each other.

Ion-trap quantum bit

Capture ions with an electric field and cool them with laser

Ion-trap qubits are made by capturing ionized atoms in a vacuum with an electric field and cooling them with a laser to align multiple ions. The features of ion trap qubits, such as room temperature handling, long time retention of the quantum state against external noise, and high precision observation of the qubit state using a laser, are major advantages in their application to quantum computation.

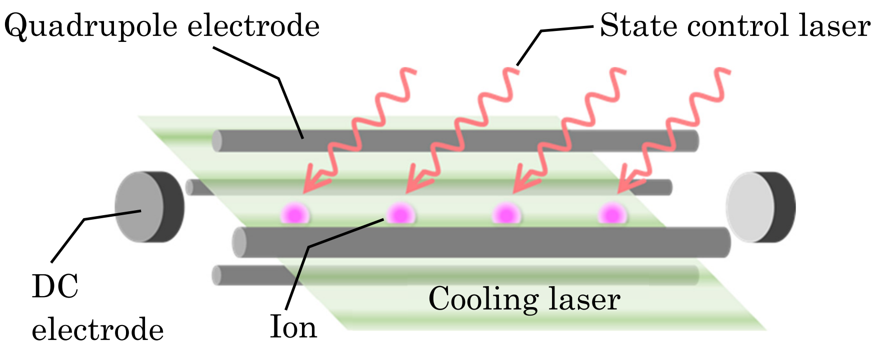


Figure 2-3. Conceptual diagram of an ion-trap quantum bit.

Ions are captured using a high-frequency voltage applied to four electrodes (quadrupole electrodes) and a direct current voltage perpendicular to this cross-section. A laser is then used to cool the ions to a few μK and bring them to rest, creating a quantum bit. The quantum state of the ions is controlled using a state-controlled laser. Information is read out by detecting the fluorescence of the ions.

Ion-trap quantum bits have different characteristics depending on the ion (element). Takasaki Lab is currently working on making quantum bits with Ba-133, which can be cooled and controlled by a visible laser beam and is expected to have higher calculation accuracy than any other elements. As a further development, we are planning to increase the number of qubits by connecting multiple modularized ion traps with optical fibers.

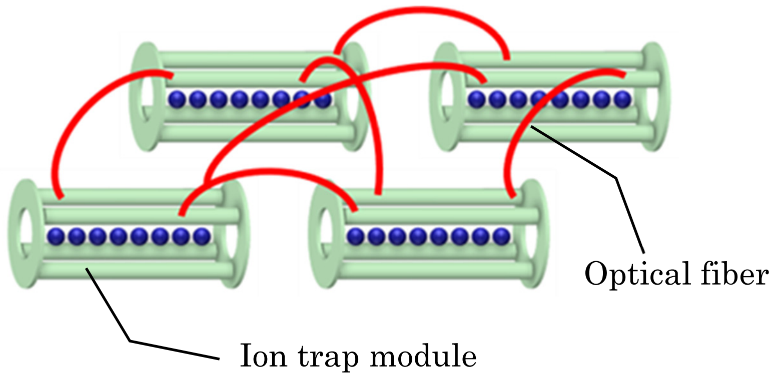


Figure 2-4. Image of ion trap quantum bits chained together to form a larger scale.

Ultra-high-speed, ultra-energy-efficient information and communication processing

The hidden key to realizing Society5.0

In Society5.0, the absolute volume of information and communication will increase enormously. The high hurdles that stand in the way are the ultra-high speed of information processing and the minimization of power consumption (ultra energy conservation), from the individual devices that form the basic unit of quantum technology to large-scale social infrastructure.

To achieve super energy conservation, new technologies based on new principles are needed that do not use moving and holding electrons, which are the cause of power consumption in current electronics. Takasaki Lab is working on the development of materials that can freely manipulate electron spin. Specifically, we have proposed a new technology called "spin photonics," which is a fusion of spintronics, which controls and utilizes the spin direction of electrons, and photonics, a cutting-edge technology that uses light (photons). We are exploring the possibility of "graphene/Heusler alloy stacking material," which consists of a graphene sheet made entirely of carbon atoms (C) and a ferromagnetic alloy called a Heusler alloy.

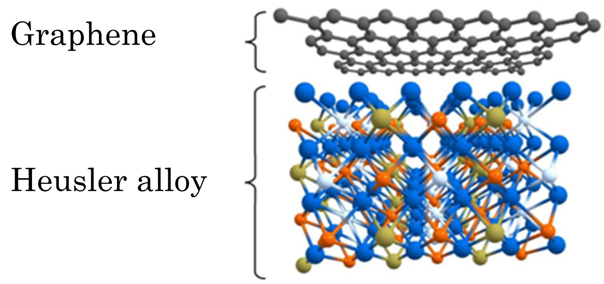


Figure 2-5. Schematic diagram of graphene/Heusler alloy laminated material.

It is becoming clear that this multilayer material can combine the "best of both worlds": graphene's ability to transfer spin more than 100 times faster than silicon and Heusler alloys' ability to perfectly align the spin direction. We expect that further enhancement of the excellent properties of the multilayer material will lead to ultra energy-saving applications.

The development of quantum materials and devices promoted by the Takasaki Research Institute will be integrated with the development of ultrafast current and spin control technology using ultra-short pulse laser technology and the evaluation of quantum devices using synchrotron radiation to promote innovation and the creation of new industries for the future society as a national center for quantum technology. The center will also work on the development of new quantum technologies and the evaluation of quantum devices.

3. Ion Beam Technology for Quantum Materials R & D

The creation of quantum functions introduced in the previous chapter is supported by ion beam technology, mainly in the generation and control of ion beams, which Takasaki Lab has cultivated over the past 30 years. In this chapter, we introduce our research on the application of ion beams to "observation (investigation)" and "creation", the high-precision irradiation technology we have developed for this purpose, and the future development of ion beam technology.

Radiation resistance testing of space environment materials

Damage to electronic components that occurs in space

The research on diamond NV centered quantum bit generation ("creation") conducted by Takasaki Lab originated from radiation resistance tests ("observation") of electronic components such as semiconductors and solar cells for space use, and is based on the knowledge of ion beam irradiation technology and crystal damage generation developed during the research.

