2021
NATIONAL INSTITUTE FOR MATERIALS SCIENCE

# NIMS NOW INTERNATIONAL No. 2

# 20 PLUS

## NIMS turns 20

### Continuing growth and New Challenges

# NIMS turns 20.

The National Institute for Materials Science (NIMS) will mark its 20th anniversary in April 2021.
Serving as Japan's sole public institution specialized in materials research, NIMS has made significant contributions in many sectors, such as public infrastructure, medicine and energy.

20-year-olds are generally perceived as inexperienced youngsters.
However, NIMS has something more than just 20 years of experience.
It was formed following the merger of two long-established research institutions.
NIMS was therefore founded on a solid foundation which had been built over decades.

These predecessors are National Research Institute for Metals (NRIM) and National Institute for Research in Inorganic Materials (NIRIM) established in 1956 and 1966, respectively.
NRIM and NIRIM together had produced a number of advanced materials that supported Japan's economic and industrial growth.
As such, NIMS' current ability to produce significant results in materials science was built upon the experience and know-how they developed.

In addition, NIMS researchers have great ambitions for the future with the passion of hopeful 20-year-old youths.
NIMS is committed to making this world a better place for people to live in through materials research.
Our visions for the future will be highlighted through this NIMS NOW issue.

Interview with NIMS President

# From our first 20 years to the next 20

**Kazuhito Hashimoto**
President of National Institute for Materials Science (NIMS)

### Changing the world with innovative materials

National Institute for Materials Science (NIMS) was formed in April 2001 through the merger of its two predecessors: National Research Institute for Metals (NRIM) and National Institute for Research in Inorganic Materials (NIRIM). Serving as Japan's sole public institution specialized in materials research, NIMS has brought a number of revolutionary materials into the world, including SiAlON phosphors—an essential LED material—highly heat-resistant alloys which have been used in aircraft engines and dysprosium (Dy)-free neodymium (Nd) magnets, powerful magnets free of rare metals. Looking back at its first 20 years, NIMS President Kazuhito Hashimoto said, "Our organization has undergone many changes and developments as we strive to fulfill our mission: making society more sustainable through materials research."


### Nurturing the talents of individual researchers

NIMS' launch as a new independent administrative institution following the merger radically transformed it from a more passive role to an active one. Teruo Kishi, the first NIMS President, believed that researchers should develop their individual expertise in addition to meeting the demands of the national government. Kishi therefore encouraged individual NIMS researchers to demonstrate their research capabilities by publishing their results in scientific journals.

NIMS as a whole has also worked to strengthen its international competitiveness in materials research. It established the International Center for Young Scientists (ICYS) in 2003 for the purpose of recruiting and supporting talented young researchers from all around the world by providing them with funding and an environment in which they can fully concentrate on their research. Through the ICYS program, NIMS has been able to improve its overall research capabilities and expand its international network. In addition, NIMS began sponsoring the publication of Science and Technology of Advanced Materials (STAM), a Japan-based journal, in 2005. This journal has grown to be one of the world's most influential materials science journals as a result of its steady effort to carry high-quality research articles.

In 2009 Sukekatsu Ushioda succeeded Kishi as NIMS President. Ushioda further accelerated the international growth of NIMS. He led NIMS' collaboration with research institutions overseas, such as France, Switzerland and China, sent a clear message to the world about the vision and capability of NIMS and raised NIMS' status to that of a world-leading research institution.

Hashimoto, who took over as NIMS President in 2016, has directed the organization to meet domestic demands—its original role—while allowing it to continue its international activities.

"It's important for researchers at NIMS to be able to carry out their research with creative freedom and flexibility, so that they can produce results to the best of their abilities," Hashimoto said. "They also have the obligation to participate in national research projects given that a large portion of our budget is nationally funded."

Hashimoto laid out a framework that would allow NIMS researchers to engage in both personal and collaborative projects, thereby giving them opportunities to both develop their expertise in their areas of research interest and make contributions to society.

### Source of innovation: the M³ (M-cube) Program

In 2016, NIMS transitioned to a new corporate status as a designated national research and development institute with a new mission: promoting innovation by acting as a bridge to encourage collaboration between the industrial, academic and public sectors. To accomplish this mission, Hashimoto launched the M³ Program with three "M"s representing three pillars.

The first M represents the **Materials Open Platform (MOP)**: a framework designed to promote private companies in the same industrial sectors to collaborate on basic research with the common goal of boosting Japan's international competitiveness in their respective sectors. This new type of open innovation system is the first of its kind in the world.

"Different companies often face the same issues, and they need to be resolved through basic research," Hashimoto said. "It would be beneficial for these companies to work together to efficiently find solutions to these issues. In practice, however, competitors are normally reluctant to join forces. To overcome this hurdle, NIMS serves as a bridge by conducting a series of interviews with each company to identify and suggest basic research projects that are collaboratively workable." Four chemical companies—Mitsubishi Chemical Corporation, Sumitomo Chemical Company, Asahi Kasei Corporation and Mitsui Chemicals—have joined the chemical industry MOP to build a polymeric materials database, while three steel companies—Nippon Steel Corporation, JFE Steel Corporation and Kobe Steel—have joined the steel industry MOP to find innovative steel strengthening mechanisms. NIMS has facilitated these inter-company collaborations and allowed them to make progress, which they can later exploit in applied research.

The second M represents the **Materials Global Center (MGC)**, which was established to bring human, physical and financial resources together at NIMS, thereby strengthening its function as an international research hub. MGC's key players are ICYS and the Center for Functional Sensors and Actuators (CFSN). CFSN's mission is to bring Japan's Society 5.0 initiative* into reality by developing sensors to collect various types of real-world data and actuators that operate in accordance with the collected data and linking them in a sophisticated manner. At CFSN,

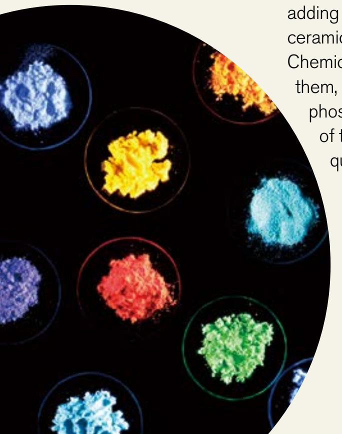
## Outstanding achievements of NIMS

**2000s**

**2002**

**SiAlON phosphors**

These phosphors were created by adding rare earth elements to sialon ceramics. NIMS worked with Mitsubishi Chemical Corporation to commercialize them, resulting in the release of a red phosphor product in 2008. The use of this product greatly improved the quality of white LEDs, leading to their widespread use.



