ISSN 1349-3531

NICT NEWS

National Institute of Information and Communications Technology

2005 AUG. 《No.353》

Photonic Network Unit Activities

— Toward the Creation of Next-Generation Optical Network Infrastructures —

Fumito Kubota, Unit Executive Director, Photonic Network Unit

Introduction

A future ubiquitous broadband society will require network infrastructure offering speed and capacity thousands or even tens of thousands of times greater than available with existing networks. In the belief that this can be accomplished through the further development of fiber-optic network technology, NICT's Photonic Network Unit is actively pursuing the R&D of next-generation optical network technology.

Current state of R&D at NICT

In the 1990s, the Internet entered into commercial use, growing rapidly with the development of World Wide Web (WWW) technology. To date Internet data traffic (the mount of data) has been increasing continuously regardless of economic trends. The total traffic within Japan is now estimated at nearly 500 gigabits per second (according to a press release dated July 27, 2005 issued by the Ministry of Internal Affairs and Communications (MIC): http://www.soumu.go.jp/s-news/2005/050727_8.html). The total traffic increased by approximately 50% in the past six months alone. If the traffic continues to increase at this pace, it is sure to exceed one terabit per second next year.

For this reason, one of our top priorities is to develop basic key technologies for optical networks, to be positioned as a national infrastructure that can provide extremely high communication capacity—reaching terabit- to petabit-classes. We need to urge this task forward as a collective national project, through collaboration among industry, academia, and government. Accordingly, to attain the specific policy goals for optical networks set by the Ministry of Internal Affairs and Communications (MIC), NICT is currently working in the R&D activities described below (Figure 1).

(1) **R&D of key technologies for photonic based network (commissioned R&D: Research and Development Promotion Dept.)**

- Trunk-system by photonic network technology
- All-optical Internet node system technology
- Access-system by photonic network technology
- Terabit-class large-scale network control technology

(2) **R&D of basic technologies for petabit-class high capacity networks (planned R&D: Information and Network Systems Dept.)**

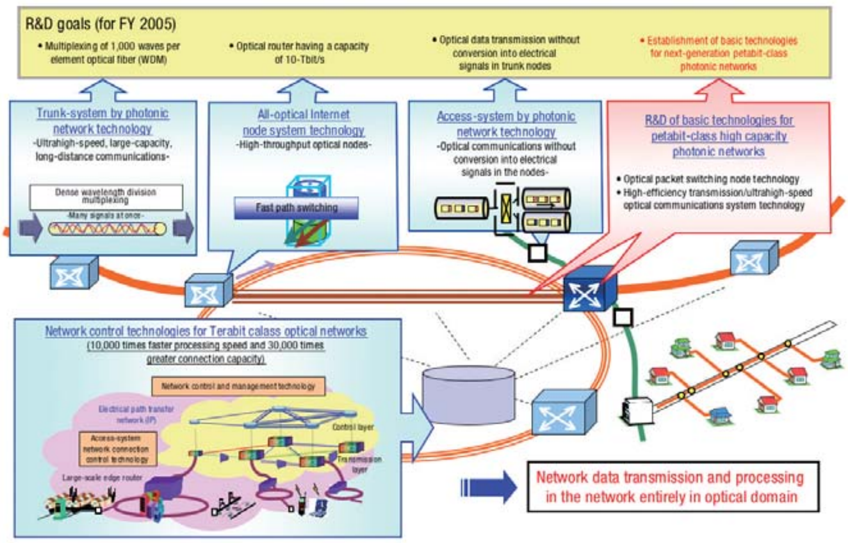


Figure 1: Overview of R&D activities in photonic network technologies

In the R&D subjects listed above, we have already accomplished many world's cutting-edge achievements; several examples of these achievements are presented below:

(1) • Successful multiplexing of 64 waves of different wavelengths on a single optical fiber; transmission of data at 43 gigabits per second over a length of 6,000 km (corresponding to intercontinental links)

Q&A — I see. Please explain in simpler terms.

