Message from Director General

Several issues are currently emerging in the ICT field, such as the explosive surge of data traffic in information communication networks, the associated increase in power consumption, vulnerability of network security, decline of information quality, and limitations on strict control due to network complexity. Based on the recognition that it is extremely difficult to solve all of these problems simultaneously with existing technologies, we believe that the mission of the Advanced ICT Research Institute is to actively promote R&D to develop innovative ICT, rather than pursuing the extension of existing technologies. In order to promote sustainable innovation, we have built a strong research organization that creates the seeds of new technologies, germinates them, and grows the sprouts until they become socially useful seedlings. Through our advanced interdisciplinary R&D activities as an international research hub, we hope to discover new information and communication paradigms in unexplored areas of ICT by breaking away from the established concepts and theoretical limitations.

Outline of the Advanced ICT Research Institute

We are aiming to create a new paradigm at the ICT frontier by uniting various research fields. We expect to provide dramatic solutions to the problems posed by an explosive increase of the transmission rate, data capacity, and electrical power consumption in the information and communications field, and thus make a contribution to society. Moreover, we are promoting research collaboration with Industry, Academia, and Government with respect to basic research on international information communication.
Quantum ICT Advanced Development Center

Our center has two main R&D projects. One is the development of quantum photonic network technology, which includes quantum key distribution networks for realization of secure encryption in the future and space-time quantum optical communication enabling to choose the optimal balance between transmission efficiency and security for various applications. The other project involves quantum node technology and includes more fundamental research, such as investigation of quantum optical control techniques, quantum interfaces between photons and artificial atoms, and quantum metrology. These elements will eventually be integrated to develop novel functionalities in future communication network nodes. Our projects have a wide diversity, extending from new theoretical developments and proof-of-principle experiments to field trials using network testbeds. Thus, we aim to contribute to society through both fundamental sciences and industrial technology.

Green ICT Device Advanced Development Center

With the mission of realizing an energy-efficient society and promoting widespread utilization of environmentally friendly information and communication technologies (ICT), the Green ICT Device Advanced Development Center is pioneering research and development (R&D) that targets electrical devices with new functionalities and unprecedented performance by exploring the properties of novel oxide and nitride semiconductors.

We are the first center in the world to propose and currently focus on R&D in relation to transistors and diodes based on a new semiconductor material - gallium oxide (Ga2O3). With its superior material properties, Ga2O3 is expected to be used to develop innovative power devices that can achieve large-scale energy savings by considerably reducing energy loss during power conversion. Ga2O3 can also be applied to high-frequency wireless communication devices and high-sensitivity signal processing and/or communication devices that can operate at extremely high temperatures and/or in high radiation settings. An industry-academia-government consortium has been established to accelerate R&D of these promising technologies, which is expected to culminate in the commercialization of Ga2O3 devices and the birth of a new semiconductor industry in the near future.

DUV ICT Device Advanced Development Center

Deep ultraviolet (DUV) light at wavelengths between 200 and 350 nm shows huge potential for a wide range of applications, including ICT, air/water purification without using chemicals, surface disinfection, detection of chemical and biological agents, lithographic microfabrication, and medical diagnostics. Therefore, solid-state DUV light sources and photonic devices are becoming the focus of much interest. In particular, environmentally friendly and economical DUV light-emitting diodes (LEDs) are an ideal alternative to traditional mercury vapor lamps, which contain toxic mercury that threatens both human health and the environment. The DUV ICT Device Advanced Development Center is promoting the research and development of game-changing DUV ICT devices, such as ultra-compact, high-efficiency and high-power DUV LEDs and sensors with excellent reliability by development of nanophotonic device technology and collaboration among industry, universities, and the government. Thus, we are opening the way to technological innovations for lifestyle and social infrastructure in various fields, including ICT, electronics, medicine, healthcare, and the environment.