**2008**

**Nickel-base superalloy**

Using an in-house alloy design program, NIMS optimized the nickel-base superalloy to enable it to withstand 1,120°C, the highest heat resistance ever recorded for this type of material. In 2012, one of the developed alloys was integrated in engines of the Boeing 787 Dreamliner which operates worldwide.

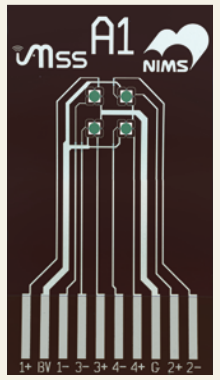
**2010s**

**2011**

**Creep tests set a new world record**

Long-term creep tests assess the durability of material at high temperature under high pressure. NIMS conducted a test for 14,868 consecutive days, setting a new Guinness World Record (certified in 2020).

For information on creep tests → P14




**2011**

**Ultra-small olfactory sensor (MSS)**

MSS can detect various types of odors. NIMS has been carrying on basic research, has launched the MSS Forum aiming to implement MSS into society and has been conducting demonstration experiments in various fields with companies, universities, research institutes and hospitals.

**2013**

**Dysprosium-free magnet**

The rare earth element dysprosium (Dy) was previously needed to be added to make neodymium magnets for applications of hybrid motor vehicles. The Dy-free neodymium magnet developed by NIMS has improved performance even in such a high-temperature environment.

**2014**

**Seismic dampers**

These dampers made of an iron-manganese-silicon alloy were developed jointly with Takenaka Corporation and Awaji Materia Co., Ltd. They were first integrated into the JP Tower Nagoya in 2014 and then into the Aichi Sky Expo in 2018.

International Center for Young Scientists (ICYS) →P14
STAM →P15
Data-driven →P10
Environmental and energy →P 8
Next-generation materials and devices →P12

NIMS and other leading researchers with expertise in sensors/actuators have been developing new devices with higher performance than existing products.

The third M stands for the **Materials Research Bank (MRB)**, a collection of resources available to researchers to enable them to produce the highest quality results possible. The Materials Data Platform Center (DPFC) is the central player in MRB. Materials developers in many countries have adopted a data-driven approach: the use of machine learning techniques to process large amounts of data for the purpose of finding materials with desirable physical properties. The size and quality of databases will greatly influence the accuracy of analytical results produced by this approach. DPFC has been building and operating materials databases with the aim of developing them into a global data platform.

"International competition to develop materials data platforms is intensifying," Hashimoto said. "NIMS has a major competitive advantage because it has developed the world's largest materials database, resulting from more than 20 years of data collection. In addition, NIMS has its own AI-based analytical technique and the ability to generate large amounts of data using state-of-the-art lab equipment. We will further increase the quality and quantity of our data with the help of the Japanese industrial sector through the MOP framework."

### Materials R&D strategies for the next 20 years

NIMS is committed to tackling the environmental and energy issues the world faces. This is one of the reasons that NIMS has been making considerable efforts to achieve innovation. Japan has set a goal of reducing its greenhouse gas emissions to net zero (i.e., becoming carbon neutral) by 2050. However, this goal will be difficult to meet with existing technologies. "We really need to achieve major scientific and technological breakthroughs," Hashimoto said.

There is a great deal of interest in using hydrogen energy as an alternative to petroleum and coal-based energy sources. This shift will require the development of hydrogen liquefaction technology in order to make hydrogen storage and transportation much more efficient, and methods of evaluating the safety of materials to be used for hydrogen liquefaction. Expectations are also high for the development of next-generation rechargeable batteries. An all-solid-state battery is similar to a lithium-ion battery, but it uses a solid electrolyte instead of a liquid one. NIMS researchers are working to create an efficient and comprehensive process for developing all-solid-state batteries, from materials exploration using materials informatics (MI) all the way to battery performance evaluation. NIMS has also launched a quantum materials project to create materials with new functions by controlling quantum phenomena occurring in them. In this project, NIMS is attempting to develop innovative next-generation materials and devices.

"I'd like to make the necessary improvements at NIMS to enable researchers to perform to their fullest potential as individuals and teams, thereby further increasing the productivity of the organization," Hashimoto said. "Through continuous reform, I hope that NIMS will develop into the most innovation-friendly organization in the world." This transformation may allow NIMS to make significant contributions to society in the future. (By Akina Horikawa)

* Society 5.0 is a Japanese development concept laid out in the 5th Science and Technology Basic Plan. The concept aims to simultaneously achieve economic growth and solve social issues by integrating cyberspace (virtual space) and physical space (the real world) in a sophisticated manner.

## 2010s


**2015**

**NMR system generates the world's strongest magnetic field**

Nuclear magnetic resonance is used to analyze the molecular structure and electronic state in proteins and other materials. This NMR system equipped with bismuth-based high-temperature superconducting wire was developed by a collaboration with RIKEN, Kobe Steel, and JEOL. It has generated a record-high 1,020 MHz magnetic field.

**2017**

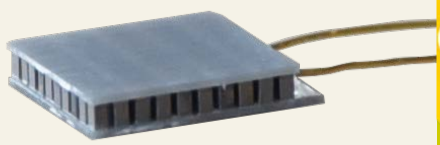
**Self-healing ceramic material**

This ceramic material is capable of self-repairing cracks. At 1,000°C, it can fill cracks in just one minute or so. Research is underway to achieve the use of this material in aircraft engine turbine blades.

