# NTT Technical Review

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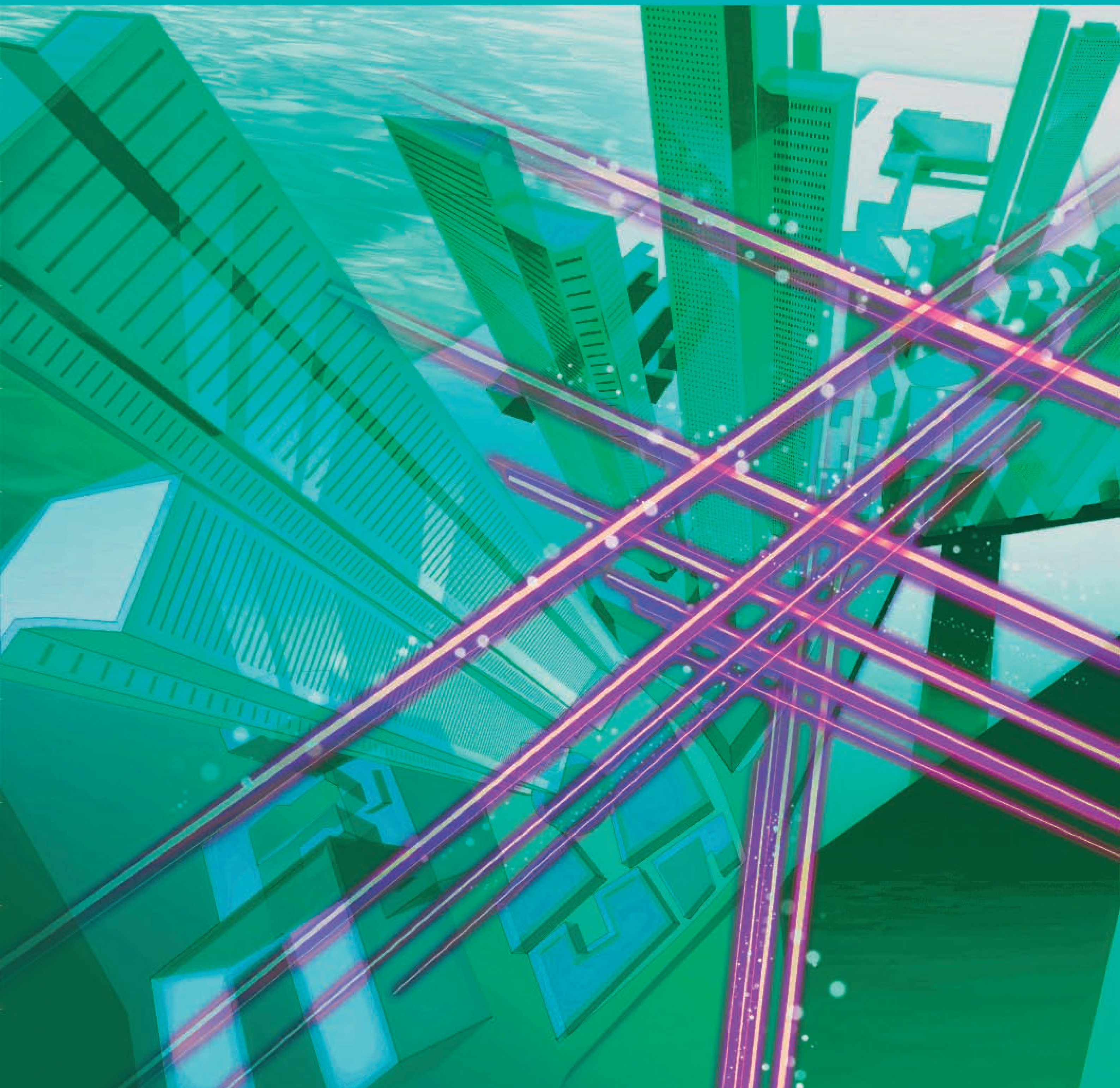
2014



April 2014 Vol. 12 No. 4

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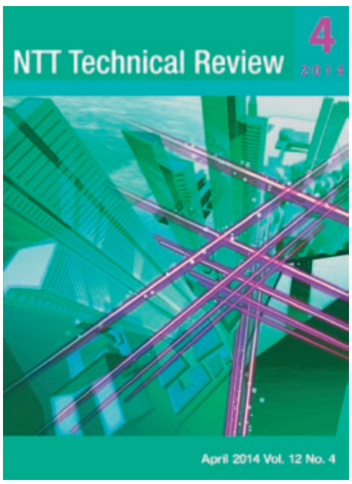

# Papers Published in Technical Journals and Conference Proceedings

# Accelerating Innovation and Collaboration for the Next Stage

*Hiroo Unoura*
*President & CEO, NTT*

**Abstract**

This article introduces a vision for new services to be achieved by 2020 and the technical challenges taken on by the NTT Group to provide behind-the-scenes support. The content of this article is based on the keynote lecture presented by NTT President and CEO Hiroo Unoura at NTT R&D Forum 2014 held on February 13–14, 2014.

*Keywords: innovation, collaboration, cloud*

## 1. Towards the Next Stage

NTT's Medium-Term Management Strategy announced in the fall of 2012 can be summarized by its subtitle "Towards the Next Stage." In this regard, we are all delighted that Japan will host the "Big Event" in 2020, and I believe that this Big Event is making the "next stage" easier to visualize while clarifying targets for our business development schedule.

The key concept of our Medium-Term Management Strategy is "value partner." For NTT, the time has come to shift from a business-to-consumer (B2C) model of selling lines and terminals to a cloud-based business model. In this shift, we aim to support a business-model transformation among our corporate customers and the creation of enriched lifestyles among our individual customers. It is in this sense that we use the term "value partner."

There are a number of major currents in the field of information and communication technology (ICT) in relation to global, cloud, and mobile technologies, and there are many and varied players in this field. While it may appear to be a highly competitive era, I personally believe that we have entered an era of cooperation and collaboration.

In a cloud or global era, customers can freely select their services. It therefore stands to reason that being competitive in such an era means the ability to be continually selected by our customers. In short, the essence of being competitive is not getting a customer to buy something just once but in retaining that customer for a long period of time.

To become the value partner that customers continue to select, I believe it is extremely important that we have cooperative and collaborative abilities to promote new businesses with a variety of players.

## 2. The year 2020

A number of interesting forecasts have been made in relation to 2020, as shown in **Fig. 1**. First of all, while the gross domestic product (GDP) looks as if it will pick up steam in China and emerging countries, Japan at the center of this figure is marked with a small circle. This forecast was made by a variety of researchers before the decision was made about the 2020 Big Event. I would therefore like to use the Big Event as an opportunity to do what we can to make Japan's circle a bit larger.

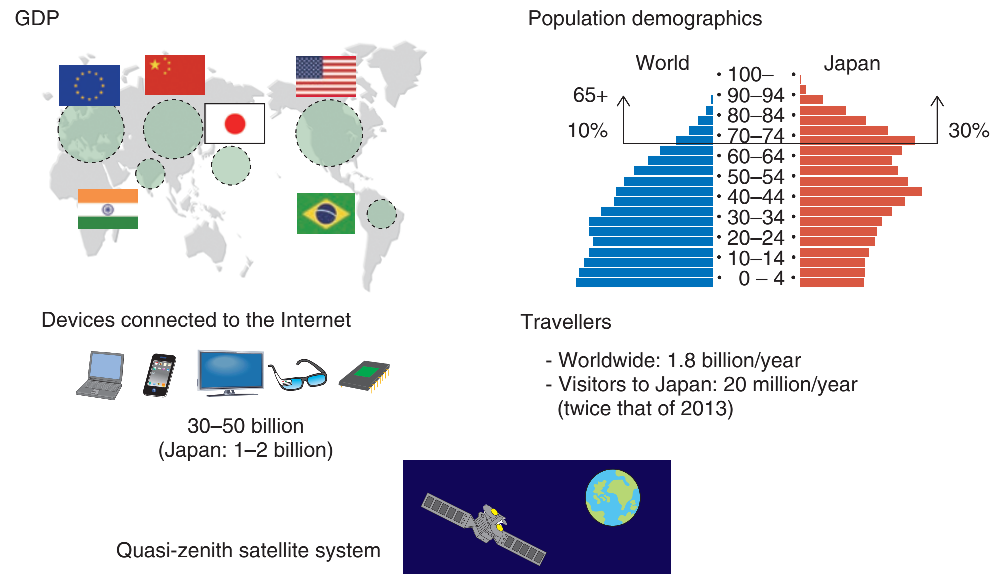


Fig. 1. Forecasts for the year 2020.

In addition, Japan is predicted to lead the world as an aging society. The number of terminals connected to the Internet, meanwhile, is expected to reach 30–50 billion, which is 10 times the current number. It is also said that Japan's quasi-zenith satellite system will be in full-scale operation by 2020. The first satellite of this system was launched in 2010, and the plan is to launch three more satellites by 2019. This system will make it possible to achieve highly accurate positioning as fine as several centimeters. I would like to consider with everyone here how these changes in the present might affect business in the future.

## 3. Smart life and smart work 2020

In the world of 2020, a variety of services will be built on and enabled by clouds (**Fig. 2**). I believe that linking and coordinating multiple clouds will lead to new services and business models.

Take transportation, for example. Linking the clouds of the bus, subway, airplane, and taxi industries could lead to an advanced intelligent transport system (ITS). In other words, linking clouds in this way can open up a new world in a certain sector, but what would happen if transportation is linked with the clouds of other industries? I will address this question next.

### 3.1 Tourism: navigation × translation

Here, I will introduce services that come about by linking technologies associated with transportation with those of tourism, navigation, and translation. To begin with, we can envision a travel service that begins when you use a smartphone to take a picture of your train station's symbol or mark and then a picture of your destination from a travel magazine or similar. You could then receive information on this trip from the station to the destination in the language that you previously set as well as information on sightseeing spots, restaurants, etc., at the destination. It was recently reported in the news that the Japanese government has issued guidelines calling for the installation of multilingual information boards in train stations. This could result in the preparation of relatively large boards in many languages, but using a smartphone would make such multilingual boards unnecessary since receiving information in your mother tongue could be achieved by simply taking a picture. I think a world with such services will be a reality by 2020.

Let me introduce such a service that has already been achieved within the NTT Group. This is PictuAR, which was developed and commercialized by NTT COMWARE (**Fig. 3**). With this service, a user who uses his or her smartphone to capture a photo that includes the PictuAR symbol will see that photo come alive as a video on the smartphone screen. For example, capturing a photo of a restaurant with the PictuAR symbol results in a video display of recommended menu items or views of the restaurant's interior.

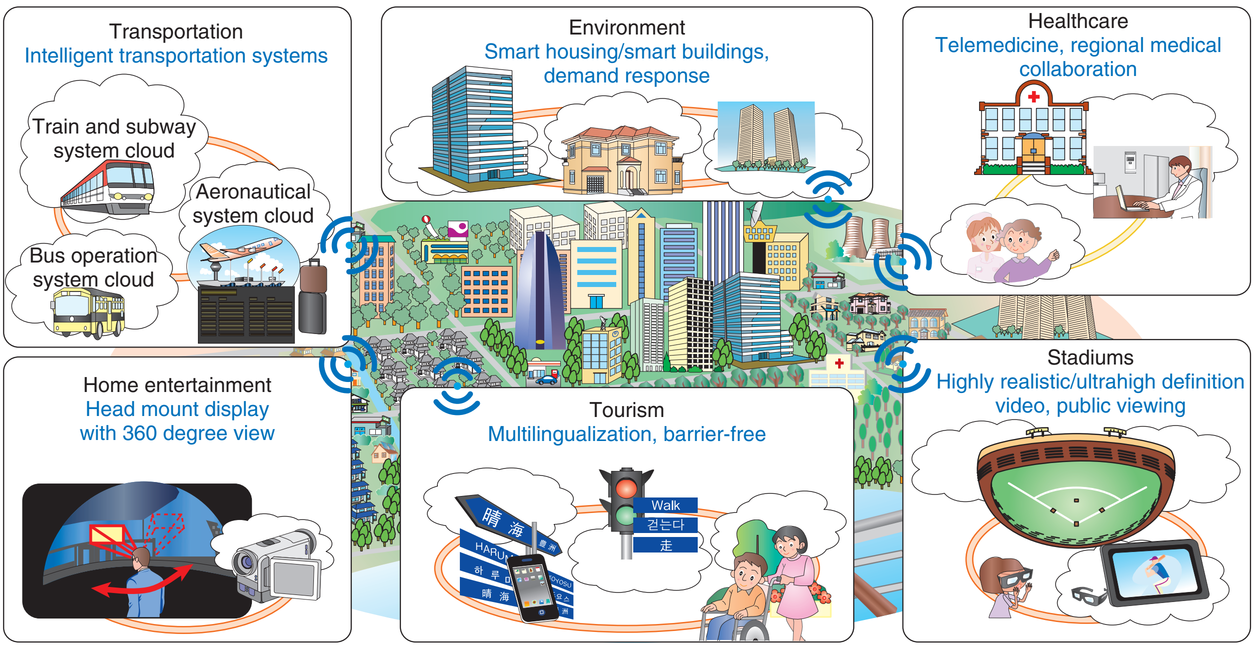


Fig. 2. Smart life & smart work 2020—Enabled with clouds.


Fig. 3. Smart life & smart work—tourism ‘navigation × multilingualization’.

### 3.2 Entertainment: video × sports

I would now like to take a look at a world of entertainment that links sports and video. For sports such as soccer or baseball, a service could make it possible for the viewer to observe play from an athlete’s view, from the manager’s or coach’s view, or from an overhead position, or to combine a view with data on individual athletes. This kind of service could be implemented on smartphones and tablets. It is already being tested in the United States, and steps are being taken toward its commercialization.

There has been much talk about the convergence of communications and broadcasting, but if we consider the potential of collaboration between broadcasters and stadium owners or baseball teams, perhaps that convergence will evolve in unexpected ways.

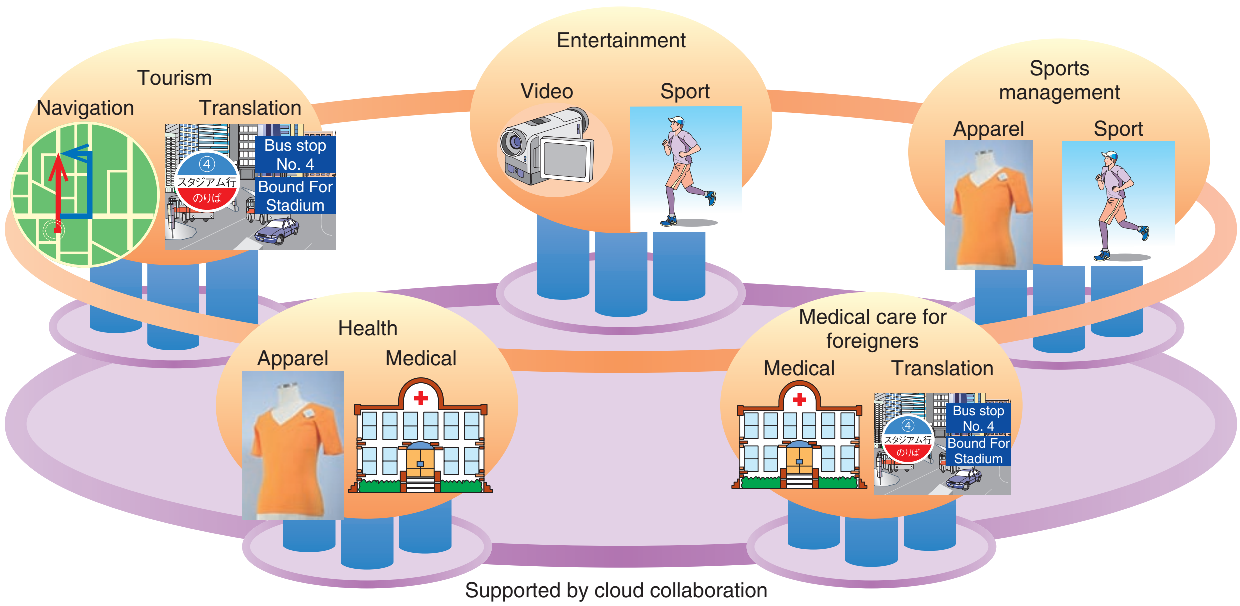


Fig. 4. Innovation through service collaboration.

### 3.3 Innovation through service collaboration

As I mentioned, new services can be developed by tying together a variety of services (**Fig. 4**). It was just announced the other day that Toray Industries and NTT had collaborated on the development of a smart shirt that can be used to obtain an electrocardiogram of the wearer. This is a good example of a collaborative effort between the apparel and IT (information technology) industries the likes of which have not been seen before. Imagining that such tie-ups and collaborative efforts continue to take place, I think new worlds will be drawn, which will lead to the creation of a new Japanese business model for the future.

Japan and the United States have often been compared with reference to the word "innovation." In the United States, old legacy systems can be replaced relatively easily, but in Japan, it is more difficult. For this reason, I believe that innovation through collaboration provides a convenient shortcut for Japanese-style innovation, service development, and business-model creation. Looking forward, technologies and services that support the linking of ICT infrastructures and the linking of clouds will be needed to promote various types of collaboration between services and enterprises. I believe that NTT R&D can make a contribution to this end and that a new business-to-business (B2B) model of NTT Group can be applied here.

## 4. NTT Group challenges toward 2020

I have talked about the possibility of creating a new business model through collaboration. Of course, we will continue to face a number of challenges both as a player participating in new markets and as a value partner opening up new markets. In the following, I would like to introduce two major challenges for NTT as a telecommunications carrier toward 2020.

### 4.1 Challenge 1: Network controls

Various predictions have been made, but I think I can safely say that the volume of information passing through our network and those of other players will increase substantially by 2020. By the way, a report from British Telecom stated that network traffic in the vicinity of venues of the London Olympics increased by seven times over that of the Beijing Olympics held four years earlier, so we can only wonder how traffic might further increase at the Rio de Janeiro Olympics, and for that matter, at the Tokyo Olympics four years after that. If traffic simply continues to increase by seven times in this way, we would get $7 \times 7 = 49$ times the amount of information.

How can such an ever-increasing amount of traffic be controlled? This is the first challenge for the NTT Group, and I introduce here four technologies that we plan to deploy to meet this challenge.

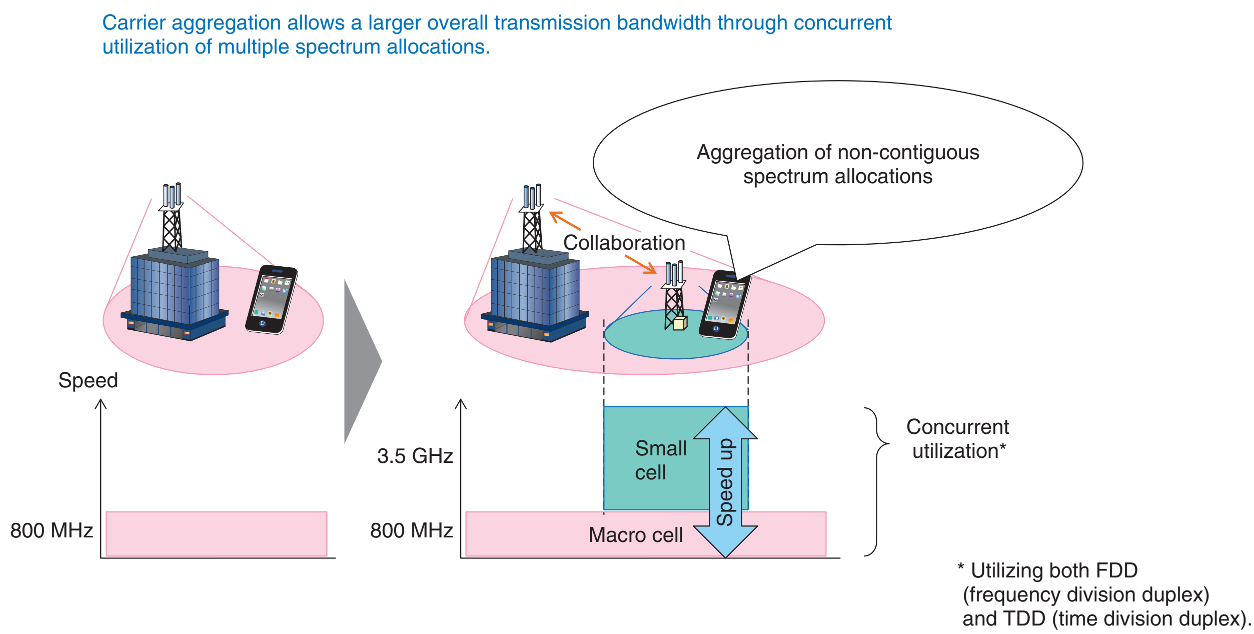


Fig. 5. Challenges—carrier aggregation.

(1) Carrier aggregation

Carrier aggregation technology will enable the simultaneous use of multiple spectrum allocations (**Fig. 5**) while accommodating both time division duplex (TDD) and frequency division duplex (FDD) wireless communications. In the future, we expect carrier aggregation to enable even higher transmission speeds by simultaneously using a number of spectrum allocations including Wi-Fi.

(2) Software-defined wireless network

If we were to attempt to deal with an increase in traffic that is several tens of times the current levels by simply adding more hardware, we would need an enormous number of new facilities. Likewise, if we were to simply increase the number of Wi-Fi base stations at stadiums and other venues, the resulting high-density configuration would generate mutual interference among those stations. In short, relying solely on a hardware solution has its limits. In contrast, base-station coordination by using software controls can reduce mutual interference and provide a comfortable wireless communications environment (**Fig. 6**).

(3) Edge computing

Edge computing is a technology that can reduce traffic in the relay network by placing cloud servers closer to users and performing distributed processing (**Fig. 7**). It can also minimize delay by shortening the distance between servers and terminals. Let's consider traffic conditions at the opening ceremony for the 2020 Big Event, when about 80,000 people will be walking around with their smartphones and tablets in the main stadium. To handle this traffic, we will need to implement distributed processing by edge computing and direct the flow of traffic through storage facilities at locations close to terminals.

(4) Proactive wide-area traffic controls

Wide-area traffic controls provide a means of adjusting bandwidths to control the overall traffic on the network (**Fig. 8**). Let's assume, for example, that a datacenter hosting cloud systems related to the 2020 Big Event is located in Sapporo. We can expect the traffic to be heavily concentrated during the period of the 2020 Big Event. This technology will predict that traffic at the Sapporo datacenter will become congested at that time and will automatically perform distributed processing at a backup datacenter in Fukuoka. In other words, it will proactively respond before that congestion has a chance to negatively affect overall cloud services. I believe that this kind of technology for achieving wide-area traffic controls will be an absolute necessity by the time of the Big Event.

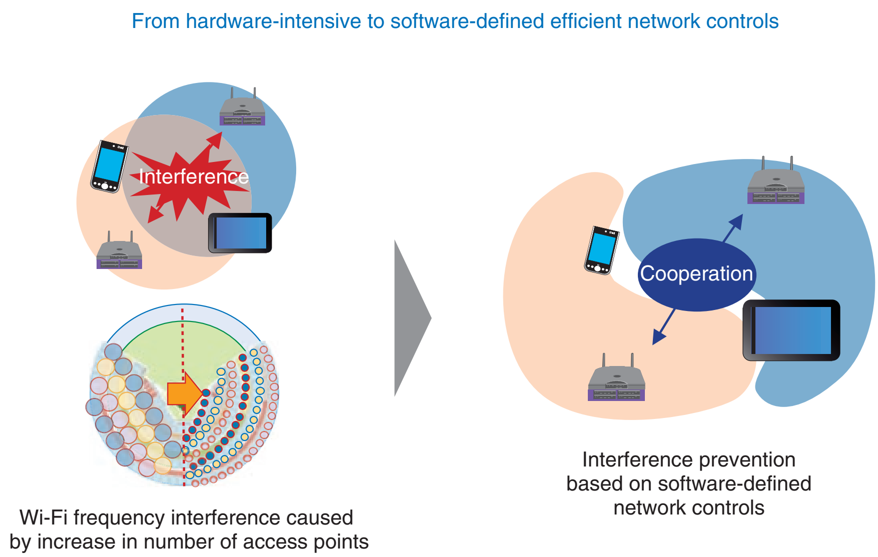


Fig. 6. Challenges—software-defined wireless network.

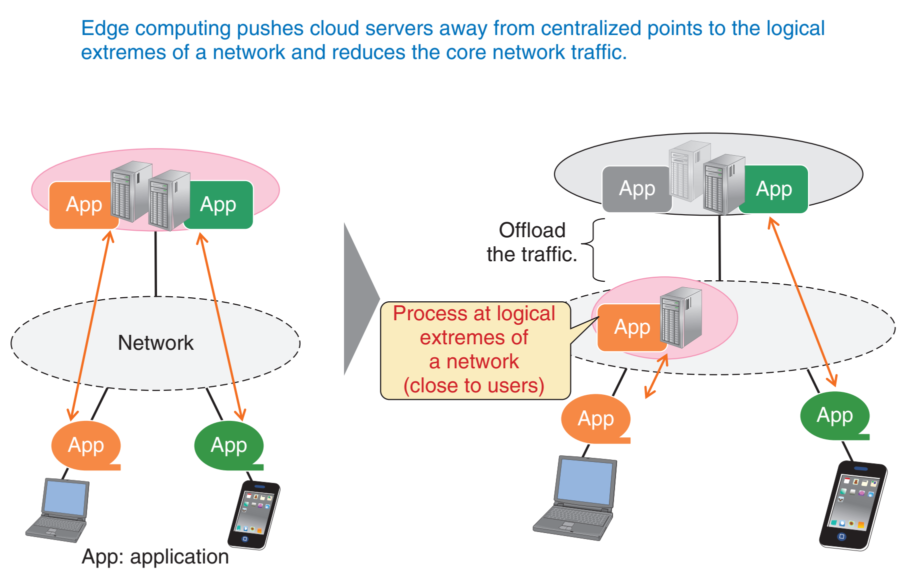


Fig. 7. Challenges—edge computing.

### 4.2 Challenge 2: Integrated security

About 210 million attacks were mounted on the official website of the 2012 London Olympics, and while British Telecom managed to fight off those attacks without incident, we can imagine that by 2020, attacks will be mounted on a more sophisticated level.

In a world in which almost all services are migrating to clouds, including those provided by financial institutions and smart cities, the risk to society is increasing (**Fig. 9**). We can assume that attackers will mount attacks by taking advantage of various vulnerabilities in networks and clouds. How then can we deal with the increased risk to society? This is also a major challenge for the NTT Group.