Terahertz Wave Electronics Project

With the aim of developing 100-Gbps wireless communication systems using terahertz waves, the project is involved in research on electronic devices suitable for terahertz frequencies and measurement technology to evaluate such terahertz devices. We are focusing on the development of high electron mobility transistors (HEMTs) composed of several semiconductor materials. These materials include indium phosphide (InP) that shows the highest operating frequency among recent technologies, gallium nitride (GaN) that has high resistivity to voltage, heating, and radiation, and silicon germanium (SiGe) that is easy to combine with commercial silicon technologies. We are also exploring some new materials for future terahertz electron devices, such as indium antimony (InSb) and graphene among others.

With regard to research on terahertz transceivers, an early prototype of a 300-GHz 100-Gbps transmitter has been created based on a silicon integrated circuit, and we are involved in ongoing research to achieve higher performances.

Terahertz Wave Photonics Project

The terahertz wave photonics project has the aim of developing key device technologies, such as signal sources and detectors, which are expected to be employed in future terahertz wireless communication systems and high-precision measurement systems working in the terahertz frequency and sub-mm/sub-millimeter wavelength regions. In particular, we are focusing our R&D on narrow linewidth and highly stable light sources and on terahertz wave generation with these devices, which can be used for both high-capacity wireless communications and wideband spectrum measurement. Through our R&D activities, we hope to contribute to the realization of terahertz technologies involved in processes such as:

- Handling terahertz wave correctly:
  - (e.g., real-time processing of ultra-high-speed signals)
  - Controlling terahertz waves accurately:
    - (e.g., advanced modulation for high-speed/high-capacity communication)
  - Measuring terahertz waves precisely:
    - (e.g., high-precision bandwidth spectrum measurement up to the spurious band)

Macroscopic Quantum Physics Project

We have discovered qualitatively new states of a superconducting artificial atom dressed with virtual photons. We used a macroscopic superconducting harmonic oscillator and an artificial atom (quantum bit: qubit), which has electronic states that follow quantum mechanics like a natural atom. We carefully designed a superconducting persistent-current qubit, interacting with an LC harmonic oscillator that has a large zero-point fluctuation current via a large shared Josephson inductance (left). Then, we used spectroscopy (right) to identify a new ground state similar to the stable molecular states of photons and artificial atom.
Nanoporous Functional Assembly Project

Advances in optical communications systems and application to short-range data communication have led to a demand for small, ultrafast, light control devices with low power consumption. The project aims at developing high functionality and integration of light control elements by combining organic materials with excellent light control properties and photonic materials, with inorganic materials with high refractive indices. Also, research and development is being performed on functional devices for controlling organic/inorganic interfaces and structures at the atomic and molecular levels to create high functionality devices and new functional materials. Organic molecules can show large optical nonlinearity arising from a resonant interaction between the optical electric field and its electronic band within a nanoporous single molecule. Organic electro-optic (EO) polymers displaying a particularly large EO effect are expected to be developed as new materials for high-speed light control devices with low power consumption, including optical modulators that are essential for optical communication systems. Based on hybrid technology employing organic EO polymers and silicon nanostructure, we are carrying out the development of new classes of light control devices, including ultra-fast optical modulators, optical phased arrays, and THz generators and detectors.

Applied Low-Dimensional Materials Project

Low-dimensional materials, such as membrane proteins of biomaterials, atomic thin films, and ordered molecular structures at interfaces, have various unique properties and functions. By applying these features on a structural level, we are involved in research and development aimed at enhancing the performance and functionality of sensors and optical devices.

Cell Biology Project

We are exploring a new ICT paradigm based on the information and communications of living cells by carrying out investigations in the following three areas:

1. Development of bioimaging technology

2. Construction of intracellular structures and control of cellular functions

3. Genetic information system in cells is an excellent product of biological evolution for 3.5 billion years. We are clarifying the regulatory principles and molecular mechanisms of the genetic information system in order to create new ICT based on the cellular systems.

