[1st Featured Article]
Change Manufacturing
NEDO's Laser Processing Technology

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Interview with NEDO's Representative Office in Europe
Industrial Innovation Gains Momentum in Europe by IoT

Perspectives on Future Technologies
Daito Manabe, Media Artist
Technology will Create Diversity
in Art

Daito Manabe,
Media Artist

The attraction of the artworks we have been creating exists in the boundary between virtual reality and the real world, and at the intersection of the analog and digital domains, or humans and machines. We always want to ensure that our works do not lean to one side but dexterously show the attraction found at the boundary between virtual reality and the real world.

For instance, performances with drones tend to require dancers to follow the movements of drones or require engineers to design drones in tune with humans’ dancing. In either case, the productions give forced expressions.

To make an artwork that impresses an audience, a dance director should preferably be able to implement his or her idea and coordinate the movements of both drones and humans. Thus, we at Rhizomatiks have been developing software to allow dance directors to control drones as they wish, as well as products like drones that, in consideration of the safety of dancers, break immediately after a collision with a dancer in contrast to general goods. The development processes entail problem awareness and challenges. We resolve these challenges using our technology, implement necessary technologies, and ideally announce a work.

We are pursuing the theme of how we do things that nobody has ever done using technologies available now. Although the technologies that can be employed are limited, we can find many combinations of technological elements that no one has tried. A “miracle of combination” does not occur if technological talents are confined within our group. Our varying combination of members including video engineers, product designers, dancers, dance directors, and musicians is unparalleled in the world and offers one feature of Rhizomatiks. As we collaborate with more people, our form of expression is gradually changing.

With advances in big data and machine learning technology, “interactive solutions” will be replaced with what IBM calls “cognitive insights.” New technology has enabled computers to express a wave of a hand not just as a graphic but as a context of whether or not it indicates goodbye. A not-too-distant technology, if introduced, will enrich our expressions. I hope that such new technology will allow us to find new expressions and create diversity in art.

I think that the role of art is to create a new sense of value and stimulate new arguments, as well as to present beautifulness, so I hope that technology will serve as a gateway to making art more accessible and open to people.
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Manufacturing is beginning to change greatly along with the progress of the fourth industrial revolution. The industry anticipates that lasers will be one of the most important tools in future manufacturing because laser beams are digitally controllable with ease. With such future trends in view, NEDO is developing unprecedented high-brightness and high-efficiency laser technologies, as well as laser processing technologies using such lasers, with the aim of putting these technologies into widespread use in society.

Global trend toward improved production efficiency

Strong need for laser processing

In line with the increased use of technologies like the Internet of Things (IoT) and artificial intelligence (AI), the coordination of machine tools and devices through cloud computing, as well as automation and unattended operation, are expected to advance at manufacturing sites in the future. In this context, laser processing, which is easy to digital-control, is attracting attention (Figure 1 on page 5).

In 2016, the global laser market revenue was around USD 10.4 billion, of which sales in the materials processing laser sector were approx. USD 3.2 Billion, accounting for 30% of total revenue. In particular, sales of lasers for materials processing are expected to grow steadily at an annual rate of 3.7% from 2017 through 2022 (Figure 2).

A breakdown of materials processing laser applications for 2016 (Figure 3) shows that macro processing (e.g. metal cutting and welding) using high power lasers of kW-class stood on a par with micro processing (e.g. semiconductors, circuit boards and electronic parts, display production, and fine metal processing) using low- to medium-power lasers in the share of the total market. This proves that lasers for both macro and micro machining applications are in requisition.

In the macro processing segment, CO₂ lasers are increasingly replaced by more efficient fiber lasers. Along with an increase in the output power of laser diodes for direct processing, the share of new additive manufacturing applications, such as metal 3D printers, is expected to grow. The micro processing segment is made up of applications for diverse needs. As the penetration of lasers as a processing tool increases, the optimal lasers will be selected.

Against this backdrop, NEDO is undertaking the project “Development of advanced laser processing with intelligence based on high-brightness and high-efficiency laser technologies (TACMI project).” Yoshihiko Sunaga, Chief Officer of Internet of Things Promotion Department at NEDO, who coordinates the project as project manager, explains, “The manufacturing industry has entered a new age
of high-mix/low-volume manufacturing with the progress of the fourth industrial revolution. One of tools that can address the needs of the age is laser processing. It is essential to refine both macro and micro processing technologies and put them into general circulation with an eye toward the growing laser processing market.

In the "Comprehensive Strategy on Science, Technology and Innovation 2016" adopted by the Japanese government, one of key platforms for realizing "Society 5.0" (The Super Smart Society) is to pursue advances in quantum beam utilization technologies such as state-of-the-art lasers that will be central to the creation of new industries and technological foundations.

Yohei Kobayashi, Professor at the Institute for Solid State Physics of the University of Tokyo, who is leading the project as a project leader, emphasizes the importance of improving laser processing technology in view of the social problems confronting Japan. "Japan has been facing a declining population ahead of other nations. Productivity improvement is necessary for making and maintaining a good living. In addition, materials for products should be as light and strong as possible to address energy and environmental challenges. However, some materials like carbon fiber reinforced plastic (CFRP) are difficult to process. Laser processing technology will offer versatility in tackling these challenges," says Kobayashi.