The NTT Group is developing world-leading technologies to counter these increasingly sophisticated attacks (**Fig. 10**). For example, NTT Communications

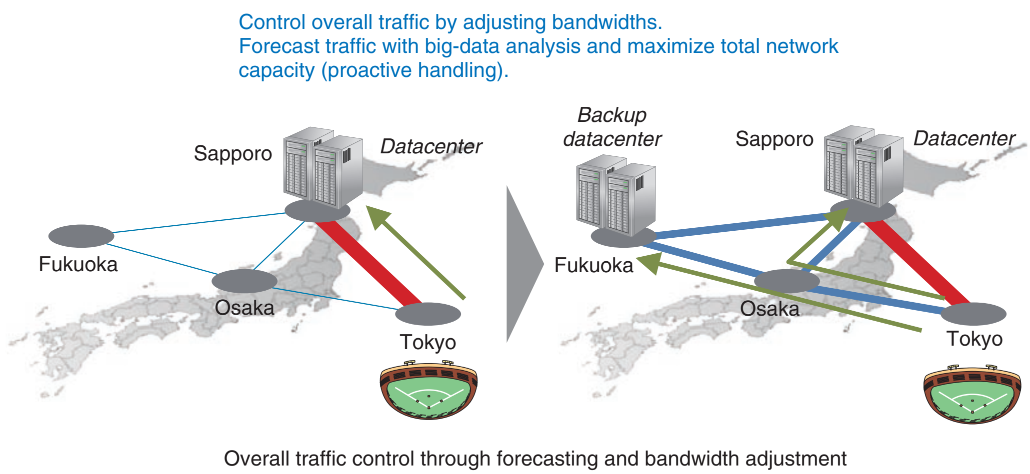


Fig. 8. Challenges—wide-area traffic controls.

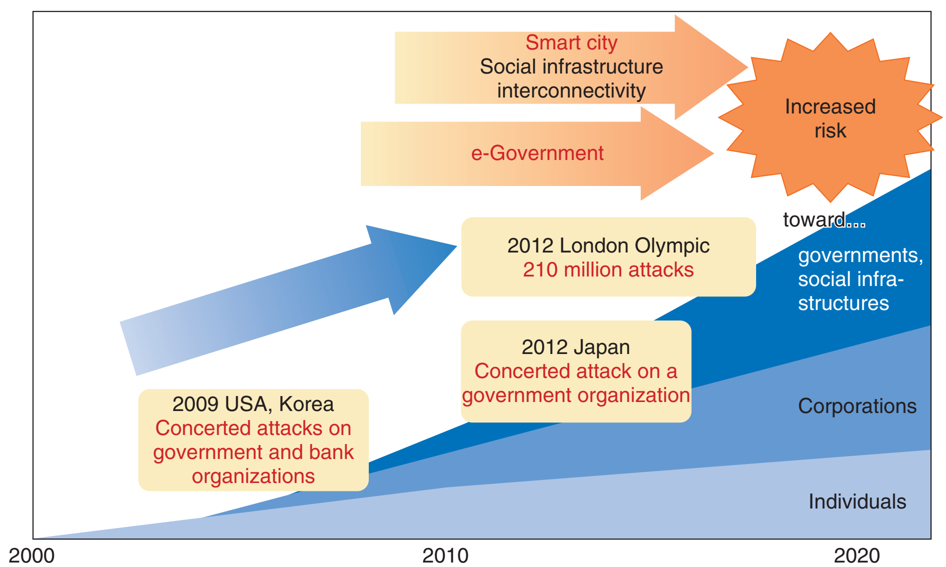


Fig. 9. Cyber attacks on social infrastructure.

is already coordinating security operations on a global scale, but coordinated operations that include overseas carriers and IT vendors will also be necessary. We can think of this as collaboration between security operations. As clouds become increasingly linked in the future, it will become impossible for the NTT Group to implement a complete set of security measures by itself. It will therefore be necessary to defend against increasingly sophisticated attacks by coordinating operations with a variety of players and even other competitors in the same industry. NTT R&D has a strong security team for dealing with such attacks, and NTT Innovation Institute, Inc. (NTT I$^3$), founded in the spring of 2013, is also preparing a range of products that incorporate advanced security technologies developed in the United States.

## 5. NTT Group future activities

Trusted relationships between partners are a major source of collaborative abilities. For this reason, I changed the words "total solutions" to "trusted

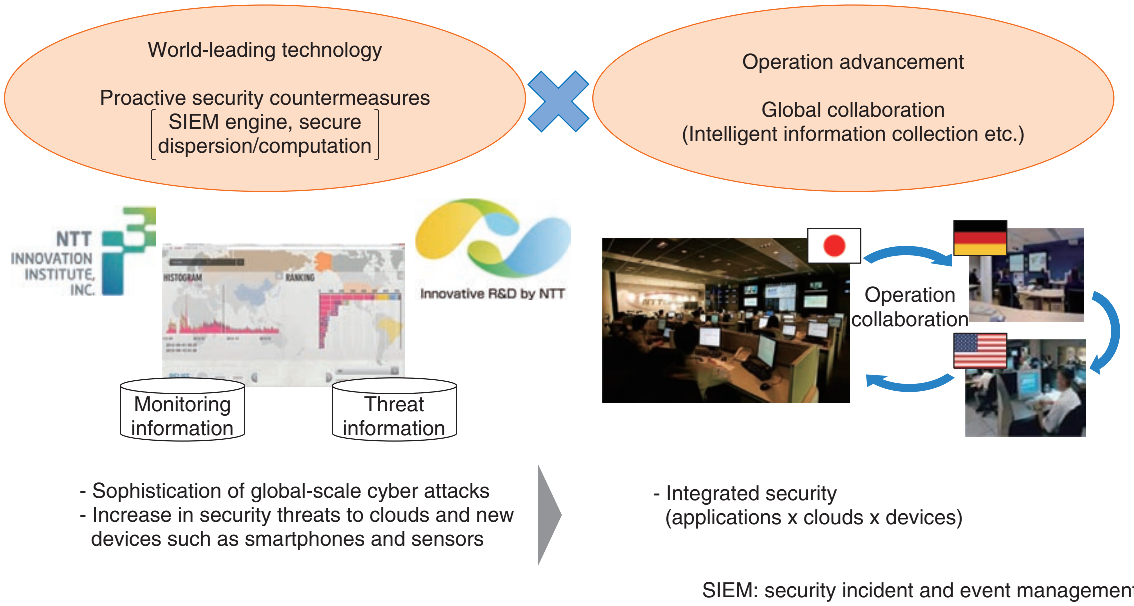


Fig. 10.   Challenges—integrated security.

solutions," so that "Next Value Partner for Transformation by Total Solutions" became the more meaningful "**N**ext Value Partner for **T**ransformation by **T**rusted Solutions." Instead of being a corporate group that simply functions as a provider as we have been so far, the NTT Group has its eye on collaborating with diverse companies and industries and assisting in the creation of new business models. I would like to shift the company toward B2B in this sense.

I believe that NTT R&D has the power to function well as a catalyst for collaboration among various industries, enterprises, and services. The year 2020 will be a time when the fundamental strengths of the NTT Group are put to a test in the areas of network controls and security management. Going forward, my aim is to plan the further growth of the NTT Group by overcoming all sorts of trials and challenges through the power of NTT R&D and the business-development abilities of the group companies.

# Co-innovation Challenges

*Hiromichi Shinohara*
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*Director of Research and Development Planning Department, NTT*

**Abstract**

NTT aims to enhance the comfort and quality of life of people by exploiting information and communications technology (ICT). This article introduces NTT's research and development (R&D) activities to achieve innovation through various collaborations. It is based on the keynote speech delivered by Hiromichi Shinohara, Director and Executive Vice President, Director of Research and Development Planning Department, NTT, at the NTT R&D Forum 2014 held on February 13–14, 2014.

*Keywords: co-innovation, ICT, R&D*

## 1. NTT R&D (research and development) design for tomorrow's world

### 1.1 Advances in ICT and the role of the NTT Group

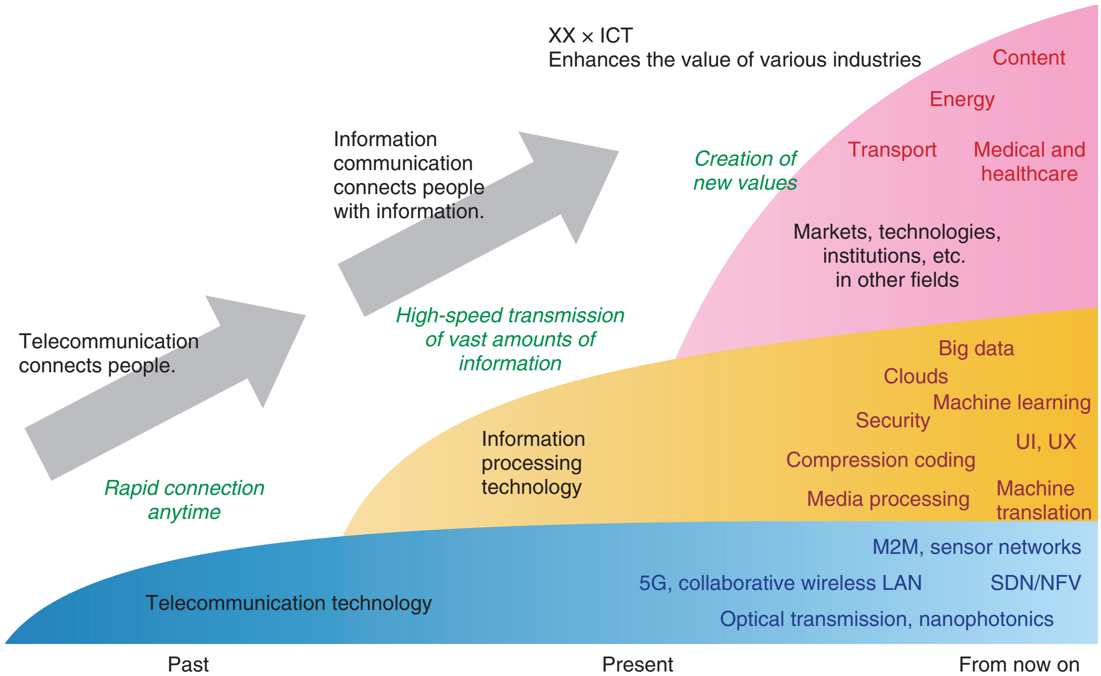
The role of telecommunication carriers used to be connecting people to people. The goal was primarily to provide connections rapidly at any time. However, in the last two decades, the role of connecting people with information has been added. It has become important to deliver vast amounts of information to customers at high speed. The NTT Group believes that it needs to take this trend a step further. It wishes to transform its role to one of enabling those in a variety of fields and industries to enhance their value, through the provision of information and communications technology (ICT) (**Fig. 1**).

Before we look to the future, let us first look back at how technology and everyday life have evolved. The computing power of super computers in the 1980s was roughly equivalent to that found in today's CPU for mobile devices. A 20-GB storage unit weighed 2 tons then and cost about 100 million yen. Today, the same amount of storage can be provided with a device weighing 0.5 g for just a few thousand yen. While technology has advanced dramatically, our everyday life and social activities do not seem to have kept pace. Instead of looking at progress in technology and thinking how it can change society, it is time to undertake technical development with the aim of realizing the forms of everyday life and the kinds of social activities that we want to create.

### 1.2 Activities that look to the future

In the years to come, Japan will see both its total population and productive population shrink. The decline in the birthrate and the aging of the population will continue unabated. It is necessary to create a society in Japan that empowers foreigners, women, and the elderly. Everyone at the NTT laboratories believes that it is important to harness ICT to promote the comfort and quality of life of society at large.

Allow me to introduce the activities that the researchers at the NTT laboratories believe they should undertake in order to realize a prosperous and healthy society, using the Japanese characters 安 (safety), 報 (inform), 健 (health), 癒 (medical care), etc. as keywords (**Fig. 2**).




LAN: local area network
M2M: machine-to-machine
SDN-NFV: software-defined networking – network function virtualization
UI: user interface
UX: user experience

Fig. 1. Advances in ICT and the role of the NTT Group.


Fig. 2. Concepts and activities required for the future.

(1) 安 (Safety)

Let us look at ICT application examples from the viewpoint of safety and security (**Fig. 3**). These days, cyber-attacks have become a serious social problem, and it is therefore becoming increasingly important to prevent attacks in cyberspace. At the NTT laboratories, it is regarded as vital to find ways of preventing various actions that threaten our lives. These include

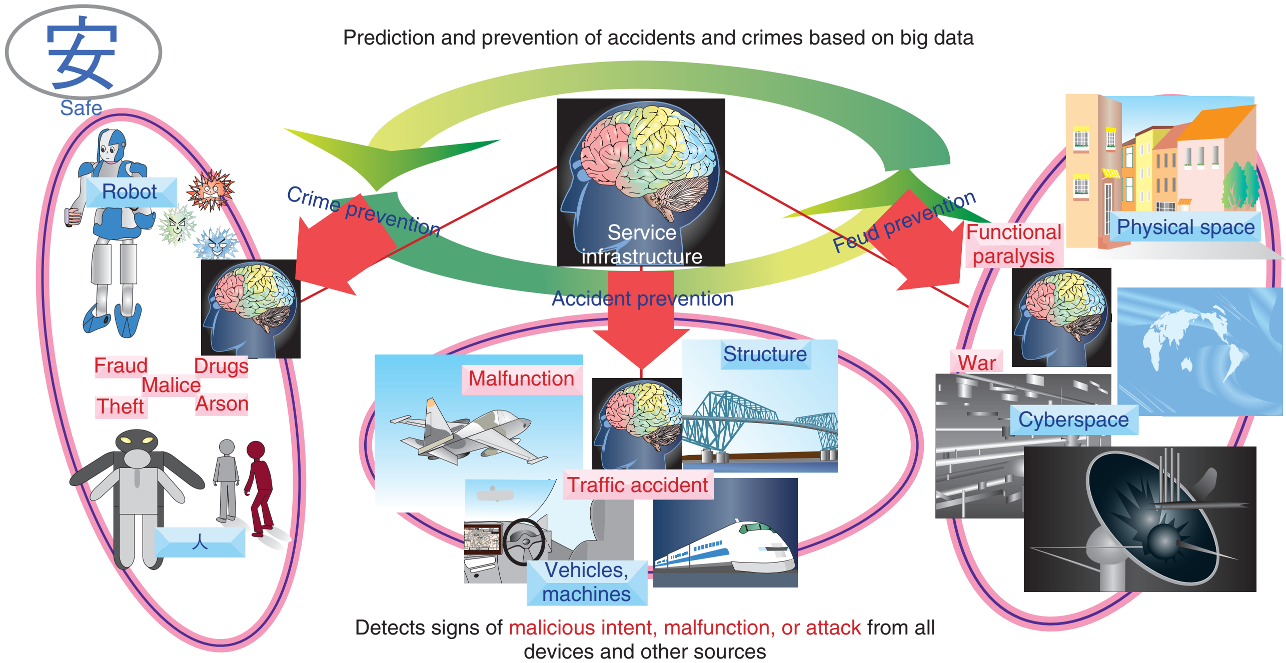



Fig. 3. ICT that supports safety.

not only attacks that take place in cyberspace but also those that alter real structures or cause them to fail or malfunction. It is therefore necessary to develop predictive security technology that detects early signs of accidents and other problems by, for example, using sensors or similar devices installed in structures to avert problems before they actually occur.

Another example of ensuring 安 (safety) is to use ICT applications to reinforce disaster response capabilities. In March 2011, Japan experienced an unprecedented disaster. At the NTT laboratories, we believe that more ICT can be usefully employed in implementing various measures in situations in the future such as those for disaster prevention, mitigation of the damage caused by disasters, and restoration through reconstruction. For example, if a large number of people take the same route to go to a shelter in the event of a disaster, bottlenecks may arise at some points. To reduce the potential harm to people, it is important to be able in the future to rapidly select appropriate shelters and routes for individual residents and send the information to them. Therefore, we need a technology that will provide globally optimized and integrated guidance rather than guidance that has been optimized for a limited area.

(2) 報 (Inform)

A service has been developed from the viewpoint of 報 (inform) as an information service that enables everyone to receive signage in their own language (**Fig. 4**). It is important to enable people from abroad to live safely and comfortably in Japan, and we therefore need to develop a technology that makes it possible to send information displayed on digital signage to individual smartphones in the user's own language by using an electronic watermark or similar technology to specify the required language. This is essential in the event of a disaster and will be used during the big event in 2020.

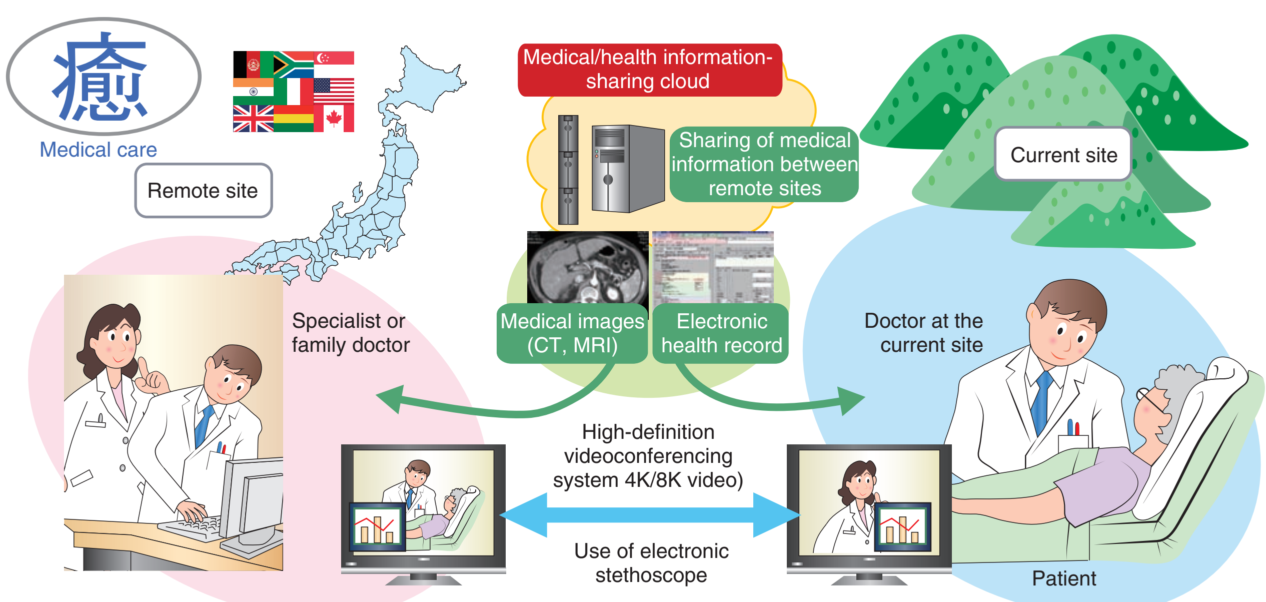
(3) 健 (Health)

ICT applications can also be used for health management. As the number of elderly people increases, a rise in the level of medical expenditure is inevitable. Preventive medicine is important in keeping medical costs to a minimum. In particular, we need to develop a technology to measure vital signs such as pulse rate and respiration, and store the data in a cloud so that health can be managed on a daily basis.

(4) 癒 (Medical care)

An ICT application example of a comprehensive family doctor service can be set up to expand 癒 (medical care) (**Fig. 5**). The international exchange of digital health records and telemedicine will enable people to receive medical services with confidence from anywhere, thereby eliminating the regional


Fig. 4. Service enabling people to receive messages in their own language.




CT: computed tomography
MRI: magnetic resonance imaging

Fig. 5. Family doctors anywhere.

disparities in the level of service provision. NTT EAST provides a remote medical support service in Hinoemata Village, Fukushima. The village residents used to have to travel several hours if they needed to see medical specialists. Now, they visit a local clinic and can get support from medical specialists over the network. We plan to strengthen this type of activity.

(5) 援 (Support)

From the viewpoint of 援 (support), I would like to introduce a crowdsourcing service used in an urban social plan as an example. Crowdsourcing needs to be expanded to harness the resources of the general public using ICT in order to make life more comfortable for people in wheelchairs, etc. It is necessary to develop technology that automatically collects data such as road surface conditions and human traffic from privately owned smartphones and sensors, makes the data available on a cloud, and outputs requests for rapid road repairs or provides a barrier-free map.

Another example conceived from the viewpoint of 援 (support) is sensory assistance intended to enable the elderly and people with disabilities to participate in social activities. We hope to help people maintain their health and live independently. To achieve this, we are developing an aid that produces a sensory stimulus that is perceived as a sense of the hand being tugged to indicate direction. We are also analyzing the characteristics of sounds that the elderly and disabled find hard to understand and using that knowledge to develop a special hearing aid that compensates for their poor ability to discriminate those sounds.

(6) 働 (Work)

From the viewpoint of 働 (work), I would like to outline a form of ICT application that gives people more freedom in choosing their workplace and working hours. The shrinking of the population is expected to accelerate a shift to more compact cities. An ever increasing number of people will have to telework or work in satellite offices. One downside of teleworking is that workers may experience a sense of isolation from their colleagues. Therefore, it will be necessary to develop technology that enables people to retain a subtle sense of being connected to remote colleagues instead of trying to solve the problem by connecting people constantly via videoconferencing.

(7) 省 (Energy)

An example of using ICT from the viewpoint of 省 (energy) is an ICT infrastructure that can operate without consuming much power. It is known that intra-LSI (large-scale integrated circuits) electrical connections account for most of the power consumed by servers in today's datacenters. Power consumption can be slashed dramatically by replacing electrical connections in LSIs with optical connections. In the field of power generation, it will be possible to develop solar cells that fit into the landscape. NTT laboratories have developed a transparent thin film made of gallium nitride (GaN) that absorbs only ultraviolet rays. In principle, the thin film can be fabricated on a glass window pane and used as a solar cell. In this way, power can be generated without marring the townscape.

(8) 産 (Production)

From the viewpoint of 産 (production), ICT can be applied to increase agricultural productivity. Today, methods to measure growth conditions with sensors and to control the yield accordingly are well established. We believe that in addition to these, we need to develop, for example, technology that analyzes big data and uses the results to improve crop varieties and to manage cultivation efficiently. It is important that practices adopted in forestry and agriculture ensure biodiversity. ICT can be a valuable tool in this area.

## 2. R&D activities looking to the future and co-innovation challenges

We are reinforcing our activities in six technical fields along with their underlying basic technologies: improvement of UI/UX (user interface/user experience); big data; easy-to-use cloud; security; high-capacity, high-reliability network; and a flexible network to build a prosperous and healthy society (**Fig. 6**). First, I will outline R&D management.

### 2.1 R&D management

In managing R&D, we would like to actualize innovation through collaboration in a variety of ways instead of sticking to developing everything within the NTT laboratories as we used to. For this purpose, we are promoting three concepts: *cohesion*, which means that NTT researchers cooperate with each other to achieve a common vision, and *fusion*, which means that NTT researchers in different fields work together to create new value. In addition, we are strengthening *boundary crossing*, which refers to open innovation in which NTT researchers cooperate with those in external organizations.

(1) Cohesion

Three virtual organizations were created within NTT laboratories last year to promote cohesion: the Nanophotonics Center, the Machine Learning & Data Science Center, and the Innovative Photonic Network Center. The employees working in these centers span a number of laboratories.

A representative example of what the Nanophotonics Center was able to accomplish in fiscal 2013 is the development of a current-injected photonic crystal

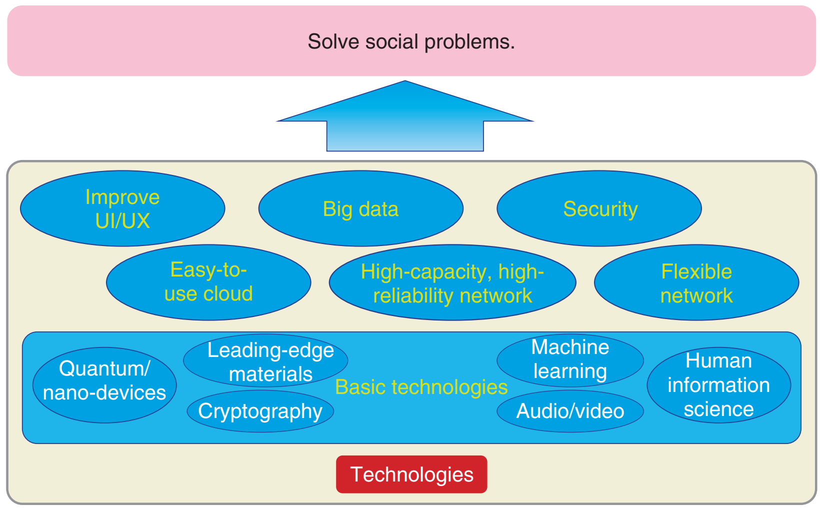



Fig. 6. Building the society we are aiming for.

laser. As was mentioned earlier, it is necessary to replace the present electrical connections with optical connections in order to achieve a major reduction in the power consumption of servers. A laser that can be used for optical communication within or between LSI chips has been fabricated on a nanocrystal. This has made it possible to transmit data with the world's lowest power consumption (5.5 femtojoules per bit).

(2) Fusion

A representative example of advances made as a result of fusion is technology that allows a silk fiber to be coated with a conductive polymer. This was developed by the Polymer Material Group of NTT laboratories last year. Moreover, this research result was combined with the system implementation technology developed by the Interface Design Group to create a T-shirt that can obtain an electrocardiogram simply by having the user wear it.

(3) Boundary crossing

NTT laboratories are seeking to approach open innovation from four perspectives (**Fig. 7**). The first is *increased speed*, which means that we incorporate external technologies into our innovation cycle. The second is *market-in*, which means that we already possess necessary technologies and have incorporated them into developments carried out by NTT operating companies or vendors in order to accelerate the introduction of these technologies into the market. The third is *missing link*, where NTT laboratories compensate for the technologies they lack by importing technologies from outside. The fourth perspective is *entry into new markets*, whereby we introduce our technologies into other industrial fields in order to enable NTT to expand its business into new non-telecommunication fields.

Naturally, this open innovation must not be confined to Japan but should be implemented on a global level. For this purpose, we established the NTT Innovation Institute, Inc. (NTT $I^3$) in North America in April 2013 as a global promotion site.

### 2.2 Technical fields

The activities of NTT laboratories are introduced below from the above-mentioned viewpoints and perspectives.

(1) Improvement of UI/UX

In the field of high-definition video delivery, we have proposed a powerful error correction technology called LDGM (low-density generator matrix). This has been incorporated into the next generation transport standard. It is now possible to transmit 8K high-definition videos over a long distance on an IP (Internet protocol) network based on this standard. We have also developed an HEVC (high efficiency video coding) encoder, which is implemented with a mix of hardware and software. The use of this encoder is being studied by the Next Generation Television & Broadcasting Promotion Forum (NexTV-F).

At the end of July 2013, we formed a business alliance with Dwango Co., Ltd. and are running a number of projects that make use of each other's expertise. In the field of UI/UX, we are working to develop interactive viewing technology for whole-sky video, which enables a user wearing a head-mounted

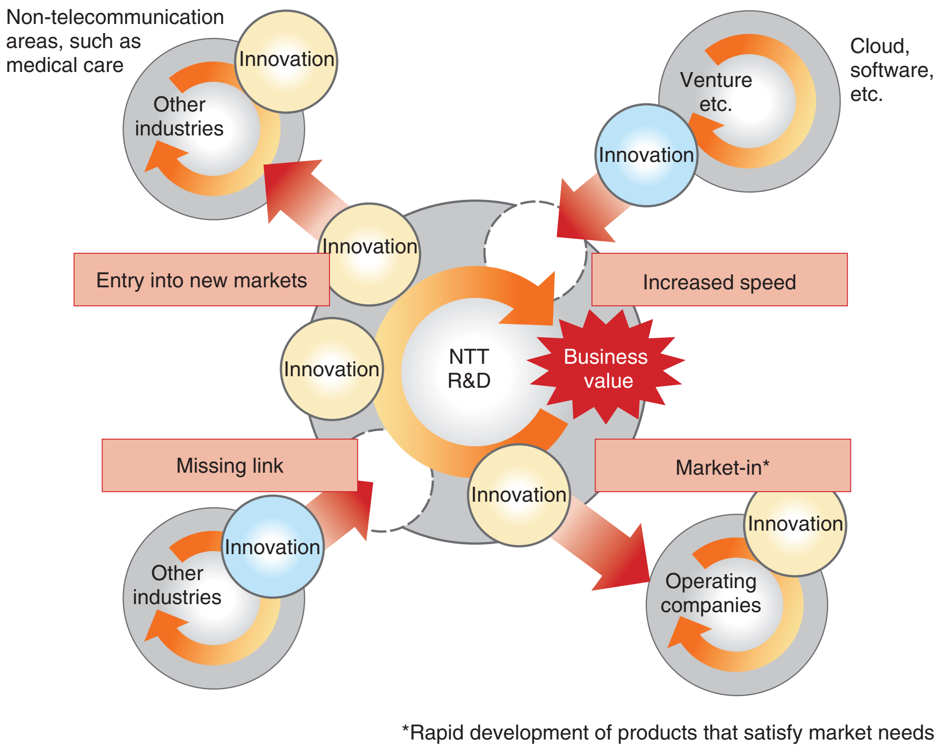



Fig. 7. Objectives of open innovation.

display to view "nicofarre," a video service provided by Dwango (**Fig. 8**). Conventional technology transmits all of the video data to the user, but the new technology reduces data traffic by transmitting in high quality only the part focused on by the viewer, with the remaining part being transmitted in low or medium quality.

