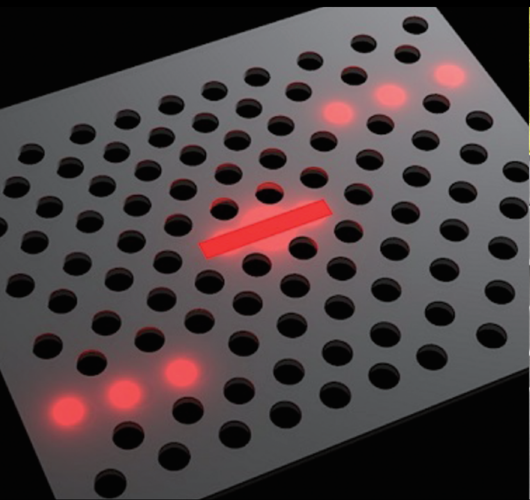
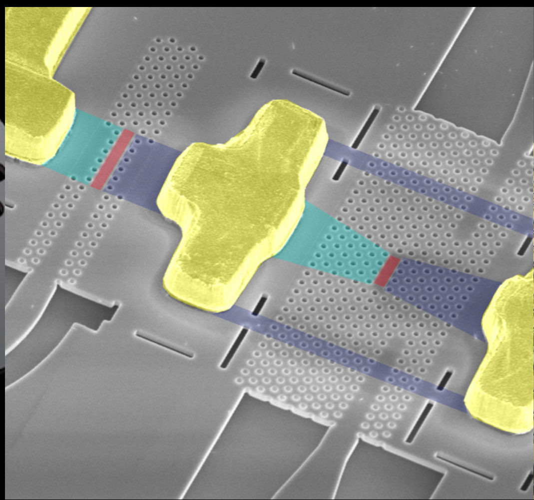
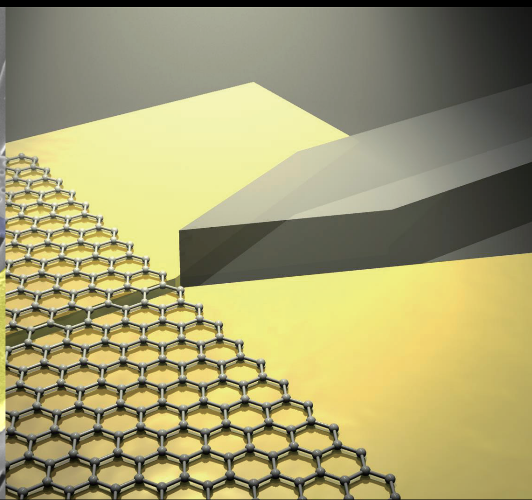
NTT Basic Research Laboratories

Annual Report 2021

NTT BASIC
RESEARCH LABORATORIES

Message from the Director

We at NTT Basic Research Laboratories (BRL) are extremely grateful for your interest and support in our research activities.

Our laboratories' central mission is to promote progress in science and innovations in leading-edge technology that can advance NTT's long-term business, overcoming current limitations in speed, size, and of course energy consumption.

To achieve this, scientists & engineers in the fields of physics, chemistry, biology, mathematics, electronics, informatics, and medicine, conduct fundamental research in material, physical, and quantum science.

An "open door" management policy allows us to collaborate with many universities and research institutes from all over the world, as well as other laboratories within NTT, further enhancing our ability to achieve our missions. We have regularly organized international symposiums and workshops at our Atsugi R&D center to disseminate our research achievements and communicate with fellow scientists, engineers and the public.

Unfortunately, in 2021, we had to postpone the "NTT-BRL School" for young researchers due to the COVID-19 pandemic, but remotely held "ISNTT", an international symposium focused on the latest developments in materials, physical, and quantum sciences for future technologies. We also remotely held our Advisory Board meeting showcasing our latest achievements and receiving their advice & recommendations for the future.

All of these activities enable us to realize our "open door" policy and mission.

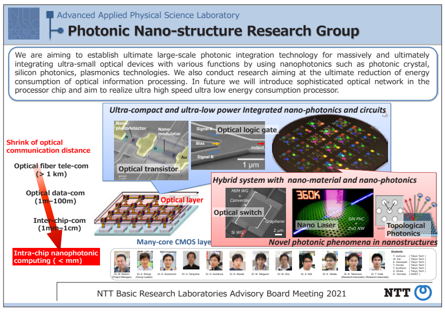
Your continued support would be highly appreciated.

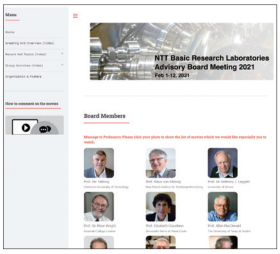
Director of NTT Basic Research Laboratories

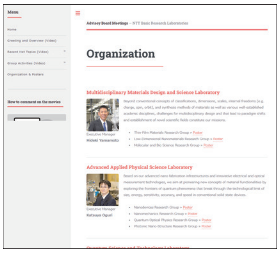
Hideki Gotoh

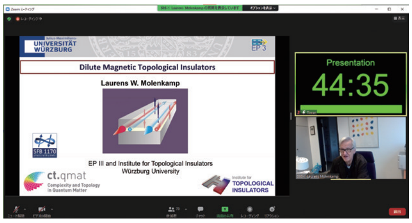
Advisory Board

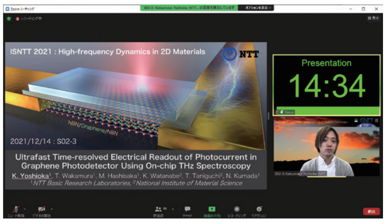
The aim of the Advisory Board is to provide a critical and objective evaluation of our research plans and activities. This enables us to employ strategic management in a timely manner. Proposals and advice received at this biennial board meeting are reflected in our actual ongoing research and its management. The 11th meeting was held online in February, 2021 due to the global spread of the coronavirus. At the meeting, we reported our latest research results and received valuable feedback.











ISNTT

International Symposium on Novel maTerials and quantum Technologies

The International Symposium on Novel maTerials and quantum Technologies (ISNTT) focuses on the latest developments in materials, physical, and quantum sciences for future technologies. This biennial symposium brings together world leading academics, scientists, and students with our NTT BRL researchers to foster interactions, discussions, and collaborations. At ISNTT 2021, keynote talks were given by Prof. Pablo Jarillo-Herrero (MIT), Prof. Yoshiro Hirayama (Tohoku University), Prof. Hidetoshi Katori (University of Tokyo, RIKEN), and Prof. Laurens W. Molenkamp (Würzburg University) alongside 17 invited talks. In addition, 32 contributed presentations were given and 84 posters were presented. In its virtual format, we had 346 participants from 20 countries compared to about 200 participants in the previous symposium.

NTT-BRL School

The NTT-BRL School's mission is to foster the development of young researchers and promote the international visibility of NTT. Since 2017, the school has been held alongside ISNTT, enabling those young researchers to directly interact with world leading experts in the field. However, the ISNTT 2021 virtual format made this extremely difficult to achieve and so the school was postponed until 2023 when the next symposium will take place.

Front image:

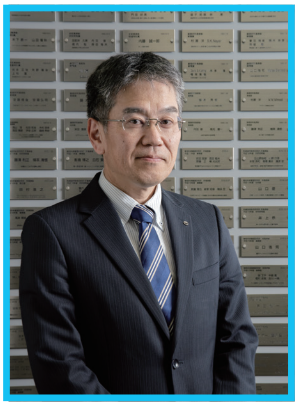
Nanophotonics

By using photonic crystals and plasmons, we can control light in structures that are as large as the wavelength of light or deep-subwavelength. We have developed optical transistors and optical resonators that operate at high speed and ultra-low energy by utilizing the nanophotonics technology, and are aiming to realize highly integrated optical information processing chips in the future.