In this project, NEDO is aiming to develop a technology for producing unprecedented high-output and high-quality laser with high efficiency, as well as a processing technology using these laser, and to put these technologies into widespread use in the society. To attain these objectives, it is imperative to overcome challenges, such as increasing processing speed, improving finishing quality, and improving power efficiency, that remain unresolved in conventional laser processing technology. This project is seeking to tackle these challenges to reduce energy consumption and strengthen Japan's manufacturing industry's competitive edge. NEDO will lead the nation's overall manufacturing capability to the next stage by encouraging synergy between themes under which these technologies are to be developed, through the use of IoT and the like.

On the following pages, we outline the main points in the themes for the development of laser processing technologies and an envisioned society where these technologies are implemented.
Pico-Second Pulse Deep UV Laser Processing Technology

Laser ablation
Essential for high-quality micro processing

Needs are created at manufacturing sites along with the advancement of smartphones and other electric and electronic devices. In order to satisfy such needs, it is desirable to realize a laser processing technology that enables unprecedented high quality and fine processing. Laser ablation (the process of removing material before the occurrence of melting and other thermal effects) is an effective technique that enables high-quality processing. Laser ablation is practiced by using short wavelength and narrow pulse widths laser light, such as deep UV(ultraviolet) light whose energy absorption ratio into metal material is extremely high, and the pulse widths range of picosecond (one trillionth of a second).

The NEDO project aims to develop technologies for generating laser light of short wavelengths and narrow pulse widths, and put them into practical use at actual manufacturing sites. The output power of the laser light is required to be increased in high level enough to be used in actual manufacturing.

University, startup company, and electronics giant cooperate to tackle challenge for higher power laser

The theme of this research and development is to increase the output power of deep ultraviolet light emitted from a laser with a 266 nm wavelength range (nm: one billionth of a meter) from 2 W (currently commercialized average output) to 50 W. If this goal is attained, the scope of application of materials processing will extend to include not only films and metallic foil but also various industrial materials such as semiconductor materials and crystal substrates. The technology necessary to achieve this goal is under development through collaboration among three parties: Osaka University making a nonlinear optical crystal to generate deep ultraviolet light; Spectronix Corporation developing a laser light source; and Mitsubishi Electric Corporation assembling these components into a laser processing machine.

A laser processing system generates laser light using a laser light source that is also called a laser oscillator. Generally, the laser light is infrared light with a 1,064 nm or 10,600 nm wavelength range in many cases. The machine goes through processes of distributing this laser light to near a target workpiece, concentrating the light through a lens, and drilling, cutting or other processing on a table. If the wavelength of laser light needs to be shortened, the laser light passes through a nonlinear optical crystal in the middle of its pathway to undergo the conversion of its wavelength.

Osaka University is developing this nonlinear optical crystal. Osaka University has research results of many years. The university is making efforts to produce a wavelength converter from a CLBO (CsLiB₆O₁₀) crystal, which it invented in 1993, and expand the size of the converter along with an increase in the output power of laser light source.
Upsizing the converter necessitates improving the composition ratio of a crystal growth solution, such as reducing the relative amount of lithium (Li), and controlling defects produced in the process of crystal formation while enhancing the quality of the crystal. "Our current device produces a crystal that weighs about 600 g. We are trying to make a larger crystal and use the crystal with minimum waste for improved economic efficiency," says Masashi Yoshimura, a professor at Osaka University.

Spectronix Corporation is developing technology for a light source that generates laser light of short wavelengths and narrow pulse widths using the large CLBO-made wavelength converter. The objective of this research is to produce high-output pulsed light with a good waveform and provide stable generation of 266 nm-wavelength deep ultraviolet light. Specifically, ultraviolet light is produced by amplifying the output power of carefully-controlled wavelength light emitted from a gain-switched laser diode at least 100 million times and converting the wavelength of far-red light twice. Yosuke Orii at Spectronix says, "Our challenge is to provide continuous stable generation of high-power light far in excess of the traditional 2W level so that this technology is put to practical use on actual production lines. Our activity includes the development of peripheral-field technologies that are new in this field."

Refining processing tool performance to readily process hard-to-process materials

A processing system needs to have a high-strength optical system in order to handle laser light generated by a high-power light source. Mitsubishi Electric Corporation, which is responsible for this work, is pursuing the development of an optical system that offers high processing quality. Another challenge in this development is to explore the conditions under which optimal processing is achieved. "We intend to integrate necessary technologies into a laser processing system after repeated trial and error by making use of data acquired through inter-theme coordination of the NEDO project," says Junichi Nishimae at Mitsubishi Electric.

Kazunari Hattori, Chief Officer of Internet of Things Promotion Department at NEDO, says with anticipation, "The project team will nearly meet an intermediate target of 20 W. Although achieving a final target of 50 W is challenging, a technology that has advanced to the ultimate level will enable precision processing of glass substrates, metals, and even composite materials and hard-to-process materials like ceramics."

Improving capacity for manufacturing electronic devices

~ Envisioned implementation of technology in society ~

If processing technology adopting deep-ultraviolet and picosecond lasers is utilized in manufacturing, information devices will come down in size and increase in performance. This technology will enable high-quality processing of glass, ceramic, and other materials that have been hard to be processed. CLBO crystals that act as wavelength converters may be used in applications other than materials processing, such as light source generation for semiconductor inspection.
Making Aircrafts and Automobiles More Eco-Friendly!