We have also worked with NTT DOCOMO to develop a chat technology that can ascertain the predicate structure of *what did what* in a speech, and generate a speech response that is relevant to the subject of the chat. This technology has been incorporated into the Drive Net Info service provided by NTT DOCOMO.

We have started trials to provide an *any-device* environment by using edge computing technology, which is characterized by distributed computing resources that are brought into close proximity with users. It offloads part of the terminal processing to edge computers allocated near users so that the user can enjoy stress-free browsing of rich content even with a low-end terminal. In the field of statistical machine translation, we have demonstrated that our syntax analysis and word-order conversion technology can dramatically improve the accuracy of translation from English to Japanese, which has been conventionally difficult because of differences in word order between the two languages.

We have also initiated another language activity that looks to the future. It is technology to make the English spoken by a Japanese speaker closer to the English spoken by a native speaker. This technology separates English speech into pronunciation and speech rhythm and adjusts only the rhythm so that the speech has the same rhythmical characteristics as those of a native speaker. This is expected to make English spoken by Japanese people easier to understand even though the pronunciation is unchanged.

(2) Big data

In cooperation with NTT DATA, we have developed high-speed graph clustering technology. This technology dynamically changes the congestion analysis area in accordance with changes in the volume of vehicle traffic (**Fig. 9**). It has been applied to NTT DATA's system that forecasts congestion from data sent from vehicles, and it controls traffic signals in a sophisticated manner to prevent congestion. It is now possible to process data for one million vehicles within several milliseconds and at low cost.

We have jointly developed Jubatus, a data analysis

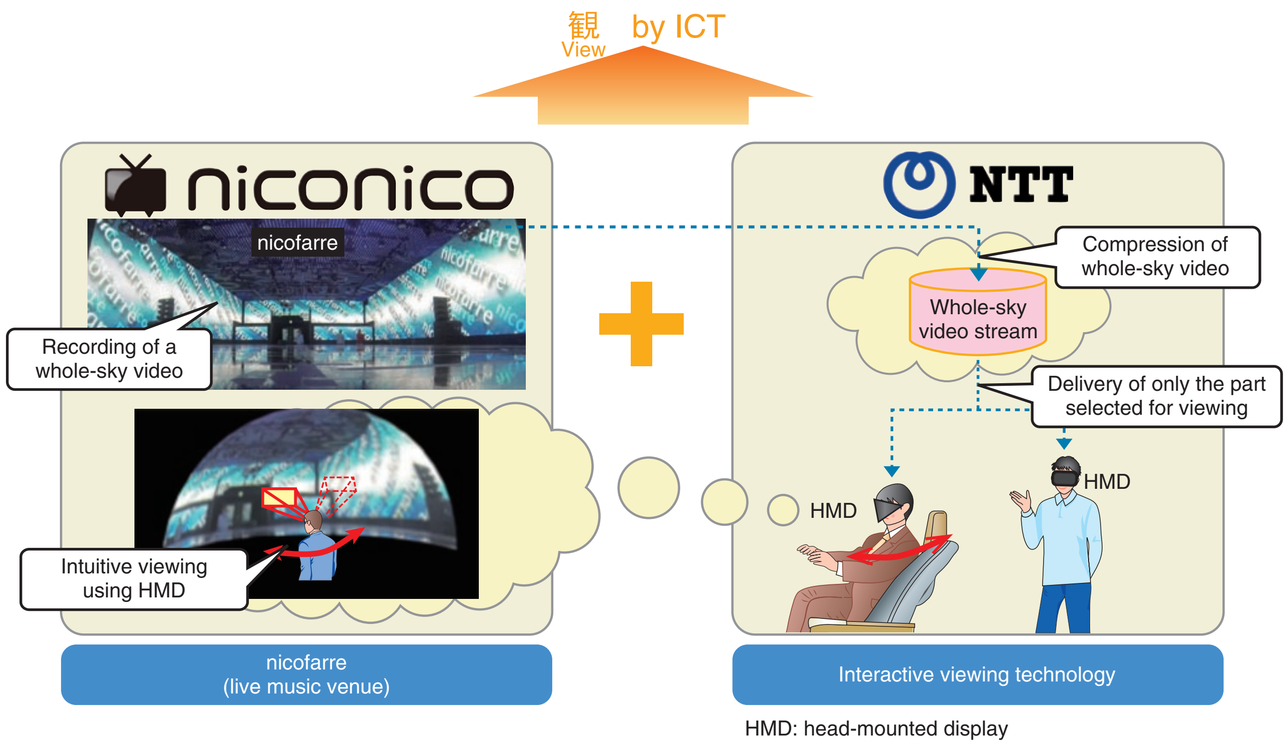



Fig. 8. Interactive viewing technology for whole-sky videos.

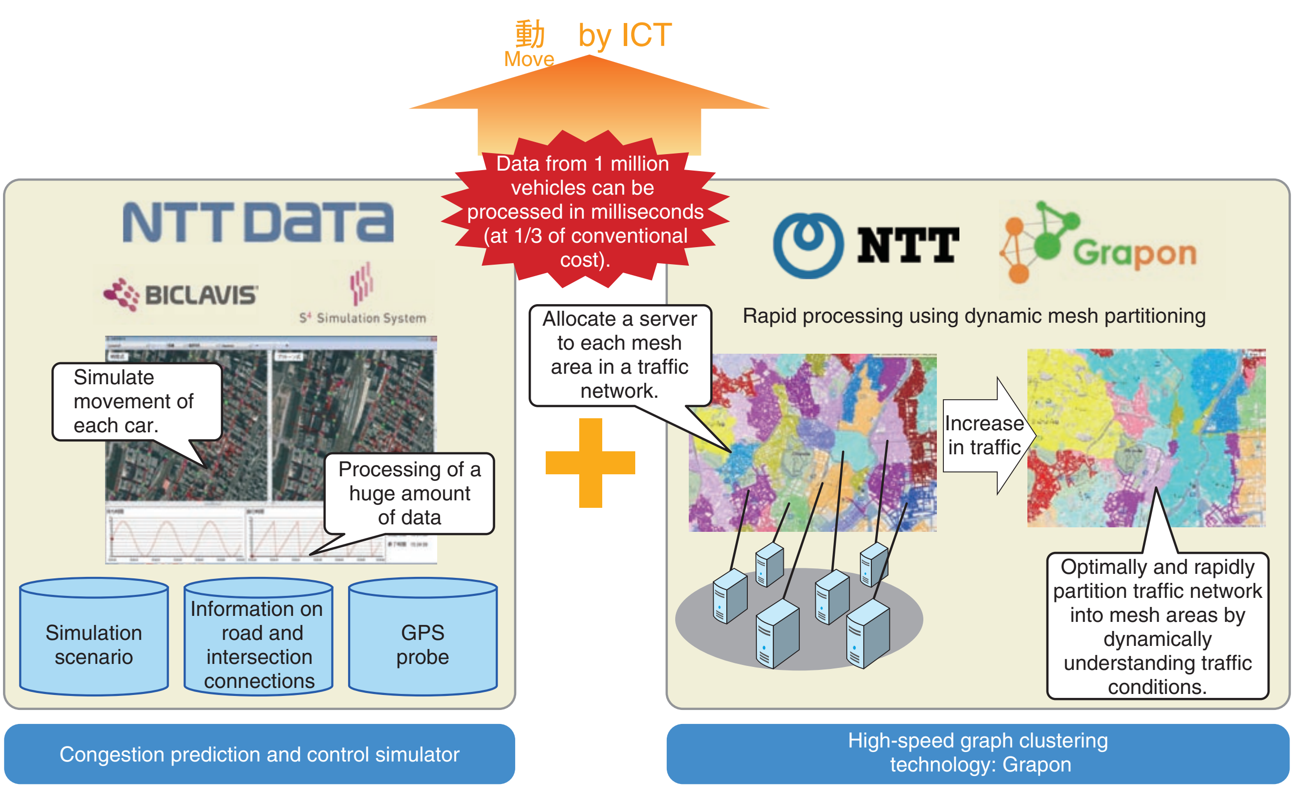



Fig. 9. High-speed graph clustering technology.

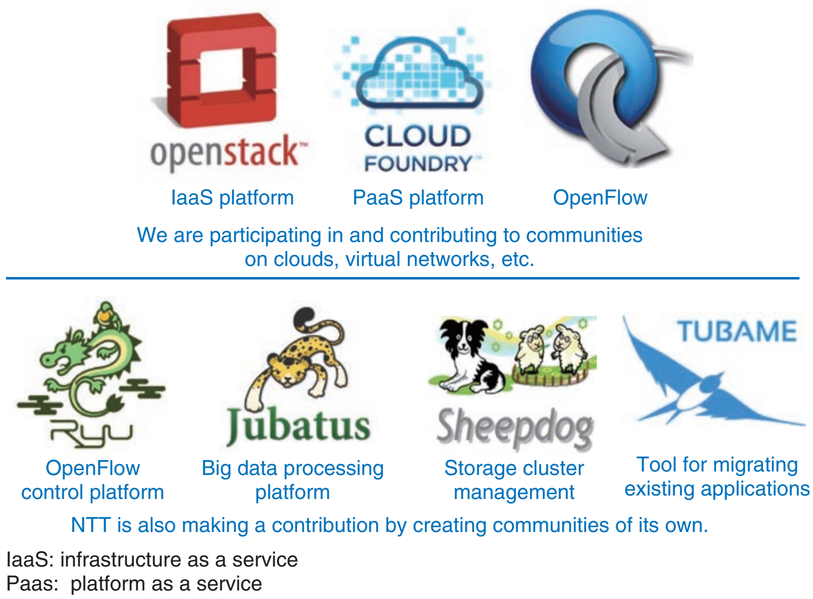



Fig. 10. Open source activities.

platform, with Preferred Infrastructure, and we provide it as open source software. We have hosted hands-on sessions (workshops) for it as part of efforts to expand its market. This has led to its adoption in 評Ban, an information analysis service provided by NTT IT.

We are also working on the anonymization of personal data. While big data are expected to create new values, there are concerns about how personal data are handled. A current solution to this is k-anonymity technology, which processes data in such a way that it guarantees that the number of people with the given attributes cannot be narrowed down to a value smaller than k. Conventional anonymization methods are often associated with a problem in which large errors occur in the analysis results. In contrast, NTT laboratories has developed pk-anonymity technology that ensures both k-anonymity and high analysis accuracy by bringing the data close to their original state using Bayesian estimation after having processed the data.

(3) Easy-to-use cloud

In cooperation with the former Nicira, we have developed technology that automates the work of changing network configurations. This is necessitated when a server installed on premises, that is, at the customer site, is to be migrated to a cloud. NTT Communications launched a service using this technology in June 2013. Since IP addresses can be reused after migration, the service lowered the barrier to migration to clouds.

To support the use of clouds, we have combined NTT laboratories' test item generation tool with NTT DATA's automatic execution tool, and developed an engine that automatically generates test items and test data from a design specification. This is expected to lead to the development of a tool that will automate the testing of a mobile terminal environment.

One method to accelerate the speed of development is the use of open source software. NTT laboratories not only participate in communities such as OpenStack, Cloud Foundry, and OpenFlow, but they have also created communities such as Ryu, Jubatus, Sheepdog, and TUBAME, and are pressing ahead with open source activities (**Fig. 10**).

(4) Security

In the field of information security, we have developed secure computation technology that makes it possible to analyze secret data without having to restore it with information theory-backed security. The technology allows secure analysis of personal data—in particular, highly confidential patient information—and is therefore expected to facilitate the discovery of new treatments and drugs. In this fiscal year, we have improved the technology to make the processing fast enough for commercial application.

We have improved traceability technology, which traces the history of operations in a cloud service. It is now possible to trace not only operations involving

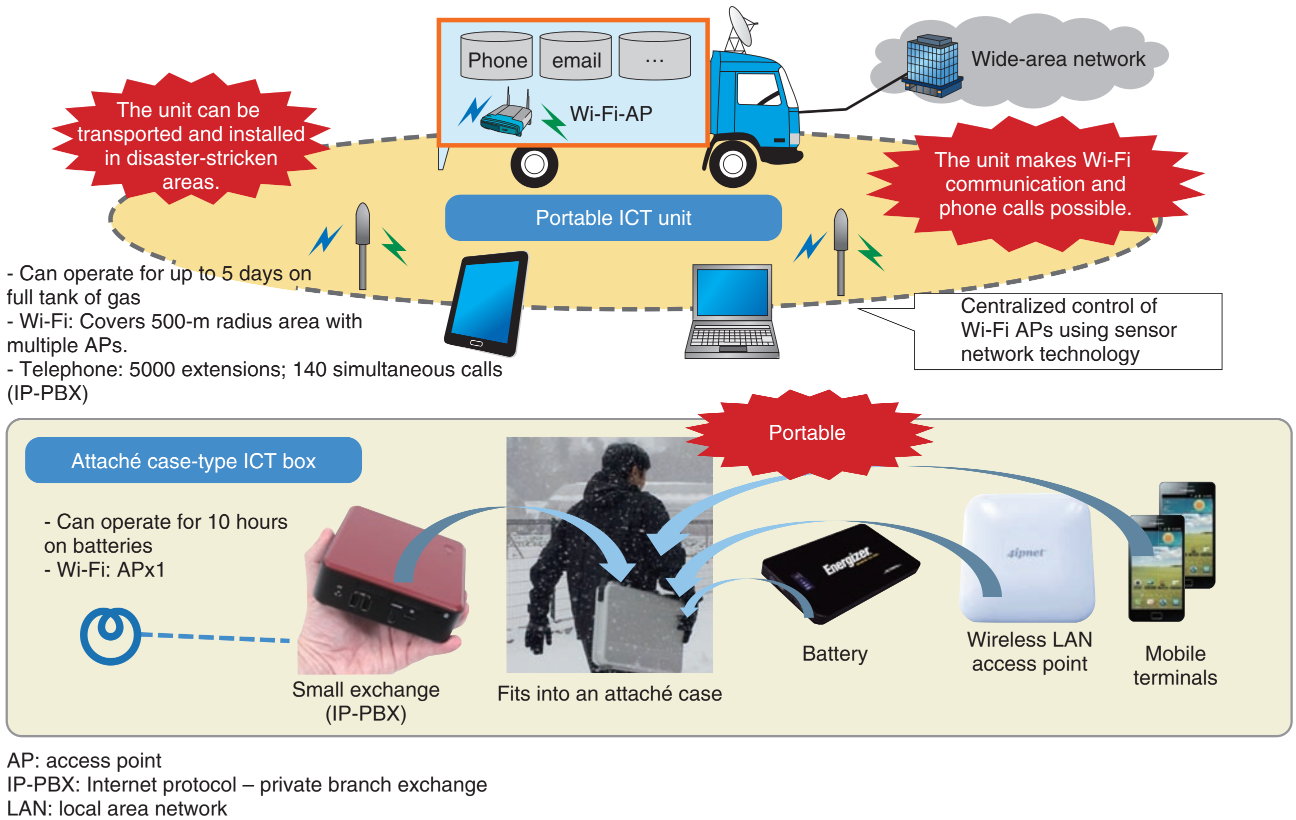



Fig. 11. Portable ICT unit.

files but also operations involving copying or deleting virtual machines. In addition, we have developed an analysis engine that focuses on data flow sequences to detect security threats. This engine has been incorporated into a security platform provided by NTT Communications.

(5) High-capacity, high-reliability network

As mobile network traffic increases, optical fibers that connect base stations to telecommunication buildings are growing in number. NTT laboratories are working on technology to multiplex mobile signals on a single fiber and technology to compress signals. We are also studying technology to conduct big data analysis of network device data in order to detect signs of possible faults before they occur. Since network growth brings about an increase in power consumption, we are studying technology to interlock the control of virtual servers and air conditioners in such a way that the total power consumption will be minimized.

Additionally, a portable ICT unit has been developed for use as a disaster prevention tool based on lessons learned from the Great East Japan Earthquake (**Fig. 11**). Various information devices are mounted on a vehicle to enable phone calls, emails, and applications of municipalities to be promptly put into service in the field, even during a blackout, by combining Wi-Fi environments. We have also developed an attaché case-type ICT Box. We have limited its functionality to make it more portable.

One example of our activities to compensate for a missing link in our expertise is software error testing technology, which has been jointly developed with Hokkaido University. Researchers at NTT laboratories studied faults affecting telecommunication devices and found that some faults are due to software errors attributable to neutrons coming from space. However, we have been unable so far to replicate an environment in which this type of fault actually occurs. This time, we constructed a software error replication environment by utilizing the neutron generation environment at Hokkaido University and ascertained that faults detected in the replication environment matched those in the field. The next step

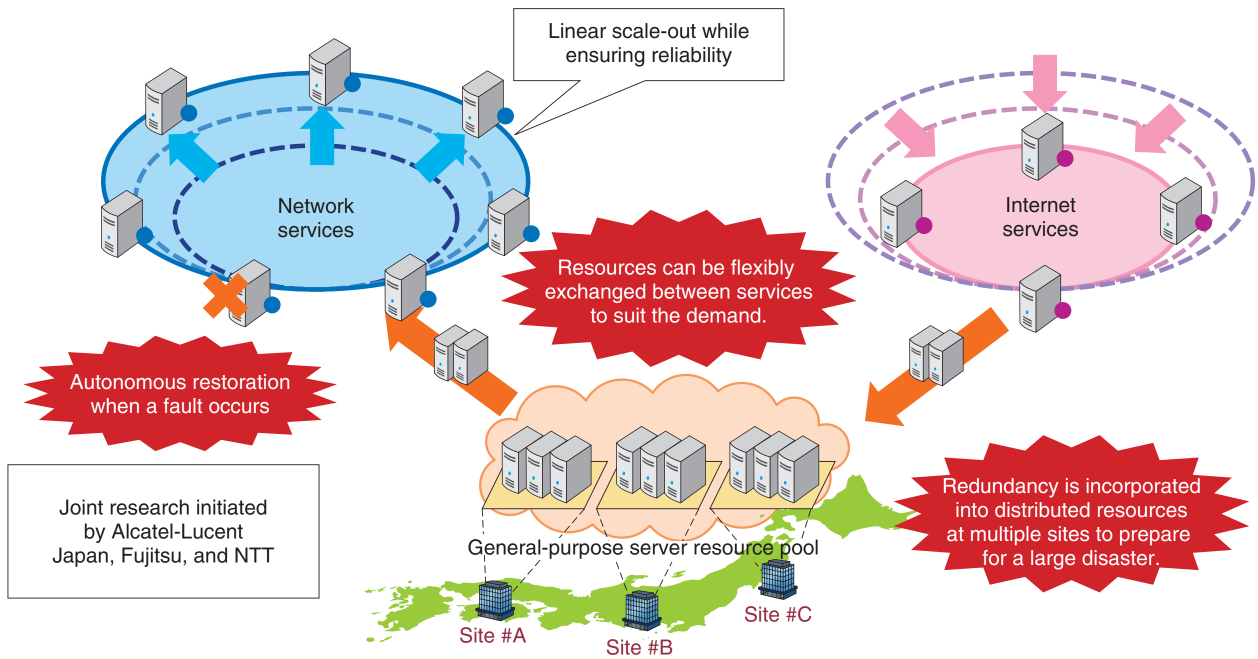



Fig. 12. Distribution platform that enables creation of high-reliability systems.

will be to study how to avoid software errors from happening.

(6) Flexible network

Quality of experience (QoE) optimization technology is another project we are pursuing in conjunction with Dwango. If the network becomes congested during the delivery of a high-quality video requiring a high delivery rate, the transmission capacity may become too constrained to deliver the video, and the playing of the video can be interrupted. We have analyzed the relationship between the state of network congestion and the user's QoE and developed a quality application programming interface (API) that recommends the optimal delivery rate. It enables Dwango to optimize the user's QoE in the *niconico* video and other services by optimally controlling the delivery rate on the basis of this API.

To facilitate the application of virtual networks to carrier networks, we have developed service tuning technology that enables the user to select which virtual network functions, available on a cloud, to use based on the history of how he/she has been using them. We have proposed a use case of this to the NFV (Network Functions Virtualisation) Working Group of ETSI (European Telecommunications Standards Institute) together with Cisco, Juniper Networks, and HP Japan.

Because network services require highly reliable servers, they conventionally use expensive dedicated servers. We have developed a distributed platform that makes it possible to satisfy requirements related to both economy and reliability (**Fig. 12**). Our aim is to implement a mix of network services with different reliability requirements on general-purpose servers by utilizing distributed processing technology. When a server fails, for example, other servers autonomously take over the services being provided. In the event of a disaster, computing resources can be flexibly adjusted to reduce the number of servers providing Internet services and to increase the number of servers providing network services. We have started joint research on this platform with Alcatel-Lucent Japan and Fujitsu.

(7) Entry into new markets

In the field of materials technology, we have jointly developed with Toray Industries, Inc. a T-shirt embedded with electrodes for taking an electrocardiogram (**Fig. 13**). It is already commercially available. By combining our conductive fiber technology and clothing design technology with Toray's nanofiber material and compression control technology, it has become possible to stably record someone's vital signs over a long period. We will collaborate with users to expand its application to medical care and


Fig. 13. Bio-electrode made of conductive polymer/fiber materials, developed with Toray.

support for the elderly.

In the audio field, we have developed technology that separates an audio sound into a direct sound and reverberation. This will make it possible, for example, to separate musical sounds in this way so that a car audio user can obtain an acoustic effect similar to that in a concert hall. It will also be possible to record only the clear direct sound in an IC (integrated circuit) recorder.

In the field of optical technology, we have developed KTN (potassium tantalum niobate: $KTa_{1-X}Nb_XO_3$) crystal technology, which deflects (bends) light. Originally developed for optical communication, this technology is now considered to be applicable to light sources for optical coherence tomography in the medical field. By combining this technology with Hamamatsu Photonics' optical design technology, it has become possible, for example, to examine the fundus oculi (interior of the eye), blood vessel walls, and skin at high speed. In addition, we are exploring the possibility of using the crystal as a high-speed varifocal lens, which can be used as a biosensor for measuring neurotransmission.

We also have a super-high-purity laser light source technology. By combining this technology with the laser spectroscopic technology of Picarro (USA), we have developed isotope ratio analysis technology that uses laser gas sensing. This will make it possible, for example, to determine where an item of produce was grown or where a gas leak is occurring by identifying the origin of a methane gas leak. We hope to use this technology to make society at large more secure.

Next, I would like to discuss our collaboration with the Japan Aerospace Exploration Agency (JAXA). If the efficiency of an ion engine used in rockets is to be enhanced, we must be able to measure the electric field distribution inside an ion engine accurately, but JAXA initially had no means of doing this. However, JAXA solved this problem by using NTT laboratories' electro-optic probe, which was originally designed to measure electromagnetic waves from a mobile phone, and discovered a mechanism for boosting the engine's propulsive power.

(8) Cutting-edge technology

In the field of basic research, which is the foundation of our open innovation, we are focusing on technology for easily delaminating and transferring thin-film elements, technology related to quantum computing and for producing high-purity phonons, and technology for human information science.

## 3. Conclusions

The NTT Group has declared itself to be a *value partner*. In the context of NTT R&D, this means that we need to be regarded by potential partners as a co-innovator worthy of their selection.

Researchers tend to do everything by themselves, which is good in general. However, we should accelerate our co-innovation initiatives to drive home the idea that far better achievements can be obtained by cooperating with others.

The objective of research is to produce excellent results. However, when these results are to be incorporated into products and introduced to the market, it will be necessary to reduce costs even if it means removing some of the good aspects of the results. Even if an excellent technology has been developed, it may not assume a commercially marketable form if it lacks something no matter how small this deficit might be. What this tells us is that researchers need to consciously shift gears when their research advances to the commercialization phase.

NTT R&D will press ahead with co-innovation to expand and develop the future vision of ICT by combining ICT with other fields instead of sticking to ICT alone.

# Innovative Services in Medicine, Healthcare, and Environment with Advanced Device and Materials Technologies

*Koji Fujii, Tadashi Sakamoto, and Yoshihisa Sakai*

**Abstract**

Device and materials technologies originally developed for the telecommunications industry can be applied to implement creative and competitive information and communications technology services. This article introduces some research and development activities we are pursuing for the creation of new business fields.

*Keywords: device, material, services*

## 1. Introduction

Science and technology have progressed and matured greatly over the years, and many of the achievements in these areas have motivated researchers to create tools or systems for solving various existing social problems. These problems include, for example, many wrongdoings that have been exposed recently in the food and environment industries, whose operations should be subject to the highest standards because they are fundamental for safe and secure daily living. Another urgent issue is the increase in atmospheric carbon dioxide density caused by human activities, which is causing rises in temperature as well as unprecedented abnormal weather patterns around the world. There is also the aging society, which threatens the sustainability of our society because the ever increasing welfare and medical-care expenses for the elderly occupy a significant portion of the national budget.

At the NTT laboratories, we are working to develop solutions to these social problems by employing our most advanced human- or environment-centric technologies. Our research and development (R&D) flow for solving the social problems is shown in **Fig. 1**.

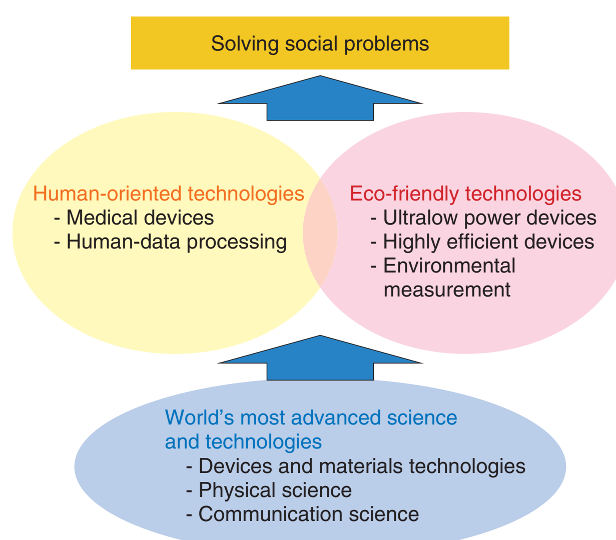



Fig. 1. Research flow for solving social problems.