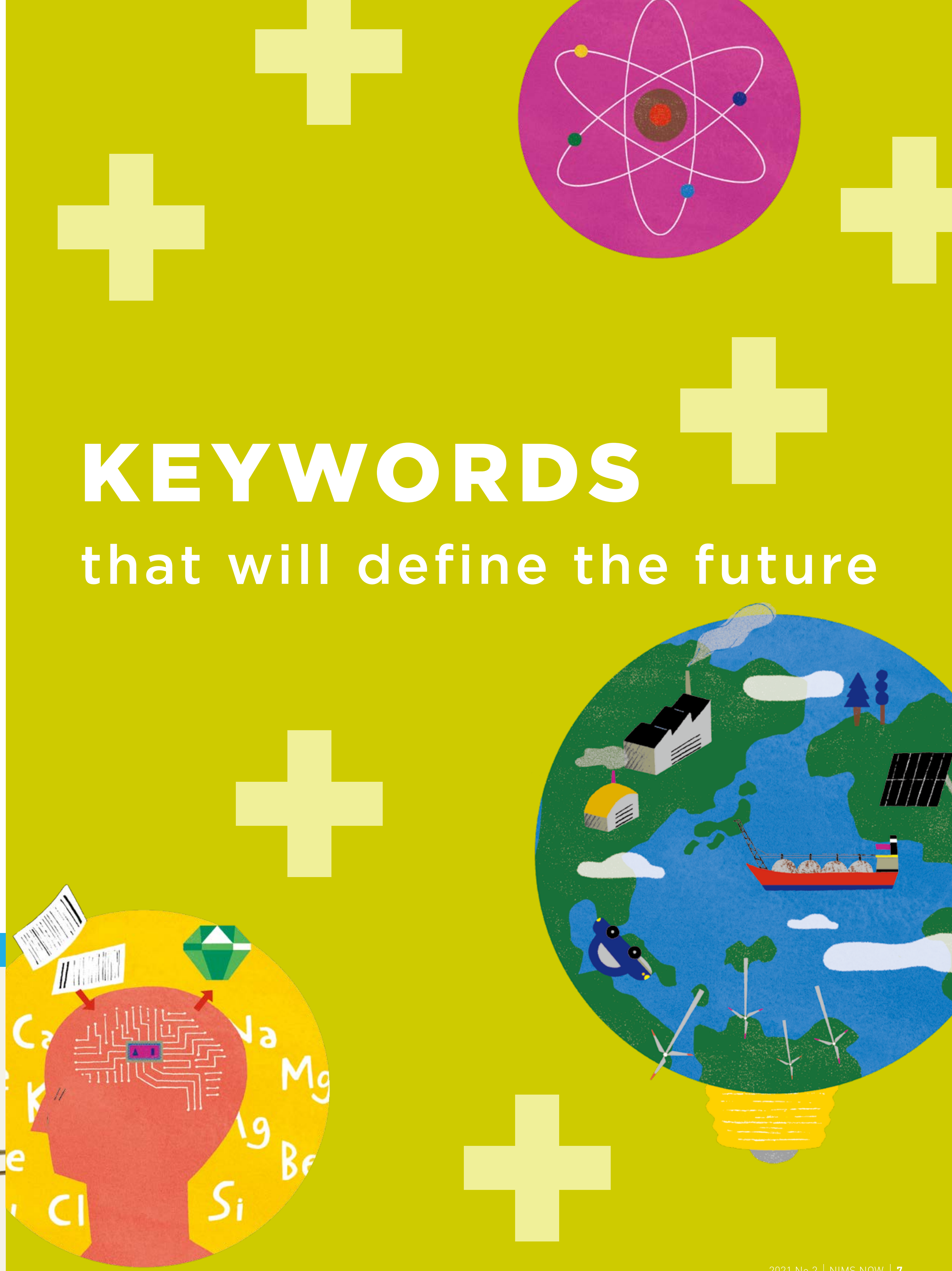
**2019**

**Fe-Al-Si thermoelectric (FAST) materials**

The FAST materials composed of iron, aluminum, and silicon can generate electricity using a small temperature difference. NIMS develops autonomous power supplies for IoT devices with AISIN CORPORATION and Ibaraki University.



# KEYWORDS that will define the future



# 1 Energy and the environment

Many countries have recently pledged to take decarbonization initiatives. Various carbon neutrality policies are being drawn up to achieve net zero emissions of global warming / greenhouse gases, such as carbon dioxide ($CO_2$) and methane ($CH_4$), and to promote more efficient energy use. One major approach to achieving this goal is reducing dependence on fossil fuels and increasing the use of renewable energy. However, renewable energy is an unstable source of electricity. For a country to maintain its economic growth, it needs to focus on community-scale energy flow patterns. The energy value chain is a set of activities necessary for the production, distribution and consumption of energy. Developing innovative materials may be key to making the energy value chain more efficient.

Hydrogen is a promising clean, next-generation energy source which can be combusted to generate electricity without releasing $CO_2$. Development of hydrogen-based technologies, such as hydrogen-powered fuel cell vehicles, is making steady progress. By contrast, methods of producing and transporting large amounts of hydrogen are still far from being established. To address this issue, NIMS focuses magnetic refrigeration technology which has been developed for many years. This technology may be used to achieve hydrogen liquefaction—the cooling of gaseous hydrogen to -253°C—in an energy- and cost-efficient manner. This process can reduce the volume of hydrogen to one eight hundredth of its original gaseous volume. This initiative led to the 2019 launch of the Cryogenic Center for Liquid Hydrogen and Materials Science (CLean) and the formulation of a 10-year roadmap to ensure steady progress in putting this technology into practice (Pick-up 1).

## Development of Next-generation rechargeable batteries

The need for rechargeable batteries is growing in response to Japan's policy to promote renewable energy use. Rechargeable batteries are vital in enabling solar cell-generated electricity to be usable at night. In addition, higher performance rechargeable batteries may be used to extend the mileage of electric vehicles (EVs).

NIMS is engaged in serious efforts to develop all-solid-state batteries and lithium-air batteries. All-solid-state batteries are very similar to lithium-ion batteries in structure, except that they contain a solid electrolyte instead of a liquid one, making them more durable and reliable. Many private companies are also working to commercialize all-solid-state batteries. Although some small all-solid-state batteries designed to supply electricity to IoT devices have already been commercialized, the capacities of these batteries need to be increased before they will be appropriate for use in EVs.

NIMS has been devoted to the research and development of all-solid-state batteries for many years. Many private companies developing these batteries have approached NIMS for advice. Through these consultations, NIMS has come to realize that these companies are all facing similar basic research-related challenges. To resolve these issues, NIMS launched a nationwide project to develop all-solid-state batteries under the Materials Open Platform (MOP; see p. 5 for details) framework. Ten companies are currently members of this MOP.