Various types of radiation emitted by stars are flying around in space. Ions flying at high speed have high energy, and when they collide with electronic components used in satellites, localized overcurrents are generated, causing malfunctions and damage.

As the number of ion strikes increases, the performance of the electronic components gradually degrades and the satellite loses the ability to control and measure. In other words, how long electronic components can maintain their function while exposed to ions in space determines the lifetime of a satellite. Accurately predicting how long electronic components can be used normally in space is very important information for planning satellite launches and operations.

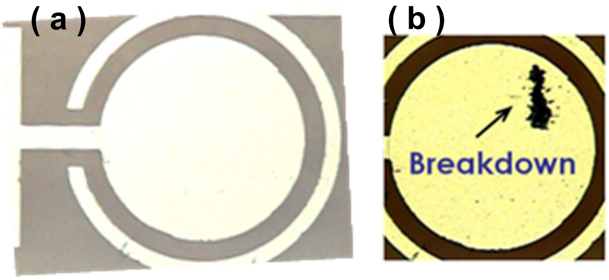


Figure 3-1. Ion irradiation damage test of semiconductors.

Ion irradiation of a test silicon carbide (SiC) storage device (a) caused damage breakdown (b).

The radiation resistance test for space environment materials is a study to evaluate the degradation of electronic components that occurs in space by reproducing it on the ground.

Single ion hit technology

Irradiate a single ion at a targeted position

The test shown in Figure 3-1 was performed on a system built to evaluate single ion hit induced transient currents (TIBIC).

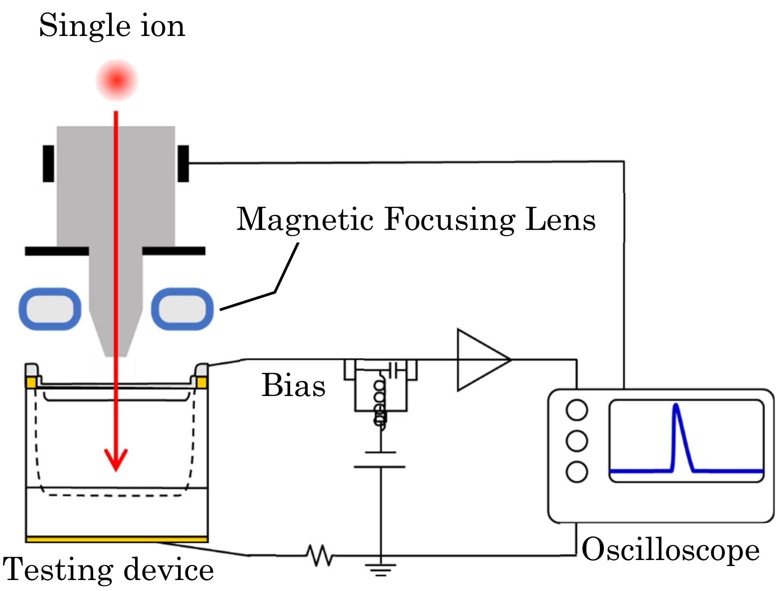


Figure 3-2. Schematic diagram of TIBIC evaluation system.

The key to radiation resistance testing is the generation and targeting technology of high-energy ions, the same as those flying in space, which requires technology to aim a single ion accelerated to several tens of percent of the speed of light at the target position of the device to be tested with an accuracy of 1/1,000 of a millimeter.

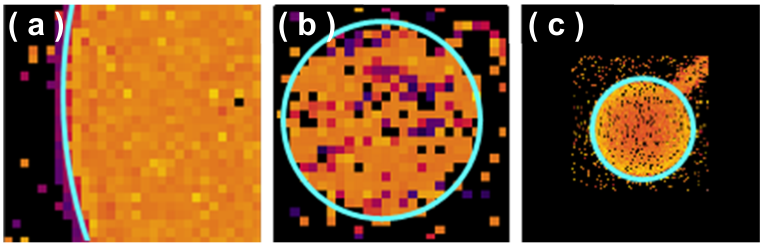


Figure 3-3. Progress in single ion aiming irradiation technology.

By improving the precision of aiming irradiation, we have succeeded in narrowing the range where the electric charge generated in the semiconductor is concentrated and distributed (orange surrounded by a light blue circle) to 170/1,000 mm (c). The initial figure (a) shows 2 mm when the technology was first developed, while the under development (b) shows 420/1,000 mm. The length of one side of all photo is 500/1000 mm.

From radiation resistance testing to quantum technology

Development of Single Ion Irradiation Technology

Single ion irradiation technology with 1/1,000 mm accuracy was developed to "observe (examine)" the irradiation damage process of electronic components caused by fast ions. Takasaki Lab has expanded the application of this technology to the "creation" of NV centers consisting of nitrogen (N) and vacancy next to N by irradiating diamonds made of carbon atoms only with nitrogen (N) ions, and has further developed the technology to generate NV centers at targeted positions at regular intervals. And has evolved into a technology that can generate NV centers in a row at targeted locations at regular intervals.