Organization

NTT Basic Research Laboratories

Director
Hideki Gotoh



Research Planning Section

Executive Manager
Kazuhide Kumakura

Multidisciplinary Materials Design and Science Laboratory

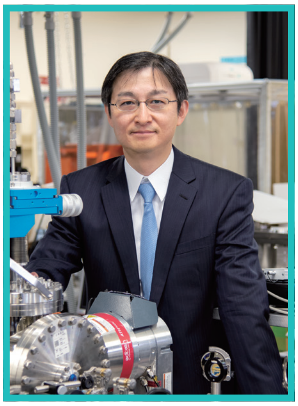
Executive Manager
Hideki Yamamoto

P5

- Thin-Film Materials Research Group
- Low- Dimensional Nanomaterials Research Group
- Molecular and Bio Science Research Group

Advanced Applied Physical Science Laboratory

Executive Manager
Katsuya Oguri



P7

- Nanodevices Research Group
- Nanomechanics Research Group
- Quantum Optical Physics Research Group
- Photonic Nano-Structure Research Group

Quantum Science and Technology Laboratory

Executive Manager
Hiroki Takesue

P9

- Quantum Optical State Control Research Group
- Theoretical Quantum Physics Research Group
- Superconducting Quantum Circuits Research Group
- Quantum Solid State Physics Research Group

The population data of NTT-BRL members

- Researchers (Foreign Researchers)…95(12)
- Research Associate/Specialist…9
- Joint Researcher…8
- International Interns…1*
- Domestic Interns…15*
- Guest Researchers…1*

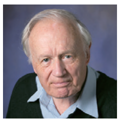
*…Jan. to Dec. 2021 total

As of Dec. 31, 2021

Advisory Board


Chalmers University of Technology, Sweden
Prof. Per Delsing


Max-Planck-Institut für Festkörperforschung, Germany
Prof. Klaus von Klitzing


University of Illinois at Urbana-Champaign, U.S.A.
Prof. Sir Anthony J. Leggett


Imperial College London, U.K.
Prof. Sir Peter Knight


Laboratoire Kastler Brossel, Sorbone Universite, Ecole Normale Superieure, CNRS, France
Prof. Elisabeth Giacobino


The University of Texas at Austin, U.S.A.
Prof. Allan H. MacDonald

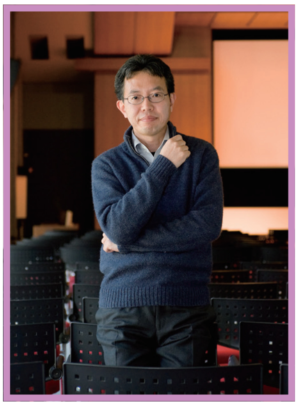

Forschungszentrum Jülich, Germany
Prof. Andreas Offenhäusser


CEA Saclay, France
Prof. Christian Glattli


University of Twente, The Netherlands
Prof. Dave H.A. Blank

Nanophotonics Center

Project Manager
Masaya Notomi



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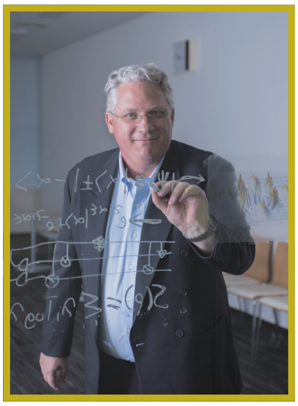
Research Center for Theoretical Quantum Physics

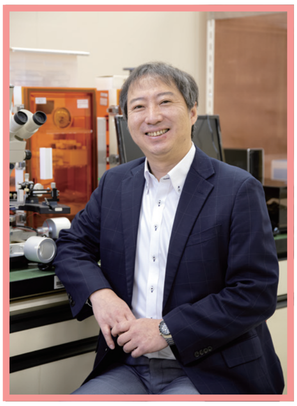
Project Manager
William John Munro



P11

Bio-Medical Informatics Research Center

Project Manager
Hiroshi Nakashima



P11

Research Professors

Director, Medical & Health Informatics Laboratories (MEI Lab), NTT Research, Inc.
Prof. Hitonobu Tomoike

Tohoku University
Prof. Masao Morita

Director, Physics & Informatics Laboratories (PHI Lab), NTT Research, Inc.
Prof. Yoshihisa Yamamoto

University of Toyama
Prof. Kiyoshi Tamaki

Multidisciplinary Materials Design and Science Laboratory

Overview

The aim of the Multidisciplinary Materials Design and Science Laboratory is to contribute to progress in materials science and to revolutionize information communication technology by creating novel materials with various internal degrees of freedom (lattice, charge, spin, orbital, etc.) through materials design and synthesis beyond conventional concepts of classifications, dimensions, scales, and synthesis methods. The research groups that constitute this laboratory are investigating a wide range of materials including semiconductors, superconductors, magnetic materials, topological materials, conductive polymers, and biological soft materials. We are conducting innovative materials research based on advanced thin-film growth technologies, high-precision and high-resolution measurements of structures, properties along with theoretical studies, and data science (informatics).

Groups and Research Themes

Thin-Film Materials Research Group

Novel Semiconductor Devices

Creation of light-emitting devices over a wide range from DUV to NIR, high-efficiency energy conversion devices, high-power devices, and novel multifunctional (optical, electric, and spintronic) devices

Low-Dimensional Nanomaterials Research Group

2D atomic-layer Materials

Creation of ultimately thin functional atomic-layer materials for next-generation electronics

Complex Oxide Thin Films

Creation of trailblazing superconductors and magnetic materials beyond conventional concepts

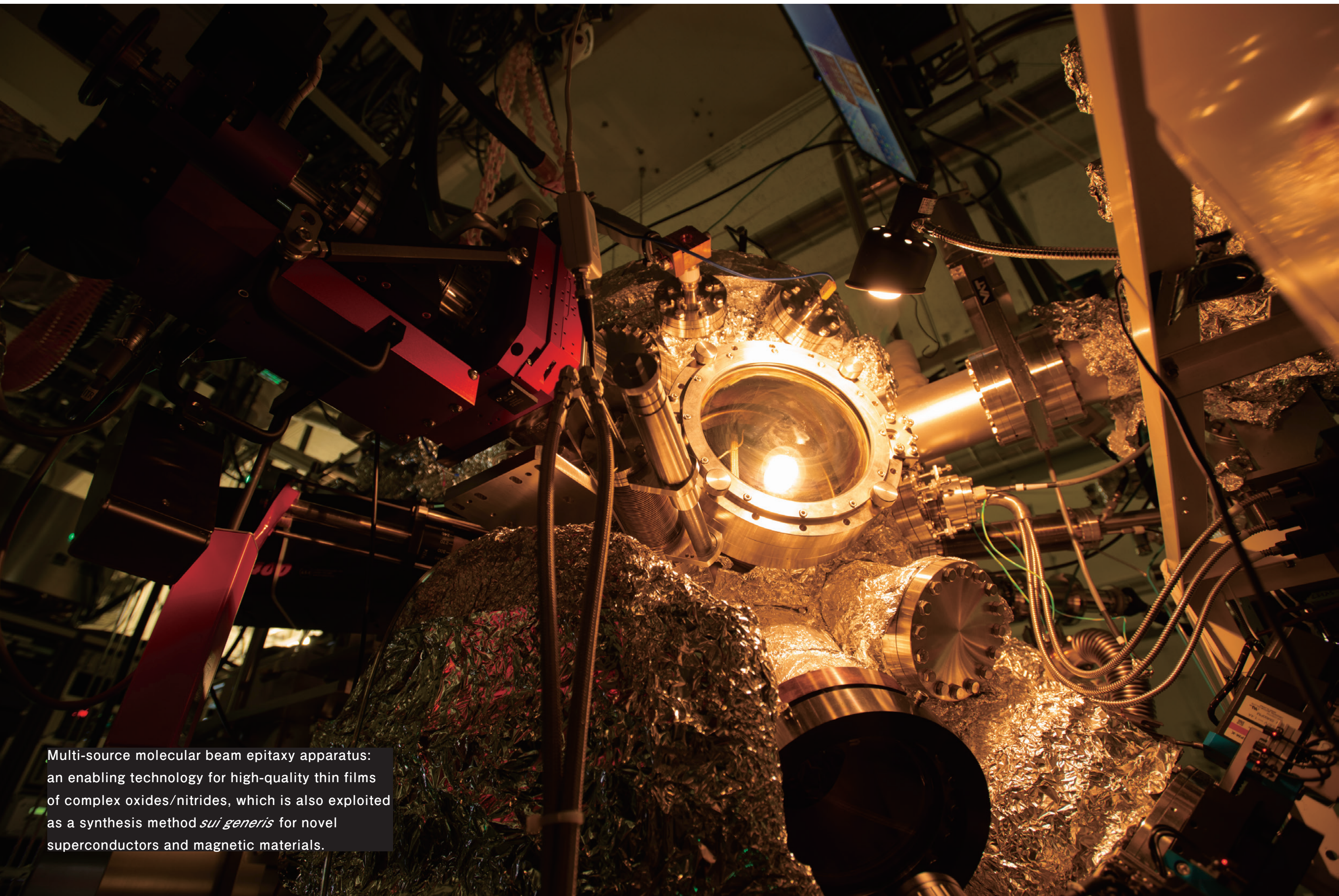
Molecular and Bio Science Research Group