Memory Neurobiology Project

The Memory Neurobiology Project is making efforts to establish basic mechanisms of memory using a fruit fly (Drosophila melanogaster) as a model animal, which allows us to perform genetic analysis at the single cell level. Although “memories” in computers are daily used devices, memory in our brain is not well understood because nobody has witnessed plastic processes when memories are formed. Our project involves real-time observation of memory formation on the “feeding neuron,” which commands feeding behavior of fruit flies, during Pavlovian conditioning. Through direct observation, we will study molecular and cellular mechanisms involved in memory formation. Understanding mechanisms of memory will allow us to design devices that mimic plasticity underlying memory formation. By controlling the feeding behaviors, we are attempting to build circuits that may function for artificial intelligence in a similar way to that used in our brain.
About the NICT Fellow

The title of NICT Fellow is the pre-eminent scientific and technical distinction of NICT, which is granted to select members of NICT in recognition of their outstanding scientific achievements, technical achievements, and leadership in science, engineering, programming, technology, and services. Since the title was established in 2009, only six experts have earned this elite status. Two Fellows are currently carrying out their activities at the Advanced ICT Research Institute.

Dr. Kazuhiro Oiwa joined the National Institute of Information and Communications Technology (NICT, former CRL) at Kobe, Japan in 1993, and he has achieved various landmark results in research on the biophysics of protein motors (biomolecular machines) using in vitro reconstitution systems and single-molecule measurements. Outstanding among his research achievements is a model of the force generation mechanism of the protein motor, dynamin, which was proposed on the basis of biophysical and structural studies. His model has led to various important research projects and the results have greatly contributed to the progress of this research field. His research papers have been cited more than 400 times in leading scientific publications. As a research group leader, he has applied his knowledge and techniques to understanding the mechanical properties of protein motors and has published more than 50 papers in leading scientific journals, such as Nature and Cell. He has also applied his knowledge of protein motors to the development of nanometer-scale devices and nanometer-scale communications (also known as molecular communications) and to understanding of ensemble behavior of self-propelled particles and resultant pattern formation (tentatively named nanocomplex intelligence). After serving as the Director General of the Advanced ICT Research Institute at NICT from 2006 to 2013, he is currently a Distinguished Researcher and Fellow of NICT. He was awarded the 23rd Osake Science Prize in 2005.

- 2001 - Group Leader, Protein Biophysics Group, CRL, Ministry of Posts and Telecommunications
- 2006 - Director General, Advanced ICT Research Center, NICT
- 2014 - present NICT Fellow

I have been engaged in research on quantum communications and cryptography since 1996. At that time, this research field was progressing rapidly, triggered by the discovery of the quantum algorithm by P. Shor in 1994. In 2001, the Quantum Information Technology Lab was inaugurated at NICT, and the NICT commissioned research program on quantum key distribution (QKD) was also launched. In 2003, our Lab succeeded in experimentally demonstrating a new principle of quantum communication which overcame the Shannon limit of channel capacity. Our Lab has further developed the quantum communication theory, and we have also demonstrated various new principles of quantum photonic technology. In collaboration with commissioned research teams, we constructed the Tokyo QKD Network in 2010. Installed QKD systems with dramatically improved key generation rates, and demonstrated QKD encrypted video transmission for the first time in the world. Recently, we have extended our research to interdisciplinary areas, such as long-term secure data storage systems combining QKD with modern cryptography and enhancement of the capacity and security of free space optical communication and mobile networks with drones. In order to benefit society by developing quantum communication and cryptography, it is essential to merge these quantum technologies with those of various other fields, including cryptography, coding, network technology, mobile device technology, and so on. This is a time consuming task, and we will often have to develop new frameworks in these relevant fields ourselves. However, I sometimes feel that such challenges allow us to catch a glimpse of the universal principles of ICT that can be applied to a wide variety of fields. Quantum-inspired ICT is cool, and always makes me excited.