Our research fields include physical science, communications science, and device and materials engineering. Together, they provide a solid foundation on

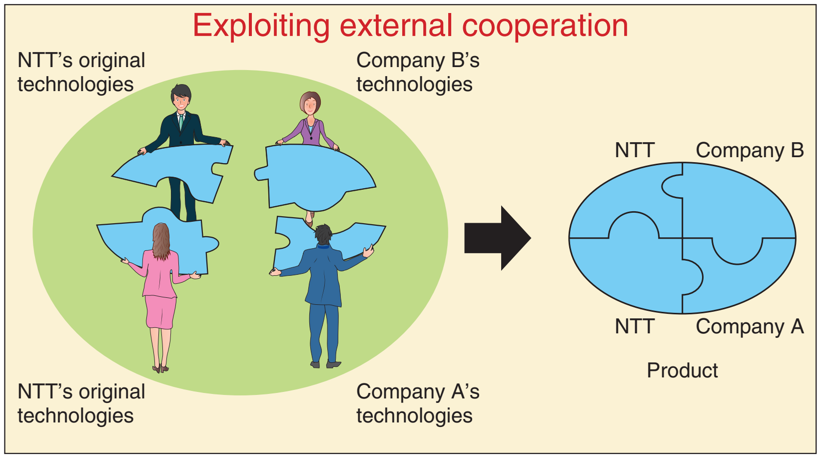



Fig. 2. R&D scheme utilizing external organizations.

which to develop human-centric technologies such as medically oriented devices and data processing of human biomedical signals and environment-centric technologies such as highly efficient and ultralow-power-consumption devices.

We are ready to license our intellectual property (IP) that has been created through our research. The effort to promote our IP to as many people as possible contributes not only to the telecommunications market but to other markets as well.

## 2. Exploiting external cooperation

Competitive devices and materials produced from research in the fields of smart living and life assistance can bring us many opportunities to create new business and expand our current business further. The expertise necessary for this kind of research, however, is quite diverse since it involves a deep technological hierarchy and broad application fields. This makes it much harder to complete the entire research process—from coming up with a concept to implementing an actual business framework—by ourselves.

Exploiting outside technical resources is a key way to tackle this difficulty. We need to define what we can do by ourselves, spot technical elements that are lacking, and exploit outside resources effectively to compensate for the missing technical elements. Open innovation is a key practice, or attitude, for expediting the commercialization of products and services since it helps us use outside technologies whenever necessary without persisting in the use of our own technologies. A rule of thumb is to start external cooperation as early as possible to ensure there is sufficient time to establish a collaborative work relationship with outside organizations. This expedites the introduction of products and services with more value added to the market.

This research attitude or practice that we are seeking is schematically shown in **Fig. 2**. We plan to continue this research practice strategically to create new business fields that expand our overall telecommunications business.

## 3. Sensing technologies and highly efficient electronic materials

Sensing technologies are crucial for creating attractive services in the smart-life and life-assistance domains. Highly efficient electronic materials are vital for making energy-saving electronic appliances and thereby for supporting or sustaining our daily life with limited natural resources. We are creating new information and communications technology (ICT) services that employ novel sensing data acquired in the fields of medicine, healthcare, and the environment. This special issue highlights some of our sensing technologies and electronic materials, and provides detailed descriptions in individual articles. Those technologies and materials with links to their corresponding applications and ICT services are outlined in **Fig. 3**.

Future sensing technologies will be capable of integrating sensing data acquired from separate sources and as a result will be able to extract larger amounts of useful information than can be obtained by

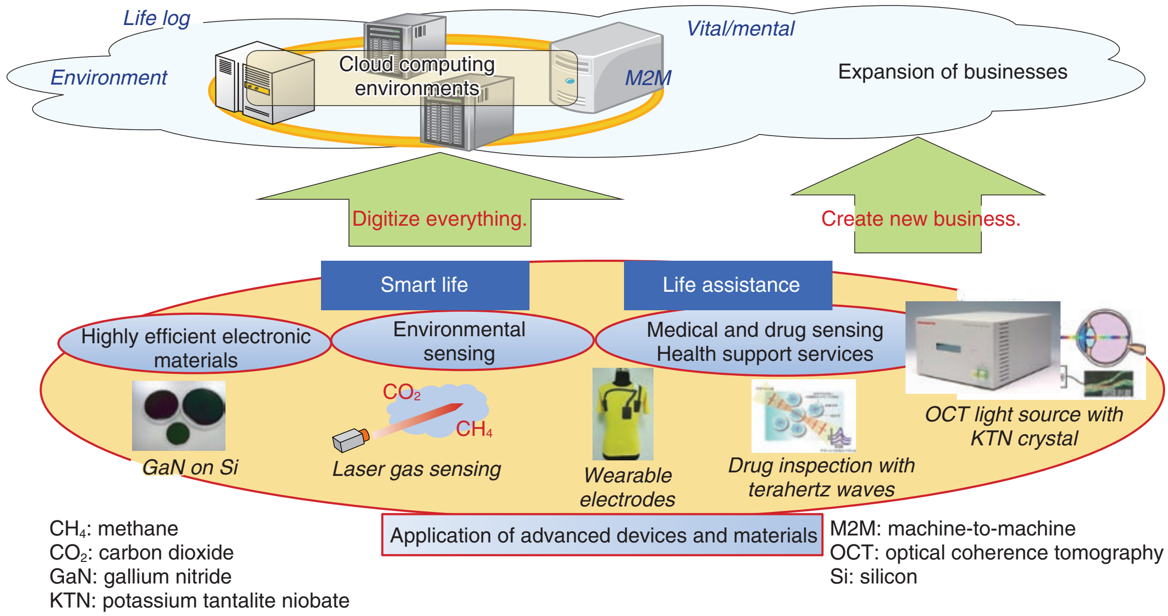



Fig. 3. Sensing technologies and highly efficient electronic materials for ICT services.

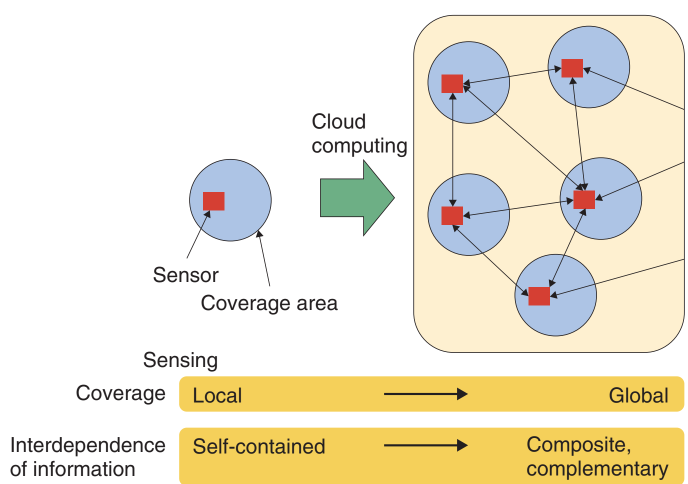



Fig. 4. Integration of sensing technologies and cloud computing for innovative services.

analyzing sensing data from a single source. Other physical phenomena that correlate with an original sensing source could add value to the analyzed information. From this viewpoint, cloud services will play a crucial role in creating innovative services in the fields of medicine, healthcare, and the environment. In these fields, various kinds of sensing data need to be easily exchanged, analyzed, and enhanced with additional values online in order for such services to become more feasible to general customers. Integrating sensing data with cloud services will help us advance related services, as illustrated in **Fig. 4**.

This special issue features five articles, each of which deals with promising technologies that can contribute to solving social problems in the fields of medicine, healthcare, and the environment. The first four articles describe sensing technologies, while the last one explains highly advanced electronic materials technologies.

## 4. Articles in this special issue

The first article, entitled "Electrocardiogram Monitoring Simply by Wearing a Shirt—For Medical, Healthcare, Sports, and Entertainment [1]," describes a sensing technology intended for measuring bioelectrical signals generated by the human body. NTT's proprietary fabrication technique for bioelectrodes makes them flexible, durable, and biocompatible at the same time. These properties were once difficult to implement in conventional bioelectrodes. However, by wearing a compression shirt affixed with these biocompatible electrodes on the inside, the wearers can easily and continuously measure their own bioelectrical signals for long periods of time. The shirt has various applications, especially in the ICT domain, such as online advisory services in sports, healthcare, and medicine.

The second article, entitled "200-kHz Swept Light Source Using a KTN Deflector and a High-speed Optical Coherence Tomography System [2]," explains a sensing technology for a medical diagnosis instrument. The medical diagnosis method called optical coherence tomography (OCT) is drawing a lot of attention these days because of its ability to quickly obtain cross-sectional images of biological tissue. NTT laboratories have successfully accelerated the rate at which a cross-sectional image can be captured by using a high-speed wavelength-swept light source fabricated with NTT's proprietary KTN (potassium tantalite niobate) crystal. The acceleration can shorten the OCT procedure and thereby reduce the burden on patients. OCT cross-sectional images of biological tissue can be shared among hospitals over the Internet and can be analyzed with the help of cloud services to create new ICT services in medicine.

The third article, entitled "Terahertz Spectroscopic Identification of Pharmaceutical Crystals: Cocrystals and Polymorphic Forms [3]," introduces a sensing technology intended for use in a drug inspection apparatus. In drug inspection, it is highly desirable to be able to observe the manner in which molecules bond to each other since such information can be used to determine a drug's effectiveness. NTT's proprietary terahertz-wave technologies enable us to observe molecular bonding, which has not been possible with conventional technologies. This inspection technique is attracting much attention for its use in clarifying how pharmaceutical crystals are dissolved and absorbed in the human body.

The fourth article, entitled "Highly Sensitive Laser Based Trace-gas Sensor Technology and Its Application to Stable Isotope Ratio Analysis [4]," explains a sensing technology applicable to the analysis of food and atmospheric gasses. With NTT's proprietary laser diode, we can analyze a tiny amount of an isotopic component with high sensitivity and cost effectiveness. The tiny amount of the isotopic component can be used as a signature for determining the origin of things, such as where or how they were produced. The signature can be obtained by investigating the ratio of the isotopic element contained in the targeted object. New ICT services such as preventing food fraud or monitoring sources of greenhouse gases could be implemented with this sensing technology in the near future.

The fifth article, entitled "GaN-on-Si Technology for High-power Transistors [5]," describes a highly efficient electronic materials technology. NTT's proprietary fabrication technique for growing GaN thin films on Si substrates makes it possible to produce more efficient and cost-effective electronic devices or more energy-efficient power devices than ever. This technology is attracting a great deal of interest because of its potential to reduce the environmental impact of our daily activities, particularly the impact of our use of electrical appliances.

## 5. Future prospects

The technologies dealt with in this special issue vary in their development phase. Some are at an early stage where they are being tested to prove their applicability to their targeted fields. To refine such immature technologies for practical use, we need to simultaneously solve a lot of issues associated with reliability, safety, and cost.

In this regard, cooperative work with other departments, laboratories, companies, and/or organizations is very effective and efficient since they can compensate for each other's elements that are lacking. We have just started this cooperative research in some fields and are trying to expand it to other fields to expedite our competitive technologies for use in real products or services in the marketplace.

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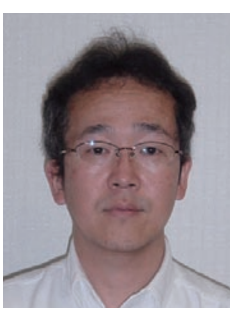

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# Electrocardiogram Monitoring Simply by Wearing a Shirt—For Medical, Healthcare, Sports, and Entertainment

*Shingo Tsukada, Nahoko Kasai, Ryusuke Kawano, Kazuhiko Takagahara, Koji Fujii, and Koji Sumitomo*


### Abstract

We developed a conductive fiber by coating the surface of silk or synthetic fiber with a conductive polymer and fabricated wearable electrodes to achieve long-term biosignal monitoring. This new bioelectrode made of a complex conductive material is flexible, biocompatible, and hydrophilic and allows stable recording equivalent to that obtained with conventional medical electrodes but without the need for any electrolyte paste, which can irritate the patients' skin. We can expect this wearable electrode to be utilized in various applications related to sports, health improvement, and early medical diagnosis by providing long-term biosignal monitoring without patient discomfort or irritation.


*Keywords: wearable electrodes, electrocardiogram, smart textiles*

## 1. Introduction

### 1.1 Biosignal monitoring in daily life

The need for early detection and treatment of diseases is increasing as the aging of Japanese society accelerates. Specifically, concern has been rising about the need for continuous, long-term monitoring of electrocardiogram (ECG) data with a view to reducing the risk of sudden death and critical health incidents such as heart attacks. Moreover, people in their 30s or 40s who are in the prime of life are often exposed to excessive stress at the office and/or at home, and monitoring the heart rate (HR) and ECG data is thought to be effective in allowing this group to recognize the state of their physical and mental health in order to maintain it in the optimal condition.

However, conventional medical electrodes used for recording ECG signals use electrolyte paste[*1], which can cause rashes and irritation. These electrodes are therefore unsuitable for continuous long-term use in daily life. Bioelectrodes based on a conductive fiber that is coated with metal, for example, silver, are often used for measuring HR and have attracted a great deal of interest lately, especially for use during participation in sports since people are becoming increasingly health conscious. However, metal-based conductive fiber, which is usually used without electrolyte paste, can result in a higher noise level because of its instability when it is in contact with skin, and thus, ECG measurement using the conventional electrodes has been difficult for medical applications.

### 1.2 Newly developed wearable electrodes

We have succeeded in developing flexible, stretchable, and highly breathable (air-permeable)

*1 Electrolyte paste: A paste or gel containing electrolyte that is applied to the skin surface and on which a metal electrode is affixed in order to obtain ECG measurements at medical facilities. The electrolyte is applied between the electrode and the skin surface and reduces contact resistance. Conductive adhesive gel is also used for Holter ECG measurements.

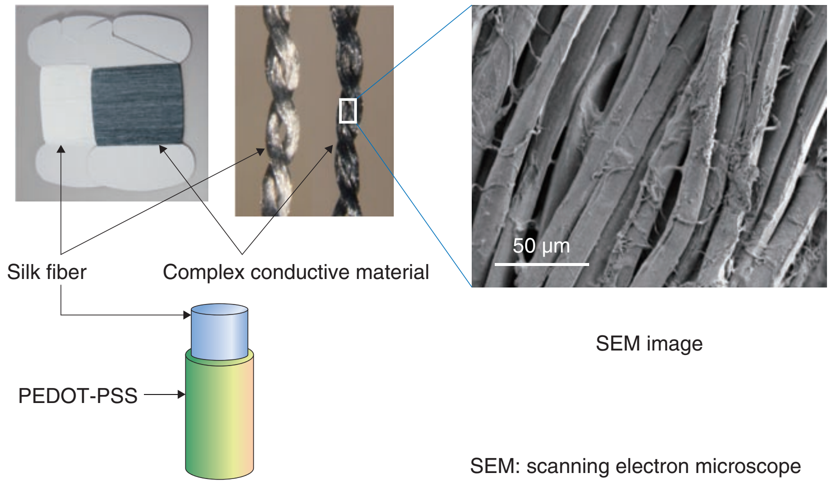



Fig. 1. Complex conductive material using conductive polymer and fiber.

bioelectrodes by coating non-conductive fibers with a conductive polymer material called poly(3,4-ethylenedioxythiophene) poly(styrenesulfonate) (PEDOT-PSS). This material makes it possible to obtain a stable ECG measurement equal to that obtained with a medical electrode without having to use electrolyte paste. This is possible because of the material's high hydrophilicity, whereby the electrode becomes better attached to the skin by absorbing sweat and steam.

We have succeeded in developing wearable electrodes that enable long-term recording of both HR and ECG signals simply by having users wear an electrode-equipped shirt, thus positioning the textile electrodes on the body. These wearable electrodes can greatly reduce the burden imposed on patients or users, and they enable monitoring of everyday biological signals.

## 2. Complex conductive material made of PEDOT-PSS and textile/fiber

PEDOT-PSS is one of the most commonly used commercially available conductive polymers, and it is important in industry as an anti-electrostatic material, an organic photovoltaic material, and a transparent conductive material that is used as an alternative to indium tin oxide (ITO) for touch-panel and flexible LED displays. Moreover, PEDOT-PSS is expected to find use as bioelectrodes because of its high hydrophilicity and biocompatibility. However, its use to date has been limited because of its poor processability and instability in highly humid environments. Our group has used PEDOT-PSS in biosensors to coat metal microelectrode arrays (MEAs)*2 for monitoring in-vitro neuronal activity, and in electrodes for implantation in order to confirm its high biocompatibility and its excellent electrical properties [1].

In our most recent work, we successfully developed a new material by coating textiles or fibers with PEDOT-PSS. This smart-textile, complex conductive material is stable in water and has good processability, thus solving the aforementioned problems. Furthermore, it maintains conductivity, hydrophilicity, and biocompatibility. Coating PEDOT-PSS uniformly onto a silk thread (**Fig. 1**) gives this compound material the characteristics of both silk fiber and PEDOT-PSS. The base material is not limited to silk fiber, and fibers or textiles made of synthetic material can be coated with the polymer. Thus, we have developed a conductive textile that is flexible, elastic, and air-permeable.

The ECG of laboratory animals (rats) was measured using this complex conductive material (**Fig. 2**). In the measurement, electric waves were obtained that were as clear and stable as those provided by a conventional medical electrode but without the need to use electrolyte paste [2]. Metal-coated fiber without electrolyte paste gives an unstable ECG baseline due to breathing-related body movement, and it induces noticeable noise as a result of contact resistance with the body surface. By contrast, we

*2 Microelectrode array (MEA): Patterned microelectrode device used to stimulate nerve cells and detect nerve signals.

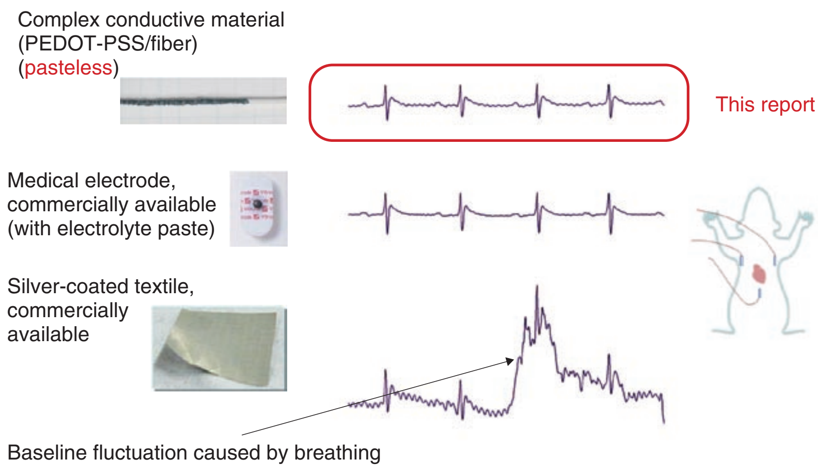



Fig. 2. Stable monitoring of electrocardiogram using complex conductive material made of PEDOT-PSS/fiber.

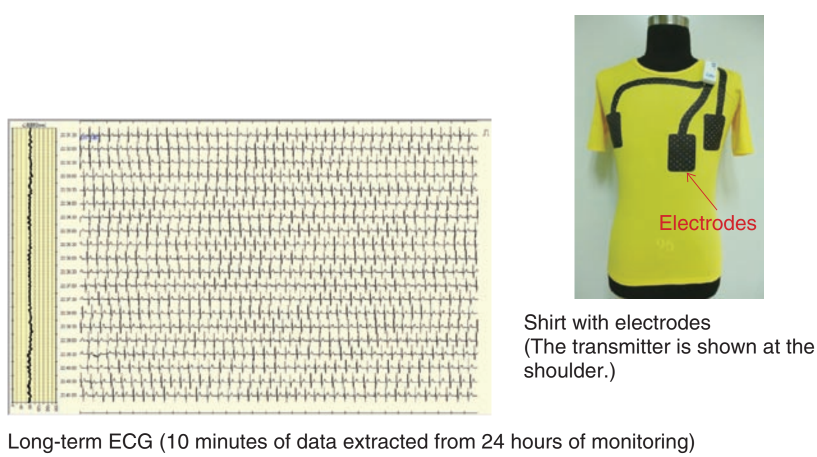



Fig. 3. Wearable electrodes and long-tem ECG.

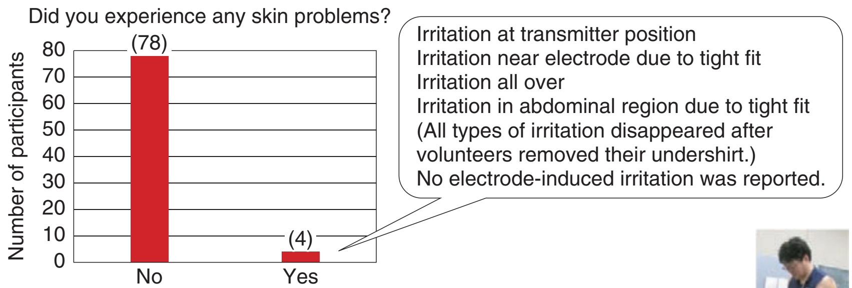
were able to obtain a stable measurement using this complex conductive material consisting of PEDOT-PSS and a textile/fiber, because it was effective in absorbing sweat and steam from the body due to its high hydrophilicity, and it adhered gently to the skin thanks to its flexibility.

## 3. Electrocardiography using wearable electrodes

We took advantage of the characteristics of conductive fibers/textiles to develop wearable electrodes, which enabled us to measure biosignals such as HR and ECG simply by having the patient wear an electrode-equipped shirt.

An electric potential distribution is induced in all parts of the body by the electromotive force caused by cardiac activity. An ECG is a wave pattern of the potential difference between two points on the body surface. When the electrode-equipped-shirt is worn, it can provide an ECG because the textile electrode adheres to the skin.

The wearable electrodes were jointly developed with Toray Industries, Inc. (Toray), one of the largest fiber manufacturers in Japan. A sample ECG obtained from the shirt in a 10-minute period during 24 hours of monitoring is shown in **Fig. 3**. This newly developed textile electrode is flexible and air-permeable, does not require electrolyte paste, and is thus capable of monitoring HR or ECG signals over long periods




Skin irritation test

| | Uncoated (control) | Coated textile (electrode) |
|---|---|---|
| Cell viability | 98.3% | 96.2% |
| Result | No irritation | No irritation |

Fig. 4. Subjective examination of wearable electrodes.

without discomfort or irritation to the wearer.

Before undertaking the joint development with Toray, we fabricated our original wearable electrodes to examine the effect of the material on human skin and the capacity for performing electrical biosignal measurements. We used 82 healthy male volunteers employed at the NTT Atsugi R&D (research and development) Center for our study. We investigated their HRs (R-R intervals) for up to 24 to 48 hours, except when they were showering or bathing. We confirmed that the HR was successfully recorded for more than 10 hours for most subjects, and that the electrode material itself caused no irritation or rash (**Fig. 4**). In addition, this experiment confirmed that the wearable electrodes provided stable and long-term HR monitoring even during sleep. Thus, the results can also be analyzed to determine sleep quality to promote better health.

In addition, we carried out a skin irritation examination in accordance with OECD (Organization for Economic Co-operation and Development) Test Guideline TG439. We conducted a comparative examination of the survival rate of cultured cells with or without a PEDOT-PSS coating, and found that both survival rates were slightly less than 100%, and that the PEDOT-PSS coating caused no skin irritation. The results revealed that the complex conductive material we have developed makes it possible to undertake long-term electrical biosignal monitoring without safety problems, and the material can be used for wearable electrodes.

This experiment indicated that reduced adhesion of the electrode (due to clothing pressure), and dryness of the skin caused noise and signal interception, which had previously prevented long-term HR measurements. The aim of the joint development with Toray of the wearable electrodes was to optimize the material specifications in order to improve the retention of moisture in the skin to ensure adherence of the electrode.

## 4. Transmitter for ECG monitoring

The electrical biosignals that show the changes in the electric potential of the body surface, measured with the wearable electrode using PEDOT-PSS, are transmitted wirelessly (e.g., using Bluetooth) to a smartphone or personal computer by our own small transmitter attached to the shirt. The device and a sample ECG obtained using the device are shown in **Fig. 5**. We obtained a high quality ECG with low noise and a high S/N (signal to noise) ratio, and we clearly observed sharp QRS waves[*3] as well as P and T waves. The HR is calculated from the intervals between the two peaks of the R waves (R-R intervals). The device is equipped with a lithium-ion rechargeable battery, and the wave pattern can be transmitted continuously for around 12 hours. The electrocardiographic information can be sent to a server via a smartphone from anywhere via the Internet, thus enabling data analysis. We will continue to improve the quality of the wearable electrode system

*3 QRS wave: Electrical waveform obtained during ventricular excitation, whose shape can demonstrate an irregular pulse (arrhythmia) or myocardial infarction.

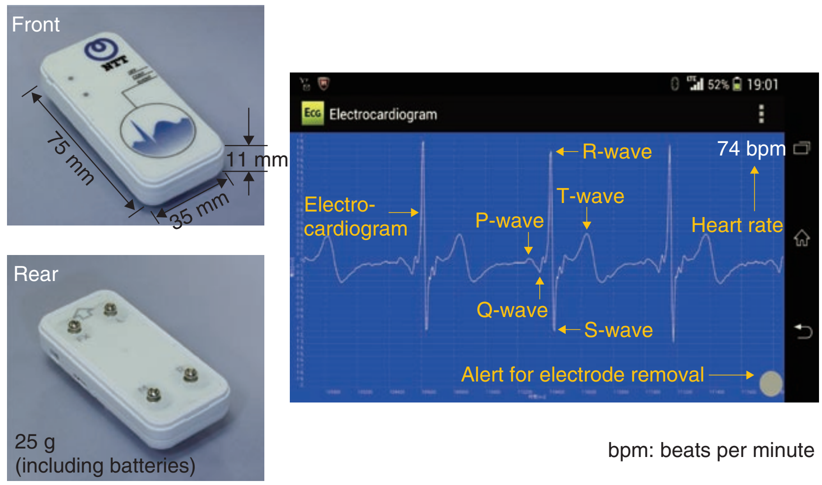



Fig. 5. Transmitter for ECG monitoring and smartphone display.

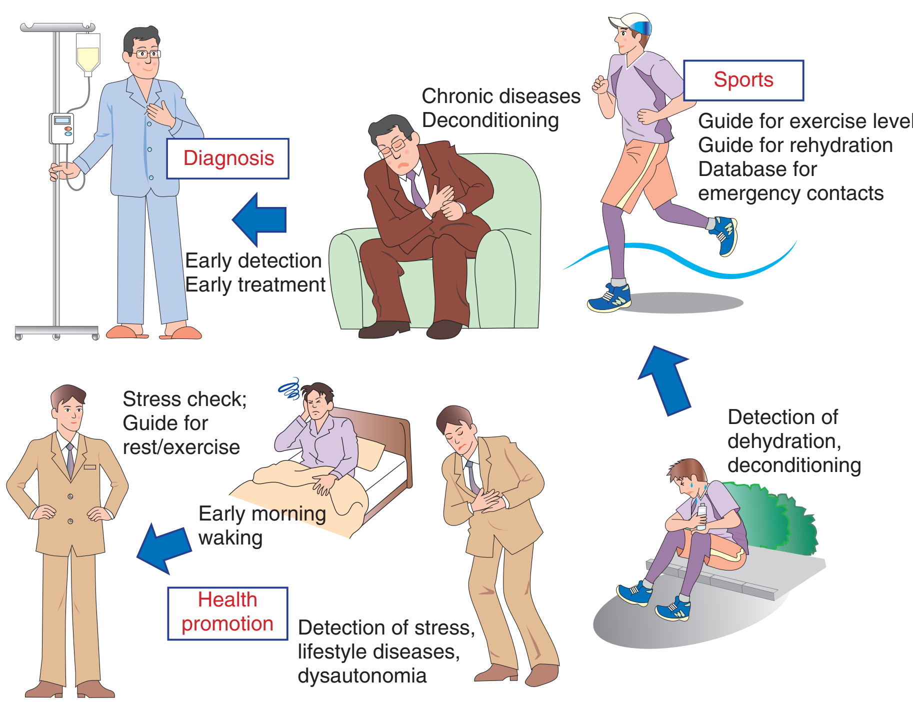



Fig. 6. Future applications of wearable electrodes.

to create new value by combining it with cloud services or big data analysis by further downsizing and reducing energy consumption, and by adding multiple functions to the system.