Biocompatible Electrode Materials

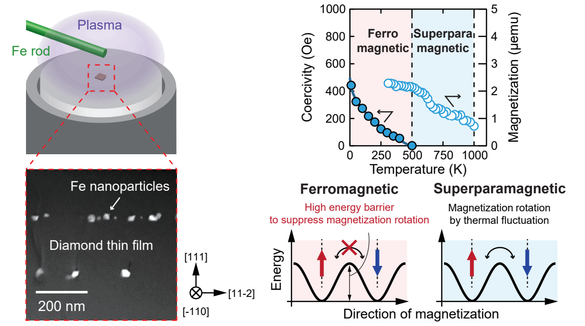
Development and application of bioelectrode materials for measurement of deep biological information

Bio-devices

Creation of bio-functional mimetic devices exploiting biomolecules, cells, and soft materials



Multi-source molecular beam epitaxy apparatus: an enabling technology for high-quality thin films of complex oxides/nitrides, which is also exploited as a synthesis method *sui generis* for novel superconductors and magnetic materials.



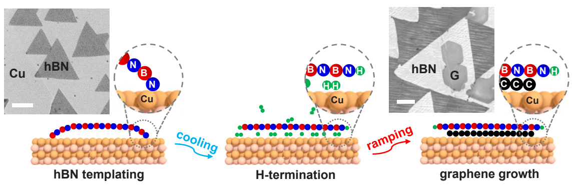
(L) Diamond thin films embedded with Fe nanoparticles grown by our plasma CVD techniques
(R) Unique magnetic properties due to the ferromagnetic and superparamagnetic state of Fe nanoparticles and the schematic of the origin of their magnetic properties

Magnetic Properties of Fe Nanoparticles Embedded in Diamond Thin Films

A spin transistor, a device that utilizes spins as a new information carrier, is expected to achieve ultralow-power consumption due to its non-volatile functionality. Diamond is a promising material as a semiconductor but also expected to show excellent spin transport properties even above room temperature. Therefore, we are exploring the application of diamond to spintronics. In this study, we succeeded in growing diamond thin films embedded with Fe nanoparticles and observing the unique magnetic properties of the Fe nanoparticles. Moreover, our analysis revealed the origin of those properties. This result is a major step toward the realization of practical spin devices.

M. Kawano, K. Hirama, and K. Kumakura, International Conference on New Diamond and Nano Carbons 2020/2021.

Epitaxial Intercalation Growth

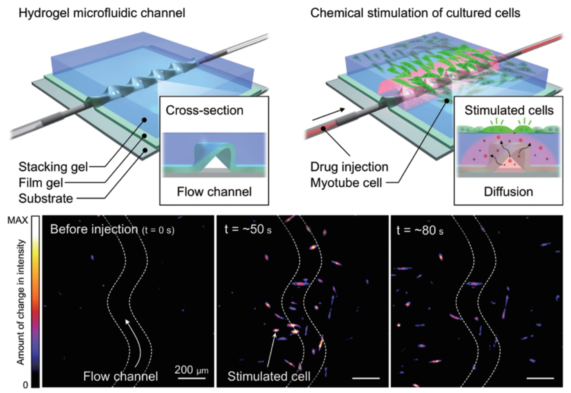


Schematic of one-pot growth of hexagonal boron nitride/graphene heterostructure via epitaxial intercalation. The scale bar is 2 μm.

Epitaxial Intercalation Growth of Hexagonal Boron Nitride/Graphene Vertical Heterostructure

High-throughput synthesis of vertically stacked two-dimensional materials with desired interlayer angles is essential to investigate their novel physical properties and consequently explore their potential practical applications. We have demonstrated a novel method named "epitaxial intercalation" for one-pot chemical vapor deposition growth of a hexagonal boron nitride (hBN)/graphene vertical heterostructure. In this method, graphene growth occurs at the interface between hBN and a catalyst, leading to good and uniform interlayer alignment. The hBN/graphene heterostructure prepared thus exhibits superior electronic properties such as high carrier mobility.

S. Wang, J. Crowther, H. Kageshima, H. Hibino, and Y. Taniyasu, ACS Nano 15, 14384 (2021).

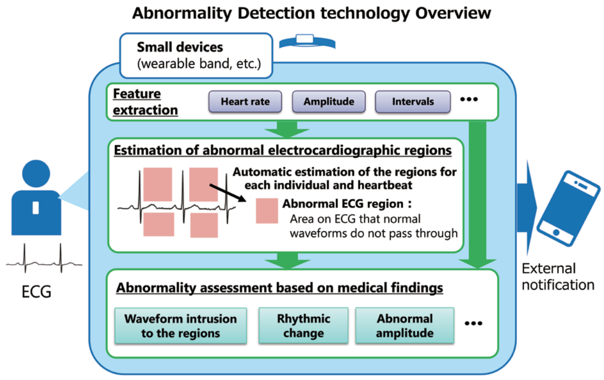


(Top left) Schematic illustration of hydrogel microfluidic channel. (Top right) Chemical stimulation of cells cultured on the device. (Bottom) Fluorescence observation of the chemical stimulation of cells from the top surface.

Creation of On-chip Hydrogel Channels for Reproducing In-vivo Environments

To express and evaluate advanced mature cellular functions, it is important to develop technologies to reproduce scaffolds with structures and properties similar to those of biological tissues in vitro. We have devised an on-chip method to fabricate a flow channel that mimics blood vessels using a hydrogel with high biocompatibility and permeability. In addition, by culturing cells on the layer-stacked gel and injecting drugs into the channels, we succeeded in local chemical stimulation of cells through molecular diffusion. This result is expected to be developed as a fundamental technology for reproducing the in-vivo environment to analyze the detailed functions and kinetics of cells.

R. Takahashi, H. Miyazako, A. Tanaka, and M. Yamaguchi, Lab Chip 21, 1307-1317 (2021).



Heart Abnormality Detection Technology for ECG Transmitters

To detect serious cardiac abnormalities early by utilizing the functional material hitoeTM, we have developed an algorithm for detecting heart abnormalities that operates inside a wearable device. The algorithm also suppresses false detection of cardiac abnormalities caused by floating bioelectrodes and body motion noise. We provided this technology to group companies as a technology to detect heart abnormalities in users of rehabilitation-support robots.

In the future, we will proceed with research and development toward the realization of new services that support us in our daily lives, such as detection of the various types of heart disease and visualization of potential heart disease risk factors.

Advanced Applied Physical Science Laboratory

Overview

The Advanced Applied Physical Science Laboratory has launched towards the creation of innovative information communication technologies and future functional devices that bring long-term value for the accelerating technology-driven society. Leading research groups in the fields of nanoelectronics, nanomechanics, nanophotonics, spintronics, and quantum electronics are closely collaborating for this exciting challenge. We will pioneer the forefront of the applied physical science field and discover novel functionalities in solid-state quantum systems based on our nanofabrication technology, advanced measurement technology, and light-wave technology.

