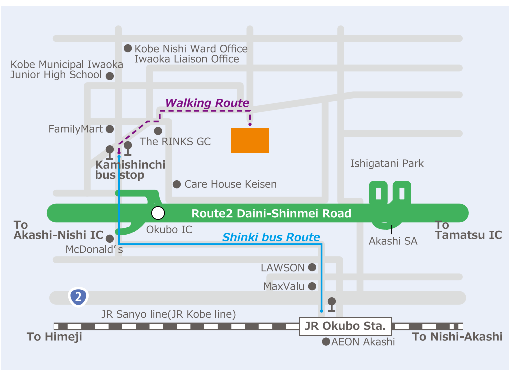
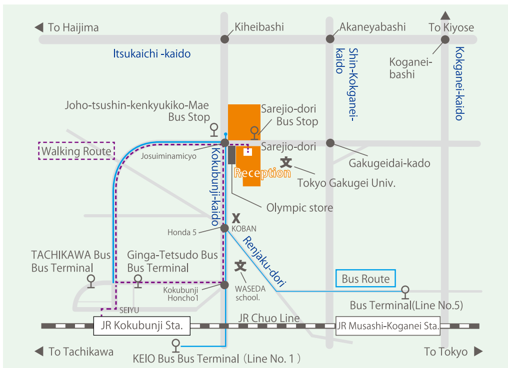
Advanced ICT Research Institute





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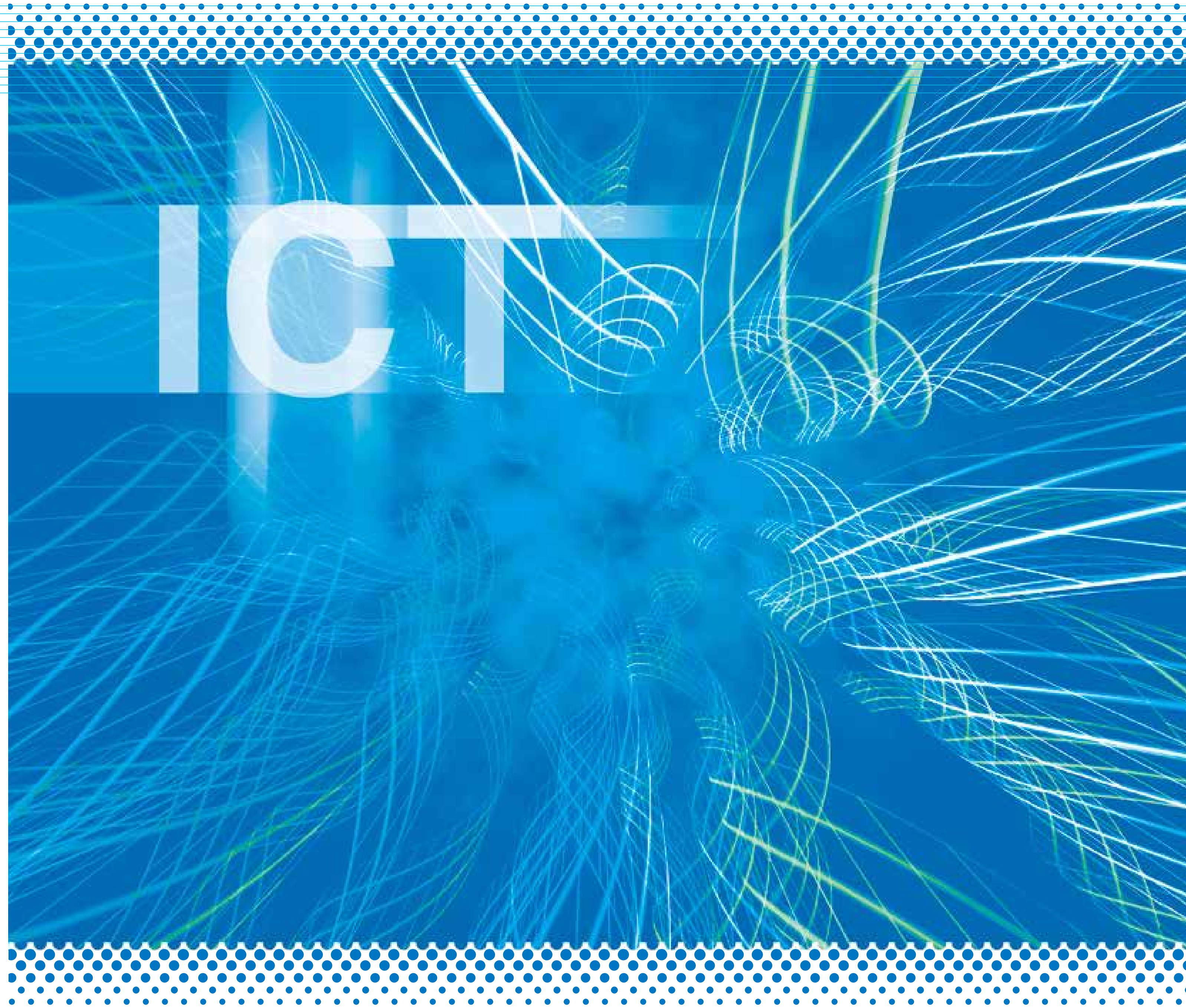
January, 2017