- 1996 - COE Research Fellow, CRL, Ministry of Posts and Telecommunications
- 2001 - Group Leader, Quantum Information Technology Group, CRL
- 2016 - present NICT Fellow

Collaboration with Industry and Academia

The Advanced ICT Research Institute promotes research and development and social application of the findings as a base of collaboration with Industry, Academia, and Government in advanced and multidisciplinary research fields.

Cooperative Graduate School Program

Our Institute and university promote research and development, as well as the exchange and develop human resources under a coordinated agreement on basic research.

Visiting the Facilities

We welcome visitors to our facilities. Various organizations may visit our institute, such as corporations, universities, high schools, and social groups. Accepting visits to the facilities is part of our outreach activities.

In some cases, we exchange an MOU with the visiting school.

Contribution to the Regional Community

AC-Net (Human Network for Researchers toward Advanced Telecommunications)

http://www2.nict.go.jp/advanced_ict/ACNet/

AC-Net was established in 1990 as a place for exchange between researchers and engineers from the Kanai district working in the information and communications fields. Since then, over 200 lectures have been given on the latest research and technology trends. AC-Net also provides the opportunity for close exchanges with Industry, Academia, and the regional community.

NICT Open House in Kobe

Our institute holds an open house at the end of July every year. There are various hands-on exhibits which was provided by our researchers so that it can be enjoyed from children to adults. At the same time, we hold the lecture for the public. The researcher explains their latest research results easily with familiar examples.

There are a lot of visitors every year and it is an important event for get to know our activities.

Exhibitions

We have actively participated in exhibitions as a good opportunity to introduce the advanced studies of this Institute. At the same time, we publicize the results that can be introduced to society, such as intellectual property and technology transfer. The exhibitions provide an opportunity to learn about the needs of society and a good chance for basic researchers to examine the direction of their research.

- International Nanotechnology Exhibition and Conference
- The Kobe International Industrial Fair
- Kansai Information and Communications Fair
- Hyogo Science Fair
**Advanced ICT Device Laboratory**

**Background & Policy**

Further development and increased sophistication of information and communication technology (ICT) is required to allow all people and things to be connected to networks, to freely utilize a large amount of content, and to lead a safe life based on access to a diverse range of information. Furthermore, in order to achieve a world of abundance based on progress of sophisticated informatization, in particular, advanced and sophisticated systems are required to achieve society, and it is crucial to conduct research and development on areas that form the "foundations" of these systems, such as state-of-the-art optical device technologies, high-frequency information communication systems, wave technologies, convergence phononic and high-frequency technologies, and creation of new materials. Selection and concentration of topics have progressed with research and development supported by society, particularly by industry, while funding for cutting-edge research and development of challenging devices has decreased. This is primarily because funding of such research is usually based on a medium to long-term perspective and involves high risk, leading to uncertainty regarding future technological development capabilities. Against such a background, the National Institute of Information and Communications Technology (NICT) is a research organization for information and communication technology that displays a high degree of neutrality and support for the public interest. NICT considers it important to improve the framework for promoting research and development by widely promoting the newly established Advanced ICT Device Laboratory while maintaining strong collaboration with industry and academia.

We would like the Laboratory to evolve into an open research base where members of industry, academia, and the government can collaborate on research that advances the information and communications field. In order to ensure that both domestic and international researchers can fully utilize this base, we will devise ways to continuously improve maintenance and operation of the facilities and equipment on a daily basis. In order to improve access to research and development environment, the facilities will be available to individually outside NICT who can conduct research at NICT primarily under a joint research framework.

**Outline of the Laboratory**

Teams of experienced engineers and relevant industrial research groups at NICT coordinate with each other to appropriately manage the facility so that users can enjoy a stable and safe work environment that meets standard requirements. Research and development at NICT encompasses the entire spectrum of ICT technologies, featuring the generation of research on fundamental device technologies with an emphasis on the development of sophisticated information and communication systems at the Advanced ICT Device Laboratory.