New Materials Processing Technology Using High-Energy Pulse Laser

Reinforcing metallic material by laser technology for weight reduction and energy conservation

High durability is required for steel, aluminum alloy, and other materials used in aircraft and automobiles. Thus, "peening" technology is used to harden the material's surface and thereby build up resistance to both abrasion and fatigue. Peening using laser technology can apply processing deeper in the material's interior than traditional shot peening involving impacting a surface with steel particles. As a result, laser peening is receiving attention because of its capability to improve a metal's overall strength. An improvement in the strength of a metal allows a reduction in the amount of consumed material. This results in a reduction in the weight of a product and a decrease in the amount of consumed fuel. In the present situation, however, the energy of laser light applied to material is low in level. One challenge in this field is to increase the level of the energy of laser light emitted per pulse.

Developing pulsed laser emitting 25 to 50 times higher level of energy compared to conventional lasers

Research institutions in Europe, the U.S., Asia, and other regions are developing high-power lasers that have much higher pulse energy than conventional lasers and are pursuing the application of these high-power lasers to industry. In line with this trend, NEDO is developing a laser system that can emit industry-leading 500 J-class pulse energy, 25 to 50 times higher the level of energy emitted by currently commercialized laser appliances.

Under the NEDO project, Hamamatsu Photonics K.K. is building a processing system that combines a high-power excitation light source module utilizing laser diode technology with an amplifier incorporating ceramic laser technology; Osaka University is undertaking the testing of irradiating material with laser light and developing simulation technologies; and the National Institute of Advanced Industrial Science and Technology is in charge of tasks such as developing technologies for nondestructive and noncontact analysis and assessment.

At present, the project team has completed a basic design for a 100-J class pulse laser system, and also the building of the system as a laser processing system is progressing smoothly. The basic design provides variable control of pulse shaping to meet a wide range of processing needs. Verification of a new processing technology incorporating such a feature will soon begin. A high-power and high-repetition-rate pulse laser, if implemented, will enable peening, as well as other types of processing including laser forming, surface cleaning, and paint removing, with improved efficiency.
Laser diodes fabricated from gallium nitride (GaN)-based materials can emit blue and similar color with short wavelengths. Under the NEDO project, several groups are accelerating the development of short wavelength light sources using GaN-based laser diodes, in which Japan is the world's leading innovator. A group led by Panasonic Corporation is developing a GaN-based laser array element, a metal's double-sided heat dissipation structure, among others, in an effort to develop a high-power blue-violet laser diode light source. The above-mentioned group of Kyoto University and companies is aiming to achieve a blue-violet laser diode with high beam quality through the development of a photonic crystal laser fabricated from a GaN-based material. The Institute of Physical and Chemical Research (Riken) and Yamaguchi University are making efforts to achieve an aluminum gallium nitride (AlGaN)-based deep-ultraviolet laser diode fabricated from an aluminum nitride (AlN) crystal substrate. Moreover, a group led by Chiba Institute of Technology, including companies, is making a visible light laser that combines a GaN-based laser diode with a praseodymium (Pr)-doped optical fiber, and is developing a small laser light source that generates ultraviolet light by a single wavelength conversion.

With an eye toward next-next-generation laser processing, NEDO is developing core technologies for high-brightness and high-efficiency laser light sources that are innovative and surpass the performance of traditional laser light sources, as well as technologies in peripheral fields.

Laser diodes offer high energy efficiency and thus are a technology indispensable for optical communications, recording media, displays, lighting, and other fields. Lasers fabricated from semiconductor materials, especially gallium arsenide (GaAs) and indium phosphide (InP), have greatly advanced in the information and telecommunications industry. These laser diodes have also started finding applications to excitation light sources, seed light sources, and light sources for direct processing in the materials processing field. Full-scale application of laser diode technology to materials processing is anticipated, although there is still room for improvement in output power and beam quality.

In line with these expectations, NEDO has convened many companies and universities for this project to pursue the development of light sources for next-next-generation laser processing, including vertical-cavity surface-emitting laser (VCSEL), quantum dot lasers, and photonic crystal laser technologies, which are sophisticated laser diode technologies originating in Japan.

A group comprised of Tokyo Institute of Technology and companies are undertaking research and development of a laser light source based on VCSEL technology that has a new structure and can be carried to a worksite. A group comprised of The University of Tokyo and companies are striving to increase the output power of a quantum dot laser that can run with extremely high efficiency. A group comprised of Kyoto University and companies are aiming to achieve a high-power short-pulse light source for processing based on a photonic crystal laser featuring high beam quality.

Aiming for practical implementation of short-wavelength laser light sources for processing having new materials and structures

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Developing new laser uses
~ Envisioned implementation of technology in society ~

Offering high energy efficiency, laser diode technology is the foundation on which all lasers will be built. A small device can be simply carried to a worksite to process an object at the site. Laser diodes can advantageously change the wavelength range for emitted light depending on the material. This technology will find extensive application in such fields as medicine, recording, lighting, printing and painting.
Data mining cycle system derives theory without relying on craftsmen’s intuition and experience

NEDO views building a laser processing platform as one of major milestones in this project. The project aims to create a system that enables the derivation of a recipe, a sequence of optimum machining conditions, from many parameters in response to a processing need.

Craftsmen or skilled personnel limited in number have determined how to laser-process new materials by their intuition and experience. Deriving a set of optimum processing conditions requires a massive amount of trial and error, and expertise acquired through such experience has rarely been shared in society. If the results of processing are assessed and stored and these results are utilized as knowledge in society, anyone can readily produce an object he/she wants to make.