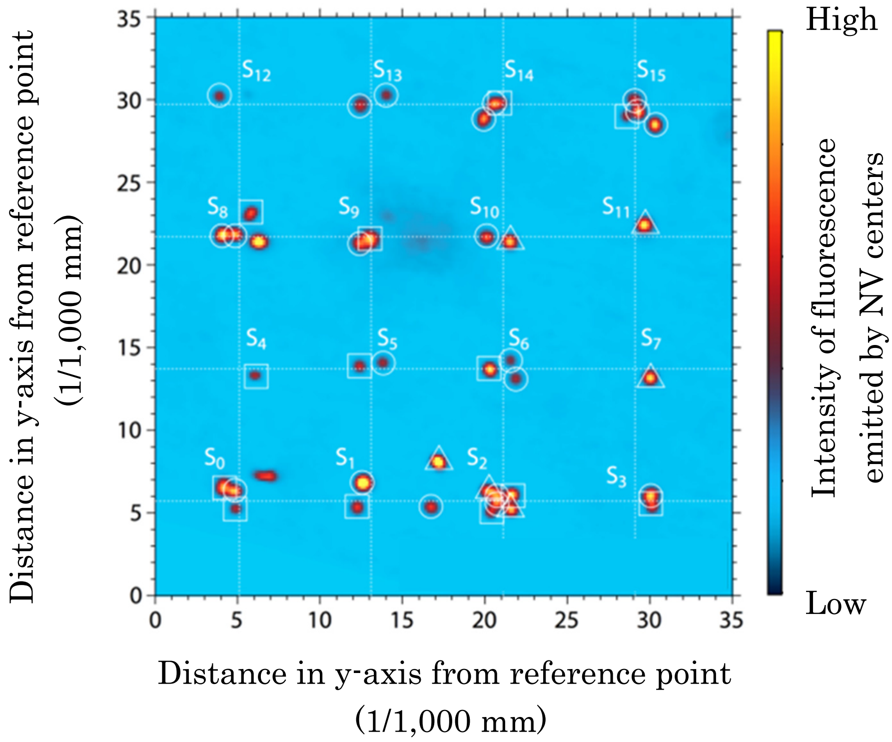


Figure 3-4. Test for generating a regular arrangement of NV centers.

Aiming and irradiating at the intersection of vertical and horizontal 8/1,000 mm intervals, the fluorescence intensity of specific wavelengths generated only when NV centers are generated was measured.

When diamond NV center quantum bits are applied to quantum computation, a large number of NV centers must exist at a distance where they interact with each other. Our goal is to develop ultra-precise irradiation technology on the order of 1/100,000 mm to achieve this, and precision irradiation technology with a precision of less than 1/10,000 mm is the first step in the development process to achieve this goal.

The shape of the ion beam has a significant impact on the accuracy of ion beam irradiation. Currently, dozens of interacting values and conditions are adjusted by operators with extensive experience in order to shape the ion beam into a clean shape. We aim to replace this task by using AI to derive the optimal combination of parameters through beam optics calculations to automatically form the smallest beam diameter in the shortest amount of time to achieve our goal.

Ultra-precise ion implantation technology

Realization of 1/100,000 millimeter scale

Takasaki Lab is also aiming to develop an even higher precision ultra-precision ion implantation technology with an accuracy of 1/100,000 of a millimeter. The difference in accuracy of two orders of magnitude is like the difference in the size of a target from one meter to one centimeter in diameter. If you imagine this, you can understand the technical difficulty.

The realization of this technology requires the development of several new techniques. It is necessary to accelerate and irradiate the nitrogen ions to be injected into diamond without any variation in energy or position. To achieve this, we use a device called an ion trap, mentioned in the previous issue, to cool calcium ions with a laser and put nitrogen ions into the trap, thereby indirectly cooling the nitrogen ions to rest and then extracting them one by one. Simulations have shown that using this method, we can focus the diameter of the orbitals down to 1/100,000 of a millimeter.

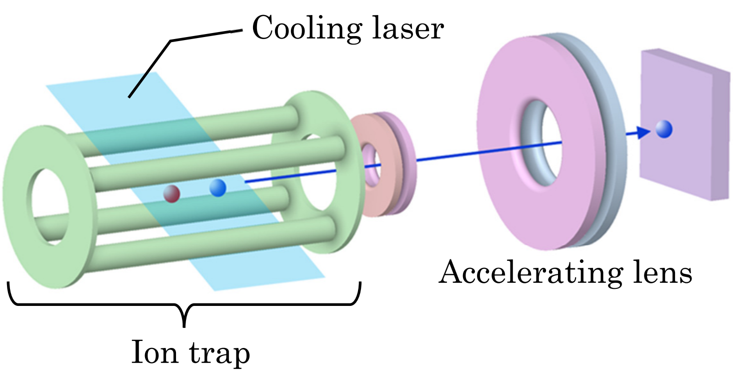


Figure 3-5. Image of ultra-precise ion implantation technology using an ion trap.

Nitrogen ions (●) are cooled to rest with laser-cooled calcium ions (●) and then extracted and accelerated after improving positional precision.

Even if theoretically possible, realization requires breakthroughs in the walls of conventional technology. The new elemental technologies required are technology to control the position of the ion beam and the position of the test material into which the ions are implanted at the level of one millionth of a millimeter, and technology to cool, extract, accelerate, position, control, and inject nitrogen ions into the test material continuously in a short time.

In this chapter, we have introduced ion beam technology that supports the creation of quantum functions. Ion beam technology is also widely applied to "observation (investigation)" and "creation" in other researches, and supports many other researches conducted at Takasaki Lab.

4. R & D for a Carbon-neutral and Recycling-oriented Society

Record-breaking heat waves and unprecedented heavy rainfall. The effects of global warming on the climate are becoming more serious.

The causative agent is greenhouse gases such as CO_2 (carbon dioxide), whose emissions have increased dramatically since the Industrial Revolution of the late 18th century, and CO_2 in the atmosphere continues to increase today.

Reducing CO_2 emissions requires a multifaceted approach that interconnects the environment, resources, energy, and other sectors.

Takasaki Lab is conducting research that contributes to energy conservation and the spread and expansion of renewable energy for this purpose, in parallel with research on quantum science and technology.

Highly conductive and durable electrolyte membrane

Essential item for energy storage and hydrogen production

Compared to fossil fuels such as coal and oil, fuel cells, metal-air batteries, and hydrogen production can reduce CO_2. emissions. Electrolyte membranes are a common and necessary material for all of these. Electrolyte membranes have both the role of a separation membrane that allows only ions to pass through without allowing electrons to pass through (conductivity) and the role of an insulator that prevents electrical shorts between the negative (-) and positive (+) electrodes (mechanical strength and chemical stability).

The development of electrolyte membranes that Takasaki Lab is pursuing began with research and development into the use of radiation to create a separator membrane that separates the anode and cathode of a button battery.

We "create" membranes with high performance and "investigate" the mechanisms that give rise to their functions and performance using state-of-the-art analytical technology. The results are then utilized to "create" membranes with even better performance.

Examination of the ultrafine structure of the high-performance electrolyte membranes we have developed so far has revealed a hierarchical structure, as shown in Figure 4-1.