**Advanced ICT Device Laboratory, Kobe Branch**

Construction of the Clean Room at Kobe City, a new facility for promoting research and development that is operated as a part of the Integrated Clean Room facility at NICT headquarters, was completed in July 2015. The building operation commenced in April 2016. The facility has class 1000 cleanroom chambers, nanofabrication chambers, and class 10000 exposure chambers. It will be used to develop next-generation information and communication technologies, including a variety of devices required to create superconducting materials and organic nanomaterials as well as to evaluate the characteristics of thin films and devices. More specifically, the laboratory has a back-end type vacuum thin-film deposition system that is capable of fabricating devices with multiple layer structures, an atomic layer deposition device that can control film thickness at the atomic scale, an electron beam lithography system that can draw using a minimum line width of tens of nanometers, a reactive ion etcher that performs etching on the nanometer scale, and an indium-gallium-arsenide heterojunction bipolar transistor (InGaAs HBT) etcher. The facility also has other devices that have been uniquely customized by researchers to perform specific functions. We aim to operate a world-class facility that can be fully utilized to develop breakthroughs in information and communication technology.

**Facility**

**Neural Information Engineering Laboratory**

(Neural Information and Neural Networks)

NICT has a 20-year history of neuro research, most of which was conducted in the No. 3 building of the Advanced ICT Research Institute. After the 1.5 T MRI apparatus was transferred from NICT headquarters in Koganei, Tokyo, the latest equipment was added such as MEG and 3 T MRI. The vast site provides a suitable environment for the sensitive work of neural imaging. Based on the advances made at this institute, the Center for Information and Neural Networks (CINN) was established in 2013. Since then, the No. 3 building in Kobe continues to play a part in CINN’s research.

The development of the electroencephalograph (EEG) is an example. The EEG was a simple invention in principle, which had the potential to be developed as a compact device. After various improvements, a wearable EEG was developed that anyone can use at any time and anywhere. Following extensive improvements to the electrodes, electrically conductive paste became unnecessary. Without the need for pastes, subjects do not have to wash their hair after testing, which makes the procedure easier. The technology has now been transferred for commercial production. The present challenge is to diversify its application.

CINN research also covers many other subjects and collaborations with universities and companies has been reinforced. CINN aims to develop technologies that enhance QOL through neural science.

**PANDA, Remote Sensing Laboratory**

(Applied Electromagnetic Research Institute)

The Remote Sensing Laboratory of the Applied Electromagnetic Research Institute develops remote sensing technologies, and promotes R&D to improve the accuracy of predicting sudden atmospheric phenomena. In 2014, the Phased Array weather radar and Doppler Eddy Network Data system (PANDA) was installed on a 20-m tower in the site of the Advanced ICT Research Institute. PANDA has been developed to predict sudden torrential rain by using data fusion technology with multiple remote sensors.

**Kobe Branch of Japan Standard Time, Space-Time Standards Laboratory**

(Applied Electromagnetic Research Institute)

NICT generates Japan Standard Time (JST) and Frequency Standards, and also disseminates them throughout Japan. The ensemble of atomic clocks which provides the reference time scale for JST has always been operated exclusively at NICT headquarters in Tokyo. In order to increase the reliability and disaster resilience of JST, NICT is distributing some of the atomic clocks to its branches, such as the Advanced ICT Research Institute, and is promoting research and development on integrated management of clocks for JST.

**Free-Space Optical Communication System, Space Communications Laboratory**

(Wireless Networks Research Center)

A small ground station was designed to perform free-space optical communications with an aircraft using near-infrared laser beams. The main part of the ground station is shown to the left of the picture, comprising the gimbals for tracking the target and the optical equipment for transmitting and receiving the laser beams. This system can track a mobile terminal installed onboard an airplane or a helicopter and can perform high-speed optical communications with data rates up to 40 Gbps.