Advanced ICT Research Institute



NICT National Institute of Information and Communications Technology

Director General,
Advanced ICT Research Institute
Hosako Iwao, Ph.D.

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.

Organization Chart of the Advanced ICT Research Institute

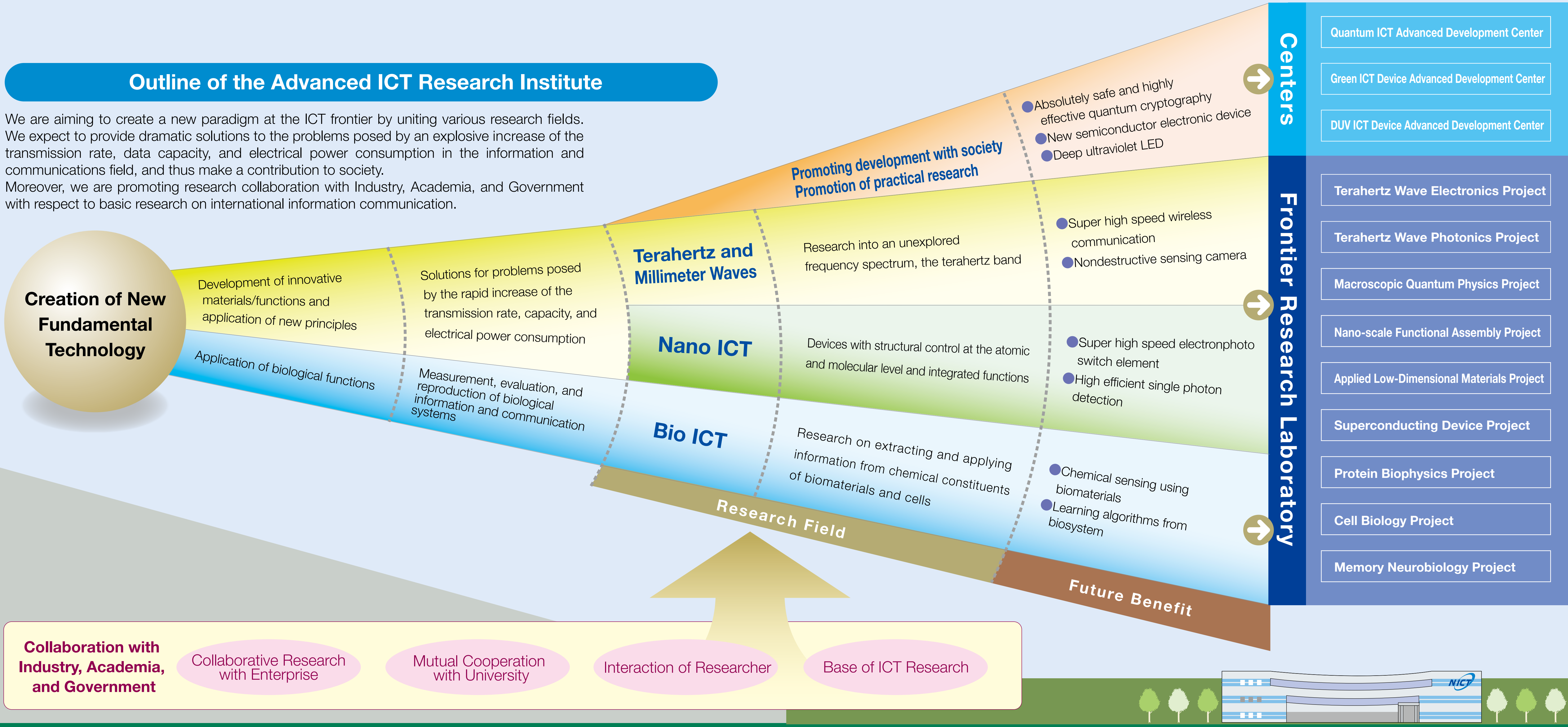
Advanced ICT Research Cluster

- **Advanced ICT Research Institute** ········ **Advanced ICT Device Lab**
  - Planning office
  - Frontier Research Laboratory
  - Quantum ICT Advanced Development Center
  - Green ICT Device Advanced Development Center
  - DUV ICT Device Advanced Development Center

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.

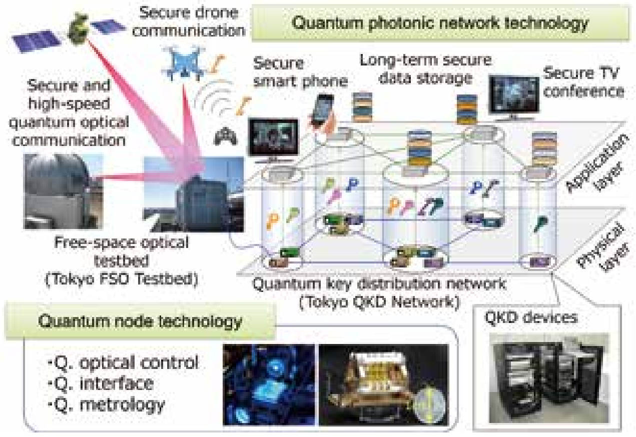
Moreover, we are promoting research collaboration with Industry, Academia, and Government with respect to basic research on international information communication.



CENTER

Quantum ICT Advanced Development Center

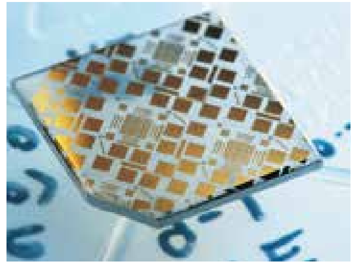
Our center has two main R&D projects. One is the development of quantum photonic network technology, which includes quantum key distribution networks for realization of secure encryption in the future and free-space quantum optical communication