IoT and AI technologies are making considerable advances. A framework for analyzing and storing processing data will presumably develop at an accelerated pace. If theoretical verification of “why does this processing make it?” is accelerated in line with this development, the time will eventually come when processing results can be precisely predicted only by simulation. Accordingly, it is essential to develop a system that enables “processing,” “measurement and assessment,” and “analysis” to run promptly in cycles.

Accumulating optimum processing recipes, ultimate universal processing system can perform for any materials

With the aim of implementing this future system, members of the NEDO project are making efforts to build a laser processing platform by firstly assembling components including a laser processing system that allows the user to greatly change parameter conditions and measuring instruments that serve to grasp facts at the time of processing. Based on this platform, the project members test processing in response to manufacturing companies’ needs and carry out a measurement, assessment, and so on to store data on processing conditions acquired from wide-ranging parameters. Machine learning of this stored data will enable the making of an “optimum processing recipe,” that is a “processing method ideal for a material having certain ingredients, hardness, and strength.” After the accumulation of these recipes, a universal processing system will be ultimately implemented so that the system can perform any processing and anyone can handle it.

Hiroharu Tamaru, Project Associate Professor at the University of Tokyo, who is an assistant leader of the NEDO project, says, “The project aims to create a situation in which the need of ‘a person obliged to complete certain processing by tomorrow’ can be promptly satisfied by sharing parameter settings that enable the processing.” Ryunosuke
Kuroda, Laboratory Team Leader at the National Institute of Advanced Industrial Science and Technology (AIST), who is another assistant leader of the NEDO project, says, "To develop a measuring technique for carrying out accurate assessment according to needs is also a theme of the project. It is important that AIST and other national institutions take the initiative in developing technologies that form a common foundation."

**Promoting open innovation in earnest**

*Increasing collaborative region to enhance industry's competitiveness*

Companies involved in laser processing sometimes compete with one another. However, it is important to build a relationship in which players in different positions, such as laser or processing system manufacturers, material suppliers, and material processors, cooperate with one another to enhance the industry's technological capability.

NEDO is supposed to play a role in motivating companies to have such awareness and build a cooperative relationship. Members of the project have been conducting interviews with both users and manufacturers. The TACMI Consortium, which was established by a participant in the project, aims to mutually enhance laser processing technologies.

"A region of collaborative activity has been increasing owing to cooperation by many people. The project is entering its third year in April 2018. By making the best use of such a region, NEDO and a participant in the project continue efforts for years to put developing technologies into widespread use in the society," says Project Manager Sunaga.
While IoT-driven industrial innovation is proceeding globally, world-leading efforts are gaining momentum in Europe. This article features an interview with NEDO's staff at the Representative Office in Europe located in Paris, France about current market trends in Europe, such as the transformation of the manufacturing industry and support for start-ups.

Aiming for integration into a unified market making use of each member nation’s characteristics, EU is stepping up efforts in energy and industrial technology

The European Union (EU) is an economic bloc of 28 member states that are located primarily in Europe. It has a population of over 500 million. The United Kingdom (UK), Germany, France, Italy, Spain, and North and East European countries are each identifying their national characteristics and pursuing various endeavors while aiming for integration into a unified market as the EU. In the EU, world-leading efforts are gaining momentum especially in the fields of energy and industrial technology, which NEDO has been grappling with.

In the energy-related field, the Paris Agreement was adopted at the 21st Conference of the Parties (COP21) held in December 2015. Calls are intensifying again for the introduction of renewable energy and the search for fossil-fuel substitutes. Large cities in Europe are stepping up efforts for the development of a smart city utilizing information technology and other advanced technologies to resolve energy and environmental problems and improve the quality of civil life. The French and UK governments, in particular, worked out a course of action in July 2017 to ban sales of fossil fuel-powered vehicles by 2040 in view of long-term carbon dioxide reduction and the environmental impact on urban areas, while public interest in electric vehicles (EVs), fuel cell vehicles (FCVs), and other next-generation vehicles is growing.

In Europe, with the advance in the liberalization of the energy market, peer-to-peer electric power trading through blockchain and other technology has begun, and signs of new business involving energy are appearing.

In the field of industrial technology, productivity in the manufacturing industry has improved owing to the progress of communications and data processing technology. EU nations are also undertaking efforts such as the introduction of new design techniques based on virtual reality technology and the introduction of 3D printing and other additive manufacturing technology. In the public transportation and restaurant business, which are closely tied to everyday life, new services such as on-demand and sharing services are becoming more prevalent.

In particular, the “Industrie 4.0” project, which was proposed in Germany to innovate manufacturing using IoT and AI technologies, has been receiving international attention. In France, technological startups are taking advantage of the nation’s inherent strength in software technology and their energetic activity is conspicuous. The French government has noticed this and has been promoting startup support policies through cooperation among industry, government, and academia to make these startups an engine for the country’s economic growth.

Meanwhile, according to startup support institutions in countries like Germany and France, the number of unicorns (any privately owned startup company valued at over USD 1 billion) in these countries is small, as it is in Japan. In one respect, they have the same concern as Japan about how to cultivate unicorns as in the U.S. and China.