The lithium-air battery is said to be the ultimate rechargeable battery because its theoretical energy density is several times that of the lithium-ion battery. In addition, it is extremely lightweight, making it an ideal power source for drones and high altitude platform stations (HAPS). In 2018, the NIMS-SoftBank Advanced Technology Development Center was established to jointly carry out comprehensive lithium-air battery R&D, from basic research to practical application.

## Recovering waste energy through multiple approaches

Various forms of energy are lost throughout the energy value chain. Waste heat—the most common form of energy waste—substantially undermines the efficiency of community-wide energy use and causes environmental issues. Materials capable of converting heat into electricity came into existence many years ago. However, they all have problems, such as toxicity and poor conversion efficiency for low-temperature heat. While scientists are still trying to address these issues, NIMS has developed a thermoelectric material composed only of abundant iron, silicon and aluminum that works effectively at room temperature. NIMS is currently working to put it into practical use in collaboration with private companies. A newly emerged scientific field called spin caloritronics (Pick-up 2) may also be applicable to the development of new technologies capable of thermoelectric conversion using the spin of electrons.

Achieving new technological breakthroughs is likely to create new public and market demands. Materials research organizations with an array of innovative technologies and strategies have an advantage in meeting these demands. NIMS will continue its efforts to address environmental issues and develop energy-related materials with an eye on the future.

PICK-UP 1

### Hydrogen liquefaction project

Energy-efficient hydrogen cooling technology is crucial in reducing the cost of hydrogen liquefaction. NIMS has been developing an energy-efficient magnetic refrigeration technology in which the distance between a magnet and a magnetic material is repeatedly changed to cause the material to absorb and release heat. NIMS is currently in search of the most effective magnetic material for magnetic refrigeration and is developing a system into which this material can be integrated. Using machine learning techniques, NIMS discovered in 2020 that holmium diboride exhibits high refrigeration capacity in the vicinity of -253°C. NIMS has also been developing processing techniques, such as a technique to process superalloy powders into spheres and a coating technique to protect materials exposed to hydrogen from degradation. In addition, NIMS is working to optimize the magnetic refrigeration system.

* For details, see the previous NIMS NOW issue (Vol. 19, No. 4)

PICK-UP 2

### Spin caloritronics

In 2008, Dr. Ken-ichi Uchida (then affiliated with Keio University and currently with NIMS) and colleagues discovered the spin Seebeck effect: the generation of a spin current by a temperature gradient in a magnetic material. This discovery led to the recent development of new thermoelectric conversion driven by electron spin. Spin caloritronics is an emerging interdisciplinary field that focuses on the study of interactions between spin, heat, and charge currents. Research in this field is now being conducted worldwide. Since 2016, Uchida has succeeded in observing various thermoelectric conversion phenomena in magnetic materials such as the anisotropic magneto-Peltier effect and the anomalous Ettingshausen effect, using a cutting-edge heat detection technique. These accomplishments in spin caloritronics have opened the door to the development of novel thermal energy control technologies which would have been impossible within the framework of conventional electronics and thermal engineering.

# 2 Data-driven R&D

The adoption of a data-driven approach in materials R&D has brought about major breakthroughs. In this approach, an analytical AI system is trained with huge amounts of data (big data) and used to find solutions to specific problems. AI systems are capable of finding novel solutions to problems by performing complex calculations and making predictions at an extremely high speed. This technique has been adopted for various applications. In materials research, a data-driven approach is leading to discoveries of new materials. The usefulness of this technique is being proven.

## Rapid methodological evolution

NIMS was keen to incorporate a data-driven approach into materials research even before this method became popular in materials exploration. NIMS worked to develop data-driven methodologies through two programs: the Cross-ministerial Strategic Innovation Promotion Program (SIP), which has been ongoing since 2014, and the Materials Research by Information Integration Initiative (MI²I), which lasted from 2015 to 2020. Even though a sufficient amount of materials data to properly run AI systems was unavailable during these projects, NIMS managed to establish a data-driven method for solving material-related problems. As a result, in the MI²I program, NIMS was able to develop a material capable of delivering one of the highest thermal insulation performances in the world. In addition, through the SIP program, NIMS developed the Materials Integration by Network Technology (MInt) system: an AI-based system capable of predicting optimum manufacturing processes, compositions, physical properties and performance for metal-based structural materials. NIMS is currently working to upgrade the data-driven methodologies by further increasing the sophistication of the AI technique and applying the technique to solving a wider range of material-related problems.