enabling to choose the optimal balance between transmission 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 science 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 exploiting the properties of novel oxide and nitride semiconductors.

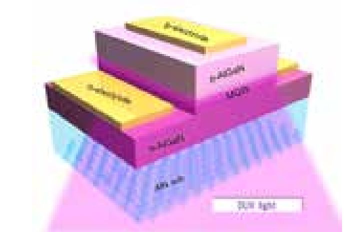
We are the first center in the world to propose and currently focus on R&D in relation to transistors and diodes based on a new semiconductor material - gallium oxide (Ga_2O_3). With its superior material properties, Ga_2O_3 is expected to be used to develop innovative power devices that can achieve large-scale energy savings by considerably reducing energy loss during power conversion. Ga_2O_3 can also be applied to high-frequency wireless communication devices and harsh-environment 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 Ga_2O_3 devices and the birth of a new semiconductor industry in the near future.



Chip fabricated with Ga_2O_3 transistors and diodes

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.



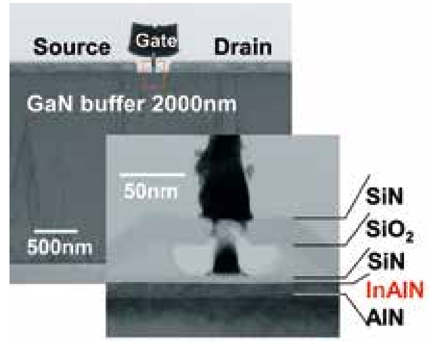
Device structure of DUV-LEDs

DUV solid-state light sources

Frontier Research Laboratory

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 performance.