## 5. Future applications

HR and ECG signals can be measured simply by wearing the electrode-equipped-shirt described in section 3. The shirt is soft, flexible, and air-permeable and does not require electrolyte paste. As a result, the shirt can be used to record electrical biosignals without irritating or imposing a burden on the person wearing it. We expect it to be used to support diagnosis leading to early detection and early treatment of illnesses through regular ECG monitoring (**Fig. 6**). As one key medical ICT (information and communications technology) device application, the device can be studied or used in such medical fields as home medical care or telemedicine. Additionally, the medical quality level provided by wearable electrodes is being studied in cooperation with the medical departments of hospitals and universities with a view to expanding its applications.

The complex electrode material incorporating conductive polymer and fiber/textile that we developed can also be applied to fields other than ECG and HR monitoring. For example, we have examined its applicability to electroencephalographic measurements and to implantation at the research level.

The monitoring of changes in HR is also useful in understanding and controlling exercise levels and for improving health care. The wearable electrodes can be used in various settings while the wearer enjoys participating in sports. In addition, the HR normally fluctuates even while a person is resting quietly in bed, and this HR fluctuation can reveal both autonomic nerve functions and stress levels. Thus, HR changes measured with precision by employing an electrocardiographic QRS wave can be useful for calculating the appropriate exercise load as well as for evaluating mental aspects of users quantitatively. These wearable electrodes are effective in supporting mental health care for people of all ages who face various stresses by enabling the daily monitoring of HR changes even while the subject is asleep.

Thus, the wearable electrodes can be used for a wide variety of applications ranging from the health and medical field to the sports/entertainment field. We will continue our development with the aim of putting the wearable electrode to practical use while extending our collaborative work both inside and outside the NTT Group companies.

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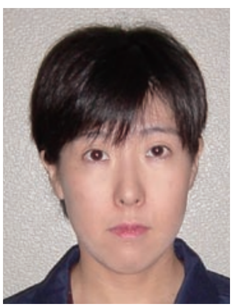

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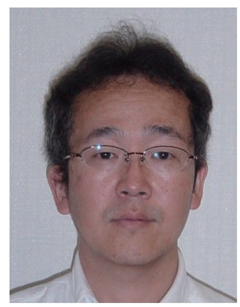

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# 200-kHz Swept Light Source Using a KTN Deflector and a High-speed Optical Coherence Tomography System

***Junya Kobayashi, Yuzo Sasaki, Masahiro Ueno, Takashi Sakamoto, and Seiji Toyoda***

**Abstract**

Optical coherence tomography (OCT) using a swept light source can acquire cross-sectional images of tissue with micrometer resolution for biomedical applications. High-speed OCT imaging is important for achieving advanced volume rendering and for reducing the number of undesirable artifacts. Here, we report the development of a 200-kHz swept light source (SS) using a KTN (potassium tantalite niobate: $KTa_{1-x}Nb_xO_3$) deflector and a high-speed SS-OCT system, which we used to successfully obtain OCT images of a human finger.

*Keywords: optical coherence tomography, swept light source, $KTa_{1-x}Nb_xO_3$ (KTN)*

## 1. Introduction

Optical coherence tomography (OCT) has attracted attention because of its potential use as a medical imaging technology [1]. OCT is an optical interferometry technique for acquiring cross-sectional images of tissue and other scattering materials with micrometer resolution. The resolution of OCT is higher than that of conventional imaging. Many studies related to two-dimensional (2D)-OCT imaging have been done. Three-dimensional (3D) OCT also promises to provide a more complete characterization of tissue structures on a par with those obtained with other medical imaging technologies [2]. However, 3D-OCT requires extremely high imaging speeds and data processing rates, in addition to the control of two scanning mirrors.

OCT using a swept light source (SS-OCT) offers the potential for high-speed data acquisition. SS-OCT reduces the quality degradation of *in-vivo* OCT images of moving artifacts caused by movement of the body, and it also achieves rapid imaging with 3D-OCT [3].

SS-OCT detects wavelength-resolved interference fringes generated by a wavelength-scanning laser. A key component of the SS-OCT system is the light source. The desirable output characteristics of a swept light source include high power, a high repetition rate, and a broad sweep wavelength range. As the repetition rate of the light source is increased, the duration of the laser irradiation decreases and the quantity of data obtained within a fixed measurement duration increases. Thus far, such light sources have used mechanical actuators for wavelength scanning [4]. In contrast, we are developing a new light source that incorporates an electro-optic deflector that we plan to employ in a high-speed SS-OCT system.

The deflector is based on a potassium tantalite niobate ($KTa_{1-x}Nb_xO_3$ (KTN)) single crystal. KTN has a very large electro-optic effect, which changes the refractive index by an applied voltage and bends the path of a light beam in a certain direction [5]. The deflection effect of the KTN is caused by a non-uniform electric field generated by injected carriers, and it exhibits a fast response and a fairly large light deflection angle [6]. The KTN deflector is useful for a fast repetition rate swept source.

We have taken the advantages of KTN crystal into consideration in developing a new swept light source using the KTN deflector (**Fig. 1**). Furthermore, we are developing a high-speed SS-OCT system using the light source in order to achieve advanced image rendering.

## 2. Swept light source with KTN deflector

The setup of a swept light source equipped with a KTN deflector, which is based on a Littman-Metcalf cavity configuration, is shown in **Fig. 2** [7]. The cavity consists of a 1.3-μm semiconductor optical amplifier (SOA) module, a collimator, a KTN deflector with electrodes, a cylindrical concave lens, a grating, and a high reflector (HR). The SOA module has a 10% reflector coupled to an optical fiber through an optical isolator on one side. The cavity length between the 10% reflector and the HR is about 60 mm. The KTN crystal is precharged by applying ± DC (direct current) voltage; then we scan the laser wavelength by applying a ±350-V sinusoidal voltage.

Fig. 1. 200-kHz swept light source using a KTN deflector (Hamamatsu Photonics K.K).

The light emitted from the SOA is collimated by the collimator, and it reaches the HR through the KTN deflector and the grating. The filter is constructed using the KTN deflector, the grating, and the HR. Light of a certain wavelength is selected according to the deflection angle of the KTN deflector, and it returns to the SOA.

The 200-kHz voltage is applied to the KTN deflector, and the corresponding interference fringe signal is successfully obtained (**Fig. 3**). We also measured point-spread functions (PSFs), namely, the relative OCT signal intensity for a single-layer reflection at various optical delays between the sample and reference arms. The PSFs were obtained by fast Fourier transforming (FFT) the interference fringe signals. We observed a decrease in the interferometry fringe amplitude (or the peak height of its FFT) as we increased the optical delay. The measured coherence length in air was approximately 7 mm for a 200-kHz scan. This indicates that a depth range of several millimeters can be covered using this frequency swept light source.

## 3. High-speed SS-OCT system using KTN swept light source

The high-speed OCT system is shown in **Fig. 4**. The setup consists of a swept light source with a KTN deflector, an optical fiber interferometer with a

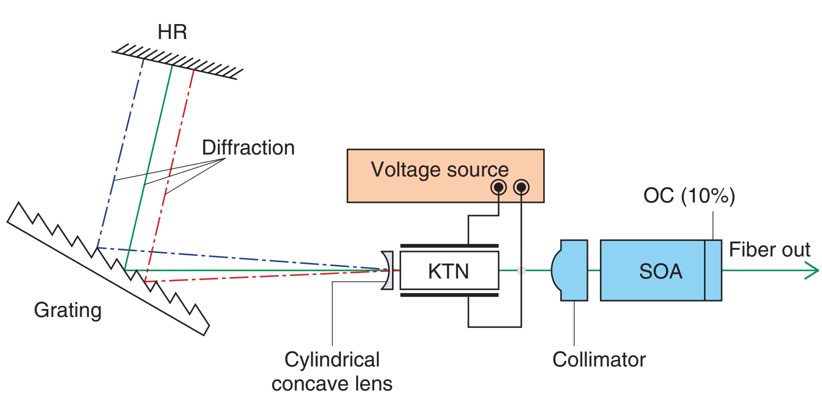


Fig. 2. Setup of swept light source equipped with KTN deflector.

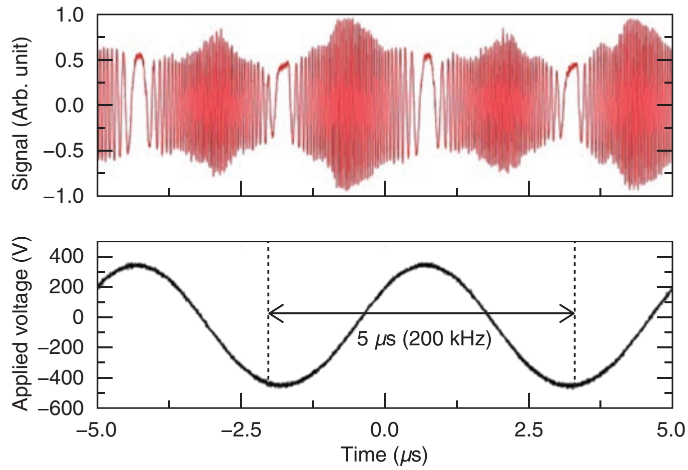


Fig. 3. Lower: voltage applied to the KTN deflector; upper: corresponding interference fringe signal.

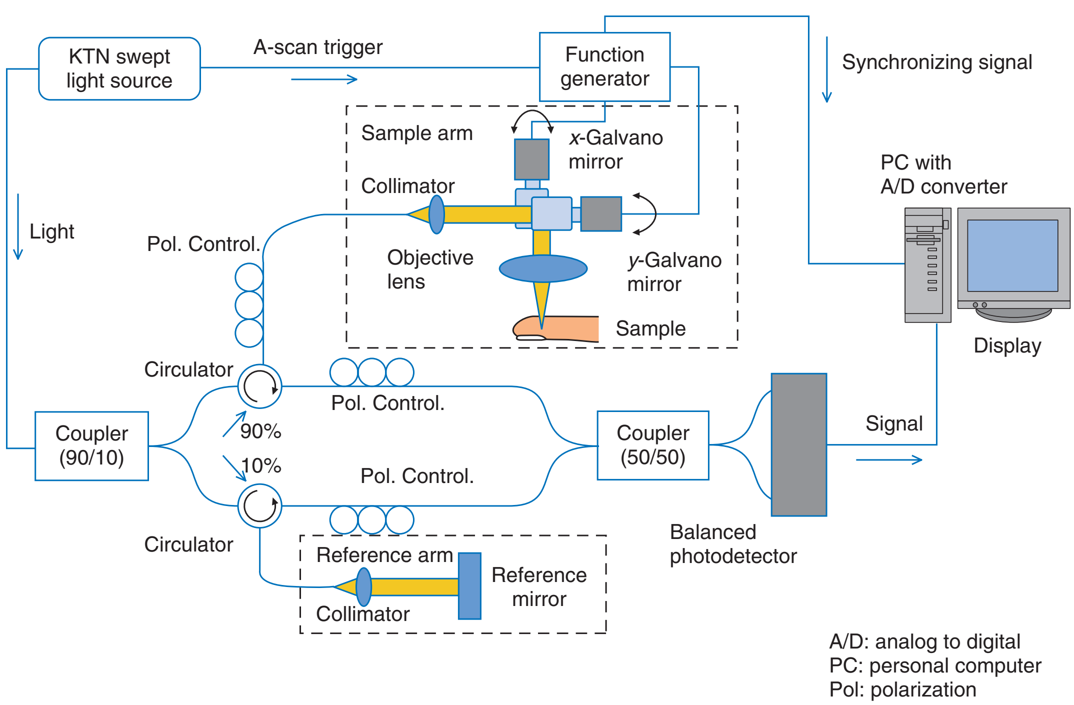


Fig. 4. High-speed SS-OCT system configuration.

Mach-Zehnder configuration, galvano mirrors, and a computer for signal processing. The source outputs light at 20 mW around a center wavelength of 1.33 μm, with a wavelength scanning range of over 100 nm.

Light from the source is split by a 90/10 coupler into a sample arm and a reference arm. The light reflected from the reference mirror and from the sample is separated by respective optical circulators. Polarization controllers in both arms are used to adjust their polarization states. Light through the two arms interferes at a 50/50 coupler, the outputs of which are detected by a balanced photodetector.

The light source also outputs an A-scan trigger in synchronization with a wavelength sweep. The A-

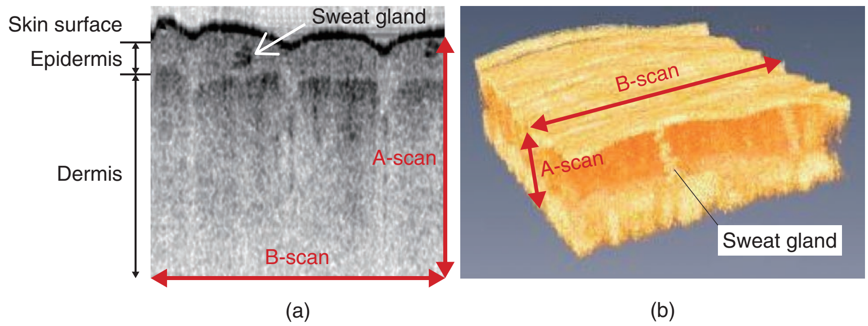


Fig. 5. (a) 2D and (b) 3D OCT images of human finger.

scan triggers generate triggers of the galvano mirrors via a function generator. Interference fringe signals and synchronizing signals are recorded on a channel of a 10-bit data acquisition board at a sampling rate of 1-G sample/s. A depth profile, as a single A-scan, is obtained by the FFT of the interference fringe signal.

In the 2D imaging, the x-galvano mirror of the sample arm is driven in synchronization with a B-scan trigger from the function generator. The beam scans a sample surface in the axial direction. All the signals for a single B-scan are detected and stored in the data acquisition board. A 2D image is constructed by mapping a transversal set of A-line scans.

Furthermore, in the 3D imaging, in addition to the operation of the x-mirror, the y-galvano mirror of the sample arm is driven in synchronization with a C-scan trigger from the function generator. The beam performs an in-plane scan of the sample surface. A typical single C-scan consists of 200 sheets as B-scans, or 60,000 lines as A-scans. All of the data for a single C-scan are stored in the data acquisition board. A 3D image is constructed by post-processing the collected data.

We acquired a 2D image of a human finger using the high-speed SS-OCT system. The image resolution was 200 × 200 pixels, and the image area was approximately 2 mm (horizontal) × 3 mm (depth), as shown in **Fig. 5(a)**. The 2D image acquisition time was about 1.5 ms, which is several times faster than conventional SS-OCT systems. A 3D OCT image of the human finger with a 300 × 200 × 200 voxel resolution and a volume image area of 2 mm (horizontal) × 3 mm (vertical) × 3 mm (depth) is shown in **Fig. 5(b)**. Here, the microstructures of the human skin including the epidermis, dermis, and a sweat gland are clearly visible as bright structures.

## 4. Conclusion

We have developed a high-speed swept light source using a KTN deflector for OCT. A 200-kHz scan rate was obtained with a 20-mW average output power at a wavelength scanning range exceeding 100 nm. The coherence length measured by using the relative signal decay from a different path delay was longer than 7 mm. We obtained 2D and 3D OCT images of a human finger using the OCT system equipped with the KTN swept light source.

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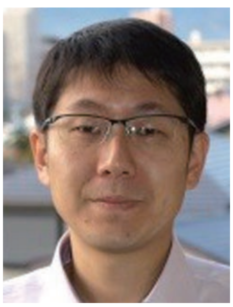

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# Terahertz Spectroscopic Identification of Pharmaceutical Crystals: Cocrystals and Polymorphic Forms

*Katsuhiro Ajito, Jae-Young Kim, Yuko Ueno, and Ho-Jin Song*

**Abstract**

Terahertz radio waves have about the same energy level as the non-covalent bonds between molecules, so they can be used in a spectroscopic technique for identifying differences in molecular networks. We introduce terahertz spectroscopy as a revolutionary technique for visualizing the molecular bonds in various forms of pharmaceutical crystals such as cocrystals and polymorphic forms that are closely related to crystal properties that have not yet been understood. Examples of such properties include solubility and systemic absorption rate.

*Keywords: terahertz spectroscopic identification, cocrystals and polymorphic forms, pharmaceutical crystals*

## 1. Introduction

The simple reactions of dissolving a crystal in water and forming a crystal from a solution are very important features of pharmaceutical crystals. Terahertz (THz) spectroscopy can clarify changes in non-covalent bonds of the molecules (**Fig. 1**), which makes it possible to understand the dynamics of crystal dissolution and crystallization. Pharmaceutical molecules are extracted from solution as pharmaceutical crystals and then formed into pills, tablets, etc. The pharmaceutical crystals must be dissolved in water to be absorbed in the body; otherwise the drug will have no effect. Pharmaceutical crystals that have greater molecular complexity are being developed every year, so the proportion of drugs that do not dissolve easily is presumably also increasing. Although the network of non-covalent bonds on the crystal surface is considered to be closely related to solubility, that network is described by data on hydrogen bonds, van der Waals interactions, or other such interactions between molecules rather than by data on the periodic structure of the crystal obtained by x-ray diffraction measurement. It is currently difficult, therefore, to observe this network directly, and this difficulty is even greater with ultra-fine particles.

We have approached the problem of elucidating the crystal dissolution mechanism by using THz (THz = $10^{12}$ Hz) spectroscopy, which can measure a spectrum in the energy band of molecular interaction. THz light frequency is in between the light and radio frequencies (**Fig. 2**) and can be used to investigate various molecular properties through resonance, such as the phonon mode of crystals, the low-frequency vibration mode of molecules, and the rotation mode of gases. Many amino acid and sugar crystals have THz resonance peaks for the hydrogen bonds between molecules in the crystal. The advantage offered by THz spectroscopy is that it can provide information on the non-covalent bond networks from the hydrogen bonds of biomolecules, organic molecular crystals, protein molecules that have higher-order

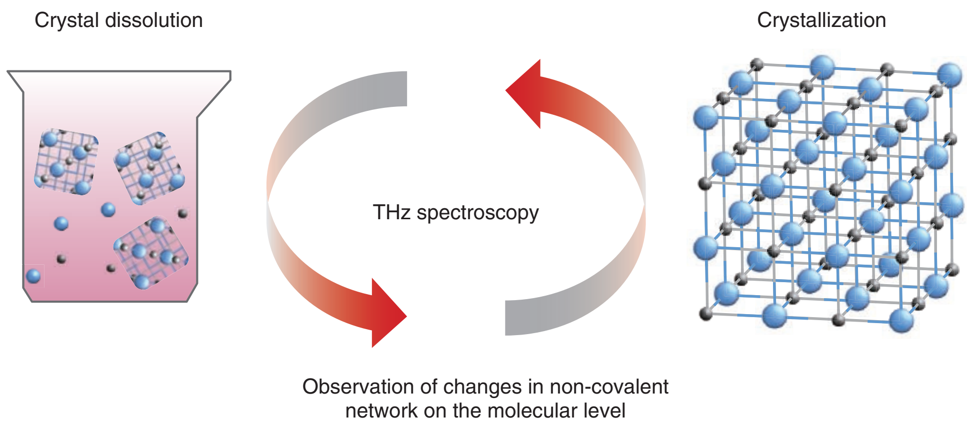


Fig. 1. Clarification of the dissolution and formation of crystals by THz spectroscopy.

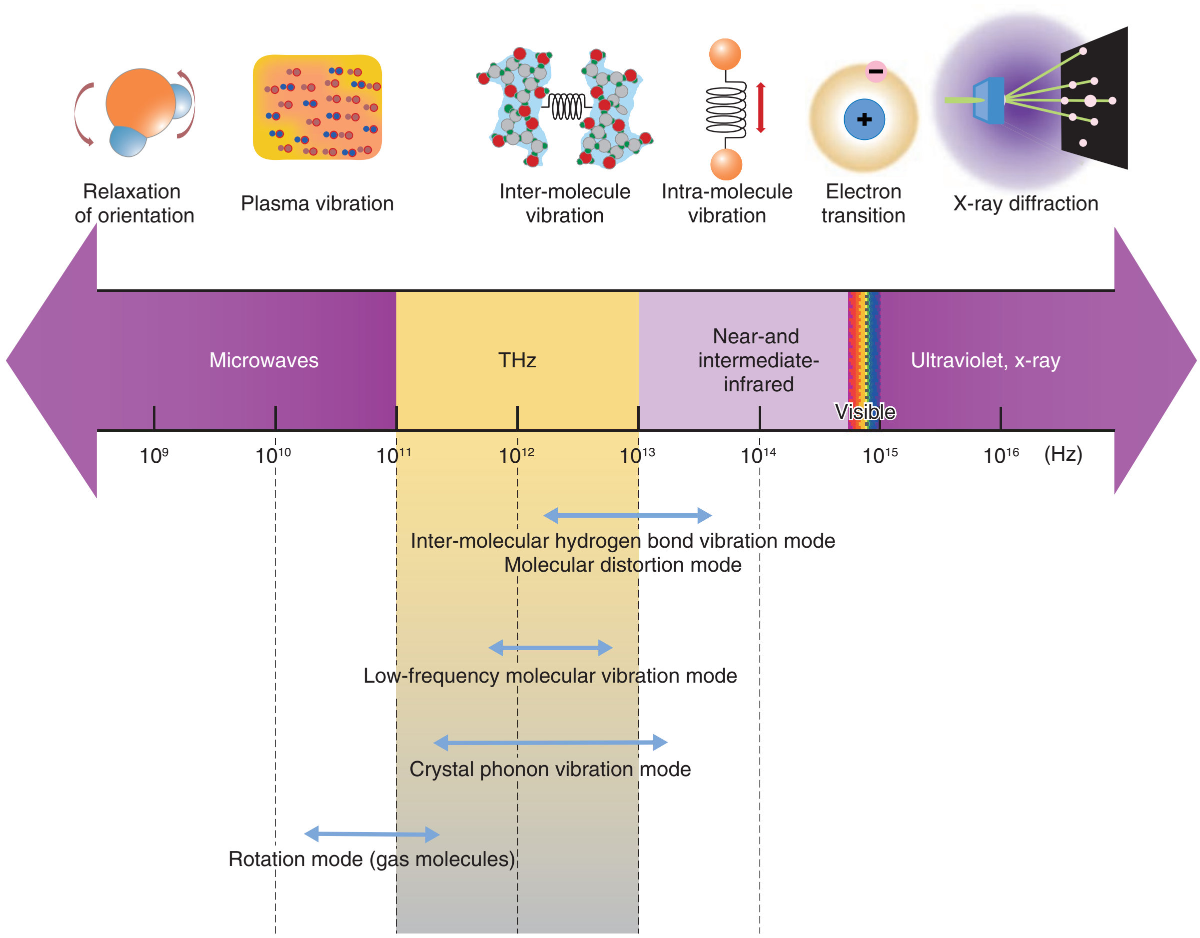


Fig. 2. THz and specific chemical absorption frequencies.

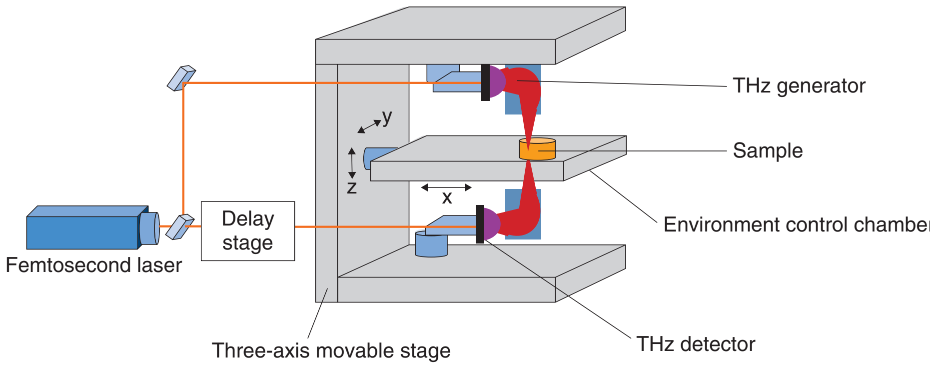


Fig. 3.   TCI analysis system.

structures, double-helix DNA (deoxyribonucleic acid), and other such molecules that dissolve in aqueous solution. [1], [2].

## 2. TCI analysis method

Terahertz chemical imaging (TCI), which visualizes the THz optical spectrum in two or three dimensions, differs from ordinary x-ray imaging in that it identifies molecules from the spectra of molecular networks. TCI can be used to investigate the non-covalent bond network of molecules as well as the molecular distribution, so it may provide a means of evaluating new medical diagnostics and pharmaceuticals. Systems for production process design, analysis, management, and final product quality assurance, generally referred to as process analytical technology (PAT), have already been introduced in the petroleum and chemical industries, and FDA (U.S. Food and Drug Administration) guidance calls for introduction of that technology to improve the quality of pharmaceuticals. The applicability of THz spectroscopy to PAT is also attracting attention. TCI analysis systems used in THz time-domain spectroscopy (THz-TDS) systems include those that use pulsed light, which can cover a wide frequency band, and those that use continuous light with frequency scanning [3].

A TCI analysis system that uses THz-TDS with an environment control chamber is illustrated in **Fig. 3**. An ultrashort-pulse laser beam is split into two beams, one of which is input to a THz wave generator and the other to a THz detector. The most typical THz wave generators and detectors are photoconductive antennas. The sample is illuminated with coherent sub-picosecond THz pulse waves, and the electric field strength of the passing waves is changed. Instead of measuring the strength of the light in the frequency domain, a delay stage is used to measure the electric field strength in the time domain. The THz pulse waves are measured repeatedly and converted to strength and phase values by Fourier transform. The waveform of the THz pulse wave is measured and recorded while scanning the stage, and the Fourier transform is used to convert the data to an image for each frequency. A feature of this system is that it can measure the images of the sample in an environmental control chamber. The temperature and pressure within the chamber can be controlled, so it is possible to change the non-covalent bond network of the molecules inside the crystal. As a result, the applications of TCI analysis now include investigating multi-component analysis, distinguishing active pharmaceutical ingredients (APIs) in diluents, and identifying differences in degree of hydration.