## Infrastructure for accelerating data collection

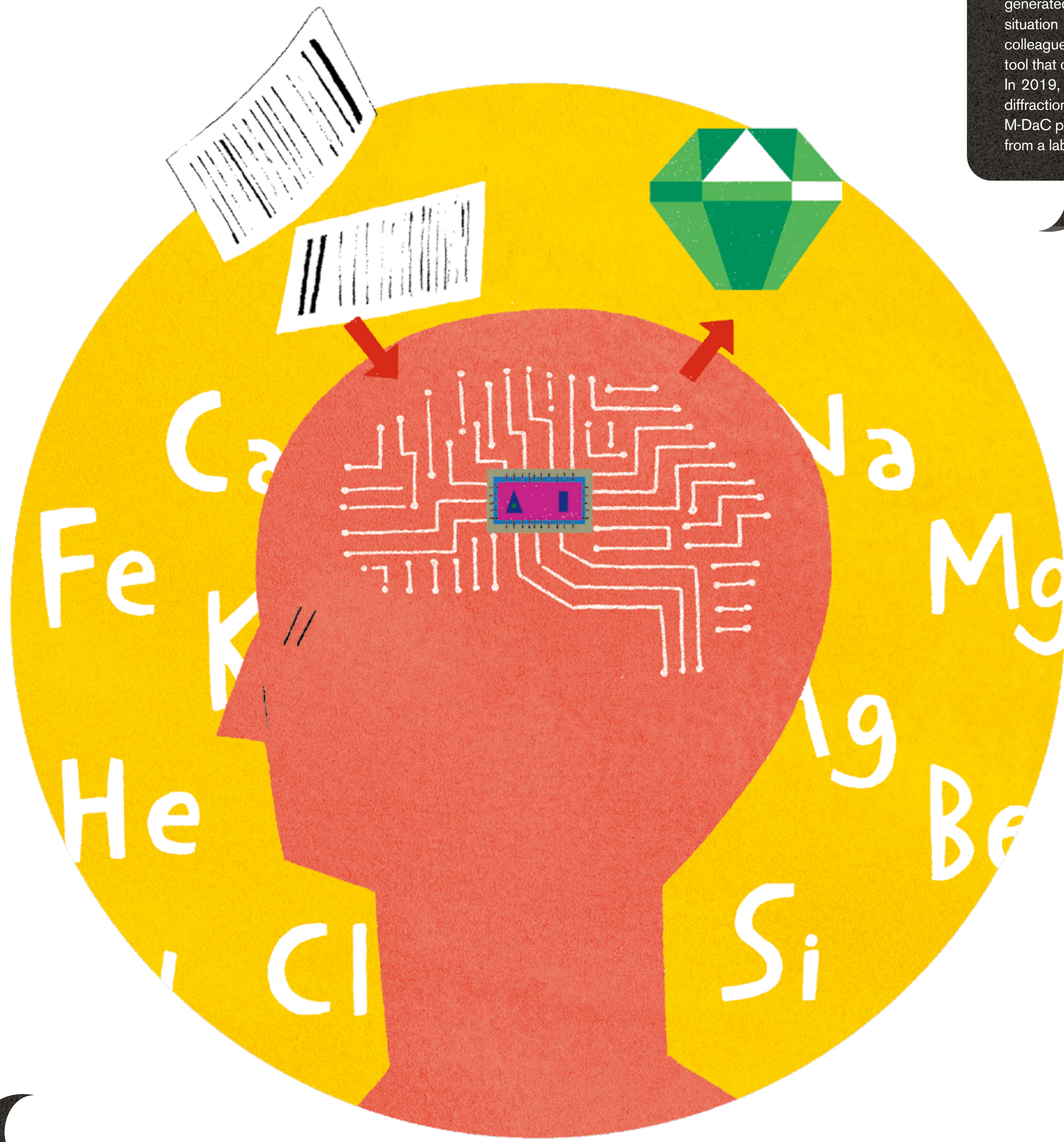
While NIMS has made significant achievements in these programs, issues concerning the quality and quantity of data were also identified and are still open. The amount of materials data currently available is still far less than the amounts of data available for other studies in which a data-driven approach has been more well-established (e.g., genetic and protein data for medical and pharmaceutical studies and social data that is analyzed to formulate marketing and product development strategies). Materials are so diverse that generating big data on them is very challenging. For example, many types of materials exist, from metals to ceramics to plastics, and there is a large number of physical or chemical property parameters, such as hardness, viscosity and electrical and thermal conductivity, to name a few. In addition, because these different types of materials and properties interact in a complex manner, enormous amounts of data are needed for adequate analysis. Furthermore, an efficient method for collecting data from individual researchers is yet to be developed.

Data formats used vary among different research institutions and private companies and even among individual researchers within the same organization. Because of these inconsistencies, data collected from different sources is not directly readable by an AI system. To address this issue, NIMS started constructing a data collection infrastructure in 2017 called the Materials Data Platform, which is capable of efficiently collecting data and processing it into formats readable by an AI system (Pick-up ❶). NIMS is attempting to develop a global data platform through such efforts as developing a new data collection tool (Pick-up ❷) and a data system to smoothly use the collected data.

## Digital transformation (DX) in materials research

NIMS intends to further strengthen its data platform function by promoting digital transformation (DX) across Japan's materials science community, thereby increasing its capability to collect materials data nationwide. It has already begun coordinating with universities and research institutions across the nation participating in the Nanotechnology Platform Japan Program and is asking for cooperation in the form of their sharing of materials data. NIMS plans to incorporate the shared data into its databases. This DX initiative is expected to significantly accelerate NIMS' effort to develop large-scale materials databases. These databases are available for use by researchers developing materials. Their research will then generate new data, which will be added to NIMS' databases, allowing for their continuous growth.

As described above, NIMS has two major strategies to lead materials R&D: strengthening its data-driven research capability and enhancing its materials data platform function—a vital resource for data-driven research.




PICK-UP 1

### Materials Data Platform, DICE

DICE is a data platform for all experts offering quality data and applications for materials science. DICE provides data resources, including the databases that NIMS has built over many years such as MatNavi, data sheets, data generated during research processes, source code, analysis tools and data extracted from research papers. We have been developing a platform system with the data consisting of four concepts: collecting, accumulating, providing and publishing data. To collect data efficiently, we are developing text data mining techniques and technologies to automatically collect data generated by lab equipment. To make our databases more reliable and secure, we assign unique IDs to individual datasets and keep track of data users. In addition, to organize the collected data into publishable forms, we have been increasing its value by transforming numerical data into graphs to enable easy visualization.

PICK-UP 2

### Development of tools for automatic translation, collection and analysis of output data generated by lab equipments

A data-driven approach to materials development requires huge amounts of diverse data. However, much of the data generated by different lab equipments are recorded in the manufacturers' original file formats and abbreviations. This situation makes it difficult for others to integrate many varieties of raw data for use of AI. Dr. Hideki Yoshikawa and colleagues therefore collaborated with lab equipment manufacturers and developed M-DaC, an automatic translation tool that convert various forms of raw data into standard technical terms and store them in highly readable file formats. In 2019, NIMS released the M-DaC for the major instruments used in X-ray photoelectron spectroscopy and X-ray diffraction widely used in materials evaluation. NIMS is currently inviting more lab equipment manufacturers to join this M-DaC project. For application of M-DaC tool, NIMS is also developing a system that adds functions for data transfer from a lab equipment using IoT and for automatic analysis of the data.

# 3 Next-generation materials and devices

Japan's Society 5.0 initiative is a vision of a more ideal or "super smart" society. This concept aims to simultaneously achieve economic growth and solve social issues by connecting people and devices via the internet. Efforts to make this dream a reality are accelerating. Sensors and actuators are two key technologies for the development of a super smart society.

As part of this initiative, IoT sensors—analogous to the five senses of humans—will be used to collect vast amounts of data nationwide. The collected data will then be analyzed by AI systems. Based on the analytical results, an actuator—a part of a device or machine that enables it to physically move—performs a mechanical action in the real world.