Q How do you measure the rapidly increasing traffic on the Internet?"

A We collected traffic data and estimated the traffic growth rate described in this article in May 2005 with the support and cooperation of universities and seven major Internet service providers (including IIJ, NTT Communications, KDDI, and SoftBank BB). We collected two types of data: traffic in terms of subscription type (i.e., broadband or dial-up), and traffic exchanged among Internet providers (including traffic at main Internet exchanges, or "IXs") in Japan. Although traffic measurement methods differ among telecom carriers, we can determine the rate of increase in traffic using routers' counter functions or counting software.

Q What is a photonic network in the first place?

A A photonic network is the category of cutting-edge optical communications network technology. The word "photonic" is derived from "photon." While electronics makes use of the behavior of electrons, a photonic network uses a photonic circuit to transfer data entirely in the form of optical signals. Existing optical communications networks use fiber-optic transmission lines, but the nodes (or switches) still make use of electronic circuit technology. By replacing these electronic circuits with optical ones, the photonic network is expected to attain much faster transfer speed and larger capacity than available with networks using electronic circuits.

- Development of an optical amplifier for a wide wavelength band (over 100 nanometers)
- Development of the world's smallest and fastest optical switch (256 x 256 channels) using micro-electromechanical mirrors; performance of test-bed experiments to verify—first in the world—successful switching and control of signal paths entirely within the optical domain, at a speed of 20 milliseconds (more than ten times faster than existing switches)

(2)
- Development of world's first prototype of an optical packet switch using optical code label recognition processing and a photonic buffer; establishment of the basic node technology for an optical packet multiplexing network that will enable more efficient link (wavelength) use; resultant I/O interface speed increased to 160 Gbps
- R&D for an ultrahigh-speed nonlinear optical communications subsystem; world's first successful field verification test of 160-Gbps ASK-DPSK transmission with combined use of multilevel modulation and OTDM on the JGN II optical test bed (approx. 200 km in length)

This R&D project will be finished at the end of this fiscal year. The Photonic Network Unit is working to meet and exceed its project goals through the efficient coordination of its numerous tasks. Never hoarding up project results within the laboratory, we are verifying these new technologies also in an optical communications test field, that is, R&D network facility "JGN II," where NICT has offered its as a test bed, conducting basic researches (Figure 2). In addition to interdepartmental collaboration within NICT, we are playing a central role in promoting industry-academia-government and cross-disciplinary collaboration, as well as putting the results of this R&D to practical use (Figure 3).