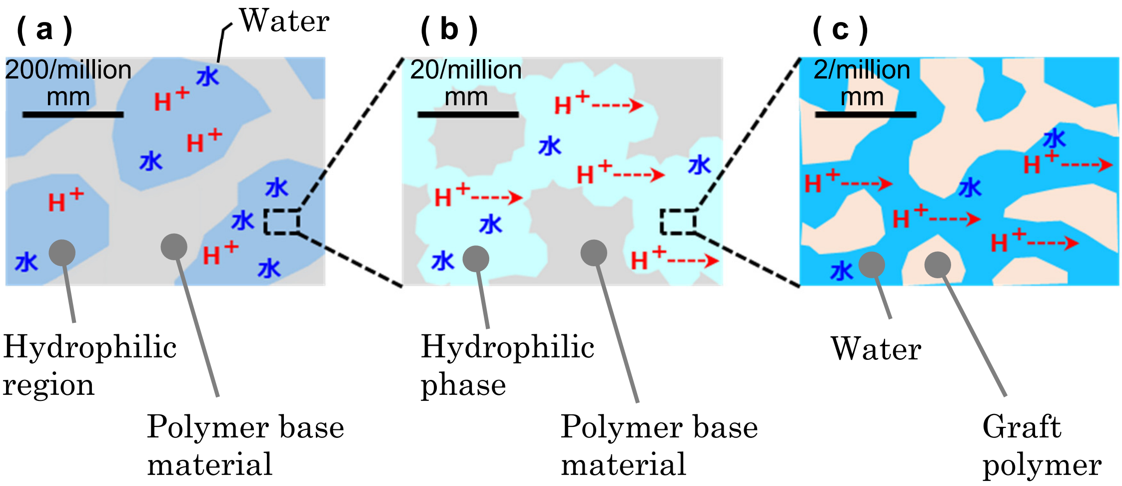


Figure 4-1. The hierarchical structure that produces the function of an electrolyte membrane (model diagram of membrane cross section based on analytical data).

The electrolyte membrane has islands of hydrophilic regions that contribute to conductivity, about 200/million mm within the base polymer that maintains the structure (a). Within the hydrophilic regions, clumps of hydrophilic phases as large as 20/million mm are interconnected and distributed (b). The hydrophilic phase consists of H^+ (hydrogen ions) and water pathways distributed around grafted polymers slightly smaller than 2/million millimeters (c).

Electrocatalysts for next-generation batteries

Aiming for hydrogen production without precious metals

An electrocatalyst literally functions as both an "electrode" and a "catalyst" (something that efficiently causes a chemical reaction). The electrode itself does not change, but acts as a catalyst to promote the chemical reaction, efficiently creating only the desired product.

To improve the performance of batteries and hydrogen production, it is necessary to increase the reaction efficiency (catalytic performance) of the electrode surface, which serves as the "field" for chemical reactions. Currently, platinum is used as a typical catalyst. However, platinum is unstable in supply, costly, and cannot withstand high temperatures (120°C).

Takasaki Lab is conducting research on electrocatalysts made from catalyst materials that are abundant in resources, inexpensive, and highly heat-resistant, with a view to hydrogen fuel cells to be installed in automobiles. The focus is on "oxide ceramics," which are baked and hardened oxygen compounds of metals such as titania (titanium with oxygen bonded to it). Oxide ceramics do not act as catalysts as they are, but by modifying their surface composition and microstructure, it has been found that they can act as catalysts (cause redox reactions).

And we now know that we need to view it as something that happens in the "quantum world.

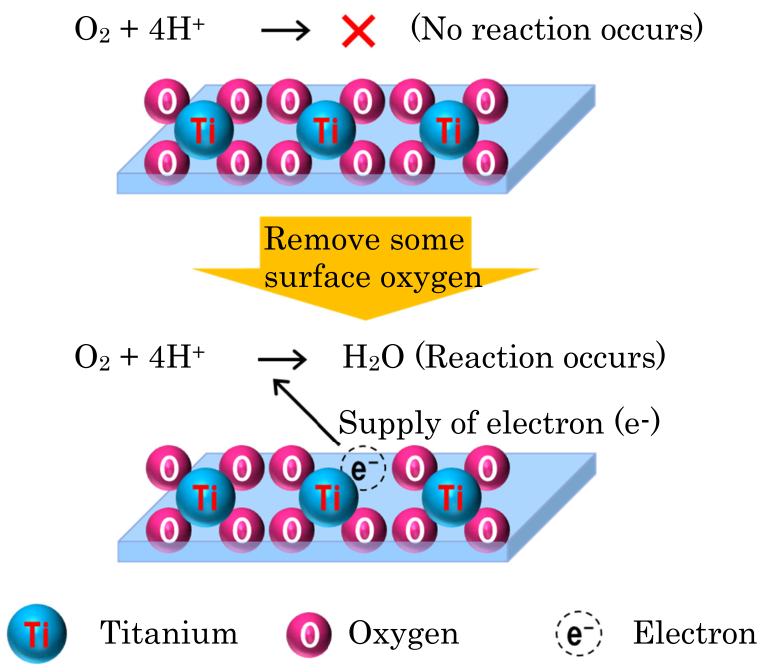


Figure 4-2. Catalytic function (promotion of redox reaction) by surface modification of titania.

Based on quantum scientific information, such as observation of the structure of electrons, researchers at Takasaki Lab are working to develop oxide ceramic catalysts with higher performance than catalysts using noble metals.

Energy conversion devices

Making jet fuel from waste oil

In Japan, policy has set a goal of replacing 10% of aviation fuel with sustainable aviation fuel by 2030. Takasaki Lab researchers are aiming to develop a "catalyst" to produce jet fuel from waste oil such as cooking oil.

Jet fuel has a structure of two hydrogen atoms (H) attached to a bead of carbon atoms (C). Waste oil originally has a similar structure. The key to the process of converting waste oil into jet fuel is the hydrogenation reaction, in which hydrogen is attached to the carbon beads.

Hydrogenation reactions have been known for a long time, but because they are performed at high temperatures and pressures, the equipment is large and energy must be input to carry out the reaction. In other words, the more you make, the more energy you consume. The way to avoid this self-contradiction is to introduce a "catalyst" that allows the hydrogenation reaction to proceed even at room temperature. If the catalyst is solidified by bonding it to a base material in the actual process, advantages such as downsizing the reaction equipment, simplifying the treatment of reaction effluent, and eliminating the need to recover the catalyst can be expected.