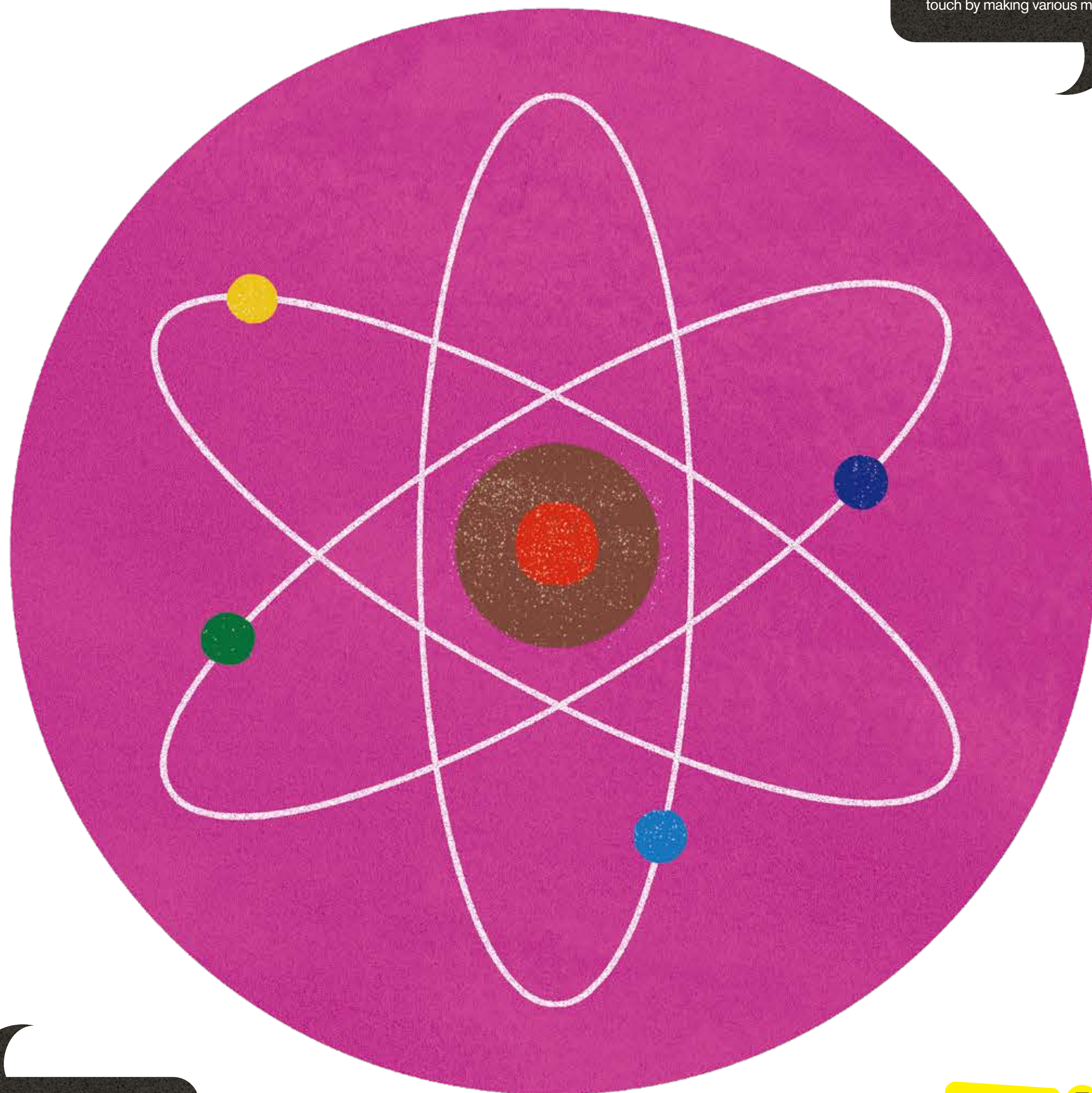
## Innovative technologies for sensors and actuators

Abundant amounts of potentially useful but largely overlooked data can be collected from our living environment and used to improve our communities. To effectively use this data, sensors and actuators with novel mechanisms need to be developed. NIMS has a number of innovative technologies that may be used to create these devices.

For example, NIMS has developed a moisture sensor capable of forecasting dew condensation before it actually occurs. This sensor may be used in agricultural greenhouses producing tomatoes, for example, to prevent plants from disease. NIMS is also developing user-friendly sensors for many different purposes, such as detecting toxic substances and bacteria that cause periodontal diseases in humans (Pick-up ❶).

Traditionally, most actuators, such as robotic arms, have been developed using hard materials. Recently, research and development of soft polymeric actuators responsive to external stimuli are becoming more common in response to the growing demand for wearable electronics. These flexible and thin actuators may be employed in next-generation micromachines. NIMS has been developing highly functional polymers as potential actuator materials (Pick-up❷).

In 2018, NIMS established the Center for Functional Sensors & Actuators (CFSN) in order to accelerate its efforts to put these technologies into practical use. Researchers at CFSN are working to improve the performance of sensor/actuator materials and enhance the coordination between these devices.



## Quantum materials: key players in next-generation communications technologies

Existing communications technologies are approaching their performance limits. The use of quantum technology may enable safer data transmission and faster computing in the future. Quantum materials, whose behavior is governed by quantum mechanics, are expected to play a central role in this new technology. In 2020, NIMS drew up plans to make major efforts to research and develop quantum materials which it is now systematically preparing to put into practice.

Among the different types of quantum technologies being developed, quantum cryptographic communication technology is already in practical use. This technology offers very secure, unbreakable communication using quantum optical effects. China and the United States have invested huge amounts of capital into its commercialization. However, this technology is still incomplete. The long-distance transmission of photons—quantum information carriers—requires the use of high-performance quantum repeaters, and the creation of such repeaters requires high-quality quantum materials. NIMS has been developing a technique to fabricate high-quality nanocrystals called quantum dots: a component of a quantum repeater (Pick-up❸). NIMS has also been developing a method of synthesizing high-purity diamond crystals which can be used to create quantum bits (qubits) for quantum computing. This is one of seven technologies NIMS has focused on in order to bring Japan's Society 5.0 concept into reality.

During the course of human civilization, materials have always driven economic and social development. Japan is currently facing various social issues, including a declining birth rate and an aging population, depopulation of rural areas and a widening gap between rich and poor. Materials science is expected to play a vital role in overcoming these challenges and making our lives richer and more comfortable. NIMS is committed to meeting social demands by developing advanced materials in line with Japan's Society 5.0 initiative.