In what forms will Japan develop business with Europe, one of its main partners? To provide a clue to answering this question, this article will present the accelerated efforts being made in Europe for industrial innovation.
In Germany, "Platform Industrie 4.0," an organization promoting Industry 4.0 through cooperation among industry, government, and academia, was established in 2013 to spread this concept into every sector of the manufacturing industry. The organization is actively pursuing research and development, as well as standardization, to achieve a smart factory in the industry.

In November 2013, the French government announced "La French Tech," a package of policies to support technology start-ups. La French Tech involves not only entrepreneurs but also investors and start-up supporters called accelerators in a framework built to assist start-ups. Specifically, the government set up a fund of EUR 200 million to increase the funding capability of accelerators. The French government also actively launched aid programs including the allocation of EUR 15 million for initiatives intended to help start-ups to make inroads into markets outside France and foreign entrepreneurs to create their start-ups in the country.

In response to these aid programs, the investment in start-ups in France has been soaring. In 2014, the number of investments was 372 and the investment amount was approx. EUR 900 million. In 2017, the number of investments rose about 1.6 times to 605 and the investment amount expanded about 2.8 times to approx. EUR 2.6 billion*1. The area of greatest investment was Internet service. Competition in this area is intensifying.

"Industrie 4.0" is a current topic in Japan and commonly referred to as the fourth industrial revolution. It is a national strategic project put forward by the German government in 2011 with the aim of digitalizing production and distribution systems in the manufacturing industry to improve productivity.

The third industrial revolution has primarily entailed factory automation (FA) through the introduction of robots. On the other hand, Industrie 4.0 means optimizing an actual supply chain in a digital space called a cyber-physical system (CPS) or digital twin using advanced communications and big data technologies, with the aim of enabling all elements of the supply chain including sales and distribution to connect and communicate with each other via the IoT.

It is said that this concept was developed from the automotive industry’s modular production system, which has the greatest efficiency.

CeBIT: NEDO showcases IoT and home care robot technologies
CeBIT is an international information and telecommunications industry trade fair held each year in Hanover, Germany. Japan was the official partner country for CeBIT 2017. NEDO showcased research results including IoT and home care robot technologies at its booth. On the first day of the 2017 exposition, Chancellor of Germany Angela Merkel and Prime Minister of Japan Shinzo Abe visited NEDO’s booth, which attracted significant attention.

Station F attracts over 1,000 start-ups
At the end of June 2017, the "Station F," the biggest start-up incubation campus in the world, opened. This start-up campus was established by the founder of Free Mobile, a French cell phone giant, with its private funds. This building accommodates public entities and other facilities to offer services such as consultation about intellectual property, subsidy, and so on. Over 1,000 start-ups have already used these services.

*1: Source: Ernst & Young "Baromètre EY du capital risque en France Bilan annuel 2017"
NEDO's Co-Funding Program

Developing innovations by enabling each other's strengths to come into play

With the increasing globalization of business nowadays, open innovation is increasing in importance. Open innovation provides a company with the mindset of creating a new innovative value by cooperating with other companies in foreign countries and mutually making up for inadequate technologies and ideas. Delayed entry into the global market may result in a delay in seizing the opportunity for international standardization.

Accordingly, NEDO, with the aim of facilitating open innovation, is undertaking a "co-funding program" for supporting domestic and foreign companies in conducting joint research technology. This scheme allows a Japanese company and a foreign company to receive a subsidy for their joint international research, on condition that the Japanese company submits a proposal of the joint research to NEDO and the foreign company submits a proposal to a support institution of the country concurrently, and the examiners of both institutions give their proposal.

NEDO is undertaking its co-funding program with a total of three countries. In FY2011, NEDO began a bilateral cooperation program with a French counterpart. At present, NEDO's list of nations for its co-funding program includes Germany, which is promoting the digitalization of the manufacturing industry under its Industrie 4.0 project, and Israel, which is strong in cybersecurity and other technology and is developing many innovations. NEDO has selected 14 themes until now and has been supporting endeavors in a wide variety of fields including IoT, laser, and nanotechnology materials.

Compared to other nations, there are quite a few companies in Japan that cannot venture into foreign markets despite possessing high technologies. Through this support program, NEDO encourages domestic companies to incorporate advanced technologies outside Japan and branch out into global markets, with the aim of promoting open innovation and enhancing industrial competitiveness in Japan.

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At the end of January 2018 in Paris, France, Konica Minolta, Inc. of Japan and France's BioAxial and Institute Pasteur co-hosted a meeting to report the results of the "Development of Drug Discovery Support System Using Fluorescent Nanoparticle Imaging Technology" project. In addition to NEDO, participants included Bpifrance, a French public investment bank that has supported BioAxial's involvement, the Embassy of Japan in France, the Japan External Trade Organization (JETRO), and a major pharmaceutical company that is a user of the system. The meeting finished on a high note thanks to the cooperation of the people involved.
NEDO’s Representative Office in Europe was opened in October 1998. Since then, the Europe office has worked on collecting information on energy and industrial technology in Europe, forming networks with governments and related agencies there, pursuing demonstration projects, and supporting collaborations through NEDO’s co-funding program in the European region.

Europe got ahead of other regions in the development of energy environmental technology and industrial technology and European countries have been making various efforts in these fields. These European efforts have been informative for Japan in looking into a new policy or course of action. However, not all aspects of these European efforts are going swimmingly although they appear to be proceeding smoothly in some respects. In reality, various challenges have arisen and they have repeated trial and error. NEDO’s Representative Office in Europe aims to convey such real European matters that cannot be comprehended at a glance.