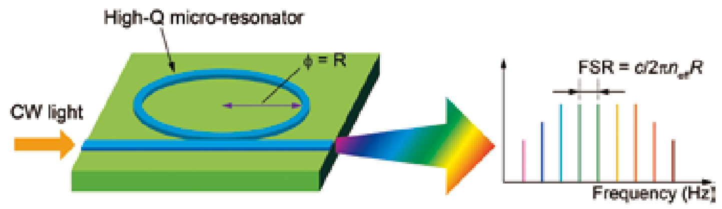


Cross-section of a GaN HEMT

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 100 Gbps-class wireless communication systems and high-precision measurement systems working in the terahertz frequency and (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:

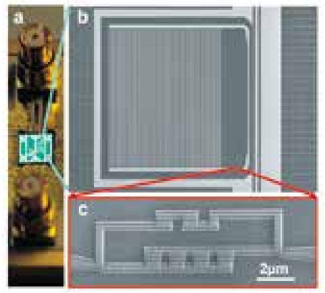
- Handling terahertz wave correctly
  (e.g. real-time processing of ultra-high-speed signals)
- Controlling terahertz waves accurately
  (e.g. advanced modulation for high-speed/high-capacity communication)
- Measuring terahertz waves precisely
  (e.g. high-precision broadband spectrum measurement up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



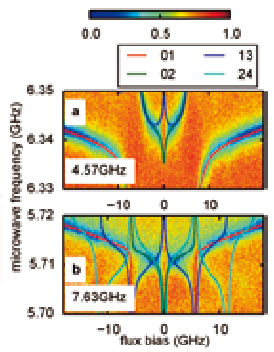
Multi-GHz optical frequency comb

Macroscopic Quantum Physics Project

We have discovered qualitatively new states of a superconducting artificial atom dressed with virtual photons. We used a micro-fabricated 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 state of photons and artificial atom.



Experimental setup
a. The chip mounted on a sample holder
b. Laser microscope image of the circuit comprising a superconducting qubit and oscillator
c. A superconducting flux-qubit

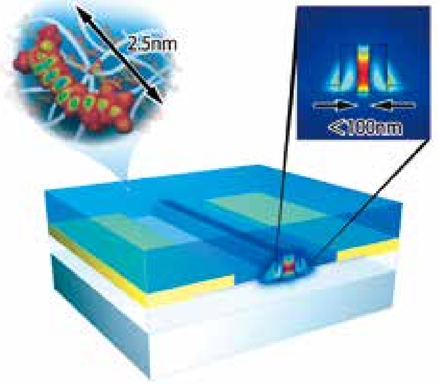


Transmission spectrum
Calculated transition frequencies are superimposed on the experimental results.
Coupling strength values are given in the panels.

Nano-scale Functional Assembly Project

Advances in optical communications systems and application to short-range data communication have led to a demand for small, ultra-fast, 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 nano-photonic structures using inorganic materials with high refractive indices. Also, research and development is being performed on fundamental technologies for controlling organic-inorganic interfaces and structures at the atomic and molecular levels in order 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 π electrons bound within a nano-scale 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.

Organic EO Polymer

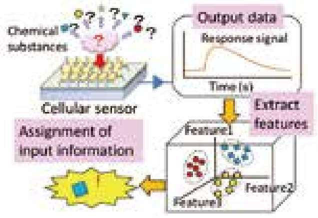


Nano-structure optical waveguide

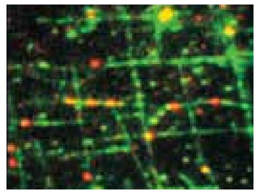
Protein Biophysics Project

The Protein Biophysics Project is conducting research and development activities that will lead to new concepts for information and communication technologies by learning from biological systems. Our research targets range from biomolecules up to the cellular network level. By measuring, analyzing, and controlling a wide range of biological materials, we are trying to understand and reproduce various biological functions. Our research activities include the following projects.

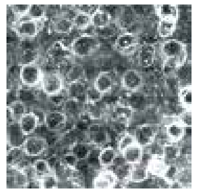
1. Reproduction of cellular and biomolecular sensing mechanisms: We are trying to reproduce the system for detecting information transmitted by chemical substances by combining the functions of living cells and machine learning techniques.
2. Research on biomolecular machines: We are analyzing the structure and functions of biomolecular machines by employing state-of-the-art technologies in order to understand how they work. We are also trying to understand the design concepts for biomolecular machines based on techniques for engineering biomolecules.
3. Research project on biomolecular systems: We are exploring the mechanisms underlying the formation of self-organized structures and their functions based on interactions among biomolecules.