Groups and Research Themes

Nanodevice Research Group

Single-electron Devices for Ultimate Electronics

Highly accurate, highly sensitive, and low-power devices based on single charge transfer and detection

Nanodevices with Novel Functions

Novel and high performance nanodevices based on silicon and hybrid materials

Nanomechanics Research Group

Semiconductor Opto/electromechanics

Novel devices using mechanical functionality in semiconductor fine structures

Phonon Manipulation

Propagation control of acoustic waves using artificial structures

Quantum Optical Physics Research Group

Manipulation of Ultrafast and Ultra-stable Laser Field

Explore ultrafast physics and establish the standard optical frequency

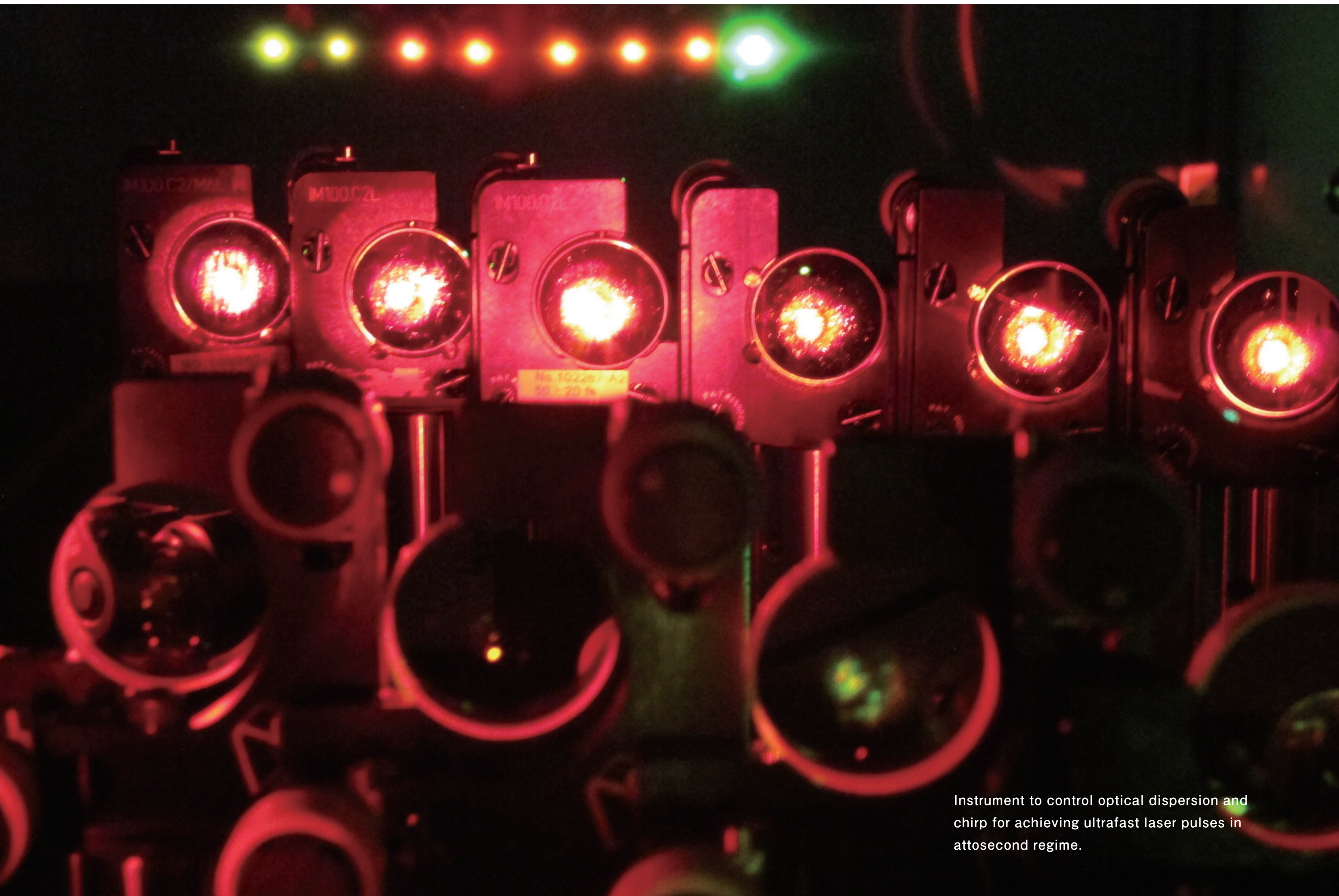
Nano-scale Physics in Optically-active Materials

Characterize photons, excitons and spins in the semiconductor nano-structures and rare-earth ions.

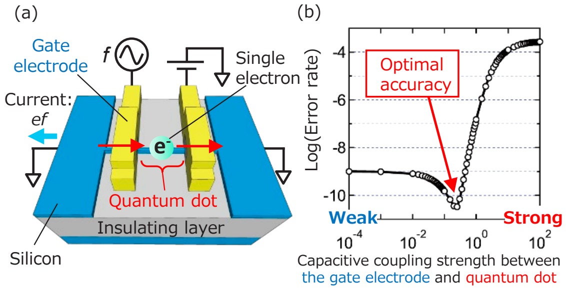
Photonic Nano-Structure Research Group

Integrated Nanophotonics Technologies

Ultra-compact and ultra-low power photonic devices and circuits, novel photonic phenomena in nanostructures



Instrument to control optical dispersion and chirp for achieving ultrafast laser pulses in attosecond regime.

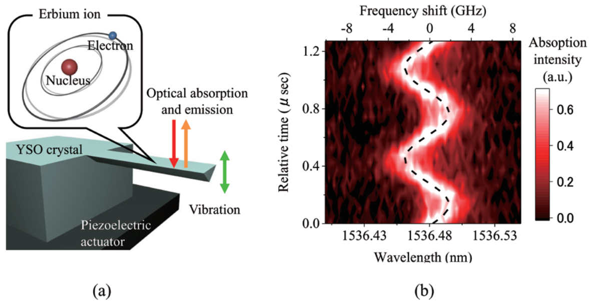


(a) Schematic of a silicon single-electron transfer device. Electrons are transferred one by one by applying a high-frequency signal (frequency *f*) to the gate. (b) Capacitive coupling strength dependence of the transfer error rate.

Discovering a Guideline for Minimizing Single-electron Transfer Error Rate

Single-electron transfer through a quantum dot can generate an accurate current, and is expected to be applied to a quantum current standard, which corresponds to a ruler with which to measure electric current. For this application, the error rate of the single-electron transfer must be sufficiently low. In this study, we investigated the transfer mechanism in a silicon single-electron transfer device (Fig. a) in detail using theoretical calculations, and found that there is an optimal accuracy (i.e., the transfer error rate is minimized) in the intermediate regime of capacitive coupling between the gate electrode and quantum dot (Fig. b). By fabricating a device with a structure in the intermediate regime, we can expect to realize ultrahigh-precision single-electron transfer.

G. Yamahata, N. Johnson, and A. Fujiwara, Phys. Rev. B 103, 245306 (2021).

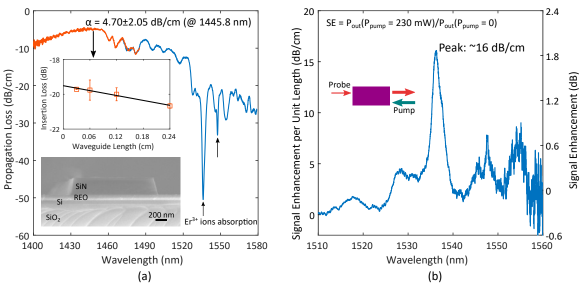


(a) Schematic image of an optomechanical device with rare earth materials
(b) Mechanical control of the emission centers of rare earth materials

Realization of an Optomechanical Device with Extremely Low Optical Energy Loss

Optomechanical devices are attracting attention as functional devices that add mechanical degrees of freedom to optical devices such as light-emitting diodes. They have so far been built by using easy-to-process semiconductor materials. In contrast, we have succeeded in creating a novel optomechanical device with orders of magnitude smaller optical energy loss than conventional ones by using rare-earth-doped crystals, whose optical properties are superior to those of semiconductors. This achievement will lead to the creation of ultrasmall, low-loss optical devices such as optical amplifiers utilizing minute vibrations.