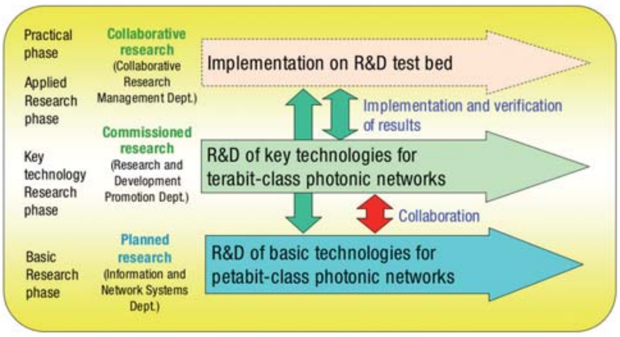


Figure 2: Collaboration in R&D at Photonic Network Unit

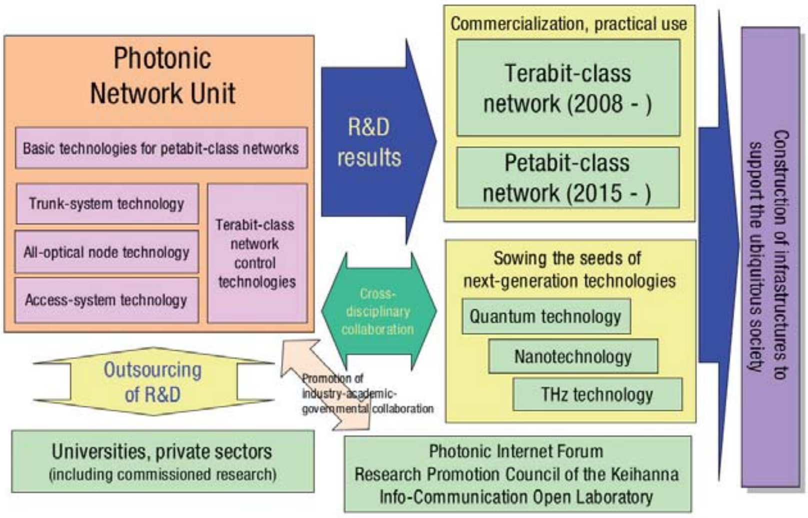


Figure 3: Collaboration with external organizations (targeted outcomes)

Photonic network symposiums

To inform to the public of NICT's photonic-network R&D activities and of the results obtained to date, we held a "Photonic Network Symposium" jointly with MIC on the morning of July 4. This symposium was in conjunction with 3rd NICT conference on research activities held on July 4 and 5. There was a large attendance, and we presented a number of our research results, including those with dynamic displays.

Conclusion

To attain the project goals of its final fiscal year, the Photonic Network Unit is now striving to conduct more efficient R&D, with enhanced support for individual tasks and greater coordination among them. We are also working with the MIC to formulate the next R&D project.

Life & Technology

● Network technologies and market potential for terabit-class data communications

With the advent of terabit-class communications, we are likely to see an increase in the capacity of metropolitan area networks (MANs) and the growth of markets related to 160-Gbps high-speed optical communications. For example, increasing demand for newly developed devices such as optical transceivers, optical amplifiers, and micro-mirror high-speed optical switches are expected to bring annual sales of tens of billions of yen around 2008. These developments will in turn enable comfortable use of a high-speed, large-capacity optical Internet.

Next-Generation Optical Communications through Nanotechnology

— Development of Antimonide-based Quantum Dot Surface-Emitting Lasers Operating in Optical Communications Wavelength Band of 1.3 to 1.55 μm —

Naokatsu Yamamoto

Expert Researcher, Optoelectronics Group
Basic and Advanced Research Department

Joined the Optoelectronics Group, Basic and Advanced Research Dept., CRL (currently NICT) in 2001. Engaged in research on the properties of optoelectronic materials and the development of optical devices based on nanostructure semiconductors. Ph.D. in engineering.

Introduction

Growing attention has been focused in recent years on optical communications technologies that will allow us to flexibly handle large volumes of contents with various communications tools. To realize the so-called "ubiquitous communications society," in which people and machines, etc. will communicate using multiple laser sources, we need techniques to mass-produce small, high-performance optical communications lasers at low cost and with minimal energy requirements. The desirable operating wavelength band of those laser devices will be 1.3 - 1.55 μm, suitable for fiber-optic communications, while lasers for wavelengths of 1.4 μm or longer will be required taking free-space communications into account.

To meet these future social needs, the Optoelectronics Group has been conducting research on a technique to mount an optical communications surface-emitting laser on an inexpensive GaAs (gallium arsenide) semiconductor substrate using the quantum dot formation method, an example of nanotechnology. We recently effected the operation of this quantum dot surface-emitting laser in the optical communications wavelength band of 1.3 to 1.55 μm; in this article I will describe this success in more detail.