Sensing system for chemical substances composed by living cells



Functional imaging of biomolecular machines



Large scale structure of self-organized biomolecular system

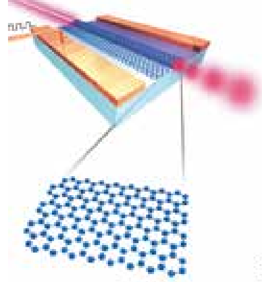
Applied Low-Dimensional Materials Project

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 ICT devices.

For example, bacteriorhodopsin (a unique membrane protein obtained from *Halobacterium salinarum*) has similar photoreceptor function to a visual pigment in animals, and it can be used to develop a biomimetic visual information processing device with computing functions at the elemental level by employing the latest microfabrication/patterning technology and recombinant gene technology. In addition, two-dimensional atomic thin films such as graphene and chalcogenide exhibit high electron mobility due to their peculiar electronic structure, and are expected to be applied in devices with an extremely high speed and broadband performance.

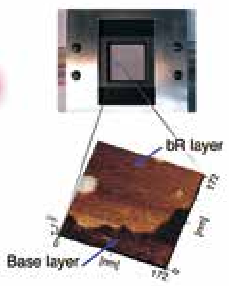
We are exploring fundamental technologies for utilizing these superior materials in devices and contributing to the development of technologies required in the future ICT society, in which sophisticated information-processing sensors and ultra-small, highly efficient optical ICT devices will be embedded ubiquitously.

Optical ICT device



Atomic thin film

Biomimetic optical sensor



Biomaterial sheet

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.

○Development of bio-imaging technology

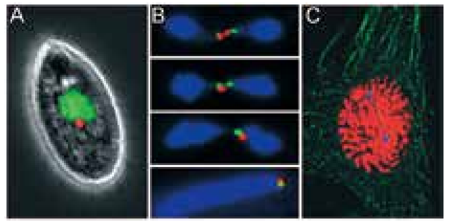
We are developing fluorescent microscope technology that can visualize the behavior of target molecules in living cells at ultra-high resolution to monitor information flow inside cells. Fluorescent microscopy is one of the most essential technologies for utilization of cellular ICT.

○Construction of intracellular structures and control of cellular function

We are developing the technology to construct artificial structures in living cells that will allow us to control cellular function. Construction of functioning artificial organelles in cells will enable us to create various artificial cells that can act as sensors for specific substances, perform drugs screening, and generate various useful materials.

○Analysis and application of cellular information systems

The 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.



Various cells used in our research

(A): *Tetrahymena* (a unicellular organism with two nuclei). The macronucleus and micronucleus are indicated in green and red, respectively.

(B): The process of nuclear fusion during sexual reproduction of *Schizosaccharomyces pombe*. Chromosomes, spindle pole bodies (a centrosome-equivalent structure in fungi), and telomeres are shown in blue, red, and green, respectively.

(C): Cultured human cell. Chromosomes, centrosome, and tubulin are shown in red, blue, and green, respectively.

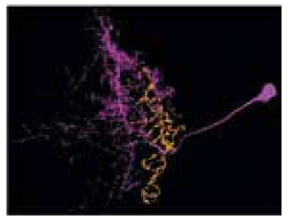
Superconducting Device Project

We have developed an ultrasensitive single-photon detector, a THz detector, and an integrated circuit operating at ultra-low power by using superconducting phenomena. Our unique research approach employs a niobium-nitride (NbN) superconductor, which has a higher superconducting transition temperature than the conventional niobium (Nb) superconductor, allowing higher operating temperatures and frequencies. Due to the requirement of cooling for operation of superconducting devices, we rarely see superconductors used in commercial products. However, ultrasensitive, low noise detectors based on our NbN thin films have already been employed in the ALMA radio telescope constructed in Chile with the cooperation of Japan, the EU, and the USA, and are also used in a quantum key distribution system that is expected to become a completely secure communication system in the future. We will spread information about the excellent performance of our superconducting devices and contribute to innovation by developing new applications of our superconducting technologies and promoting collaborative research with scientists in various fields.