## 3. Identification of pharmaceutical crystals using TCI analysis system

An example of using a TCI analysis system to distinguish between pharmaceutical crystal polymorphs and diluents is shown in **Fig. 4** [4]. Crystal polymorphs consist of the same molecules but differ in how the molecules are linked. They thus can have large differences in solubility and other chemical properties that affect drug efficacy. Also, diluents such as cellulose and/or sugars, which themselves have no drug efficacy, are used when pressing pharmaceutical crystals into pills or tablets. Those diluents also often have high absorbance in the THz band, making identification difficult. Famotidine, a component of stomach medicines, has two crystalline forms, type A, which has low solubility, and type B, which

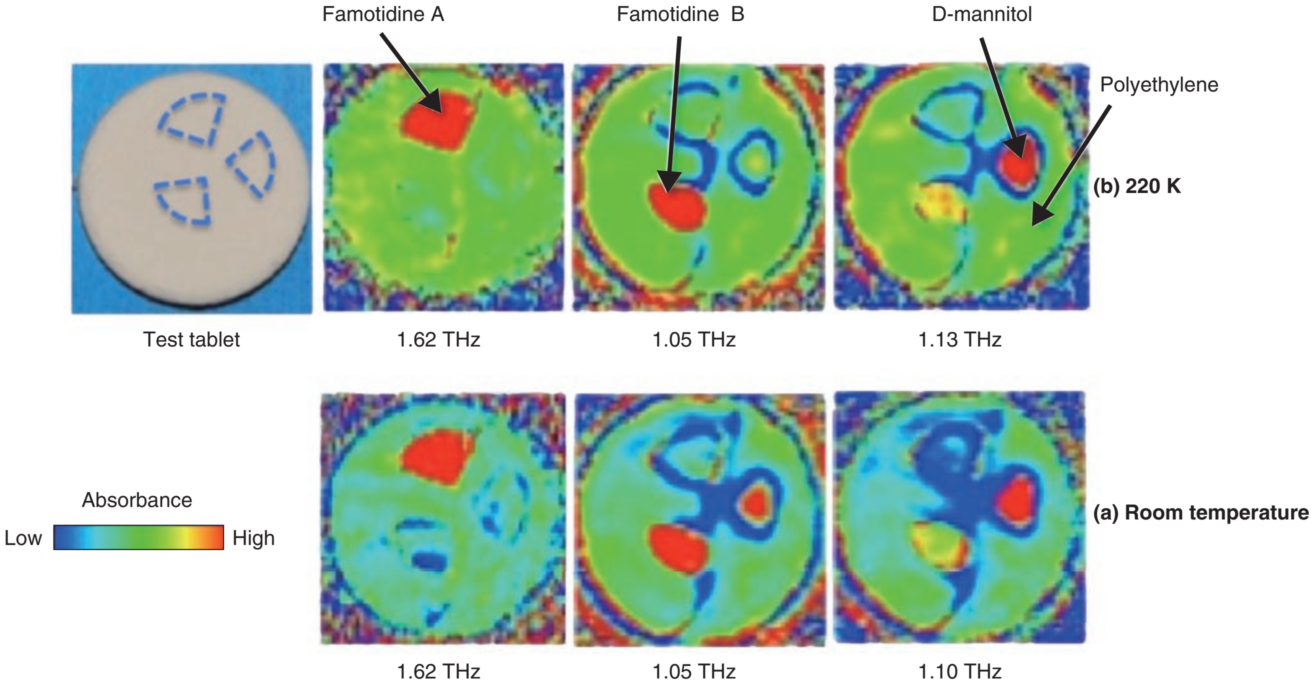


Fig. 4. Example of distinguishing pharmaceutical crystal polymorphs.

has high solubility. Only the highly soluble famotidine B has drug efficacy. These two crystal polymorphs exhibit entirely different THz spectra and are therefore easily distinguished, but it is often difficult to distinguish the drug from the diluent. In this example of a test tablet, the peaks for D-mannitol and famotidine B are very close and cannot be distinguished in the image acquired at room temperature (Fig. 4(a)). However, if a low temperature of 220 K is maintained within the environmental control chamber, we can see clear separation of famotidine A, famotidine B, and D-mannitol as shown in Fig. 4(b). This is due to the differences in structural changes such as the distance between molecules in the crystals at different temperatures.

## 4. Analysis of crystal distribution

An example analysis of pharmaceutical cocrystals is shown in **Fig. 5** [5]. An advantage of cocrystallization is the discovery of functions and properties that cannot be obtained with single-compound crystals. In particular, because improved solubility can lead to relaxed constraints on dose absorbability and selection of formulation, it is very important in exploratory research on drug development. TCI analysis has been attracting attention as an effective method for distinguishing high clarity cocrystals and the pharmaceutical molecules that constitute them, and additives as well, in the analysis of pharmaceutical cocrystals whose structure is stabilized by hydrogen bonds, and other interactions between and within molecules. In this example, we created a tablet model with an uneven distribution in which readily soluble oxalic acid is used as an additive for cocrystallization with insoluble caffeine, a drug that has a stimulating effect. We used a TCI system to analyze the cocrystal distribution in test tablets formed from a mixture of the active compound with polyethylene powder. Comparison of the THz spectra showed that the single compound caffeine or oxalic acid crystal exhibited almost no absorption, but the caffeine and oxalic acid cocrystal exhibited a particularly strong absorption peak at low temperature. We know from this result that it is possible to clearly distinguish a cocrystal and its constituent API and diluent. We also learned that the component distribution in a non-uniform tablet model can be visualized as a two-dimensional image by applying TCI analysis and using the characteristic absorbance peak data.

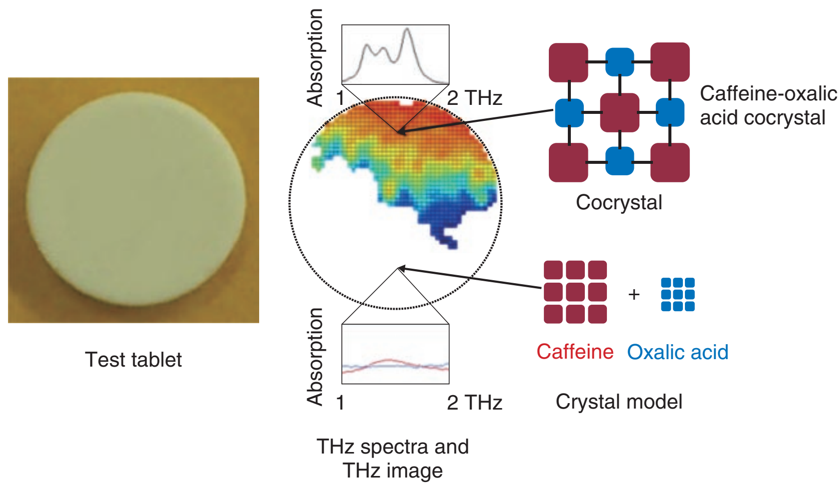


Fig. 5. Example of distribution analysis of a pharmaceutical cocrystal.

## 5. Conclusion

We described THz spectroscopy as a revolutionary technique for visualizing the molecular bonds in various forms of pharmaceutical crystals such as cocrystals and polymorphic forms. THz spectroscopy and TCI analysis have not come into widespread use because of the high equipment cost, but differences in molecular non-covalent bond networks can only be identified in the THz energy band. We can therefore expect further development of THz spectroscopy as a revolutionary technique for visualizing the molecular bonding that is closely related to pharmaceutical crystal solubility and systemic absorption rate but that has not previously been understood, and as a technique for carrying out early diagnosis of cancer and other such diseases.

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# Highly Sensitive Laser Based Trace-gas Sensor Technology and Its Application to Stable Isotope Ratio Analysis

*Ryoko Yoshimura, Masaki Kohtoku, Koji Fujii, Tadashi Sakamoto, and Yoshihisa Sakai*

**Abstract**

Laser based trace-gas sensor technology has been used in various fields such as greenhouse gas monitoring. It has attracted a lot of attention in recent years due to its use in stable isotope analysis. This form of analysis is expected to have many applications, including verifying the geographic origin of food and determining the emission sources of greenhouse gases. These applications are promising for their role in overcoming various social problems.

*Keywords: laser-based trace gas sensor technology, isotope analysis, semiconductor laser*

## 1. Introduction

Laser based trace-gas sensor technology [1] has attracted a lot of attention because it is an extremely effective tool for detecting and quantifying gases such as carbon dioxide and methane with a view to reducing global warming and air pollution and contributing to a safe and secure society. NTT Photonics Laboratories has been developing laser light sources for gas sensing along with the corresponding application technology, which are expected to be useful in resolving various social problems.

The principle of laser based trace-gas sensor technology is illustrated in **Fig. 1**. Gas molecules absorb the energy of light at a particular wavelength and generate molecular vibration. These molecules can absorb many light wavelengths, which are called absorption lines because the wavelengths are very narrow. When we sweep the wavelength of a laser light whose emission wavelength is about the same as the absorption line of the gas to be measured, we find a dip around the absorption line in the detected light power, as shown in Fig. 1. We can find the type and density of the gas to be measured from the position (wavelength) and the depth of the dip. This is the fundamental principle of laser based trace-gas sensor technology.

## 2. Technology to increase sensitivity of laser based trace-gas sensors

One of the most important advantages of laser based trace-gas sensor technology is that it is highly sensitive compared with other sensor technologies. We describe in this section the factors that increase the sensitivity of laser based trace-gas sensors.

One of the simplest ways to increase sensitivity is to lengthen optical path L. This is the path by which the laser light passes through the gas to be measured, as shown in **Fig. 2(a)**. This method is often used in open path measurement techniques such as remote sensing. One problem, however, is that the apparatus becomes too large for L to be lengthened because most conventional trace-gas sensors have gas cells inside them. Therefore, the limit for this method is usually from tens of centimeters to several meters.

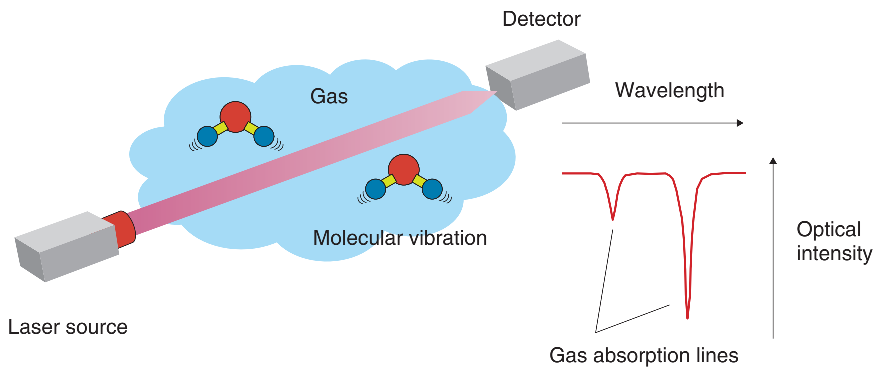



Fig. 1. Principle of laser based trace gas sensor technology.

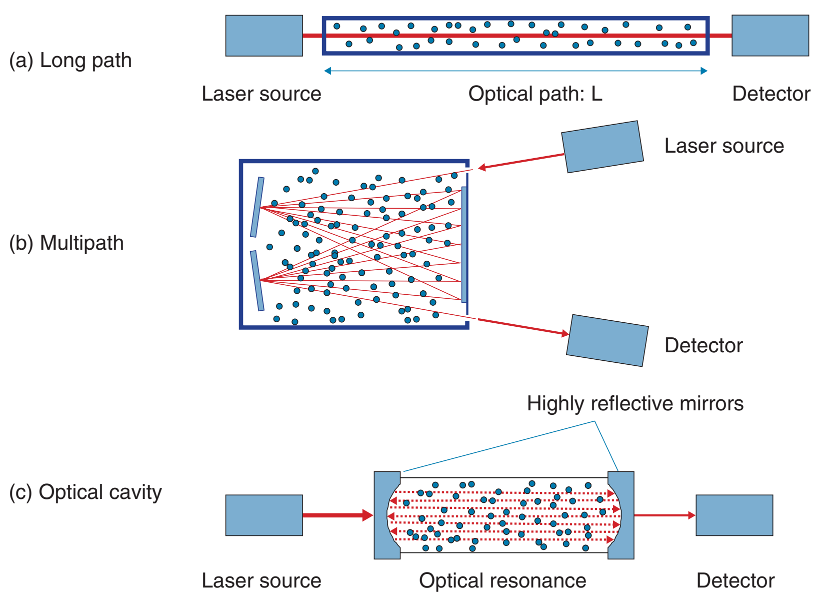



Fig. 2. Technology to increase sensitivity of laser based trace gas sensing.

Another method is shown in **Fig. 2(b)**. We can increase the sensitivity and reduce the size of the apparatus by using a multipath cell. The laser light enters the gas cell and is reflected many times by mirrors that are located at either end of the cell. The light then exits the cell and is sensed by a detector. We can obtain a long effective light path of tens to hundreds of meters with a gas cell whose actual length is less than 1 m if we use multiple (from a few dozen to several hundred) reflections.

Another method that uses an optical cavity is shown in **Fig. 2(c)**. This approach greatly improves sensitivity and has attracted a lot of attention in recent years. Several techniques fall into this category, including cavity ring-down spectroscopy (CRDS) [2] and cavity enhanced absorption spectroscopy [3]. This method utilizes optical resonance with highly reflective mirrors and traps laser light in a cell. We can obtain a very long effective light path that exceeds several kilometers by using optical resonance.

## 3. Application of laser based trace-gas sensor technology

Laser based trace-gas sensor technology is useful in various fields. Application examples in which NTT's

Table 1. Example applications using NTT's laser technology.

| Environmental protection |
|---|
| - Real-time monitoring of GHG to prevent global warming<br>- In-situ monitoring of exhaust gas to prevent environmental pollution<br>- Real-time gas monitoring for surveillance and optimization of DeNOx process<br>- Global and environmental studies (water cycle, carbon cycle, methane emission from freezing tundra, etc.) |
| Ensuring safety of work environment |
| - In-vehicle gas leak detection system<br>- Remote methane leak detector<br>- Hazardous gas (toxic gas, inflammable gas) detectors used in oil fields, coal mines, petroleum refineries, etc.<br>- Fire/smoke detector |
| Industrial fields |
| - Real-time gas monitors for combustion control in coal-fired power plants<br>- Real-time gas monitors for engine development<br>- Process gas monitors in metal industry (steel and aluminium manufacturing)<br>- Highly sensitive moisture analysis for semiconductor process gases |
| Safety and security; medical and health |
| - Technology to prevent the disguising of geographic origin or production history of foods and beverages<br>- Medical diagnosis by expiration analysis (study phase) |

DeNOx: removal of nitrogen oxide
GHG: greenhouse gases

laser technology is used are listed in **Table 1**.

Greenhouse gas monitors designed to help prevent global warming are representative examples. Many global organizations including the World Meteorological Organization and the Japan Meteorological Agency use laser based trace-gas sensors because of their many advantages such as providing quick, highly sensitive measurements with high resolution. Furthermore, they make it possible to reduce operating costs because they are easier to calibrate and maintain than conventional monitors.

Hazardous gas detectors that ensure a safe and secure work environment are another important example. Laser based trace-gas sensors can detect a small amount of hazardous gas even if its source is far away. Therefore, they are often used for detecting toxic gases such as hydrogen fluoride and hydrogen sulfide or inflammable gases such as methane in oil fields or coal mines. Furthermore, laser based trace-gas sensors have another important advantage in that they are more compact than other analyzers with the same high level of performance. Therefore, they are also used as portable sensors, for example, as a portable remote methane leak detector [4] and an in-vehicle gas leak detection system [5], which enables us to investigate gas leaks while driving a vehicle. These detectors have been used for inspection work by gas companies.

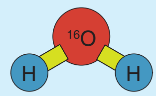
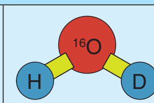
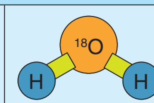
High-precision isotope analyzers have been developed using highly sensitive laser technology such as CRDS, and they have attracted increased attention in recent years.

Stable isotope ratio analysis has been used for a long time in various fields including earth science, environmentology, and archaeology because it is a useful technology for detecting or estimating the origin of a material. However, it is necessary to use large analytical equipment such as an isotope ratio mass spectrometer or a nuclear magnetic resonance spectrometer, which require a large laboratory room and a complicated operating procedure. This creates difficulties in expanding the areas of application. Newly developed laser based isotope analyzers have many advantages including a more compact size and excellent portability and operability, and we can therefore expect the application fields of stable isotope analysis to expand greatly.

## 4. Stable isotope analysis of water and determination of geographic origin of food

Many atoms have different mass numbers, which indicate the weight of the atom, despite being atoms of the same element and having the same number of protons. These atoms are called isotopes. A lot of information can be obtained about the origin of a material if we can precisely measure its isotope ratio. In this section, we give a concrete example of how the geographic origin of a water sample can be determined.

Table 2. Water molecules including isotopes.

| | Light water → | | Heavy water |
|---|---|---|---|
| Molecular structure |   |   |   |
| Molecular formula | $H_2{}^{16}O$ | $HD^{16}O$ | $H_2{}^{18}O$ |
| Mass number (weight) | 18 | 19 | 20 |
| Abundance ratio (standard water) | 99.75% | 0.02% | 0.20% |

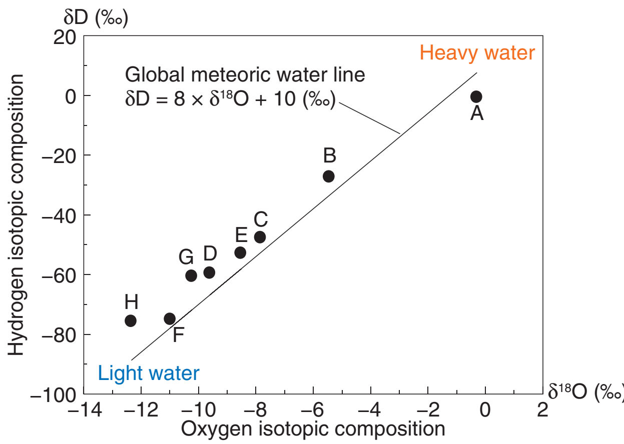
The molecular formula of water is expressed as $H_2O$. This formula means that a water molecule consists of two hydrogen atoms (H) and one oxygen atom (O). The mass numbers of most hydrogen and oxygen atoms are 1 and 16, respectively. Therefore, the molecular formula of most water molecules can be expressed as $H_2{}^{16}O$, which means it consists of two hydrogen atoms whose mass number is 1 (H) and one oxygen atom whose mass number is 16 ($^{16}O$). However, since there is also an isotope of hydrogen called deuterium whose mass number is 2 (D), as well as an isotope of oxygen whose mass number is 18 ($^{18}O$), there are isotopic water molecules that include these isotopes ($DH^{16}O$ and $H_2{}^{18}O$), although their abundance is low (see **Table 2**). The abundance ratios of these isotopic water molecules are closely related to their geographic origin [6]. Since $DH^{16}O$ and $H_2{}^{18}O$ are slightly heavier molecules than $H_2{}^{16}O$, we call water with a relatively high content of these isotopic water molecules *heavy water*, and that with a low content *light water*. The rainwater that falls in hot areas, for example tropical regions, is known to be heavy water, whereas the rain or snow that falls in cold areas, for example, the polar regions, is light water. The origin of river water and groundwater is rainwater. Animals and plants consume the rainwater that falls in the region they inhabit. Therefore, their oxygen and hydrogen isotopic ratios are related to those of the rainwater that falls in the region. We can therefore expect to apply isotope analysis technology to determine or estimate the geographic origin of foods and beverages.

We measured the isotope ratios of eight types of water available in Japan: seven bottled waters sampled from various places in Japan, and one tap-water sample from Atsugi, the location of our laboratory, using a laser based water isotope analyzer. The measurement results are shown in **Fig. 3(a)**, and the sampling locations and their latitudes are in **Fig. 3(b)**. The horizontal axis indicates the oxygen isotopic composition $\delta^{18}O$, and the vertical axis indicates the hydrogen isotopic composition $\delta D$ in Fig. 3(a). The isotopic composition is usually denoted $\delta$, as defined by the following equation:

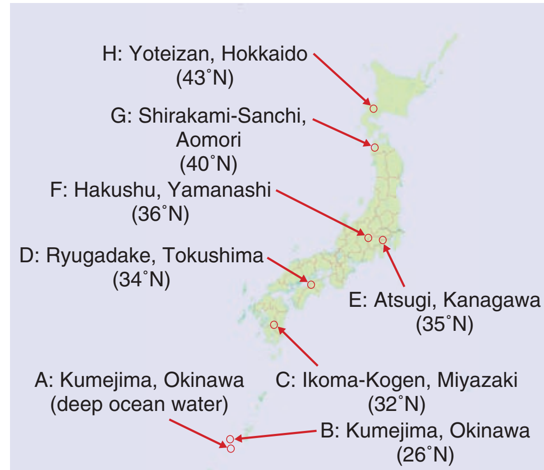
$$\delta X\ (‰) = ( R_{sample}/R_{standard} - 1 ) \times 1000$$

where X represents $^{18}O$ or D, and R represents the isotope ratio of each element, that is, $^{18}O/^{16}O$ or D/H for oxygen or hydrogen, respectively. The isotopic composition $\delta X$ is defined by the difference between the isotope ratio of the sample ($R_{sample}$) and the standard material ($R_{standard}$), and is expressed in per mille units (‰), as shown in the above equation. For oxygen and hydrogen, Vienna Standard Mean Ocean Water (VSMOW), which is managed by the International Atomic Energy Agency, is usually used as the international standard material. The solid line in Fig. 3(a) indicates the Global Meteoric Water Line, which gives the average relationship between hydrogen and oxygen isotopic compositions in natural terrestrial waters, expressed as a worldwide average.

Although A and B are both examples of water sampled in Kumejima, Okinawa, there is a big difference between them. A is deep ocean water, and B is spring water sampled on the island. Since VSMOW was composed of ocean water collected from different locations around the globe as the standard mean ocean water, the oxygen and hydrogen isotopic




(a) Oxygen and hydrogen isotopic composition of water in Japan




(b) Sampling location and latitude

Fig. 3. Isotope analysis of water in Japan.

compositions ($\delta^{18}O$, $\delta D$) of the deep ocean water A are both nearly zero. We denote the lower to higher latitude order as B to H. We found that as the latitude of the sampling place became higher, the isotopic composition became lower, with two exceptions, namely Ryugadake, Tokushima (D) and Hakushu, Yamanashi (F). We believe this is because the water sources are at a higher altitude than in the other locations.

The isotope ratio of precipitation is related to the geographic characteristics because light water molecules are easier to vaporize and harder to condense than heavy water molecules. Therefore, the water molecules in the atmosphere are lighter than those in the ocean. First, the relatively heavy light-water molecules in the atmosphere condense into liquid water and cause rain in hot regions near the equator, and then, the water molecules, which become lighter and lighter, move to colder regions and condense and bring light rain or snow.

The oxygen and hydrogen isotope ratio of the water is closely related to such geographic information as the latitude and altitude of its source, and we can expect to determine or estimate the geographic origin of different types of water by using this property. Furthermore, the isotope ratio of water affects that of the material composition of animals and plants, which consume the rainwater that falls in the region. Therefore, a lot of research has been done on the use of isotope analysis technology to detect the geographic origin of various foods including agricultural and livestock products.

The material composing food contains not only oxygen and hydrogen but also carbon and nitrogen, so we can also measure the isotope ratio of carbon or nitrogen to achieve a more precise determination. For instance, the carbon isotopic composition ($\delta^{13}C$) is known to be related to certain species of plants and their growing environment or the kind of feed used for livestock. Therefore, it is also useful for determining or estimating the geographic origin of food.

## 5. Future developments

We have mainly focused in this article on the use of isotope analysis technology to determine the geographic origin of food, but we can also expect this technology to be applied to various other fields including quality inspection of manufacturing methods, the production history of food (e.g., as a screening method to reveal the adulteration of honey or fruit juice with lower cost sweeteners and for discriminating between straight fruit juice and concentrated fruit juice), and the determination of the source of greenhouse gases such as carbon dioxide (e.g., fossil fuels, biomass, animal exhalation), which will be a very useful technology for maintaining food safety and improving the global environment. NTT Photonics Laboratories will promote the research and development of laser source technology and its corresponding application technology in line with efforts to resolve various social problems.

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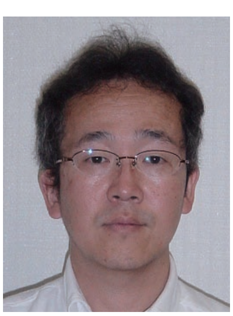


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# GaN-on-Si Technology for High-power Transistors

*Noriyuki Watanabe*

**Abstract**

Group-III nitride semiconductors are very promising materials for high-power electronic devices. The physical properties of these semiconductors make it possible to develop devices that show better performance than the silicon (Si)-based devices that are currently used for integrated circuits. In particular, replacing Si-based devices in inverters, which are widely used in home appliances, with gallium nitride (GaN)-based devices is an effective way to reduce electric power consumption in homes. In this article, a technique for forming GaN and related materials on Si substrates is introduced. This technique is suitable for low-cost mass production techniques because Si substrates have the largest size and lowest cost among various substrates.

*Keywords: GaN, Si substrate, epitaxial growth*

## 1. Overview of nitride semiconductors

Nitride semiconductors are a type of compound semiconductor that are composed of a group-III element and nitrogen, for example, gallium nitride (GaN), aluminum nitride (AlN), indium nitride (InN), or a combination of these materials. These semiconductors have a band gap corresponding to short-wavelength light, and they are chemically and mechanically very stable. This gives them high potential strength even in high-temperature environments. Recently, light-emitting diodes (LEDs) have come to be widely used as lighting devices in place of incandescent light bulbs or fluorescent lamps. These LEDs are made with nitride semiconductors. Nitride semiconductors are thus widely used in many familiar applications.