Formation of high-density antimonide-based quantum dots

To date, it has been very difficult to form a material that emits light in the optical communications wavelength band of 1.3 to 1.55 μm on a GaAs substrate through conventional technologies. However, we recently discovered that an antimonide-based quantum dot can be used as a new material to operate within this wavelength band. The antimonide-based quantum dot is a compound semiconductor crystal composed of indium, gallium, and antimony (InGaSb); the dot has a fine particle shape of the order of several nanometers, as shown in Figure 1 (lower right). This figure shows quantum-dots on a 1-μm square surface area observed by an atomic force microscope. These quantum dots are embedded into GaAs for use in actual devices, with their crystallinity maintained. Such quantum-dot structures can be constructed using the molecular beam epitaxial system shown in Figure 1. In addition, to develop a suitable material for use in lasers, we had to increase the density of quantum dots. Devising a technique irradiate the substrate surface with silicon atoms just before the formation of quantum dots, we were able to increase the surface density of quantum dots by a factor of 100. As a result of these steady efforts in materials research, we succeeded in making up highly efficient antimonide-based quantum dots operating in the wavelength band for optical communications.

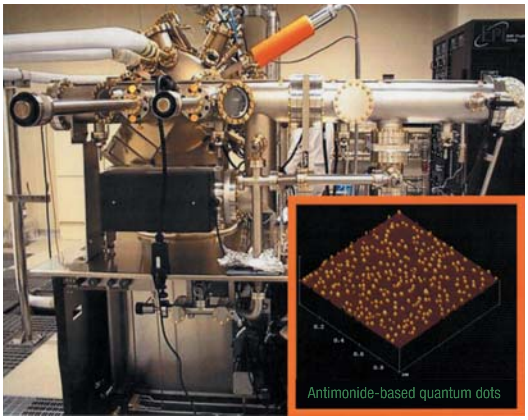
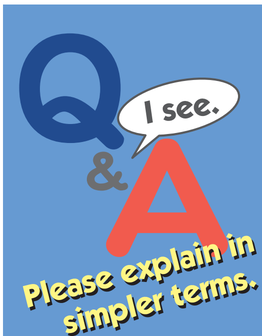


Figure 1: Molecular beam epitaxial system and formed quantum dots

Development of quantum dot surface-emitting lasers

A surface-emitting laser emits light perpendicular to its substrate. This laser is seen as a promising next-generation light source that will facilitate miniaturization, reduce power consumption, increase speed, allow for mass production, and permit higher packaging density relative to conventional semiconductor lasers



Q What is a surface-emitting laser?

A This refers to a laser that emits light perpendicular to its semiconductor surface. The surface-emitting laser is receiving a great deal of attention as a next-generation laser source for use in ultrahigh-speed optical communications. Conventional semiconductor laser fabrication techniques involve complicated processes such as the division of a substrate into areas only several hundred microns wide. However, the surface-emitting laser eliminates the need for these complex processes. In addition, through the high-density packaging of identical laser elements, production costs and power consumption can be reduced.

Q What sort of a substance is antimony?

A Antimony is an element in the periodic table with atomic number 51, with the symbol Sb. There are four so-called "allotropic" forms of this element; the stable form at atmospheric temperatures and pressures (gray antimony) is a silvery-gray, hard, brittle metalloid. As an industrial material, antimony has a wide range of applications: as an additive in semiconductor materials, a catalyst for polyester production, a material for lead storage battery electrodes, a flame-retardant additive in textiles and plastics, and type metals (i.e., for use in alloys). Historically, legend has it that the ancient Egyptian queen Cleopatra used antimony for eye shadow.