PICK-UP 1

### Periodontal bacteria sensor

Periodontal bacteria cause severe systemic diseases, such as stroke and myocardial infarction, when they enter and circulate in the blood stream. Prevention and early treatment of periodontal disease are important to extending the healthy life expectancy. However, it is difficult for dental providers to quickly measure the abundance of these bacteria in patients' oral cavities. NIMS has been developing a sensor capable of easily detecting periodontal bacteria. In 2016, Dr. Akihiro Okamoto discovered for the first time in the world that periodontal bacteria belong to a group of so-called "electrogenic bacteria" capable of transferring electrons to an electrode metabolically. Exploiting this physiological property of periodontal bacteria, Okamoto is aiming to develop a sensor that can be used to easily and quickly detect the presence and abundance of certain periodontal bacteria in a small saliva sample. Users simply need to place a saliva sample on an electrode and the sensor measures electric current changes in the saliva caused by the bacteria. Okamoto's current challenge is understanding the electricity generation mechanisms of periodontal bacteria and developing an ideal electrode material for this sensor.

PICK-UP 2

### Actuator composed of ion-conductive liquid crystal capable of replicating sense of touch

NIMS has been attempting to develop a technology that can allow people to experience the real feeling of touching objects in virtual space. This technology may potentially enable medical doctors to remotely perform an operation on a patient from a distant location and fashion designers to virtually feel apparel products during the process of clothes making. To allow people to experience the sense of touch in virtual reality, a hand-wearable technology needs to be developed using a soft, thin and light material with the ability to vibrate at high speed in an energy efficient manner. With these requirements in mind, Dr. Masafumi Yoshio has been developing an actuator composed of a structurally strong liquid crystal film through which ions can rapidly flow. When an electric voltage is applied to the film, ions within it polarize, causing it to bend. This material is currently able to vibrate 10 times per second. Yoshio is working to make the material replicate a more delicate sense of touch by making various modifications, such as adjusting the liquid crystal structure and testing different types of ions and electrode materials.

PICK-UP 3

### Quantum dot capable of emitting entangled photon pairs

The use of quantum cryptography is expected to ensure secure communications. In this communication technology, "entangled" photon pairs, which carry information, travel through optical fibers. Quantum dots, made of semiconductor nanocrystals, can emit entangled photon pairs. When quantum dots are given a symmetric shape, such as an equilateral triangle, they can emit highly entangled photon pairs. To fabricate high-performance quantum dot emitters, NIMS has been developing an original droplet epitaxy technique. Dr. Takashi Kuroda and his colleagues recently improved this technique and succeeded in creating a quantum dot capable of emitting photons at 1.55 μm—the wavelength that can most effectively minimize the transmission loss within optical fibers. They are currently developing a portable, multipurpose photon-pair emitter which does not require the use of large cooling equipment to keep photon pairs in a purely quantum state.

## Creep tests

### Evaluating the durability of materials to be used in power plants and factories

Thermal power plants generate electricity by rotating turbines with hot, pressurized steam. The steel pipes that transport this steam are constantly exposed to a harsh environment. To ensure that these pipes can withstand extreme conditions, their durability needs to be adequately assessed. NIMS has been conducting creep tests since 1966. Steel samples are continuously subjected to a constant tensile force at temperatures ranging from 500 to 700°C. During these tests, the level of deformation of the samples and the time to fracture are recorded.

The durability of steels intended for use in thermal power plants and factories needs to be assessed for 100,000 hours (approximately 11.4 years). NIMS has been performing long-term creep tests, using a total of 500 creep testing machines with slightly different temperature and loading settings.

When NIMS first started creep testing, its role was to verify the reliability of materials produced by manufacturing companies. This has since expanded to include analysis of creep testing data to determine the effect of materials compositions on their strength and recommending revisions to existing specifications for materials used in industrial plants. In addition, since 2017, NIMS and 10 private companies have been jointly conducting remaining life assessments on welded steel pipe joints—the portion of pipes most susceptible to deterioration—using large specimens cut from welded pipes.

NIMS has evaluated a total of approximately 12,000 such specimens over the last 55 years. In 2020, NIMS began a new project to develop an AI system capable of determining the causes of damage and the severity of deterioration in materials by training the system with nearly 50,000 cross-sectional photographs of fractured materials. Through these activities both new and well-established, NIMS ensures the safety of public infrastructure.

## International Center for Young Scientists (ICYS)

### Recruiting and fostering talented researchers from around the world

NIMS is committed to developing human resources in addition to its other missions (R&D, publicizing achievements and sharing facilities). ICYS, established by NIMS in 2003, has played a vital role in fostering young researchers in materials science. The ICYS program offers an invaluable research environment to qualified researchers who have earned their doctorates within the past 10 years.

A major focus of the ICYS program is helping ICYS research fellows develop the capability to conduct independent research. Funding is provided to individual ICYS research fellows, allowing them the freedom to concentrate on their projects using the NIMS Open Facility for up to three years. In addition, each ICYS research fellows works under the mentorship of two NIMS researchers who provide advice and support as needed. Moreover, an annual workshop provides ICYS fellows with opportunities to interact with other scientists across different disciplines and nationalities, develop different perspectives and gain insight into international competition in materials R&D. Because NIMS deals with a wide variety of materials, including metallic, organic and bio-materials, it has the resources to offer diverse experiences for ICYS research fellows.

A total of 166 researchers from 29 countries have completed the ICYS program as of FY2020. About 30% of them have been employed by NIMS in permanent research positions while others are continuing their research at universities, private companies and other research institutions in various countries, allowing NIMS to expand its international network. ICYS accepts applications twice a year. Its main acceptance criteria are a researcher's previous research records and the originality of his/her research proposal. This program will continue fulfilling its mission—human resources development—arguably the most important driver of scientific advances.