Takasaki Lab researchers plan to use AI to optimize physical and chemical parameters (variables) for the production of solidified catalysts, including the selection of materials to be used as catalysts, the composition and three-dimensional structure of the polymeric substrate to which the catalyst is immobilized, and the bonding method between the materials used as catalysts and the polymeric substrate, to predict which parameters are important for production and make development efficient and fast.

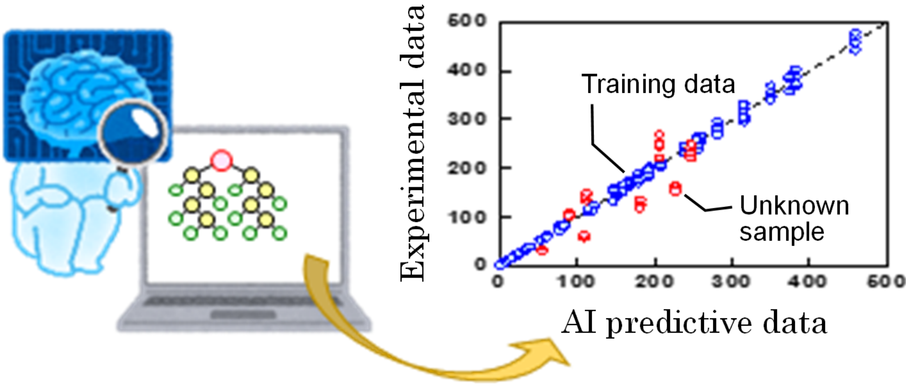


Figure 4-3. The usefulness of predictive data by AI.

Training image by AI (left) and comparison of experimental data and AI predictive data (right). Blue symbols indicate experimental data and red symbols indicate AI predictive data.

By promoting the research and development described in this chapter, Takasaki Lab will also contribute to carbon neutrality and the continuous recycling of resources.

5. Aiming to create new value from the collaboration of different fields of research

Takasaki Lab researchers actively promote collaboration with researchers in different fields of expertise in order to open up new fields and create new value.

In this chapter, we introduce the research being conducted by researchers who aim to develop materials for culturing human cells in an organized and three-dimensional manner, and by researchers who are creating radiation-emitting nuclides for use in diagnosis and treatment, all working toward the common, overarching goal of bringing health to all people.

Human cells needed to develop cures for disease

Two conditions required for culture

Experiments and research are conducted on various aspects of a single disease before its cause is investigated and a cure is developed. In the first step, basic experiments, cultured human cells are used as experimental materials. Cell culture can be divided into two main types depending on the purpose of the experiment. One is for experiments in which as many as possible are performed under the same conditions. The other is for experiments that are performed under the same conditions as in the body as much as possible.

Do a large number under the same condition

Mammoth housing complex of 1 million cellular households per postcard

In experiments in which the same conditions are used to perform as many experiments as possible, for example, to test the effects of a drug candidate, a culture vessel called a microplate, which is about the size of a postcard and has multiple well-shaped holes, is used. The number of holes is generally 96, but can be as large as 9,600. It shows the importance of aligning an enormous number of tests under the same conditions.

The size of a human cell is approximately 20/1,000 mm. The cells are placed one by one in a row of puddles (hollows) that are just large enough to hold a single cell. The number of hollows that can be arranged on a single postcard is more than one million, creating a mammoth complex of more than one million cells. We ask the cells to play a game of musical chairs to fill all 1 million holes.

The key is to make the surfaces of the dimples water-permeable so that cells that enter can stay there easily, while the surfaces of the walls between the adjacent dimples repel water so that cells cannot stay there. These two conditions were achieved through the selection of the substrate material and surface processing using quantum beams, and a mammoth housing complex of 1 million cell households was successfully realized.

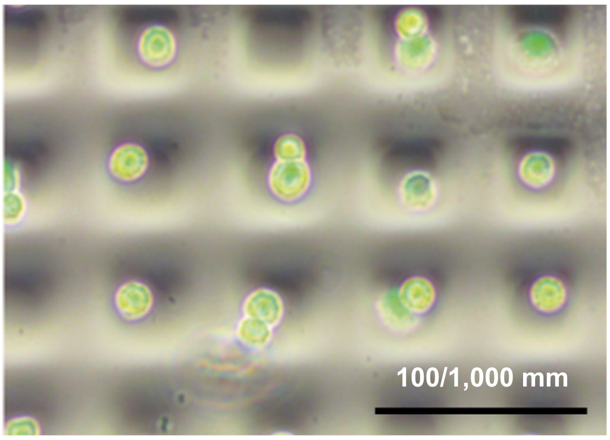


Figure 5-1. Cells fitted into dimples (puddles) arranged in a grid pattern on the substrate.

Each greenish-yellow sphere is a cell. The size of a dimple is 35/1,000 mm, and the depth is 30/1,000 mm.

Create the same situation as inside the body

Mammoth complex of 1 million households per cell per postcard

Create the same conditions as inside the body as much as possible. Many of the organs in the body have three-dimensional (3D) structures such as folds and protrusions on their surfaces. If we can create cultured cells that mimic these structures, we can expect to contribute to research and regenerative medicine.

The reality, however, is harsh, and research on using iPS cells to create three-dimensional shapes in cultured cells has only just begun. The researchers at the Takasaki Institute are boldly taking up the challenge.

How can we make cells, which normally form only a smooth sheet when cultured, create a three-dimensional structure? What we focused on was the property of cells, which when active, pull on the interface with the substrate with a weak force. This force causes the cells to create wrinkles similar to when a soft cloth is picked up. To achieve this, the surface of the base material must have high flexibility to deform even with the smallest force from the cells. On the other hand, it is no good if the surface of the base material is crumpled before the start of culture. Therefore, we came up with a mechanism whereby the surface of the substrate peels off as a thin film when the small force of cells is applied to it in a liquid at 37°C after the start of cell culture.

By finding a way to irradiate ion beams of different energy densities at different depths, we succeeded in creating a two-layer structure with different properties on the substrate. After culturing human cells for three days on this substrate, they were able to produce giant folds that were clearly visible to the naked eye.