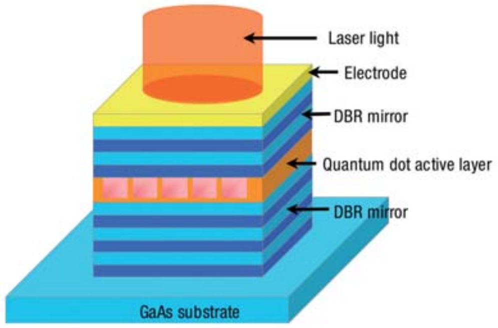


Figure 2: Schematic diagram of quantum dot surface-emitting laser

(which emit light horizontally). In addition, the use of a GaAs substrate will allow for low-cost implementation of a larger light-emitting area. However, it has proven very difficult to form a surface-emitting laser element on this substrate that can operate in the optical communications wavelength band. With the development of antimonide-based quantum dots, we were able to master this challenge. Figure 2 is a schematic diagram of the newly developed antimonide-based quantum dot surface-emitting laser. This laser mainly consists of an antimonide-based quantum dot active layer and two distributed Bragg reflectors (DBRs). The lower DBR mirror, just above the substrate, has a periodic structure of gallium arsenide (GaAs) and aluminum arsenide (AlAs). The active layer is made of laminated GaAs, in which the antimonide-based quantum dots are embedded. The upper DBR mirror is composed of a periodic structure of GaAs and AlAs for current injection pumping, or a similar structure of two types of dielectric thin films for optically pumping. For this surface-emitting laser, these DBR mirrors need to offer reflectivity of nearly 100%. The active layer, sandwiched between these two mirrors, acts as a microcavity to confine the light. Figure 3 shows an electron microscope image of the surface-emitting laser. The striped patterns in this cross-sectional view show the periodic structures of the DBR mirrors. The layer between these two mirrors is the active layer containing the quantum dots, although the dots are too small (several nanometers in diameter) to be observed directly by the microscope. When an electric current is passed through an electrode on the substrate, as shown in the upper left of Figure 3, carriers (electrons and holes) will be generated within the quantum dots to emit light. Carriers can also be generated by a method known as optical pumping. In our research we used both methods to evaluate laser emission.

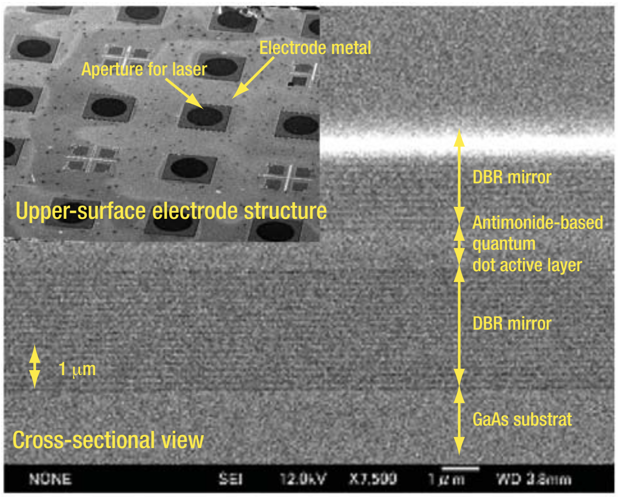


Figure 3: Upper-surface electrode structure and cross-sectional electron microscope image of developed surface-emitting laser

Successful laser emissions in optical communications wavelength band

Figure 4 shows the emission characteristics of the newly developed antimonide-based quantum dot surface-emitting lasers. We were able to observe the continuous emission of each surface-emitting laser structures at room temperature by either optical pumping or current injection, within the entire optical communications wavelength band of 1.3 μm to 1.55 μm. In particular, the obtained wavelength of 1.55 μm represents the world's longest emission wavelength of existent surface-emitting laser structures based on GaAs substrates; this is also the most suitable wavelength for fiber-optic communications.

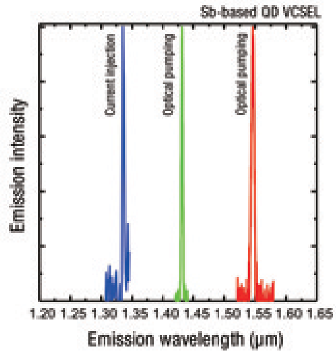


Figure 4: Emissions of antimonide-based quantum dot surface-emitting lasers at wavelengths of 1.3 to 1.55 μm

Conclusion

An optical communications surface-emitting laser that can be mass-produced at low cost would be an ideal device, and is in fact essential for the future development of optical communications technology. Through a risky R&D project to combine a new antimonide-based compound with the applied nanotechnology of the quantum dot formation method, we succeeded in developing surface-emitting laser structures that emit in the optical communications band of 1.3 to 1.55 μm. I'd like to express my gratitude to the staff of NICT Pnotonic Device Technology Center for their enormous contribution to the success of this project. We will pursue our further researches to develop original technologies and practical, innovative, widely useful devices.