R. Ohta, L. Herpin, V. M. Bastidas, T. Tawara, H. Yamaguchi, and H. Okamoto, Phys. Rev. Lett. 126, 047404 (2021).

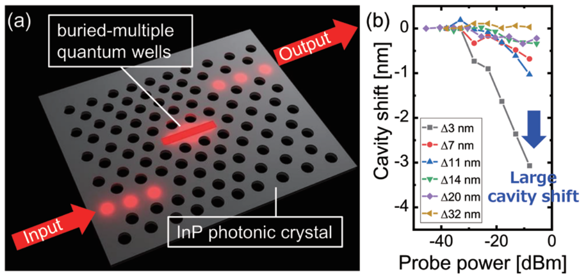


(a) Propagation loss spectrum of rare-earth oxide thin film waveguide.
(b) Signal enhancement spectrum of rare-earth oxide thin film waveguide.

Low-loss Rare-earth Oxide Thin Film Waveguides and Optical Signal Enhancement in Them

Expitaxial single-crystal rare-earth oxide thin films are one of the most promising candidate materials for silicon-based active photonic and quantum optical devices. We have proposed and demonstrated low-loss waveguides based on the mechanism of bound states in the continuum. We have also successfully observed large optical signal enhancement in the telecommunications band in these waveguides upon optical pumping. Our results represent an important step towards the realization of high-performance monolithically integrated optical amplifiers and lasers on silicon, as well as provide us a promising platform for on-chip quantum memories.

X. Xu, T. Inaba, T. Tsuchizawa, A. Ishizawa, H. Sanada, T. Tawara, H. Omi, K. Oguri, and H. Gotoh, Opt. Express 29, 41132 (2021).



(a) Schematic of MQWs buried in an L3 photonic crystal cavity
(b) Probe power vs cavity wavelength shift for different detuning conditions

Excitonic Nonlinear Shifts in Photonic Crystal Nanocavities with Buried Multiple Quantum Wells

A buried multiple-quantum-well well confines excitons, so-called quasiparticles, in a nano-region. We demonstrated large nonlinear refractive index changes in a photonic crystal nanocavity with buried multiple-quantum-wells, which induce large light-matter interactions. These structures can realize attojoule-level all-optical photonic crystal switches and will contribute to the future realization of high-performance optical processors.

M. Takiguchi, K. Nozaki, H. Sumikura, N. Takemura, T. Fujii, E. Kuramochi, A. Shinya, S. Matsuo, and M. Notomi, Appl. Phys. Lett., 118, 111101 (2021), Editors' Pick

Quantum Science and Technology Laboratory

Overview

The Quantum Science and Technology Laboratory will contribute to the exploration of the quantum science field and the development of new technologies for overcoming the conventional information processing limits with quantum-enabled devices and systems. With quantum information theory and our experimental research in photonic, semiconductor, and superconducting systems as a basis, we aim to achieve new technologies in the areas of quantum communication, quantum sensing, optical oscillator-based computing, and quantum computing based on superconducting circuits and topological phenomena.

Groups and Research Themes

Quantum Optical State Control Research Group

Photonic Quantum Communication

Control of quantum state of light and its application to novel communication systems

Non-von Neumann Computation Using Quantum Optics

New computers based on coupled optical oscillators

Theoretical Quantum Physics Research Group

Theoretical Quantum Information Science

Proposal and systematic design of quantum computation, communication, network and metrology schemes including architectures.

Superconducting Quantum Circuits Research Group

Superconducting Quantum Circuits

Manipulating quantum states using superconducting devices

Ultimate Quantum Measurement and Sensing

Highly sensitive measurement technologies using quantum mechanical effects

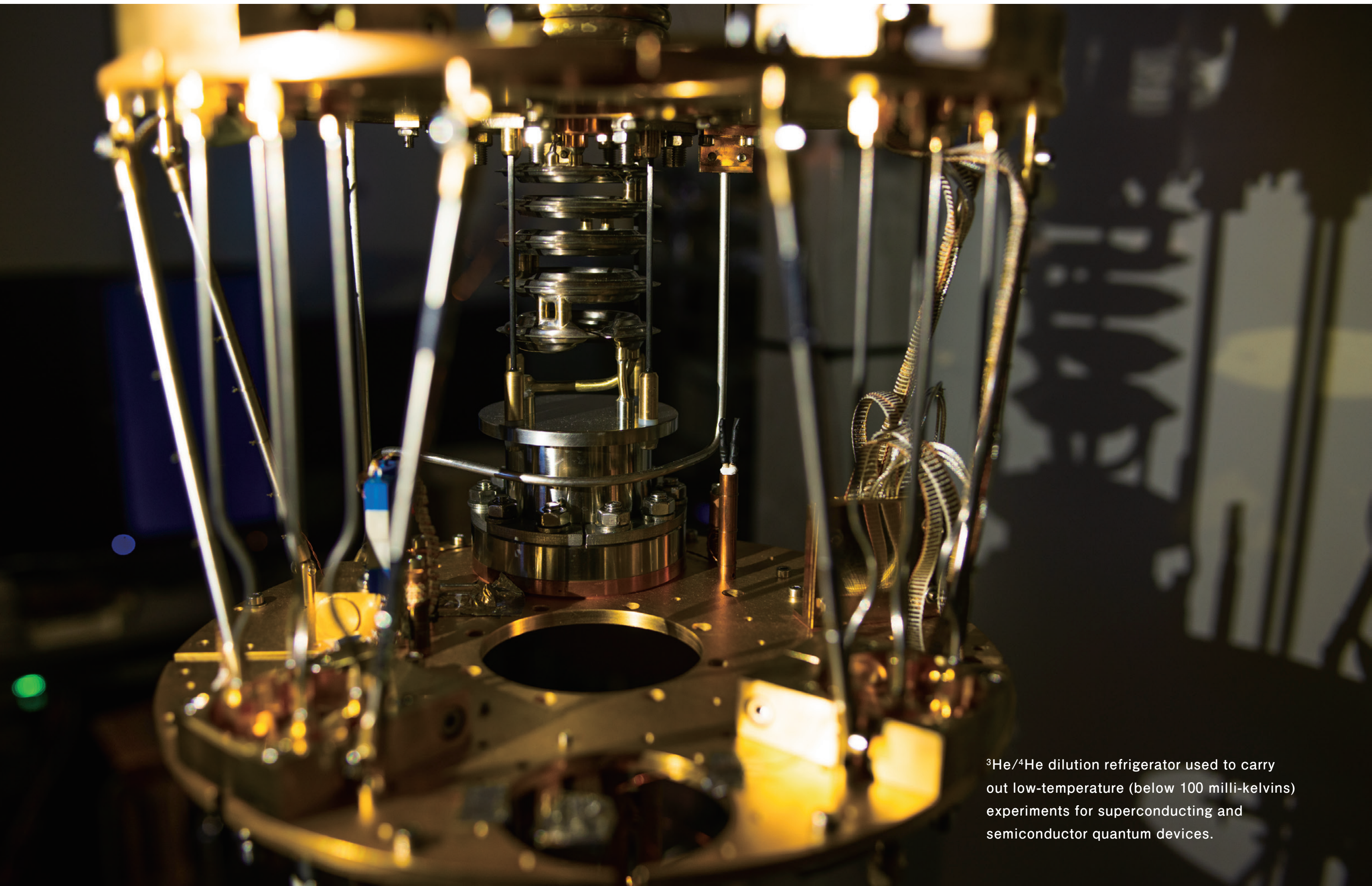
Quantum Solid State Physics Group

Quantum Transport in Hetero- and Nano-structures based on Semiconductor and 2D Materials

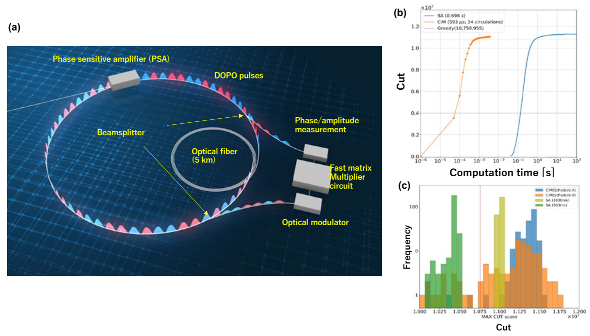
Unconventional charge and spin transport phenomena in quantum devices

Fast Coherent Carrier Dynamics in Electronic Devices

Information processing with coherent electron motion



$^{3}He/^{4}He$ dilution refrigerator used to carry out low-temperature (below 100 milli-kelvins) experiments for superconducting and semiconductor quantum devices.