NEDO thinks that not only learning from Europe but also effectively incorporating admirable aspects of European efforts into Japan’s endeavors are a key to enhancing Japan’s industrial competitiveness. Some Japanese companies may hesitate to enter into cooperation with European counterparts because of the large physical distance and differences in language and cultural backgrounds.

NEDO supports joint international research and development projects between companies in Japan and Europe, taking advantage of strengths in both Japanese and European companies through its co-funding program (see page 14). International research and development pursued with differences in language and culture may pose tougher challenge than those that arises in research and development cooperation between Japanese companies. NEDO, however, believes that the former offers the potential for more business expansion than the latter. The NEDO’s European office hopes that Japanese companies who have interest in collaboration with European counterparts will use this program as a first footing for international research and development.

If you have an opportunity to come to Europe, please visit NEDO’s European office in Paris. The entire staff at the office will welcome your visit.

NEDO's activities in Europe
News Release

Development of a New Photocatalytic Panel Reactor for Scale-Up and Low-Cost Production

– Realization of water-splitting inside the reactor filled with only a 1-mm-deep layer of water –

The NEDO research team demonstrated that this reactor is the first to split water at a rate adequate for practical implementation and discharge hydrogen and oxygen. Compared with conventional reactors, it requires a substantially lower amount of water inside the reactor and can be produced with lighter and cheaper materials. This configuration provides the possibility of achieving enlarged panel surface area. Furthermore, NEDO and the other participants constructed a large prototype of a 1 m^2 photocatalytic panel reactor (see Figure 2 on page 17) and demonstrated that the reactor split water into hydrogen and oxygen under natural sunlight.

Enlarging the panel surface area and lowering the production cost are essential for practically implementing an artificial photosynthesis system using a photocatalyst. The results of this research represent a major breakthrough in providing a fundamental principle for designing a photocatalytic panel reactor with a larger surface area at a lower cost, with the ultimate goal of implementing an artificial photosynthesis system for societal use.

The newly-developed reactor contains sheets fabricated by coating a particulate photocatalyst on substrate and splits water with a depth of only 1 mm. The NEDO research team demonstrated that this reactor is the first to split water at a rate adequate for practical implementation and discharge hydrogen and oxygen. Compared with conventional reactors, it requires a substantially lower amount of water inside the reactor and can be produced with lighter and cheaper materials. This configuration provides the possibility of achieving enlarged panel surface area. Furthermore, NEDO and the other participants constructed a large prototype of a 1 m^2 photocatalytic panel reactor (see Figure 2 on page 17) and demonstrated that the reactor split water into hydrogen and oxygen under natural sunlight.

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The results of this research were published on the website of the American science journal Joule on Wednesday, January 17, 2018 (EST).

For details, please refer to the following website.
http://www.cell.com/joule/fulltext/S2542-4351(17)30224-6

January 19, 2018 News Release

Glossary

Artificial Photosynthesis Project “Development of Chemical Processes for Producing Fundamental Chemicals Utilizing Carbon Dioxide”
The artificial photosynthesis mentioned herein is a technology for converting water, carbon dioxide, and other substances at a relatively low energy level into hydrogen and other organic compounds at a relatively high energy level using solar energy. This project involves developing key technologies related to artificial photosynthesis.

C2–C4 olefins
Hydrocarbon compounds with two, three, or four carbon atoms and having a double bond. The subscripts C2, C3, and C4 refer to ethylene, propylene, and butane, respectively. These compounds are fundamental chemicals used as raw materials for plastics and others.

Japan Technological Research Association of Artificial Photosynthetic Chemical Process (ARPChem)
Participants include INPEX Corporation, TOTO Ltd., Japan Fine Ceramics Center, FUJIFILM Corporation, Mitsui Chemicals, Inc., and Mitsubishi Chemical Corporation.

Photocatalytic panel reactor
The photocatalytic panel reactor mentioned herein is a flat-shaped reactor that contains a substrate and a photocatalyst layer fixed onto the substrate and is designed to split water into hydrogen and oxygen.

<Summary>
NEDO is working on the development of key technologies for manufacturing core chemical products (C2–C4 olefins) from carbon dioxide and hydrogen obtained from water by means of photocatalysts using the energy of the sun, under the Artificial Photosynthesis Project “Development of Chemical Processes for Producing Fundamental Chemicals Utilizing Carbon Dioxide.” This project is made up of three research and development themes shown in Figure 1 on page 17 and is positioned as a research project that ought to be pursued over the medium to long term in developing one of the innovative technologies that contribute to reducing carbon dioxide emissions.

NEDO is pursuing the research and development of a photocatalyst, one of the three research and development themes, to achieve an ultimate target of 10% in solar energy conversion efficiency by the end of FY2021. Another key challenge that needs to be met along with that target is to provide a photocatalytic reactor system with an increased panel surface area at a lowered cost. Since enlarging the panel surface area and lowering production cost are indispensable for practical implementation of a water-splitting reactor system using solar energy-driven photocatalysis, this challenge has to be addressed at the stage of research and development.

NEDO, the Japan Technological Research Association of Artificial Photosynthetic Chemical Process (ARPChem), the University of Tokyo, TOTO Ltd., and Mitsubishi Chemical Corporation have successfully developed a photocatalytic panel reactor with a larger surface area at a lower cost, with the ultimate goal of implementing an artificial photosynthesis system for societal use.