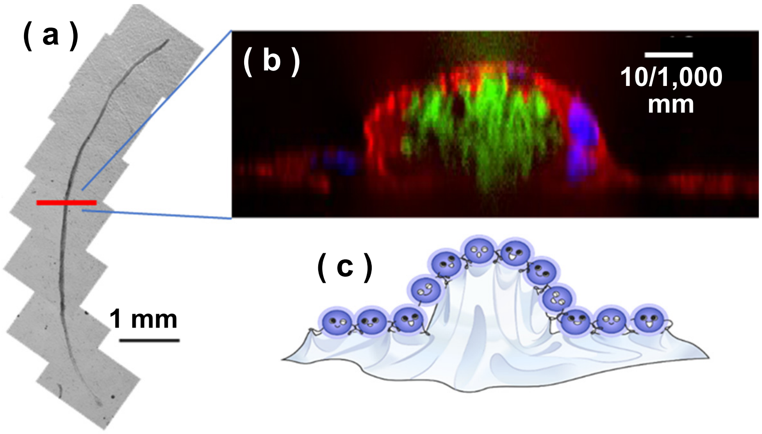


Figure 5-2. Giant folds created by cultured human cells.

(a) Cultured cell about 7 mm in total length.

(b) Fluorescence microscopic image of a cross section of the red line in (a). A bulge the size of several cells is formed.

(c) Schematic image of (b)

Takasaki Lab researchers are also working to reproduce the in vivo environment by creating protein gels that are more biocompatible and can be made with a greater degree of freedom in shape and hardness through precision processing. The goal is to develop biodevices that package cultured cells that spontaneously organize into three-dimensional structures.

Challenges in research on RI-labeled agents

Expectations for development of experimental biodevices

Radioactive isotope (RI) is a generic name for nuclides that have the ability to emit radiation and are used for diagnosis, treatment, and life science research.

At Takasaki Lab, we are conducting research on the production of various RIs using a cyclotron accelerator, research on the incorporation of RI into agents, and research on the use of agents with RI (RI-labeled agents) for diagnosis and treatment. For example, if RI can be incorporated into a agent that collects only in cancer cells, diagnosis can be made by studying how the agent collects in the body, and treatment can be made by killing only the cells to which the drug has bound or cells very close to it.

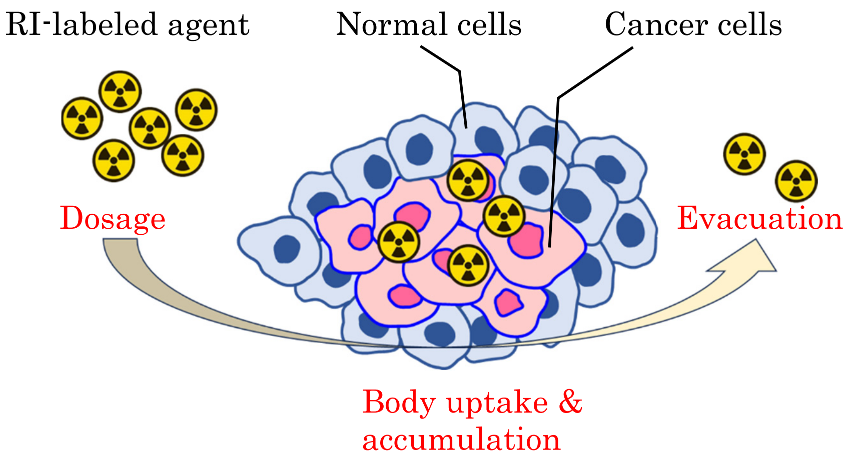


Figure 5-3. Image of cancer treatment with RI-labeled agents.

The ideal drug is absorbed and stored only in cancer cells. Radiation is emitted only for the period necessary for treatment, killing cancer cells but having little effect on normal cells. Drugs that have not been absorbed are quickly ejected from the body.

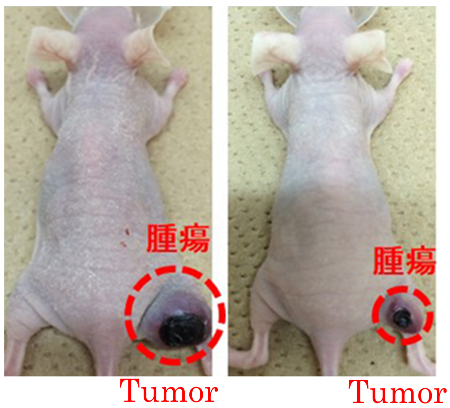


Figure 5-4. Effects of cancer treatment with the RI-labeled agent developed at Takasaki Lab.

RI-labeled agent succeeded in shrinking tumors in mice to half their original size.

Experiments evaluate the effects and impact of drugs on cultured cancer cells and normal cells, but to study the effects on cancerous clumps that form in normal tissue, laboratory animals must be used.

If we can create a large number of biodevices with clusters of cancer cells inside normal cells, we can conduct more of these experiments, more accurately, and above all without the sacrifice of animals. In addition to cancer drugs, it is expected that the development of other drugs and research to clarify the causes of diseases will also advance dramatically. To realize this goal, researchers at Takasaki Lab are challenging the creation of new value through collaboration that transcends the differences in their fields of expertise.

6. Advancement of Technology for Observation (Investigation) and Pioneering New Science and Technology

This is the final chapter in the introduction of Takasaki Lab (Takasaki Advanced Radiation Research Institute). In this chapter, we introduce the development of analytical technology, a means of "seeing (examining)," which can be said to be the starting point of our research.

The basics of facing Natural Science: Observing (Investigating)

The means to transform the world of science

The basis of research in the natural sciences is often based on observing closely, noticing something, and trying to figure out why what we notice happens or why it is the way it is. And new means for this sometimes transform the world. Take, for example, the microscope created by Löwenhoek in the late 17th century. A single lens opened the door to the microscopic world of the cell, which mankind had never seen before. Since then, various new tools have supported the progress of science.

Now, if we look at "observing (examining)" as a technology, what are we doing? Optical microscopes used in science experiments focus light on the object to be observed and examine its structure according to the differences in reflection or transmission. Electron microscopes, which are used to examine finer structures, bombard the object with electrons.