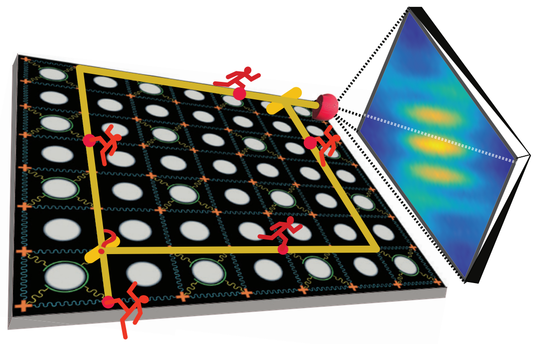


(a)Schematic diagram of the CIM concept.
(b)Evaluation of computation time.
(c)Evaluation of solution accuracy.

100,000-spin Coherent Ising Machine

Coherent Ising machines (CIMs) are drawing attention as a new type of computer that can solve combinatorial optimization problems using a network of degenerate optical parametric oscillators (DOPOs). We have constructed a CIM based on a network of 100,000 DOPOs-the world's largest CIM. We solved a maximum cut problem of a fully connected 100,000-node graph, and found that the CIM could find approximate solutions with a particular solution accuracy 1,000 times faster than simulated annealing (SA) implemented on a CPU. We also found that the CIM operated at near the DOPO threshold could deliver a broad solution distribution with some very good solutions compared with the distribution obtained by SA.

T. Honjo, T. Sonobe, K. Inaba, T. Inagaki, T. Ikuta, Y. Yamada, T. Kazama, K. Enbutsu, T. Umeki, R. Kasahara, K. Kawarabayashi, and H. Takesue, Sci. Adv. 7, abh0952 (2021).

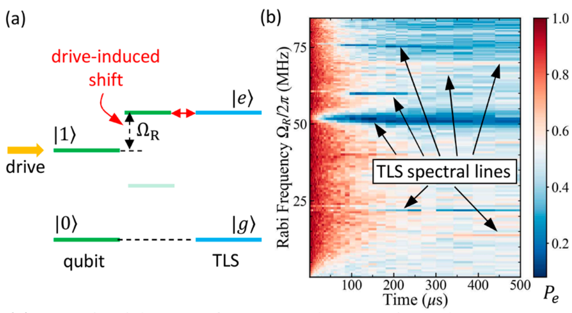


Interference pattern of two quantum walkers in the Mach-Zender interferometer.

Quantum Walks on a Two-dimensional Programmable 62-qubit Superconducting Processor

Quantum walks have attracted considerable world-wide attention and have been experimentally realized in various platforms ranging from photonics to trapped ions. However, the implementation of multi-particle quantum walks in programmable devices has remained a technological challenge. In our work, we have designed and fabricated an 8-by-8 square programable superconducting array with 62 functional superconducting qubits. The design allows the creation of multiple excitations that play the role of quantum walkers. We experimentally demonstrated high-fidelity single-particle and two-particle quantum walks, which allows us to measure the propagation velocity of information and to realize a two-particle Mach-Zehnder interferometer. Our demonstration of 2D quantum walks shows the potential of superconducting devices to exploit quantum advantages for future applications in quantum search and universal quantum computation.

M. Gong, *et al.*, Science 372, 948 (2021).

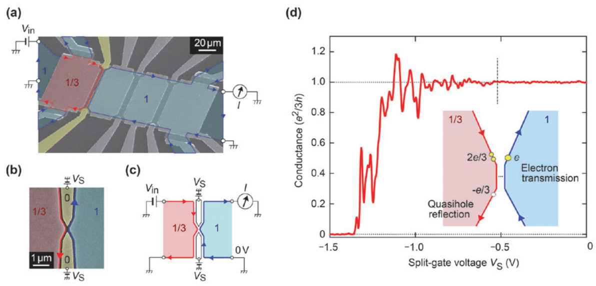


(a) Energy level diagram of a superconducting qubit and a parasitic two-level-system (TLS) defect.
(b) Results of TLS defect detection using a strong qubit drive.

Detection of High-frequency Defects in Superconducting Qubits

Parasitic two-level-system (TLS) defects are among the dominant sources of decoherence in superconducting qubits. We realized a novel method of high-frequency TLS defect spectroscopy using a strong qubit drive. By irradiating a qubit with a strong microwave pulse at the qubit transition frequency, the qubit is dynamically coupled to an initially off-resonance TLS defect, and defect characteristics are determined by probing the qubit state relaxation. This method of TLS defect spectroscopy can be used for quality control in the fabrication of both flux-tunable and fixed-frequency qubits, enabling further improvement of the coherence times of superconducting qubits.

L. V. Abdurakhimov, I. Mahboob, H. Toida, K. Kakuyanagi, Y. Matsuzaki, and S. Saito, APS March Meeting 2021, abstract J28.00002 (2021).



(a) False-color electron micrograph of the sample.
(b) Magnified view of the quantum Hall junction. (c) Schematic of the measurement setup.
(d) Conductance I/V_{in} measured as a function of V_S. Conductance exceeding $e^2/3h$ indicates the current enhancement due to the Andreev process.
(Inset) Schematic Andreev reflection of fractional quasiparticles.

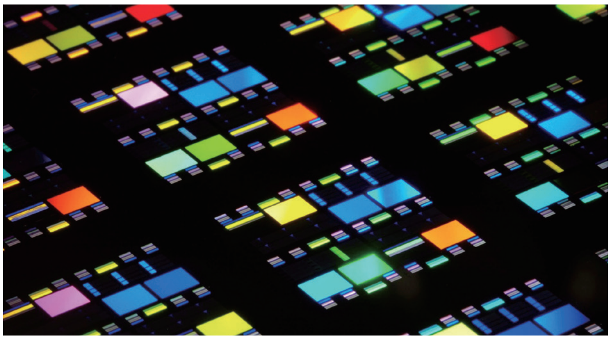
Andreev Reflection of Fractional Quantum Hall Quasiparticles

We observed an Andreev-type reflection of a fractionally charged quasiparticle in a semiconductor. In this phenomenon, the incidence of fractionally charged quasiparticles at an interface between fractional and integer quantum Hall states of a two-dimensional electron system causes transmission of an electron and reflection of a hole having a fractional charge. This is an analogous process of Andreev reflection at a normal metal-superconductor junction. Our observation will accelerate the development of topological quantum information technology based on exotic quantum Hall quasiparticles.

M. Hashisaka, T. Jonckheere, T. Akiho, S. Sasaki, J. Rech, T. Martin, and K. Muraki, Nat. Commun. 12, 2794 (2021).

Nanophotonics Center

Nanophotonics Center



Overview

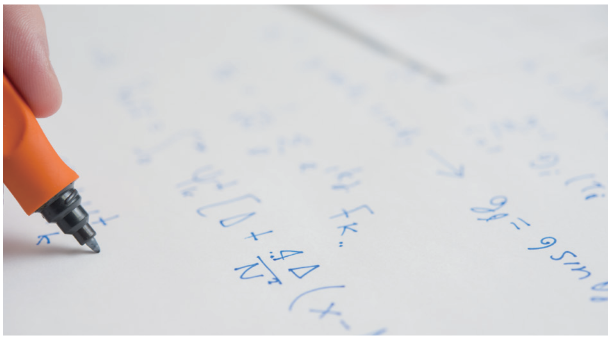
The Nanophotonics Center was established in April 2012 and is composed of several groups involved in nanophotonics research at NTT Basic Research Laboratories and NTT Device Technology Laboratories. We are conducting studies of photonic crystals to reduce the footprint and energy consumption of various photonic devices, such as optical switches, optical memories, modulators, lasers, and photo-detectors. We are also studying various photonic nanostructures to greatly enhance light-matter interactions, and exploiting photonic integrated circuits and devices for on-chip signal processing.