January 19, 2018 News Release
Splitting water into hydrogen and oxygen using sunlight

Artificial Photosynthesis System

Artificially performing photosynthesis by means of photocatalysts using solar energy with the aim of achieving low carbon society.

Here are the key points!

- Development of key technology for a photocatalytic panel reactor that stably splits water with a depth of only 1 mm
- Reactor requires less water for photosynthesis and thus can be produced with light and inexpensive materials
- Enlargement of reactor surface area to 1 m² due to lowered production cost
- NEDO demonstrated that the reactor can split water into hydrogen and oxygen at a rate adequate for practical implementation under natural sunlight

◆ Commentary

A new system to effectively use sunlight and CO₂ and contribute to reducing CO₂ emissions

NEDO’s Artificial Photosynthesis Project aims not only to implement a water-splitting reactor system using solar energy-driven photocatalysis, but also to develop a photocatalyst that helps to produce hydrogen and oxygen from water with high energy conversion efficiency using solar energy, developing a high-function separation membrane that separates hydrogen (solar-hydrogen) from the mixture of hydrogen, oxygen, and others, ultimately producing fundamental chemicals from solar-hydrogen and CO₂ to yield raw materials for plastics and others. (Figure 1).

A practical version of this system will enable effective use of renewable energy, i.e. sunlight and CO₂ discharged from factories and other facilities and contribute to reducing CO₂ emissions. Unfortunately, photocatalytic panel reactors have been demonstrated at laboratory bench scale using small flask-type reactors and the like. The newly-developed key technology allows the reactor to split water with a shallow depth of 1 mm and thus represents a breakthrough in practically implementing a photocatalytic panel reactor with an enlarged panel surface area.

◆ Outlook for the Future

Aiming to achieve solar energy conversion efficiency of 10% by end of FY2021

Achieving a photocatalytic panel reactor with an enlarged panel surface area at a lowered production cost is indispensable for implementing an artificial photocatalysis-prompted photosynthesis system for societal use. With an ultimate objective to manufacture core chemical products like plastic materials from both hydrogen (solar-hydrogen) obtained by artificial photosynthesis and CO₂, NEDO is aiming to develop a photocatalyst that offers solar energy conversion efficiency of 10%, a target set for the end of FY2021. At the same time, NEDO will pursue the development of technologies for further enlarging the photocatalytic panel surface area and a technique for combining these technologies with gas separation technology.
Fluorocarbon-Free refrigeration system using CO₂ refrigerant for refrigerator showcases

What is Development of Fluorocarbon-Free Energy-Saving Refrigeration and Air-Conditioning Systems?

The Kyoto Protocol was adopted in 1997 to oblige nations to reduce greenhouse gas emissions. However, in those days, refrigeration and air-conditioning systems using safe and low global warming potential (GWP) refrigerants in place of alternative fluorocarbons were not fully developed. Thus, NEDO undertook the “Development of Fluorocarbon-Free Energy-saving Refrigeration and Air-conditioning Systems” from FY2005 to FY2010. Through this project, NEDO promoted the use of fluorocarbon-free refrigerants in refrigerator/freezer display cases, which are mostly equipped with alternative fluorocarbons as refrigerants, and encouraged the implementation of energy-conservation measures.

Chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs) deplete the ozone layer. After the discovery of this fact, alternative fluorocarbons such as hydrofluorocarbons (HFCs) were developed as substitute refrigerants. However, it turned out that HFCs have an extremely high greenhouse gas effect, and as a result, a substantial reduction in the use of HFCs is called for to prevent global warming. Against this backdrop, the Appliances Company of Panasonic Corporation, which has long recognized the importance of using natural refrigerants such as CO₂, participated in NEDO’s project starting in FY2005. The company succeeded in developing Japan’s first large fluorocarbon-free refrigeration system using CO₂ as a refrigerant.

CO₂ natural refrigerant, an ideal solution to global warming

CFCs were originally developed as refrigerants for safe and efficient cooling and heating. CFCs were also used as aerosol propellants, cleaning solvent for precision parts, and others. After the total abolition of controlled substances (HFCs and CFCs) was determined, HFCs, which are high-performance refrigerants, replaced most of the controlled substances as refrigerants for refrigeration and air-conditioning systems. However, HFCs, a typical alternative fluorocarbon, produce extremely high greenhouse effects although they do not destroy the ozone layer. Consequently, HFCs and two other alternative fluorocarbons, i.e. perfluorocarbons (PFCs) and sulfur hexafluoride (SF₆), were designated as greenhouse gases subject to reduced emissions in the Kyoto Protocol.

Accordingly, natural refrigerants having low GWP started receiving attention. People have high hopes for the widespread use of natural refrigerant CO₂ in particular because this gas has many advantages in safety aspects such as inflammability and toxicity compared to ammonia and other natural refrigerants.

Panasonic Corporation, which has long recognized the importance of using natural refrigerants, already developed and started selling EcoCute, a residential heat pump water heater using a CO₂ refrigerant, in the early 2000s. In order to further utilize CO₂ refrigerants, Panasonic tackled the challenge of researching and developing Japan’s first fluorocarbon-free CO₂ refrigeration system under NEDO’s “Development of Fluorocarbon-Free Energy-saving Refrigeration and Air-conditioning Systems” project. While developing the CO₂ refrigeration system, the company also aimed to make it more energy efficient than HFC refrigeration systems. The company worked toward developing a product that contributes to global warming prevention in both HFC reduction and reduced energy consumption.