Light and electrons are not the only "objects" used to observe (examine). Researchers search for the sample they want to study and the "something to hit" that is appropriate for what they want to study, and develop a method to capture the changes that occur when the sample is hit as a signal.

C_{60} Whole Molecule Mapping Technology

What are the components of the surface of a sample ?

Using the accelerator at Takasaki Lab, molecules such as phthalocyanine can be accelerated and sent flying. Similarly, heavy molecules called fullerenes (C_{60}), which consist of 60 carbon atoms connected in a spherical cage shape, can also be sent flying. What does it mean to bombard a sample with C_{60} ?

Imagine a large meteorite impacting the moon. The soil on the moon's surface is scattered into space, leaving craters in its wake. The C_{60} whole molecule mapping technique is a micro-scale version of this. By bombarding a sample with high-speed C_{60}, the molecules present on the surface are ejected. They are collected and analyzed by mass spectrometry to estimate what molecules were present on the surface.

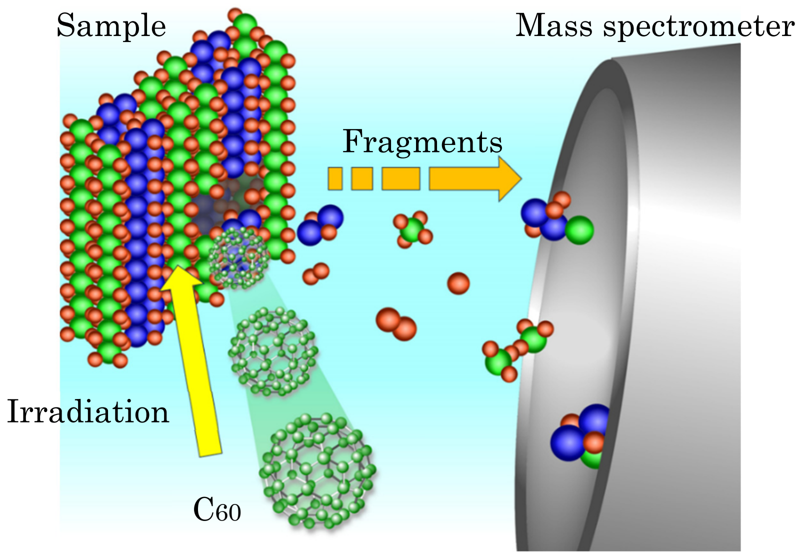


Figure 6-1. Image of C_{60} molecular mapping.

Takasaki Lab researchers are aiming to complete the C_{60} molecular mapping technique as “an analytical technique to identify all the components that are there”. To achieve this, it is necessary to develop a fast C_{60} ion microbeam that can hit a target only 1/1,000 of a millimeter in size with C_{60} flying at 1.5 km/s. Once the “C_{60} whole molecule mapping technique,” in which all the components of a sample surface are played out and identified with a fast C_{60} ion microbeam, is completed, it is expected to be used in research and technological development in various fields.

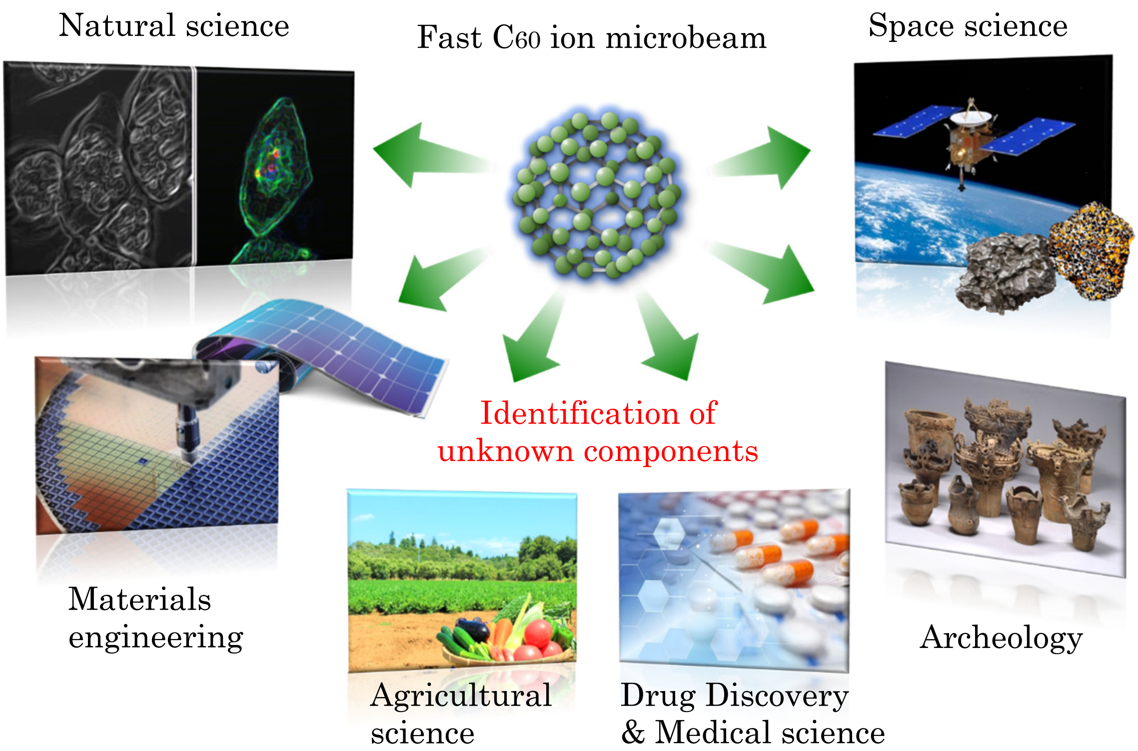


Figure 6-2. The C_{60} whole-molecule mapping technology will help promote a wide range of research and technology development areas.

In fact, C_{60} molecular mapping can be applied to the analysis not only for "hard" samples such as quantum functional materials but also "soft" samples such as biological tissue.