Research Themes

- **Extreme enhancement of light-matter interactions by using photonic crystals and plasmonics**
- **Integrable nanophotonic devices with extremely small energy consumption**
- **Novel optical platforms using nanomaterials and nanophotonics**
- **Nanophotonic computations with photonics-electronics convergence**

Research Center for Theoretical Quantum Physics

Research Center for Theoretical Quantum Physics



Overview

The twentieth century saw the discovery of quantum mechanics, a set of principles that explains the nature of matter and light at the atomic level. These counter-intuitive principles have not only dramatically changed our understanding of the reality of our physical world but also enabled a technological revolution. They are responsible for the digital age in which we live. Naturally arising questions are what further we can learn from these principles and what technological advances could be enabled. The Center for Theoretical Quantum Physics established in July 2017 brings together diverse researchers (physicists, computer scientists, mathematicians and even chemists) from across NTT to pursue cutting edge research in a highly collaborative environment.

Research Themes

- **The foundation of quantum mechanics**
- **Quantum matter**
- **Quantum algorithms and complexity**
- **Quantum communication, simulation and computation**
- **Quantum metrology and sensing**
- **Atomic, molecular and optical physics**

Bio-Medical Informatics Research Center

Bio-Medical Informatics Research Center

Overview

The Bio-Medical Informatics Research Center (BMC) was established in July, 2019 as a research organization in which related NTT laboratories collaborate with the goal of creating data-driven medicine using ICT and AI. The BMC engages in basic and applied research on AI analysis of medical and health data, genome information and behavior information, real-time biomonitoring in daily life, biomimetic nanodevices, and new biocompatible materials. In addition, it promotes innovations in medical and health fields in cooperation with partners at medical institutes and Medical & Health Informatics Laboratories (MEI Lab), NTT Research Inc.

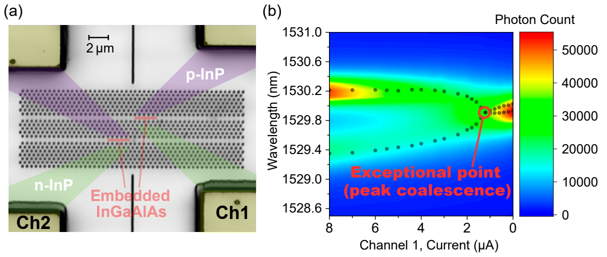
Research Themes

- **Personalized medicine by AI analysis of personal medical data (precision medicine)**
- **Cardiac modeling and rehabilitation activities supported by AI-tele stethoscope and hitoe® ECG measurement**
- **Lifestyle-related disease management based on noninvasive blood glucose sensor and core body temperature sensor**
- **Fabrication of implant materials and artificial neural networks that complement biological functions**

Spontaneous Emission of Coupled Photonic Crystal Lasers Operated under Exceptional Point Degeneracy

An exceptional point (EP) is a peculiar degeneracy of eigenstates, which can be induced by processes where energy is not conserved, such as gain and loss. In this work, we fabricated a system of two coupled photonic crystal lasers that can be controlled independently by current injection. By introducing the contrast of their absorption loss, we observed the first spontaneous emission of lasers operated at an EP. As a result, we successfully demonstrated the spectral narrowing and enhanced radiation that are particular to the EP. Our work will open up a new frontier of optical signal control by gain and loss in nanophotonics.

K. Takata, K. Nozaki, E. Kuramochi, S. Matsuo, K. Takeda, T. Fujii, S. Kita, A. Shinya, and M. Notomi, Optica 8, 184-192 (2021).

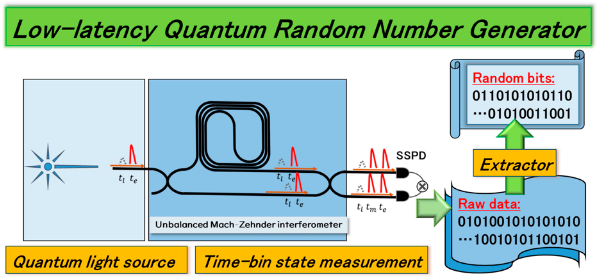


(a)Two coupled photonic crystal lasers based on current-injected buried heterostructure nano cavities.
(b)Color plot of the spontaneous emission spectra of the device for constant current to channel 2 of 100 μA and different current to channel 1.Black points: eigen-wavelengths of theoretical analysis.
Adapted with permission from © The Optical Society.

A Simple Low-latency Real-time Certifiable Quantum Random Number Generator

Random numbers are important resources consumed within many applications used in our everyday lives. Generating truly random numbers is a challenge; however, they can be generated by measuring quantum mechanical systems. Previous quantum random number generators (QRNGs) unfortunately suffer from high latency between the initial request and the delivery of the random bits. We have realized a low-latency real-time certifiable QRNG by measuring photonic time-bin states, where every 0.12 seconds we generate 8,192 random bits which are secure against all quantum adversaries. Our semi-device-independent QRNG is ideal for the realization of a high-speed continuously operating quantum randomness beacon with high security.

Y. Zhang, H.-P. Lo, A. Mink, T. Ikuta, T. Honjo, H. Takesue, and W. J. Munro, Nat. Commun. 12, 1056 (2021).

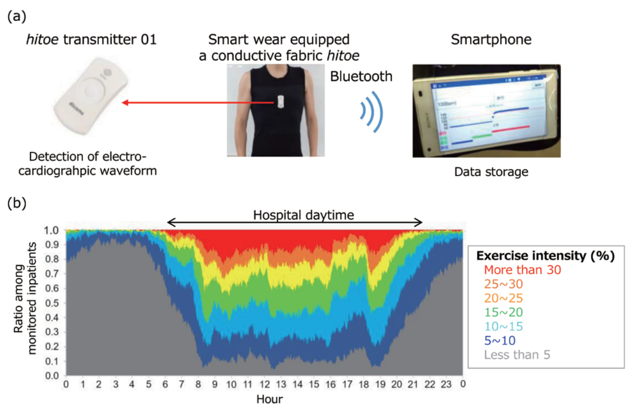


Schematic diagram of the time-bin-based quantum random number generator.

Exercise Intensity Monitoring of Stroke Rehabilitation Inpatients

Increasing the amount of daily activity through self-training has been shown to improve physical strength as well as to facilitate learning of motion skills for achieving independence in activities performed in daily life To increase the amount of activity safely and effectively, we have been facilitating a clinical study with a wearable monitoring system using functional textile 'hitoe' to monitor the activity of stroke inpatients in a rehabilitation ward. In this study, we developed a novel data imputation method by using ensemble averaging. This method reduces day-to-day variations of measured data and imputes data loss more effectively with significance compared with a conventional method. The method enabled the visualization of the exercise intensity of 63 stroke rehabilitation inpatients over a period of 24 hours.

T. Ogasawara, M. Mukaino, Y. Otaka, H. Matsuura, Y. Aoshima, T. Suzuki, H. Togo, H. Nakashima, M. Yamaguchi, S. Tsukada, and E. Saitoh, J. Med. Biol. Eng. 41, 322–330 (2021).