## 2. Promising applications of nitride semiconductors

The use of LEDs made of nitride semiconductors can contribute to reducing electric power consumption, and this is one reason why nitride semiconductors are promising materials. Another large energy-saving effect is achieved when nitride semiconductors are applied to devices used in power supply units in home appliances. One such example is the circuit that drives the motor in compressors used in refrigerators and air conditioners. In Japan, a circuit called an inverter is used in most home appliances. The inverter generates an AC (alternating current) signal with an arbitrary frequency by using the switching function of transistors, and it can control the amount of electric power that is supplied by changing the frequency. The power consumption of the inverter is much lower than that of the power unit that controls the supplied power by simply switching the electric power on and off. As described above, most refrigerators and air conditioners in Japan already have power units that include an inverter. However, the use of inverters is not as widespread in other developed and developing countries. An extremely large reduction in power consumption around the world could be achieved by replacing non-inverter products with inverter ones (**Fig. 1**). The power-saving effect from replacing all non-inverter type power units in refrigerators and air conditioners throughout the world with inverter ones is estimated to equal the amount of electric power produced by eight thermal power plants [1]. Moreover, the use of GaN-based transistors instead of silicon (Si)-based transistors, which

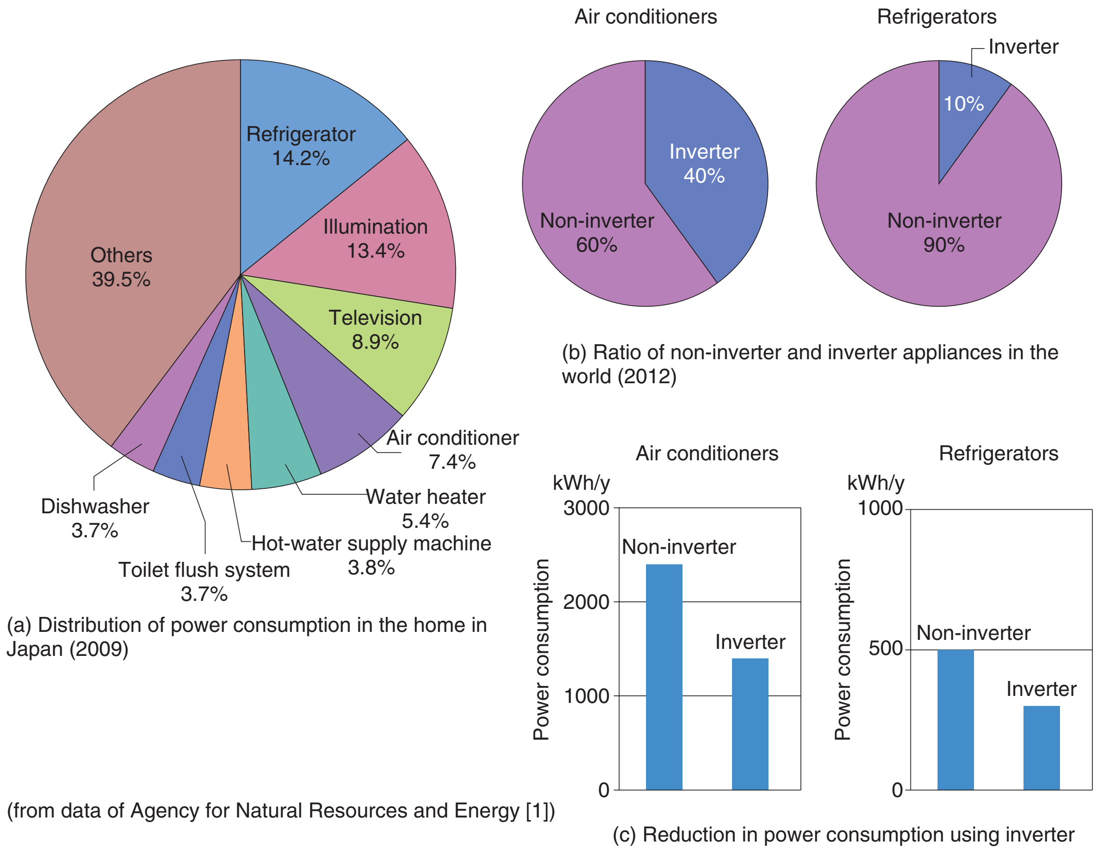


Fig. 1. Electric power saving effect using inverter.

are included in inverters, is estimated to result in a one-third to one-half reduction in power consumption. Therefore, GaN-based transistors are considered to be very promising devices for saving power.

## 3. Mechanism of achieving low power consumption with GaN-based transistors

I discuss here the mechanism in which power consumption can be reduced using GaN-based transistors [2]. There are two main factors in the power loss that occurs because of the characteristics of transistors in the inverter circuit. One is the conduction loss, which corresponds to the power loss when current is flowing through transistors. Conduction losses increase as the *on-resistance* increases. This refers to the resistance of the current path between terminals when the transistor is in the on-state. The other factor is the switching loss that occurs when transistors are switched from the on-state (in which current flows through transistors) to the off-state (in which current does not flow) and vice versa (as shown in **Fig. 2(a)**). These are described in more detail in the following subsections.

### 3.1 Conduction loss

Si-based devices called insulated gate bipolar transistors (IGBTs) are typically used in the inverter circuit. The IGBT has three terminals consisting of a gate, emitter, and collector. Current flows from the collector to the emitter; we can switch the IGBT from the on-state to the off-state by applying bias voltage to the gate. The electron density in the area where current flows in the IGBT is relatively low in order to avoid breakdown during high-voltage operation. This is one reason why the on-resistance of IGBTs is large. Moreover, no current flows below a certain voltage (called offset voltage) between the emitter and collector because of this operating principle. This is another reason for the large on-resistance in IGBTs. In turn, transistors called high-electron mobility transistors (HEMTs) are widely used in GaN-based transistors.

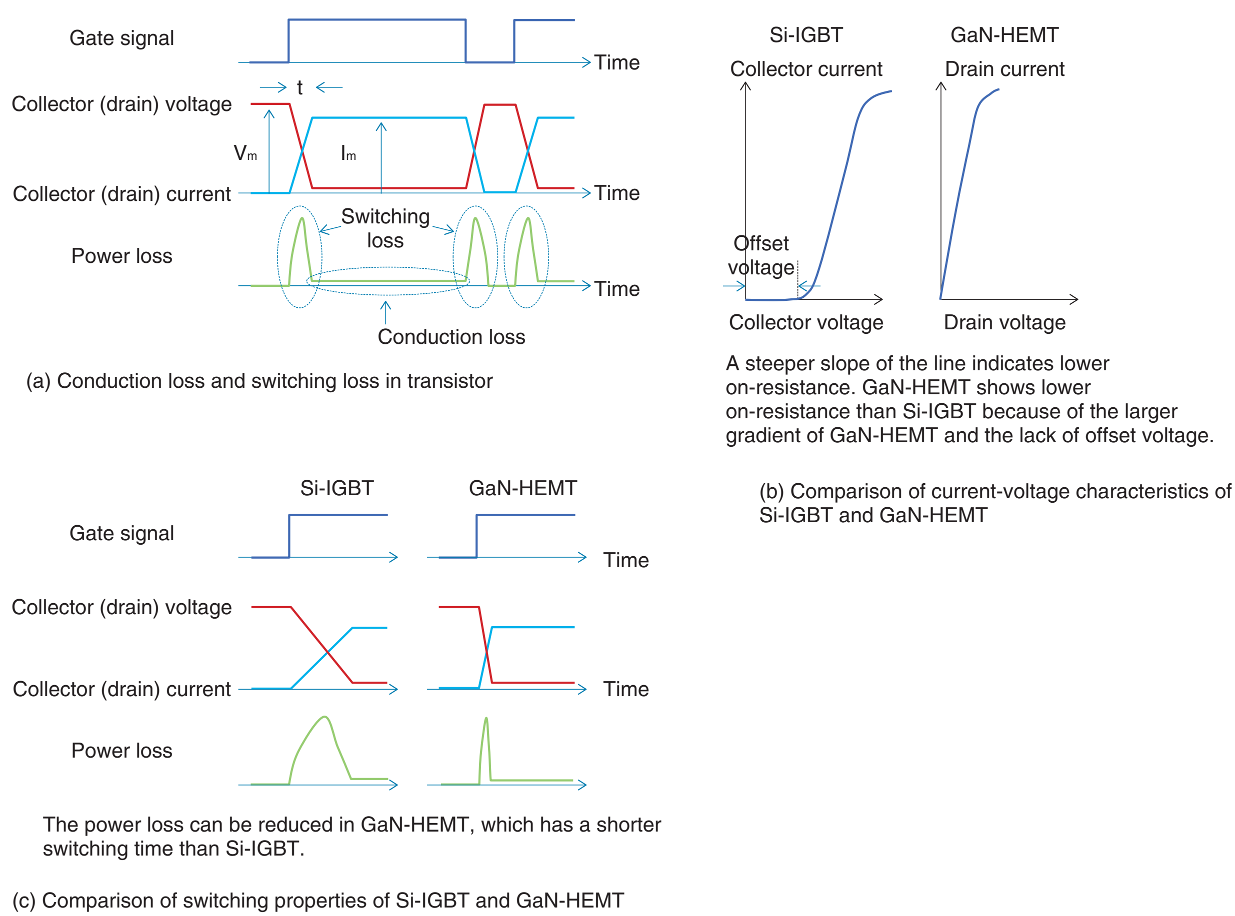


Fig. 2. Reduction in transistor power loss using GaN.

The HEMT has a channel layer with a very high density of electrons, which is known as two-dimensional electron gas (2DEG). The electron mobility of 2DEG is very high, as the device name suggests. HEMTs also have three terminals consisting of a gate, source, and drain. Current flows from the drain to the source, and we can switch the HEMT from the on-state to the off-state by applying bias voltage to the gate in the same manner as the IGBT. Consequently, because nitride-based semiconductors have higher breakdown strength than Si, a GaN-based HEMT can be operated under higher voltage. In addition, the HEMT has essentially no offset voltage (**Fig. 2(b)**). Therefore, GaN-based HEMTs have much smaller on-resistance than Si-based IGBTs. As a result, using GaN-based HEMTs instead of IGBTs can reduce the conductive power loss to half or less.

### 3.2 Switching loss

In the inverter circuit, transistors are switched from the on-state to the off-state, or vice versa, by changing the gate bias voltage. In the on-state, the current flowing from the collector to the emitter (IGBT) or from the drain to the source (HEMT) shows the maximum value ($I$m) when the voltage between the collector and emitter or the drain and source is very small (limited by the on-resistance). On the contrary, in the off-state, a certain voltage ($V$m) between the collector and emitter or the drain and source is applied while the current from the collector to the emitter or from the drain to the source is almost zero. Therefore, the power loss per unit time in the on- or off-state itself is very small. The power loss during the switching between the on-state and the off-state is called the switching loss. Power consumption in transistors is approximately given by the product of the current, voltage, and duration time. If the switching from the on- to off-state or from the off- to on-state is fast enough, the switching loss is negligible. However, the switching time in actual devices is not zero but a finite value. As a result, switching loss occurs. The switching loss can be reduced by shortening the switching time. The operating speed of GaN-based HEMTs is much higher (about 10 times higher) than Si-based IGBTs. Therefore, the switching loss can be reduced by replacing Si-based IGBTs with GaN-based HEMTs.

## 4. Low-cost GaN-based HEMTs using GaN-on-Si technology

With Si-based transistors, devices are fabricated directly on Si substrates using various process technologies such as thin film deposition, impurity diffusion, ion implantation, or electrode formation. On the contrary, in the case of GaN-based transistors, the transistors cannot be fabricated until nitride semiconductor films are first formed on the substrate using an epitaxial growth technique. This section focuses on the epitaxial growth of GaN-based materials.

### 4.1 Growth of semiconductor materials on substrates

The first process in fabricating III-V compound semiconductors, including nitride semiconductors, is the epitaxial growth of semiconductor materials on substrates. There are various methods of growing semiconductor materials; the vapor phase epitaxial technique is one widely used method. Substrates made of the same material or made with other materials that have similar properties are commonly used for epitaxial growth because high quality semiconductors can be obtained using such substrates. However, substrates consisting of nitride semiconductors are currently very expensive, and their size is rather small because of the difficulty in producing nitride substrates. Because GaN-based HEMTs are used in home appliances, it is essential to achieve cost competitiveness. In view of this, GaN-on-Si technology, by which nitride semiconductor materials are grown on Si substrates, has attracted a lot of attention. That is, nitride semiconductors are grown on a large scale on high-quality and low-cost Si substrates that are easily obtained.

### 4.2 Technical problems related to growth of materials

Many technical problems first need to be solved, however, in order to successfully grow GaN-based materials on Si substrates. The most serious issue to be solved is the mismatch in material properties between GaN and Si. The process of growing semiconductors is greatly affected by the properties of substrates. One of the most important properties is the lattice constant, which is the unit size of the crystal structure of the material. Individual materials have different lattice constants. The mismatch in the lattice constant between a substrate and a material grown on the substrate should generally be less than 0.1%. However, the lattice mismatch between GaN and Si is over 14%. Therefore, we have to overcome a lattice mismatch that is 100 times larger in order to develop effective GaN-on-Si technology.

Another important property is the thermal expansion coefficient. The lattice of the material expands and shrinks as the temperature increases and decreases. The thermal expansion coefficient is defined as the ratio between the change in the lattice constant due to a temperature change of 1 K and the lattice constant itself. The growth temperature of GaN and related materials is very high at about 1000°C. When the substrate is cooled down to room temperature after growth, both the GaN layer and the Si substrate shrink. Because GaN has a larger thermal expansion coefficient than Si, the Si substrate with the GaN layer has a concave shape. If the curvature of the substrate exceeds the limit of the mechanical strength of the material, the GaN layer will crack over the entire substrate (**Fig. 3(a)**). Therefore, it is also necessary to overcome the mismatch in the thermal expansion coefficient between GaN and Si. A buffer layer that can compensate for the mismatch between material properties such as the lattice constant and the thermal expansion coefficient is usually grown between the Si substrate and the GaN layer. At NTT Photonics Laboratories, we have been investigating the structure of the buffer layer and have successfully obtained high quality GaN-based HEMT structures on Si substrates [3] (**Fig. 3(b)**). We are now planning to develop GaN-on-Si technology that is even more cost-effective. Until now, we have been able to successfully grow GaN-based HEMT structures more than 4 μm thick on large Si substrates up to 6 inches in diameter by using an improved buffer structure. This has resulted in electrically robust properties in which the fabricated structure does not crack even if subjected to very high voltage exceeding 1000 V (**Fig. 4**). The GaN-based HEMTs fabricated using GaN-on-Si technology are expected to be widely used in *green* devices that will contribute to achieving an energy-saving society in the near future.

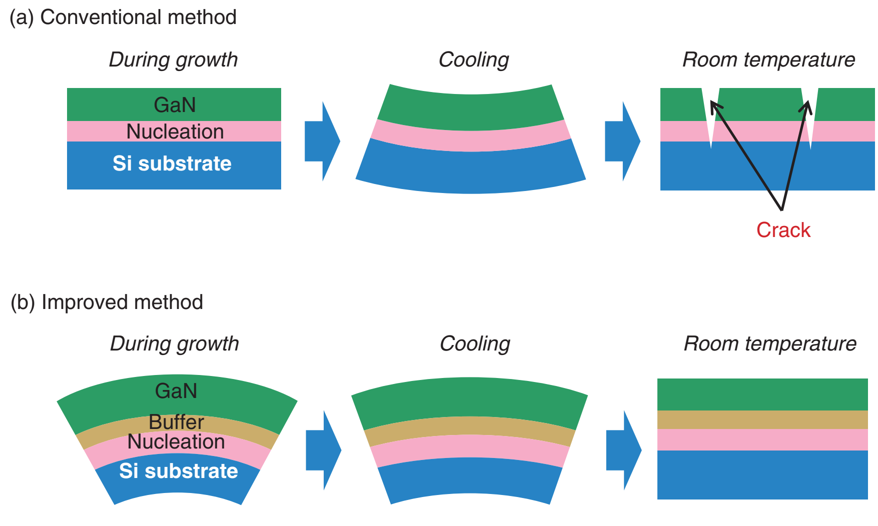


Fig. 3. Growth of GaN and related materials on Si substrate [3].

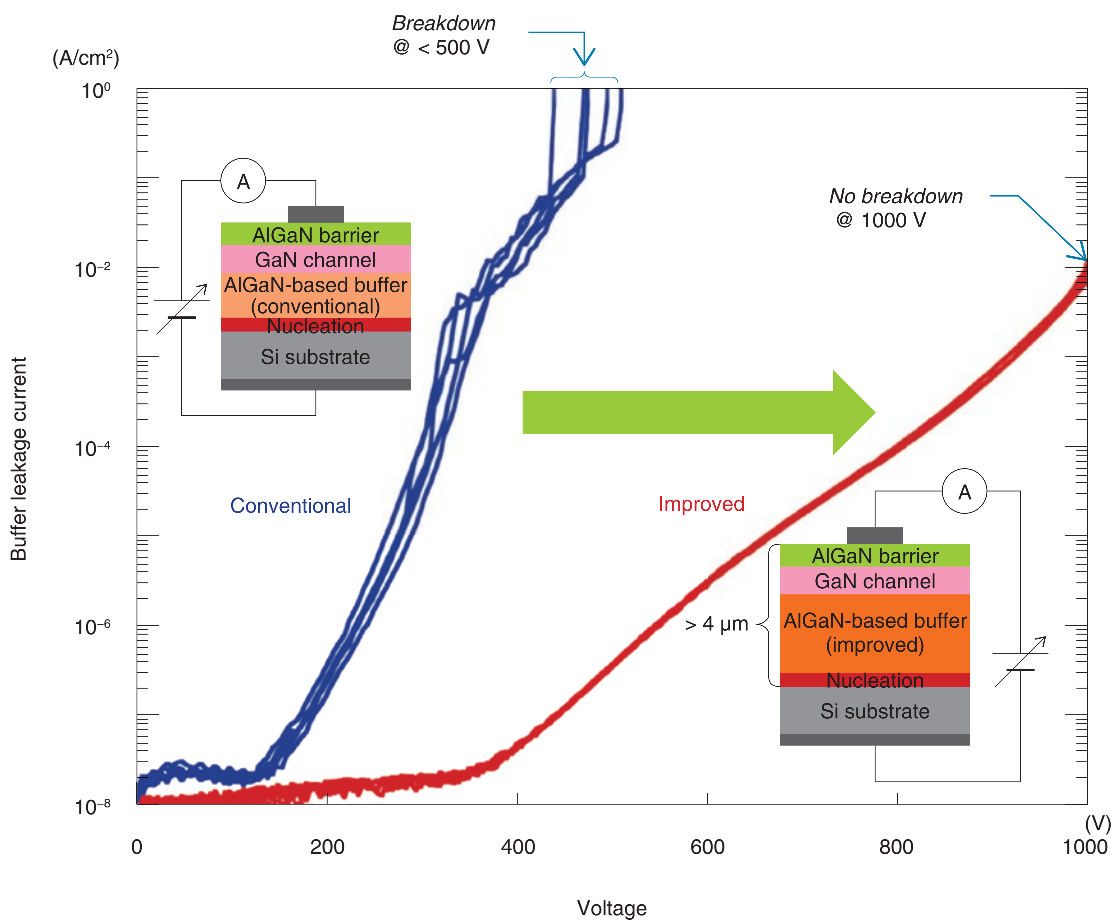


Fig. 4. Current-voltage curve of GaN HEMT on Si substrate.

## 5. Conclusion

This article described a technique for forming GaN and related materials on Si substrates. This technique is suitable for low-cost mass production because substrates fabricated from Si are the largest in size and lowest in cost among various substrates. However, some issues remain to be solved. One of the most serious issues is current collapse, a phenomenon in which the on-resistance of a transistor gradually increases during transistor operation. These issues are now under investigation. Nevertheless, the GaN-on-Si technology is expected to lead to the development of devices that are indispensable for an energy-saving society.

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# Standardization Activities on EMC for Telecommunication in ITU-T SG5

*Yuichiro Okugawa, Yasuhiro Honma, and Kazuhiro Takaya*

**Abstract**

The NTT Group participates in the development of electromagnetic compatibility (EMC)-related standards as part of its effort to provide safe and secure telecommunication services. This article reports on the latest standardization activities on EMC for telecommunication. Specifically, it presents an overview of the first meeting of ITU-T SG5 (International Telecommunication Union, Telecommunication Standardization Sector, Study Group 5) in its new study period (2013–2016), including details of discussions held.

*Keywords: EMC, ITU-T, standardization*

## 1. Introduction

The NTT Group aims to enhance the quality and reliability of telecommunication services and has therefore defined an internal standard on electromagnetic compatibility (EMC) called *Requirements for EMC of Telecommunication Systems*, which specifies technical requirements that must be met in formulating specifications for the development or procurement of telecommunication systems (**Fig. 1**). The technical requirements for EMC define permissible values of electromagnetic interfering waves radiated by telecommunication systems, requirements for resistance to overvoltages generated by electromagnetic interfering waves from other systems, lightning, etc., and test methods related to these requirements. These requirements conform to international standards on IT (information technology) systems or telecommunication systems defined by the IEC (International Electrotechnical Commission), CISPR (International Special Committee on Radio Interference), and ITU-T (International Telecommunication Union, Telecommunication Standardization Sector). Therefore, activities in these international standardization organizations greatly affect the quality and reliability of telecommunication services provided by the NTT Group. This article introduces international standardization activities related to EMC, particularly the activities of ITU-T.

## 2. Overview of ITU-T SG5 WP1/WP2

ITU-T is headquartered in Geneva, Switzerland and issues recommendations in the field of telecommunications. ITU-T has ten Study Groups (SGs). Recommendations on EMC are developed by SG5 (Environment and climate change). SG5 consists of three Working Parties (WPs), of which WP1 (Damage prevention and safety) and WP2 (Electromagnetic fields: emission, immunity, and human exposure) are working on standards related to EMC.

In the current study period (2013–2016), WP1 and WP2 are addressing the questions shown in **Fig. 2**. The first meeting of SG5 was held in Geneva from January 29 to February 7, 2013. Discussions held on these questions in the first meeting are introduced below.

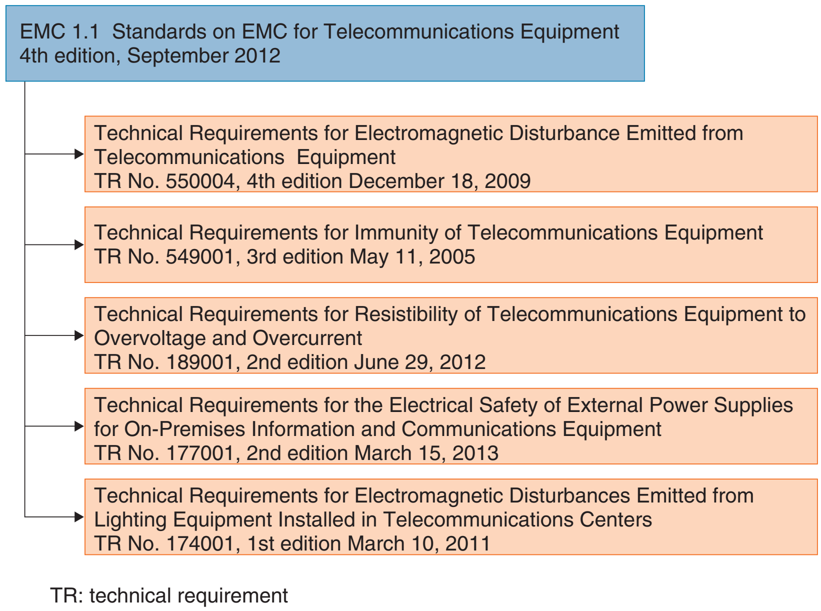



Fig. 1. NTT Group's requirements related to EMC in telecommunication equipment.

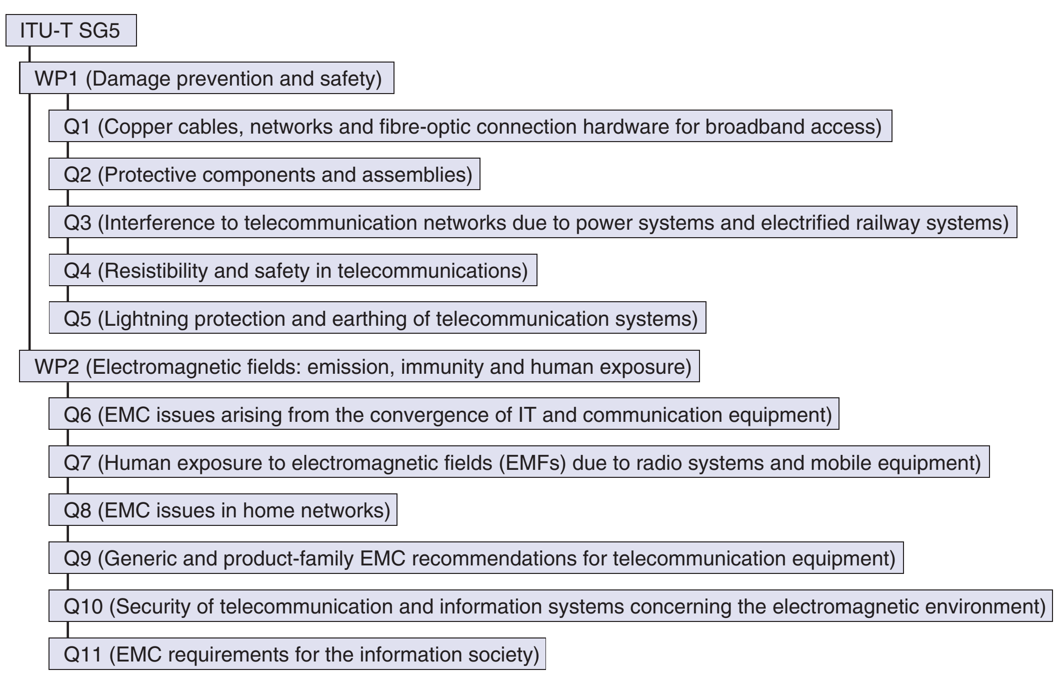



Fig. 2. Questions (Qs) discussed by WPs 1 and 2.

### 2.1 Discussions in WP1

WP1 is studying how to protect telecommunication systems from overvoltages generated by lightning and other sources, and from electromagnetic interference due to electromagnetic induction from power systems, electrified railway systems, and other sources. In particular, in view of the fact that reports of lightning damage have begun to come from areas that have conventionally seldom been hit by lightning and that the extent of damage from localized lightning has been increasing in recent years owing to global climate change, WP1 is studying new and additional recommendations to protect telecommunication systems from overvoltages generated by lightning.

Discussions on each question are summarized below.

Question 2 concerns test methods, requirements, and methods of use related to components and assemblies that protect against overvoltage such as fuses, varistors, surge arresters, and transformers. In the current study period, WP1 is focusing on developing recommendations on the basis of K.appl4, a new draft recommendation on the application of isolation transformers in telecommunication systems, and K.LIT, a new draft recommendation on requirements for isolation transformers.

In the first meeting, in order to advance discussions on K.appl4, NTT proposed a method of increasing the dielectric strength of telecommunication systems by using isolation transformers in both the telecommunication system and the associated power supply system. Whether the proposed method should be included in the new proposed recommendation will be discussed at the next meeting. China proposed a surge protective device (SPD) to be applied to 400-V direct current (DC) systems. Discussions on this proposal will continue in subsequent meetings.

Question 3 relates to the issue of how to protect telecommunication systems from electromagnetic induction from power systems and electrified railway systems, and the safety of workers in the event of ground faults. In the first meeting, NTT submitted the results of an experiment on measuring the voltage that rises in the metallic tension member of an optical fiber cable when a ground fault occurs in the power line. It was decided to study the need for protection from such voltages. At the next meeting, a questionnaire will be distributed to collect information about such cases in other countries. Greece submitted a contribution concerning protective measures taken when installing telecommunication devices at the tops of poles. It was decided to study this issue under a new draft recommendation, K.tup.

Under Question 4, WP1 studies requirements for overvoltage resistibility at interfaces of telecommunication systems that are installed in telecommunication centers, outdoors, or in customers' premises, methods of protection against overvoltage, and electrical safety. WP1 also keeps existing relevant ITU-T recommendations up to date. In the first meeting, NTT submitted a contribution that reports on the results of an overvoltage test in which high-voltage pulse transformers were used to raise the overvoltage resistibility at the Ethernet port of devices connected to a home network. The contribution showed that an overvoltage resistibility of 7 kV can be provided at the Ethernet port. This has given Japan a strong position to drive the discussion on Ethernet ports with the aim of developing an overvoltage protection guide and a new draft recommendation K.lit (Question 2) at the next meeting.

Question 5 addresses methods of risk management related to lightning protection and the earthing of telecommunication systems. At the first meeting it was agreed to study during this study period the earthing of 400-V DC systems, a new draft recommendation, K.dbs, concerning lightning protection of power transformers near wireless base stations, and lightning protection of concrete poles installed near wireless repeater stations to protect these stations from lightning. At the next meeting, we will submit a proposal on the earthing of 400-V DC systems based on studies done by ETSI (European Telecommunications Standards Institute).