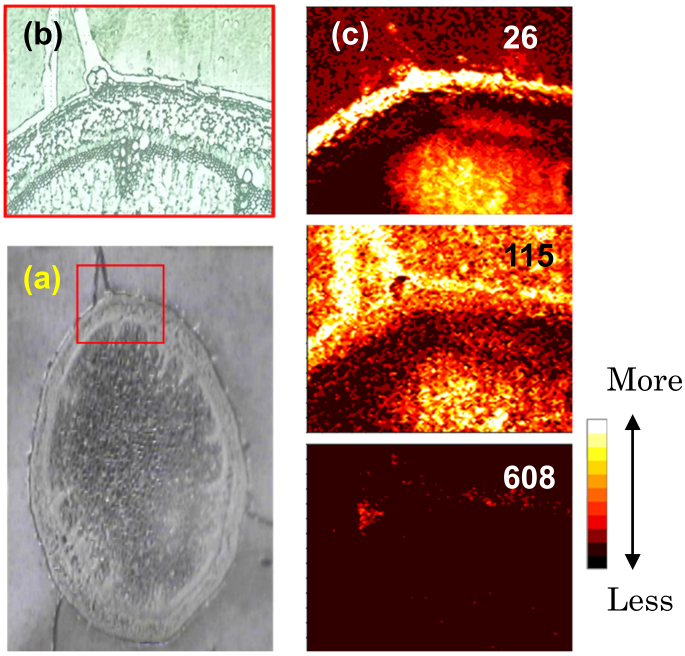


Figure 6-3. Example of analysis of tomato stem cross section.

(a) Tomato stem cross section.
(b) Micrograph of the C_{60} molecular mapping analysis area in (b) (1.4 mm long x 1.8 mm wide).
(c (right column)) Results of C_{60} molecular mapping analysis. The numbers on the right shoulder indicate the distribution of components with weights of 26, 115, and 608 (the weight of one hydrogen atom is 1).

An example of analysis of a tomato stem cross section shows that it can provide information that cannot be obtained by methods that observe the structure, such as the presence or absence of a component of a particular weight, depending on its position, and the bias in the distribution of that component.

How can we investigate the function of organisms and materials?

The C_{60} molecular mapping technique is a powerful analytical method to determine what components are present and distributed on the surface of a sample. However, it is not good at observing "movement".

On the surface of a material that facilitates a chemical reaction as a catalyst, molecules, atoms, and electrons move through the reaction process, and the catalytic function appears for the first time. In addition, as living organisms maintain their life activities, various materials are in motion inside their bodies and cells. Thus, regardless of the field or subject of research, there is a growing need for technology that allows us to "directly observe what is happening there. The object of observation to focus on, the range (size) to observe, and the time to observe (the time it takes to complete a series of functions) vary depending on the subject of what we want to study.

For example, a tomato observed by C_{60} molecular mapping. It transports water and nutrients through the stem. Isn't it obvious? You might think. Have you ever actually observed how tomatoes transport nutrients? Takasaki Lab practices this observation. We are developing "Plant RI Imaging Technology," a technique to observe the movement of nutrients in living plants using RI of the elements that make up nutrients, and are conducting research to help solve food production and environmental problems.

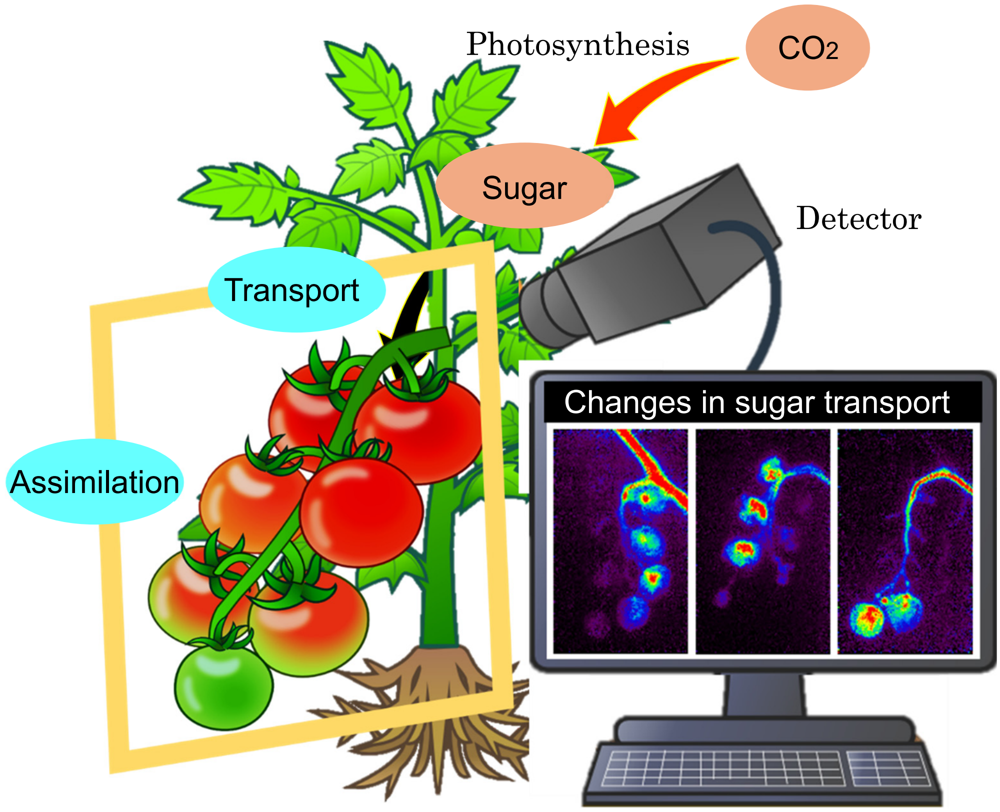


Figure 6-4. Image of observation using plant RI imaging technology.

RI-labeled CO_2 is absorbed from tomato leaves, and the sugar produced by photosynthesis in the leaves is distributed to multiple fruits in the same bunch.

Finally

We have introduced what the “Takasaki Lab” is doing in its 60th year since its establishment.

Takasaki Lab will promote research and development of quantum materials and devices, focusing on leading-edge quantum functional materials research utilizing quantum beams, which is one of our strengths, and also promote research and development for social implementation of these materials in various fields such as materials, energy, environment, and biotechnology, in order to realize our goal of a super-smart society. We will promote activities to realize our goal of an ultra-smart society.

We look forward to your further support and encouragement for Takasaki Lab, which aims to serve and contribute to society.