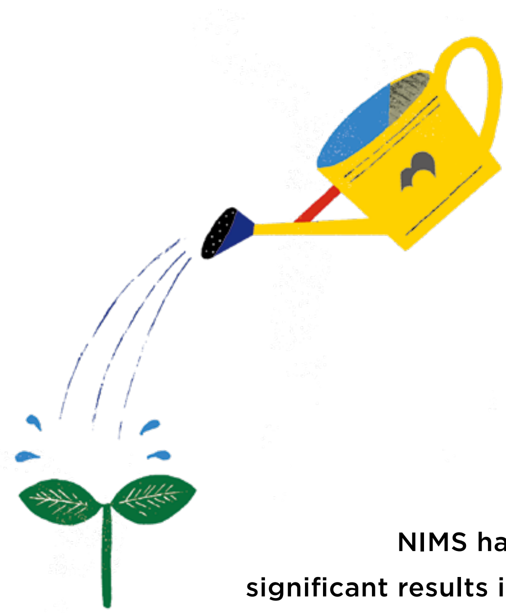
## Science and Technology of Advanced Materials (STAM)

### Open access journal managed by NIMS

Scientists can distribute their research findings globally by publishing them in scientific journals. Prestigious journals can have a profound influence on research communities as they carry articles by world-renowned scientists, as well as other high-impact articles, and also special features that reflect current trends in the scientific fields they cover. Most major scientific journals are produced by publishers based in Europe and the United States. STAM was jointly established in 2000 by a number of Japanese groups involved in materials science. STAM's mission was to publish research articles showing current global trends in materials science, and to thus promote advances in this field of science. The Department of Materials Engineering at the University of Tokyo initially served as editor-in-chief for STAM, then NIMS took over this role in 2005.

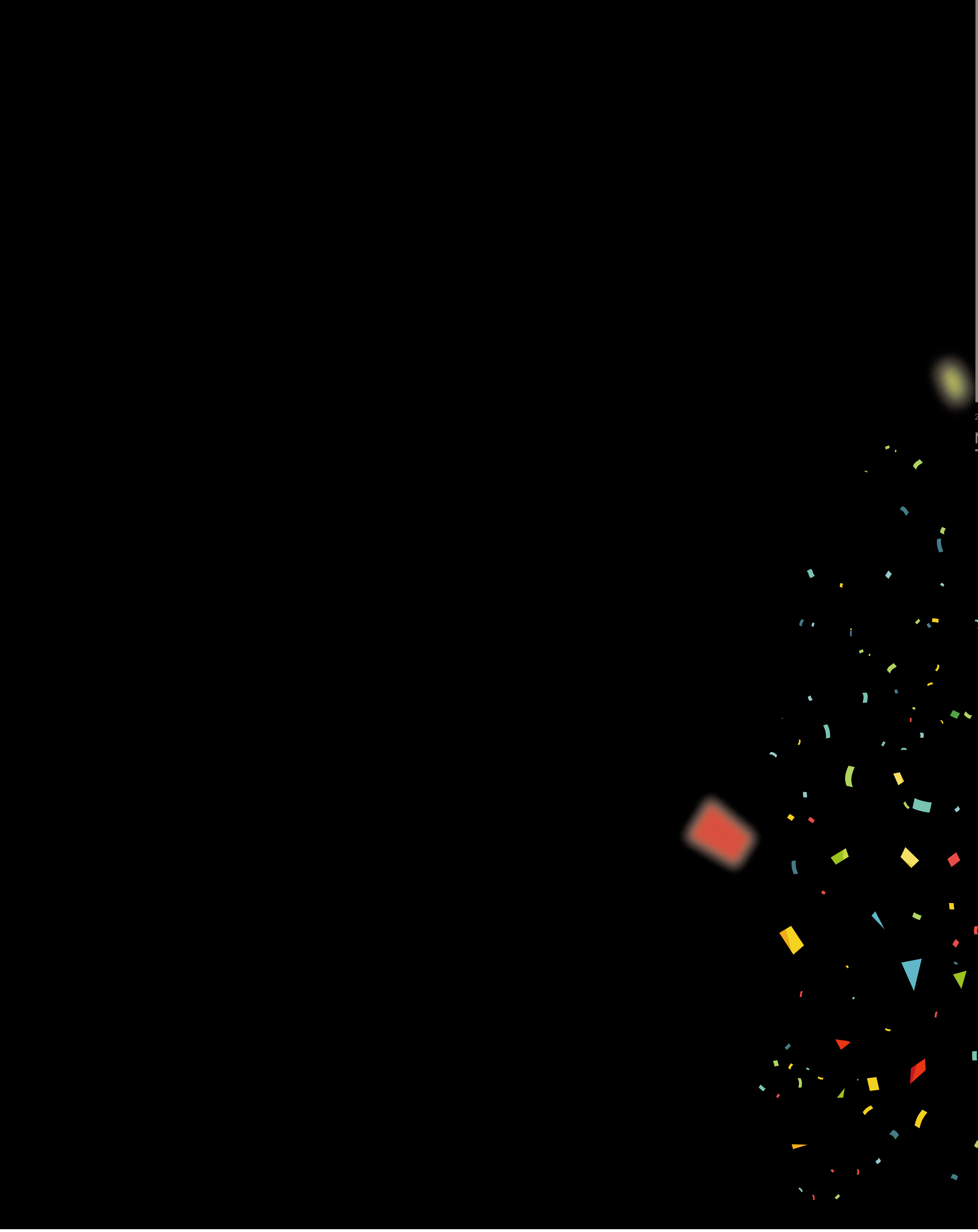
NIMS has taken strategic initiatives to increase the quality of articles published in STAM and to popularize it in international materials science community. NIMS has invited scientists globally to the journal's editorial board who represents the quality of peer-reviewed journal. While STAM was initially a subscription-based journal, in 2008 it transitioned to an open access journal (i.e., distributed online free of charge) in order to increase its readership in the world.

STAM's editorial board currently consists of about 70 materials scientists from 14 countries. The board carefully selects high-quality manuscripts and prepares special features on the latest materials science topics, which are chosen by a network of researchers associated with NIMS. As a result of these efforts, STAM has earned a high reputation with its impact factor (IF, an index that measures how often a journal's articles are cited in other research) having risen to 5.866 as of December 2020. An additional development was the publication, in January 2021, of the first issue of the journal STAM Methods, an offshoot of STAM. This brand-new journal focuses on the topics of informatics and data science, which can be used to facilitate the acceleration of materials development. NIMS will continue to lead in the area of materials science by publishing up-to-date information to serve the global open science community.

# NIMS initiatives

NIMS has supported advances in materials science not only by producing significant results in materials research but also by conducting material safety tests, developing human resources and publicizing material-related information. Here, we describe some successful NIMS initiatives.



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