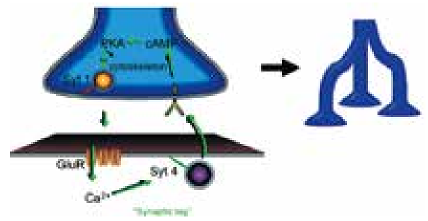
Superconducting single-photon detector (SSPD) system

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 connecting such devices, we are preparing to build circuits that may function for artificial intelligence in a similar way to that used in our brain.



"Feeding neuron", which commands feeding behavior of a fruit fly (*Drosophila melanogaster*)



"Local feedback" hypothesis: a candidate principle of memory mechanism

FELLOW

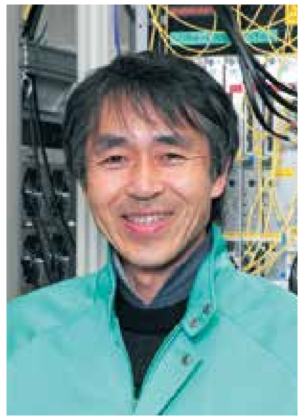
About the NICT Fellow

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.

Kazuhiro Oiwa, Ph.D.
Distinguished Researcher

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, dynein, 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 natural intelligence). After serving as the Director General of the Advanced ICT Research Institute at NICT from 2008 to 2013, he is currently a Distinguished Researcher and Fellow of NICT. He was awarded the 23rd Osaka Science Prize in 2005.

2001- Group Leader, Protein Biophysics Group, CRL, Ministry of Posts and Telecommunications
2008- Director General, Advanced ICT Research Center, NICT
2014- present NICT Fellow



Masahide Sasaki, Ph.D.
Distinguished Researcher

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

EFFORT

Collaboration with Industry and Academia

The Advanced ICT Research Institute promotes research & 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 high 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 Kansai 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 example.
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
- Keihanna information and communications fair
- Hyogo Science Fair

DEVICE LABO

Advanced ICT Device Laboratory

Processing equipments in the clean room

Photo-lithography equipments
in the clean room with yellow lights

[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, as well as to achieve a world of abundance based on progress of sophisticated informatization. In particular, advanced and sophisticated systems are required to achieve such a world, and it is crucial to conduct research and development on areas that form the “foundation” of these systems, such as state-of-the-art optical device technologies, high-frequency millimeter wave and terahertz wave technologies, convergence photonic 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 fields. In order to ensure that both domestic and international researchers can fully utilize this base, we will devise ways to continually improve maintenance and operation of the facilities and equipment on a daily basis. In order to improve access to this research and development environment, the facilities will be available to individuals outside NICT who can conduct research at NICT primarily under a joint research framework.

Kobe Clean Room

Facilities to fabricate nano-devices
in the Kobe clean room

[Outline of the Laboratory]

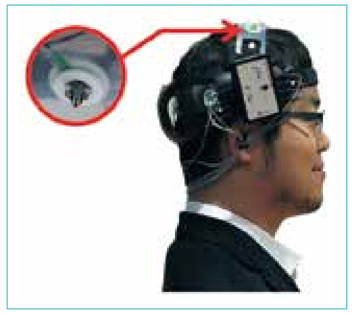
Teams of experienced engineers and relevant internal research groups at NICT coordinate with each other to appropriately manage the facility so that users can enjoy a stable and safe work environment that meets standard requirements. Research and development at NICT encompasses the entire spectrum of ICT technologies, featuring the promotion 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 unit of the integrated Clean Room facility at NICT headquarters, was completed in July 2015 and full-scale operation commenced in April 2016. The facility has class 1000 film-forming chambers, nanofabrication chambers, and class 1000 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 load-lock type vacuum film-forming device 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 inductively coupled plasma (ICP) 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 Facilities of other Institutes and Center in Kobe

Brain Networks and Communication Laboratory, Brain Function Analysis and Imaging Laboratory
(Center for Information and Neural Networks)



Developed wearable EEG

NICT has a 20-year history of neural 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 City, 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 (CiNet) was established in 2013. Since then, the No. 3 building in Kobe continues to play a part in CiNet’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 paste, 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.
CiNet research also covers many other subjects and collaboration with universities and companies has been reinforced. CiNet aims to develop technologies that enhance QOL through neural science.

PANDA, Remote Sensing Laboratory
(Applied Electromagnetic Research Institute)

PANDA tower and container installed
at the Advanced ICT 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 lidar 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)

Time measurement system

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)

Small Optical Ground Station

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 on the left of the picture, comprising the gimbal 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.