Life & Technology

● Ushering in the optical communications age with the fusion of new semiconductor materials and nanotechnology

If we are to have large-capacity optical communications in the context of a future ubiquitous society, we must develop low-cost, low-power, and high-performance light sources. Using these surface-emitting lasers made up by a combination of antimonide-based semiconductor materials and the latest in nanotechnology, we can expect to rise to confronting challenges to realize large-capacity optical communications. This breakthrough will be achieved soon, although it may take a while for surface-emitting lasers to become familiar elements of daily life.

Makoto Kusakai
Group Leader, Science and Technology Information Group
Research Support Division, General Affairs Department

NICT's 3rd Conference for the Presentation of Research Results

NICT held the third NICT conference on research activities at Meiji Kinenkan (in Minato Ku, Tokyo) on July 4 and 5, 2005. The main theme of this meeting was "Toward the Creation of a Next-Generation Network." The research results presented were mainly concerned with next-generation network technologies, an essential research field for the establishment of a future ubiquitous network society.

Exhibition hall

The Photonic Network Symposium was held on the morning of the first day, prior to the conference. Based on joint efforts between the Ministry of Internal Affairs and Communications (MIC) and NICT to promote R&D in photonic network technology, this symposium (co-hosted by the two organizations) was designed to inform the public of the research results relating to these next-generation network technologies.

Opening address by Dr. Nagao, President of NICT

In spite of the bad weather, many participated in the symposium and in the conference on the first day—which shows the high level of public interest in this research field.

The conference started after the symposium, with Dr. Nagao, President of NICT delivering the opening address. He spoke of the themes of the conference and of NICT's overall missions. The individual research and development promotion units then made a series of presentations.

On the first day, the Photonic Network Unit gave five presentations. On the second day, the Optical and Quantum Communications Unit, Next-Generation Mobile Unit, and the R&D Network Unit gave four, three, and six presentations, respectively.

It is worth noting that at this conference, research results came from different, cross-departmental units. Each of these units

Conference hall

conducted its own presentation session under the supervision of each unit executive director; this allowed participants to get a sense of the individual characteristics of the units.

There were approximately 30 thematic exhibits or demonstrations in total, including large-scale dynamic displays. On the second day, Mr. Tamotsu Yamamoto, Parliamentary Secretary for the MIC, visited the exhibition hall, enthusiastically touring these exhibits for approximately two hours.

This two-day event ended with the closing address of Dr. Kunihiro Kato, Vice President of NICT.

Female Researchers at NICT vol.1

Today, there are approximately 80 female researchers and staff members at NICT.
Beginning with this issue, NICT News will feature a series of interviews with these researchers.

Researcher and Mother

Mina Aoki, Senior Researcher, Internet Application Group, Information and Network Systems Department

Ms. Mina Aoki
Completed master's course at Keio University, Graduate School of Science and Technology in 1989. Joined the Communications Research Laboratory (currently NICT) in the same year. Since then, involved in experimental research on visual information processing based on eye movements. Hobbies include playing musical instruments. Mother of two sons and one daughter.

"Eye gaze" research for a ubiquitous society

—Could you explain briefly why you went into the information and communications fields, and what you're working on at the moment?

Aoki: I was interested in the mechanisms of the human body, including the medical aspects, particularly in terms of what is called human information processing. This is why I became involved in research into speech recognition while I was at university. After finishing my master's degree, I joined CRL (now NICT) as a researcher in 1989. At first I worked on research in image compression; today I'm studying the "relationship between the intention and eye gaze," based on the measurement of human eye movements. Through this research, I hope it will become possible for people to convey their intentions to an interface just by looking in a certain direction. This sort of technology will of course be immensely useful in a ubiquitous computing society.

Increased number of women in information and communications fields

—What are your thoughts on the situation facing female researchers, including your current workplace environment?