### 2.2 Discussions in WP2

WP2 is studying emissions from telecommunication systems and devices, immunity to such emissions, and protection against human exposure to electromagnetic fields. Owing to the widespread use in recent years of electrical appliances and power converters that use inverter control to save energy, there is an increasing number of reports of telecommunication failures caused by electromagnetic disturbance waves at low frequencies (up to 150 kHz), which are problems not covered by existing ITU-T recommendations. WP2 will study EMC problems that arise from such electromagnetic disturbance waves, discuss new draft recommendations, and revise existing recommendations as necessary. The main questions that WP2 is discussing are introduced below.

Question 6 concerns EMC problems that arise from the mutual use of telecommunication networks by different providers, which has resulted from the liberalization of telecommunication policies, and the maintenance of existing relevant recommendations. At the first meeting it was agreed to study the new draft recommendation, K.eun, which addresses methods of estimating the leakage of broadband signals from cables and which had been discussed in the previous study period (2009–2012), and to treat it as a draft revision to the existing recommendation, K.60 (Emission levels and test methods for wireline telecommunication networks to minimize electromagnetic disturbance of radio services). Similarly, WP2 decided to discuss the new draft recommendation, K.mit, which is intended to define methods of reducing the effects on next-generation access systems, as draft revisions to K.58 (EMC, resistibility and safety requirements and guidance for determining responsibility under co-located telecommunication installations) and K.59 (EMC, resistibility and safety requirements and procedures for connection to unbundled cables).

Question 7 deals with human exposure to electromagnetic fields near antennas of radio systems and mobile equipment. WP2 is studying methods and procedures for estimating, calculating, and measuring electric field strength. In the first meeting, a rapporteur proposed a revised version of the software program for calculating equivalent isotropically radiated power (attached to the existing recommendation, K.52: Guidance on complying with limits for human exposure to electromagnetic fields (EMFs)), and a revised version of the software program for calculating the EMF (attached to the existing recommendation, K.70: Mitigation techniques to limit human exposure to EMFs in the vicinity of radiocommunication stations). WP2 approved the addition of these revised programs to the Appendix of each of these recommendations.

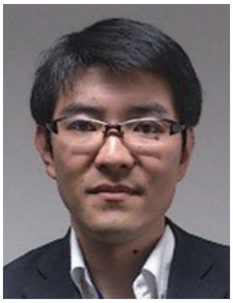
Question 8 covers immunity specifications, overvoltage and electrical safety specifications, and electromagnetic environments for communication devices that make up a home network. The first meeting included a discussion of the policy for revising the existing recommendation, K.74 (EMC, resistibility, and safety requirements for home network devices). Additionally, a new draft recommendation, K.mhn (Version 3) was studied, which concerns how to mitigate disturbances caused by radio signals in cables or devices connected to broadband cables. WP2 agreed to develop a recommendation on the basis of K.mhn by collecting further information about cases of interference between CATV (community access television) and wireless devices, which are referred to in the Appendix to K.mhn, and by exchanging information with ITU-R.

Question 9 relates to the study of EMC specifications for new telecommunication equipment and services, and the maintenance of existing relevant recommendations. In the first meeting, NTT submitted cases of telecommunication service failures caused by a sub-150-kHz conducted disturbance wave emitted by inverters. The meeting participants recognized the need to specify emission immunity in sub-150-kHz frequency bands, and they agreed to develop a new recommendation on this subject. In addition, NTT reported on the results of its tests of a radiation immunity testing method. This method assumes the use of wireless devices near telecommunication systems, and it was studied in order to meet the growing demand for using wireless devices in NTT's telecommunication equipment rooms. The meeting agreed to incorporate this issue in revising the existing recommendation, K.80 (EMC requirements for telecommunication network equipment (1 GHz–6 GHz)).

Question 10 focuses on issues pertaining to the electromagnetic security of telecommunication systems. WP2 is studying methods of protecting electronic systems from the electromagnetic effects of HEMP (high altitude electromagnetic pulse) and HPEM (high power electromagnetic) attacks, and measures to prevent information leaks in attacks that take advantage of electromagnetic properties. At the first meeting, a new draft recommendation, K.secmiti (Version 3) was discussed, which has been developed since the previous study period. It defines a method of mitigating threats to electromagnetic security. WP2 agreed to incorporate NTT-developed technology for preventing information leaks via electromagnetic waves as one of the countermeasures.

## 3. Conclusion

This article introduced standardization activities in ITU-T SG5 WP1/WP2. The main issues to be addressed in this study period are the development of new recommendations to prevent lightning-derived failures of telecommunication systems and finding solutions to new EMC problems arising from a conducted disturbance wave emitted by inverters, along with the revision of existing recommendations. These are important issues for telecommunication services in Japan, so NTT will be active in submitting proposals, thereby contributing to solving EMC problems. NTT will also enhance the quality and reliability of telecommunications by incorporating useful test methods and countermeasure technologies adopted in ITU recommendations into its technical requirements.



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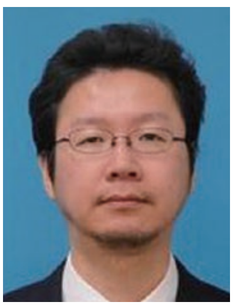

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# Case Studies of Insulation Failures in Outdoor Facilities and Countermeasures against Failures

**Abstract**

In this article, we introduce failure cases in outdoor access equipment and a countermeasure to them. This is the twenty-second in a bimonthly series on the theme of practical field information on telecommunication technologies. This month's contribution is from the Materials Engineering Group, Technical Assistance and Support Center, Maintenance and Service Operations Department, Network Business Headquarters, NTT EAST.

*Keywords: countermeasures, access equipment, outdoor facilities*

## 1. Introduction

NTT EAST has been developing and deploying outdoor optical access equipment that accommodates multiple lines (referred to below as remote terminal (RT) equipment) in order to economically upgrade the metallic cable network. Compact RT equipment can be installed in small spaces such as in the corners of public sites and facilities and under pedestrian bridges, and many units have been installed throughout Japan (**Fig. 1**).

However, more than ten years have passed since the development and deployment of this equipment began, and in recent years, the number of requests for consultation regarding problems in compact RT equipment has increased. At the Technical Assistance and Support Center, we have analyzed the cause of insulation failures throughout the country that have been brought to our attention in these consultations and have studied countermeasures to prevent such failures. We report here on our investigation into the cause of insulation failures in compact RT equipment and also describe a preventive measure.

## 2. Insulation failures in compact RT equipment

Compact RT equipment has been designed for outdoor installation and the need to maintain communication functions even when the equipment is exposed to wind and rain. However, equipment that has been in the field for more than ten years is inevitably affected by the installation environment (rain, humidity, corrosive gases, etc.) over the long term. Such equipment is at greater risk for problems as deterioration progresses.

Consultations on insulation failures in compact RT equipment have been requested from all regions of Japan from Okinawa to Hokkaido. These failures, moreover, have been reported in all seasons, from Japan's relatively long rainy season and severe typhoon season to its dry winter season.


O-PW: Outdoor Cabinet with Power
RSBM-F: Remote SuBscriber Module-Feeder

Fig. 1. Examples of outdoor RT equipment.

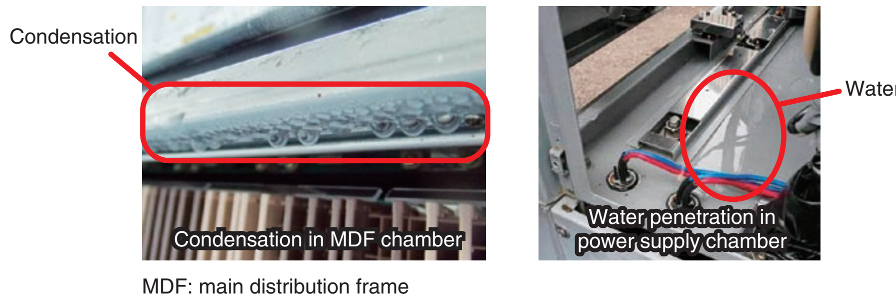


Fig. 2. Examples of water penetration in equipment.

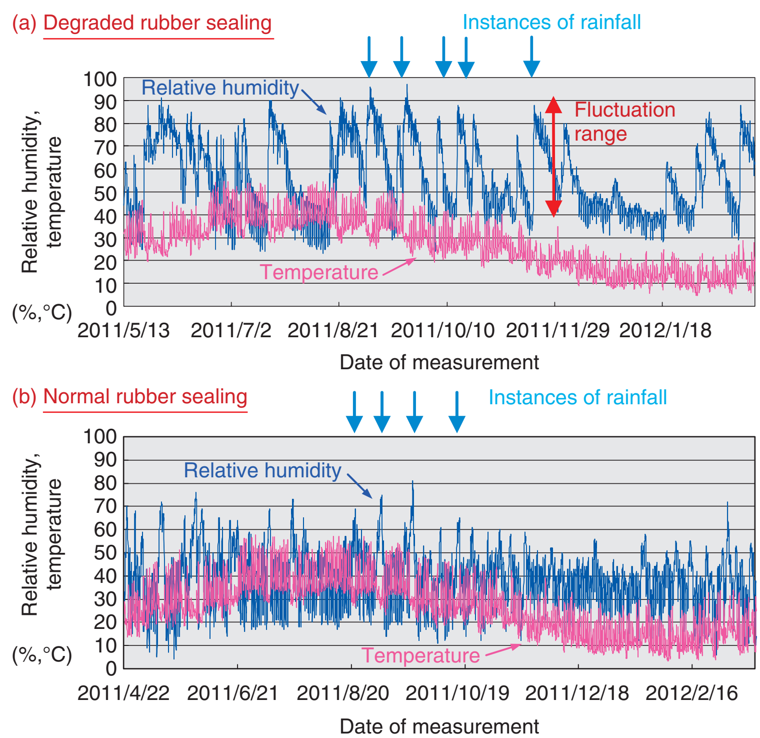


Fig. 3. Temperature/humidity inside compact RT equipment before and after rainfall.

Similar characteristics have been found in compact RT equipment in which insulation failures have occurred. Condensation has been observed inside the equipment on the inner side of the door and on the underside of the top panel, and traces of water have been found on the inspection sheet inside the equipment. In the worst cases, water has been found to collect on the floor of the power supply chamber (**Fig. 2**). These conditions led us to infer that external environmental factors such as rain and humidity contributed to the insulation failures in the equipment.

The Technical Assistance and Support Center conducted a survey on the causes of individual failures in order to develop countermeasures against them.

## 3. Causes of severe condensation inside equipment

Humidity inside compact RT equipment tends to rise whenever the equipment doors are opened and closed in rainy weather when deploying new circuits or carrying out maintenance. Most equipment,

Fig. 4. Clogged drainage duct.

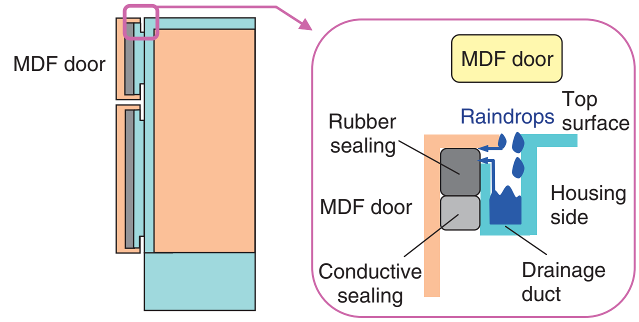


Fig. 5. Penetration of rainwater through equipment door.

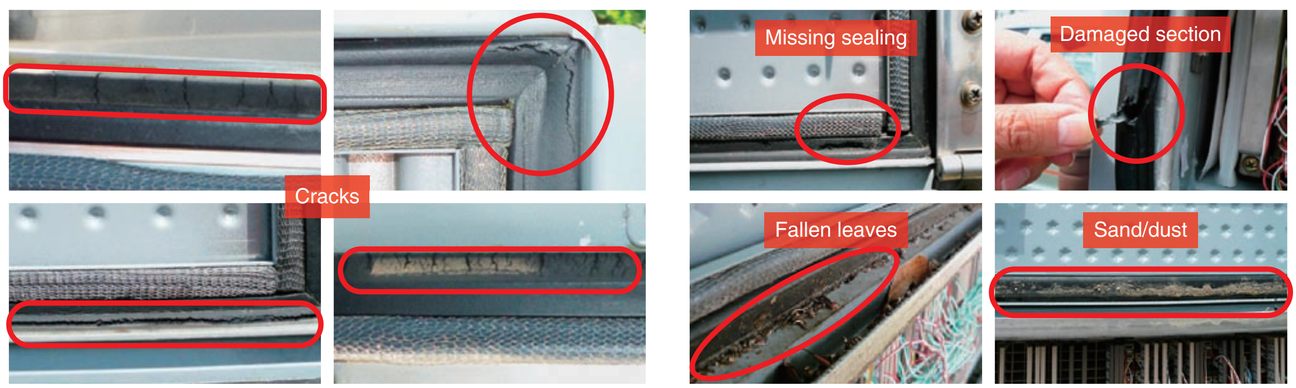


Fig. 6. Examples of problems in rubber sealing.

however, does not develop problems when exposed to such conditions, which led us to believe that equipment in which insulation failures occur are subjected to particular conditions.

The changes in temperature and humidity inside equipment were measured when there were cases of normal and degraded rubber sealing. The results are shown in **Fig. 3**. These graphs show that after a rainfall, the internal relative humidity rises remarkably in equipment with degraded rubber sealing, whereas it shows little change in equipment with normal rubber sealing. In other words, it can be inferred that the housing is not airtight in equipment with degraded rubber sealing, and that the equipment can consequently be affected by moisture in the outside air or can be penetrated by rainwater.

A drainage duct is installed in each door of the compact RT equipment in order to lower the risk of rainwater penetration. However, if fallen leaves clog the drainage duct (**Fig. 4**), or if the amount of water flowing into the drainage duct is excessive due to heavy rain, the rubber sealing may come into contact with rainwater as the drainage duct overflows. This raises the risk of rainwater penetrating the equipment through gaps in the rubber sealing (**Fig. 5**). Surveys that we have conducted to date have revealed that rubber sealing often deteriorates and cracks when equipment doors are frequently opened and closed during circuit-deployment or maintenance work. They have also shown that it is not unusual for rainwater to penetrate the equipment when leaves and branches become wedged between the door and the housing when the door is opened and closed (**Fig. 6**).

## 4. Mechanism behind insulation failure

The interior of compact RT equipment is always in a warm state due to heat generated by the power supply section and other areas. At night, the outside surface of the housing can be cooled by cold outside air, and if the warm air inside the equipment comes into contact with the cooled inner side of the housing under such conditions, condensation can occur due to the temperature difference. However, the occurrence of condensation does not necessarily mean that an insulation failure will occur. We examined problem equipment in various regions and found that insulation failures had occurred under severe condensation in which many water droplets formed on the inside of the top panel. With this in mind, we postulated that insulation failures occur by the following mechanism (**Fig. 7**).

(1) Rainwater and humidity (moisture) penetrate the equipment through gaps between the rubber sealing and housing.
(2) Temperature inside the equipment rises when the penetrated rainwater vaporizes due to heat inside the equipment.
(3) The temperature difference between the inside and outside of the equipment causes condensation (water droplets) to form on interior parts of the equipment at relatively lower temperatures (such as the top panel).
(4) The water droplets drop into the gaps between terminals of the equipment, causing an insulation failure to occur.

## 5. Overview of preventive measure

Here, we introduce a preventive measure for the RSBM-F (remote subscriber model-feeder) model of compact RT equipment. In the past, the response taken when insulation failures occurred was to ask the equipment manufacturer to replace the rubber sealing. This approach, however, was costly and time consuming and did not guarantee that an insulation failure would not occur again. Given these problems, the Technical Assistance and Support Center proposed a countermeasure commonly referred to as a waterproof roof to prevent water penetration (**Fig. 8**) instead of replacing the rubber sealing. The idea behind this waterproof roof was to prevent the penetration of rainwater that can trigger an insulation failure. In addition, we collaborated with the manufacturer to (1) give the roof a structure tailored to the part of the equipment that was most susceptible to water penetration, thereby lowering costs, and to (2) optimize the structure for more efficient maintenance operations.

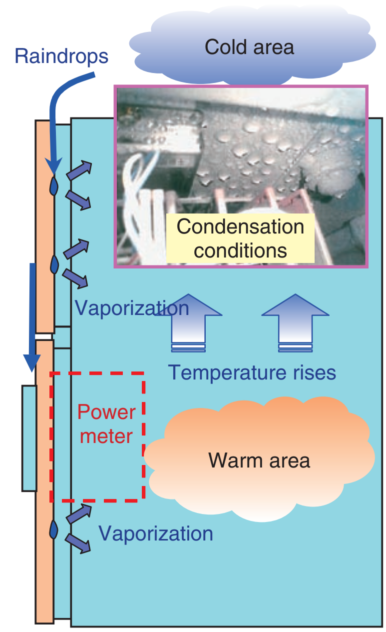


Fig. 7. Mechanism behind insulation failure.


Fig. 8. Countermeasure to prevent penetration of rainwater.

The features of the developed waterproof roof are listed in **Table 1**, and the half-year result of a test case using the roof on actual equipment throughout Japan is shown in **Fig. 9**. This graph indicates the relative humidity before and after installation of the waterproof roof. It is clear from these results that installing the waterproof roof suppresses the fluctuation in relative humidity when rainfall occurs. Consequently, installation of a waterproof roof has the effect of preventing the penetration of rainwater and suppressing a rise in humidity within the equipment, which means that this countermeasure is effective in preventing insulation failures.

Table 1. Features of waterproof roof.

| Location of waterproof roof | Ease of installation | Ease of maintenance work |
|---|---|---|
| - Equipment door (MDF chamber) | - Compact design, stacked storage, portable<br>- Installation time: about 5 min<br>- Technicians required for installation: 2 | - Equipment side door can be opened/closed by opening waterproofing door |

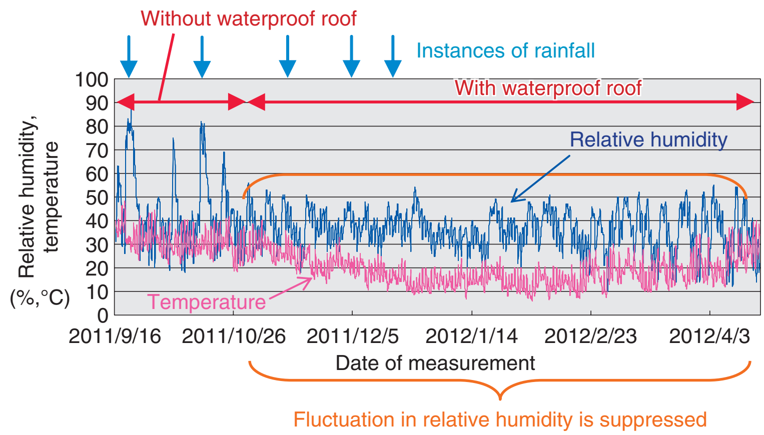


Fig. 9. Temperature/humidity before and after installation of waterproof roof.

## 6. Conclusion

In this article, we introduced case studies of insulation failures in compact RT equipment and a preventive measure. Our findings can be summarized as follows.

- Insulation failures frequently occur in equipment within which rainwater has penetrated through rubber sealing. Attention should be paid not only to cracks in the sealing and sealing that is missing due to aging but also to cases in which fallen leaves and sand and dust become wedged between the sealing and housing when the equipment door is opened and closed.
- Preventing the penetration of rainwater through the rubber sealing can suppress a rise in humidity within the equipment; therefore, installing a waterproof roof can be expected to prevent the occurrence of insulation failures.

Looking forward, we consider the possibility that the number of insulation failures in compact RT equipment will increase as equipment continues to age. To prevent failures from happening in the first place or to at least reduce the occurrence of failures, it is essential that equipment be adequately maintained as a preventive measure.

The Technical Assistance and Support Center works continuously to improve the reliability of all NTT facilities. We ask those having a difficult time with equipment-related problems and countermeasures to feel free to contact us.

# New NTT Colleagues
## —We welcome our newcomers to the NTT Group

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# Papers Published in Technical Journals and Conference Proceedings

### Outdoor AP Measurement in Tokyo

T. Aoki, T. Adachi, M. Kubota, R. Okada, K. Mizutani, M. Morikura, M. Matsui, M. Mizoguchi, Y. Inoue, and A. Yamada

IEEE 802.11 HEW SG, Vol. IEEE11–14, No. 0086, Los Angeles, CA, USA, 2014.

We conducted outdoor access point (AP) measurements around Tokyo. The results indicated that the outdoor inter-AP distance was about 50 m.

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### The New Public Phone Service—Non Contact Ultra High Speed Contents Download

M. Shimizu, K. Hiraga, K. Sakamoto, T. Seki, T. Tsubaki, H. Toshinaga, and T. Nakagawa

IEEE 802.11 WNG SC, Los Angeles, CA, USA, 2014.

This contribution presents the non-contact ultrahigh speed transmission service over the 60-GHz band. The 60-GHz band is expected to be useful in non-contact file download kiosk systems with up to 24 Gbit/s and with over 100 Gbit/s using MIMO (multiple input multiple output).

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### An SD Method Utilizing Null Dependency on Transmission Distance Due to Two-ray Fading

K. Hiraga, K. Sakamoto, M. Arai, T. Seki, T. Nakagawa, and K. Uehara

Antennas and Wireless Propagation Letters, IEEE, Vol. 13, No. 1, pp. 126–129, 2014.

A spatial division (SD) transmission method utilizing the characteristics of two-ray fading due to ground reflection with linear antenna arrays horizontal to the ground is proposed. Formulations of the optimum array arrangements as functions of the transmission distance and achievable channel capacity are clarified. For two- and three-element arrays, channel capacity is respectively doubled and tripled over that of free-space propagation. The proposed method provides increased capacity without the extra signal processing cost incurred when using conventional MIMO (multiple-input and multiple-output) transmission.

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### A Study of Home Measures for Children's Safe Internet Use

N. Chiba, Y. Seki, Y. Horikawa, and Y. Hashimoto

IPSJ Journal, Vol. 55, No. 1, pp. 311–324, 2014 (in Japanese).

With the spread of smartphones, the degree of Internet usage has increased even more, and Internet safety is an urgent problem facing young people. Our research focuses on parents and the home situation of young Internet users. We constructed a hypothetical model that provides a framework for discussing how to lessen the risk for young people using the Internet at home based on our qualitative analysis. Furthermore, we tested the hypothetical model based on a quantitative investigation of 300 smartphone-using junior and senior high school students and their mothers. The investigation results clarify the correlation model considering such factors as parenting concepts, family relations, in-home rules and measures as domestic elements that control the risk when children use the Internet. In addition, we clarify that home measures are related to family relations, the parents' learning experience regarding the risk of Internet use, and the implemented parenting concepts.

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### Compact Optical Devices for High-speed Digital Coherent Link

S. Kamei

Photonics West 2014, SPIE, Vol. 9008, No. 1, p. 900805-, San Francisco, CA, USA.

This paper describes recent progress in relation to the key optical devices for high-speed digital coherent transmission, namely coherent receivers and advanced-format modulators. Miniaturization and higher performance have been achieved on a silica-based PLC (planar lightwave circuit) platform and it has been integrated with other key materials.

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### A Study of Short-range MIMO Transmission Utilizing Polarization Multiplexing for the Simplification of Decoding

K. Hiraga, K. Sakamoto, K. Nishimori, T. Seki, T. Nakagawa, and K. Uehara

IEICE Trans. on Communications, Vol. E97-B, No. 2, pp. 459–468, 2014.

One of the procedures for increasing the number of multiple-input and multiple-output (MIMO) branches without increasing the computational cost for MIMO detection or multiplexing is to exploit parallel transmissions by using polarization multiplexing. In this paper, the effectiveness of using polarization multiplexing is confirmed under the existence of polarization rotation, which is inevitably present in short-range multiple-input and multiple-output (SR-MIMO) channels with planar array antennas. It is confirmed that an $8 \times 8$ SR-MIMO transmission system with polarization multiplexing has 60 bit/s/Hz of channel capacity. This paper also shows a model for theoretical cross polarization discrimination (XPD) degradation, which is useful for calculating XPD degradations on diagonal paths.

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### MulDiRoH: A Multi-view Human Representation System Using a QDA Screen with Multiple Cameras

S. Ozawa, S. Mieda, Y. Yao, M. Date, H. Takada, T. Kawakami, S. Nasu, T. Ishinabe, M. Kano, M. Sasai, and T. Uchida

IEEE Journal of Display Technology, Vol. 10, No. 2, February 2014.

We have developed a human representation system we call MulDiRoH. It consists of a multiview display that uses a quantized-diffusion-angle (QDA) screen and multiple cameras. The QDA screen has a large, wide viewing area that enables observers to comfortably watch the display. It is also convenient in that accurate projector orientation is unnecessary; this makes easy system construction possible. In this paper, we describe the MulDiRoH system and propose a Tiled Image Method to achieve shorter projection distance with it and a Perspective Transform Method to correct views obtained with it.

### Structural and Electrical Transport Properties of MOVPE-grown Pseudomorphic AlAs/InGaAs/InAs Resonant Tunneling Diodes on InP Substrates

H. Sugiyama, A. Teranishi, S. Suzuki, and M. Asada

Japanese Journal of Applied Physics, Vol. 53, 031202, 2014.

We report metal-organic vapor-phase epitaxy (MOVPE) growth of pseudomorphic AlAs/InGaAs/InAs resonant tunneling diodes (RTDs) on InP substrates for the first time. XRD (X-ray diffraction) measurements and TEM (transmission electron microscopy) observations reveal that a uniform strained InAs subwell is coherently grown in the double-barrier (DB) structure. The AlAs/InGaAs/InAs RTDs exhibit excellent current–voltage characteristics with a high peak current density ($J_P$) of around $2 \times 10^5$ A/cm$^2$ and peak-to-valley ratio (PVR) of around 6. A comparison with control RTDs consisting of AlAs/$In_{0.8}Ga_{0.2}As$ DB confirms the effectiveness of InAs subwell insertion for the improvement of PVR.

### Proposal and Evaluation of Agent-based Service Platform by Applying on BMI-enabled Services

S. Takeuchi, R. Banno, K. Umakoshi, A. Kanemura, M. Kawanabe, T. Kawano, T. Kambayashi, M. Takemoto, M. Matsuo, and R. Kakinuma

IPSJ Journal, Vol. 55, No. 2, pp. 681–694, 2014.

Real world services that affect entities in the real world through actuators deployed by extracting the environmental context based on sensing data will be available in the future. These real world services are expected to be provided by combining dynamic and diverse devices, processes, and varieties of data, and therefore, a flexible and scalable service platform is essential. Thus, an agent-based service platform that represents a service as a series of agents is proposed. While the overhead is generally larger than that of integrated systems, the feasibility of an agent-based system in the real environment is not clear. Therefore, the proposed platform was applied on BMI (brain-machine interface)-enabled services that should be provided in real-time and evaluated through simulation and in a real environment. As a result, the latency on the platform is less than a few hundreds of milliseconds, so the platform can be applied to a practical service.

### Pedestrian Navigation System Utilizing Effectiveness of Dynamic Exploration for Force Direction Perception

T. Amemiya and H. Gomi

IEICE Trans. on Information and Systems, Vol. J97-D, No. 2, pp. 260–269 (in Japanese).

Integration of an information presentation device and a position and orientation tracking system is required for effective indoor pedestrian navigation. We developed a pedestrian navigation system with a mobile haptic display. The haptic display creates a sensation of being pulled using asymmetric oscillation and provides precise angular resolution of force direction with a rotation mechanism. The experimental result showed that actively moving the hand facilitated understanding of the directional cue. We discuss the feasibility of the system for indoor pedestrian navigation.