Solving problems while capitalizing on CO₂’s advantages

While CO₂ as a refrigerant offers superior features in safety, this gas has a low critical temperature of 31°C and thus changes into a supercritical fluid even at normal temperatures. As a result, it was assumed that CO₂ faces difficulty in attaining highly-efficient refrigeration performance for cooling purposes under high ambient temperatures although it is suitable for producing hot water with temperatures of 60°C or above for EcoCute or similar applications.

Highly efficient operation of a CO₂ refrigeration system under ambient temperatures above the critical temperature necessitates an increase in the pressure of the compressed refrigerant gas such that the pressure reaches four times that of HFC refrigerants. This requires the system to have a compressor and other components with increased pressure resistance. The design of components with increased pressure...
A solution that Panasonic arrived at to address the technical challenges was its proprietary "two-stage rotary compressor" technology, which has been utilized for its water heaters since the development of EcoCute. This technology allows the compression process to be divided into two stages, i.e. high- and low-pressure phases, so that the inside of the shell is at an intermediate pressure and thereby offers increased efficiency and size reduction. This two-stage compression structure halves load placed on the compressor compared to traditional single-stage compression structures, and as a result excels in durability and reliability.

This two-stage compressor originates from the company's "twin rotary" technology, which was developed for reducing air conditioners' vibration. The CO\textsubscript{2} refrigeration system incorporates the technology for reduction of noise and vibration, as well as a downsized compressor with increased efficiency, and thus comes down in size to equivalent to existing HFC refrigeration systems.

**CO\textsubscript{2} refrigerant achieving energy efficiency comparable to that of HFC refrigerants**

Another key technology is the "split cycle" mechanism. Conventional CO\textsubscript{2} refrigerant cycles experience difficulty in radiating heat in summer temperatures exceeding 30°C due to an inadequate difference between the refrigerant and outside-air temperatures. Panasonic addressed this challenge by developing the split cycle mechanism that maintains a high level of heat radiation irrespective of ambient temperature. This mechanism involves splitting a part of a high-pressure refrigerant (gas) that has been cooled at a radiator (gas cooler), expanding the split refrigerant to an intermediate pressure level via an expansion valve, and cooling the mainstream refrigerant to the ambient temperature or lower through a split heat exchanger placed near an outlet of the refrigerator.

The refrigerant which lost cooling effect returns to the intermediate pressure level specified for the two-stage compression compressor. A combination of these technologies enables the CO\textsubscript{2} refrigerant to show energy efficiency comparable to that of HFC refrigerants even under high temperature conditions, which CO\textsubscript{2} refrigerants are not good at.

Panasonic installed a fluorocarbon-free refrigeration system at the food section of the MaxValu Express Rokugodote Ekimae store in Tokyo and had conducted demonstration tests on it for two years from FY2008, the fourth year of this project.

Kazutiko Mihara, the then Team Leader of the Second Team of the Fifth Development Group at Air Conditioning and Cold Chain Development Center of Technology Division, says, "The fluorocarbon-free refrigeration system was a product of accumulated technologies carefully verified for years. However, the tests were conducted at a supermarket where many customers shop. This required our full attention to ensure that no fault occurs." Mihara recalls, "After the installation of the system, we confronted many problems we did not imagine previously. The problems racked our brains more than before the start of the tests. Finally, we really understood the advantages of the CO\textsubscript{2} refrigerant."

As a consequence, the fluorocarbon-free refrigeration system achieved about a 10% power consumption reduction in rated condition compared to existing refrigeration systems using HFC (R404A) refrigerant. The annual CO\textsubscript{2} emissions reduction equivalent to power consumption reduction was approximately 3 tons. Moreover, the greenhouse effect of CO\textsubscript{2} refrigerant was small (one-several thousandth of that of R404A), and the amount of reduced CO\textsubscript{2} emissions calculated in terms of refrigerant leakage during system use was 35 tons. In consideration of the indirect impact of reduced power consumption and the direct impact of refrigerant leakage, the amount of reduced CO\textsubscript{2} emissions reached 38 tons. Thus, it was estimated that the fluorocarbon-free refrigeration system can reduce CO\textsubscript{2} emissions by 61% compared to existing systems.

**New system reducing greenhouse gas emissions by over 50% and contributing to global warming prevention in and outside Japan**

Panasonic started sales of the newly-developed Japan's first fluorocarbon-free CO\textsubscript{2} refrigeration system for supermarkets in September 2010, and the number of stores equipped with the system has been gradually increasing. In response to a reduction of at least 50% in greenhouse gas emissions at the demonstration testing, the AEON Group, which operates the store where the demonstrations tests were conducted, announced in November 2011 that it will adopt the natural refrigerant for all refrigerator/freezer showcases at the group's new stores that will open in and after 2015 and gradually replace alternative fluorocarbons used at its existing stores with CO\textsubscript{2} natural refrigerants.

Panasonic has installed 8,500 units of the CO\textsubscript{2} refrigeration system at a total of 3,100 stores in Japan (as of the end of FY2017). The company installed it at a store in Taiwan in January 2016, and then started demonstration tests and installation of CO\textsubscript{2} refrigeration system at actual stores in Asian and European countries. The fluorocarbon-free system has improved in performance and will be rolled out globally as an energy-saving product that contributes to global warming prevention.
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