Aoki: It's only recently that we've seen more women entering the information engineering fields. Traditionally, fewer women than men have chosen to enter engineering departments of university. I think this phenomenon is attributable to the methods of primary education in this country, although personally I felt free to enjoy science classes in school. Since researchers are evaluated based simply on their research results, I don't come across any particular gender discrimination in my current workplace. However, the proportion of female researchers is still low and there are few female workers in managerial positions, due to the lower proportion of women with longer tenures. Fortunately, the number of female workers is increasing at NICT.

—Is there much networking among female researchers at NICT?

Aoki: Although there has existed not a few branch offices all over the country since the days of NICT's predecessors, the RRL and the CRL, no real network of female researchers was established until recently. Last November, however, I started to put together a mailing list of women researchers. I would include any women researcher at NICT, regardless of employment status—regular, fixed-term, or expert (part-time) researchers. To date, about half of the female researchers have joined the mailing list. One day, we received a message from a listed researcher telling us that she wasn't able to use her maiden name within the accounting system and that she was finding this inconvenient. We talked to the people in charge of the accounting system about the problem, and they modified the system to allow women to use their maiden names. That's one example of the ways we're using the mailing list—for anything from small talk to the exchange of ideas, such as suggestions for improvements in our workplace.

Need for social understanding toward working mothers as researchers

—It's not easy to fill both roles as a mother and researcher, is it?

Aoki: My husband is also an NICT researcher and understands the importance of my research. He helps me, or we work together for me to fill both roles. In fact, many female researchers are married to another researcher, probably because they want a partner who can understand their working lives. Anyway, I hope we will be able to cultivate our society in which female researchers can freely work and also raise children, regardless of their partner's profession. Since women usually bear more of the burden in raising children, society as a whole needs to foster a better understanding toward the demands of child-raising.

I think NICT's work environment is good in this sense—we can work flextime and don't have difficulty taking child-care leave. In ordinary cases, female researchers get back to their old jobs after maternity leaves, having nearby nurseries take care of their small children. However, since these childcare facilities have usually limited capacity, they won't always find one when they want to return to their jobs. So individual workplaces may need to provide internal daycare. Since a number of male workers are also actively involved in child-raising, we all could benefit from improving the understanding for people who have children in our whole working environment.

It seems hard to juggle the profession of a researcher and motherhood. However, I don't think it's that hard in practice; I actually cope with work-induced stress by spending time with my kids—and vice versa.

Ms. Aoki working at an eye tracker

Thank You for Coming to the Open House at the NICT Facilities.

During this year's open house days, many people visited the NICT facilities.

Hiraiso Solar Observatory

Keihanna Human Info-Communication Research Center

Kashima Space Research Center

Okinawa Subtropical Environment Remote-Sensing Center

Koganei Headquarters

Kansai Advanced Research Center

Site	Date	Number of visitors
Koganei Headquarters	Jul. 22 (Fri.), 23 (Sat.)	4,622
Hiraiso Solar Observatory	Jul. 30 (Sat.)	698
Kashima Space Research Center	Jul. 30 (Sat.)	1,273
Keihanna Human Info-Communication Research Center	Jul. 30 (Sat.)	990
Kansai Advanced Research Center	Jul. 30 (Sat.)	932
Okinawa Subtropical Environment Remote-Sensing Center	Jul. 30 (Sat.)	436
Total		8,951

We'd like to thank all of our guests for visiting our facilities, as well as those involved in preparing for and hosting these events. We hope that you're looking forward to our open house days next year.

NICT NEWS
Aug. 2005 No. 353
Published by:
Public Relations Division, General Affairs Department
National Institute of Information and Communications Technology
4-2-1 Nukui-Kitamachi, Koganei, Tokyo 184-8795 Japan
■ Tel: (042) 327-5392 ■ Fax: (042) 327-7587
■ e-mail: publicity@nict.go.jp ■ URL: http://www.nict.go.jp/
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