(a) Configuration of wearable monitoring system
(b) Exercise intensity of 63 stroke rehabilitation inpatients during 24 hours

NTT Fellow

Shingo Tsukada

Medicine, Physiology, Biomedical interface & data analysis

Research Subject

Biological Information Elucidation Using Advanced Medical Materials

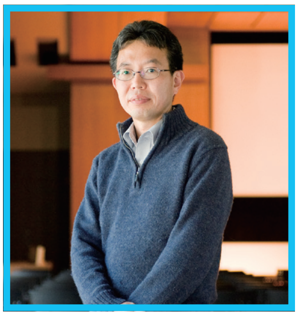
The title of "NTT Fellow" is reserved for our most gifted scientist and engineers whose research and development activities have brought them significant distinction both within NTT and internationally. Our "Fellows" are extremely highly regarded. Next the title of "Senior Distinguished Researcher" is given to outstanding individuals who have established themselves as global intellectual leaders of their own research areas. The "Distinguished Researcher" title is given to innovative researchers whose impressive achievement has been recognized both within and outside NTT.
They all are responsible for leading innovative research and cutting-edge technical developments in research areas considered important to NTT.

December 31, 2021

Senior Distinguished Researcher

Masaya Notomi

Nanophotonics Center Project Manager



Research Subject

Photon Manipulation in Photonic Nanostructures

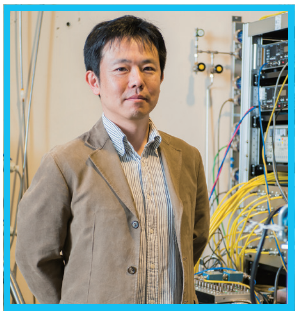
Hiroshi Yamaguchi

Quantum and Nano Device Research

Research Subject

Nano-mechanics in Semiconductors

Koji Muraki

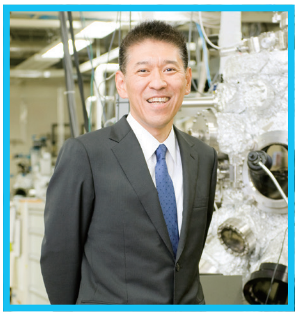


Research Subject

Electron Correlation in Semiconductor Nanostructures

Hideki Yamamoto

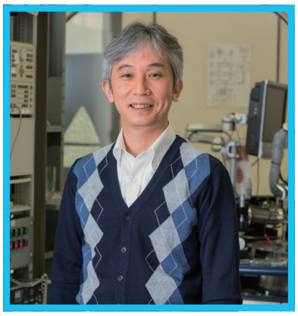
Multidisciplinary Materials Design and Science Laboratory Executive Manager



Research Subject

Design and thin-film synthesis of novel superconductors and magnetic materials with elucidation of the underlying physics

Akira Fujiwara

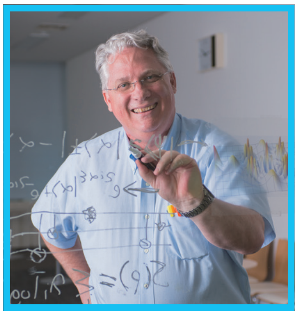


Research Subject

Ultimate Electronics Using Semiconductor Nanostructures

William John Munro

Research Center for Theoretical Quantum Physics Project Manager



Research Subject

The Design of Quantum Technologies

Hiroki Takesue

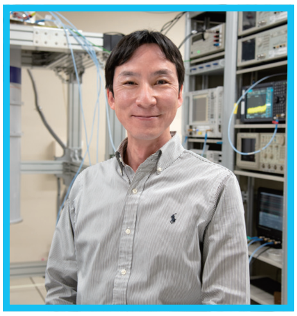
Quantum Science and Technology Laboratory Executive Manager

Research Subject

Quantum Communication Experiments in Telecommunication Band Coherent Ising Machine

Shiro Saito

Quantum Optical Physics Research Group Leader



Research Subject

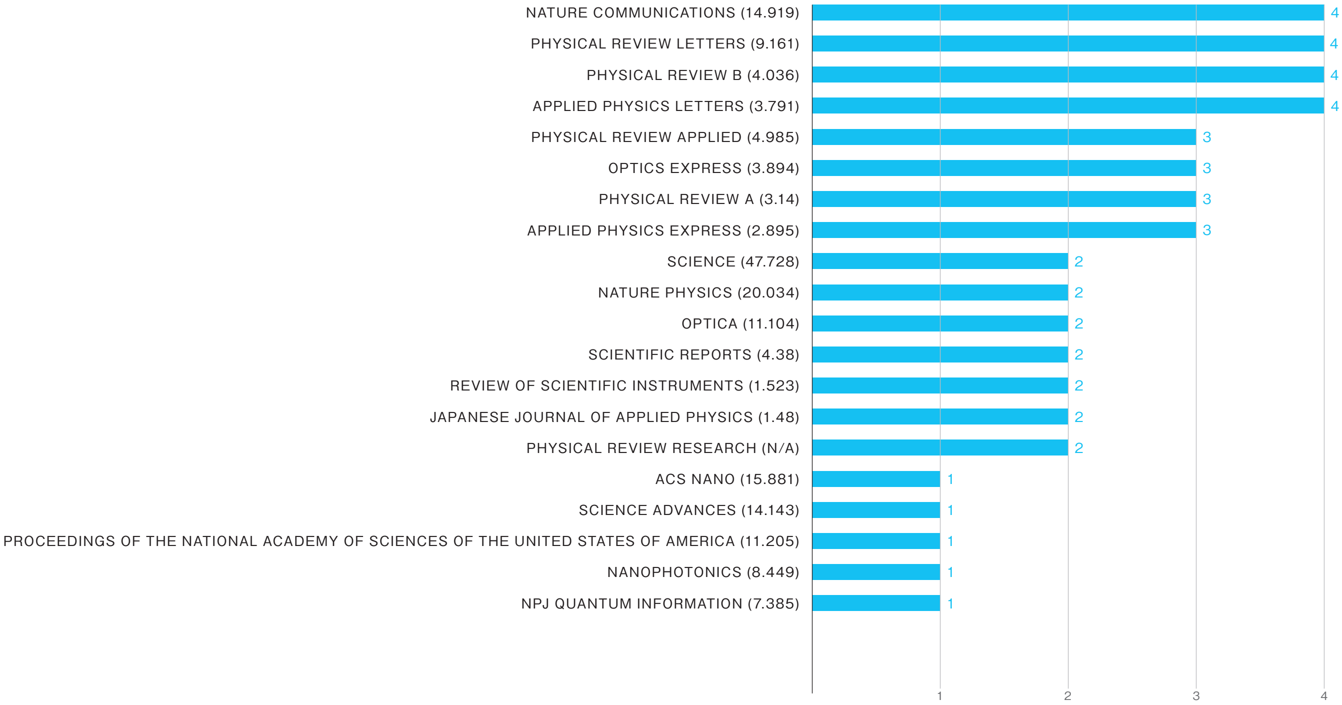
Quantum information technologies based on superconducting quantum circuits

Distinguished Researcher

Norio Kumada
Katsuhiko Nishiguchi
Haruki Sanada
Imran Mahboob
Kengo Nozaki
Koji Azuma
Takahiro Inagaki
Hajime Okamoto
Gento Yamahata

Publication List

The total number of NTT Basic Research Laboratories papers published in international journals in 2021 is 67 with an average impact factor of 7.122. The 2020 impact factor of those individual journals are shown in ( ).



Number of Presentations

156
(33 Invited talks)

Number of Patents

55

List of Award Winners

The Young Scientists' Award, the Commendation for Science and Technology by the Minister of Education, Culture, Sports, Science and Technology
High-accuracy Single-electron Control Using Silicon Quantum Dots **Gento Yamahata**

APSIPA Industrial Distinguished Leader
Nanofiber-Electroconductive Textile "hitoe" for ECG Monitoring and Cardiac Pacemaker Electrodes **Shingo Tsukada**

IEICE Distinguished Achievement and Contributions Award
Masaya Notomi

JSAP Promotion and Nurturing of Female Researchers Contribution Award
Research on Functional Devices Based on Large-scale Graphene **Makoto Takamura**

American Physical Society Outstanding Referee
William John Munro
Kenta Takata

IEICE Best Paper Award
Methods for Reducing Power and Area and BDD-based Optical Light Circuits
Ryosuke Matsuo, Jun Shiomi, Tohru Ishihara, Hidetoshi Onodera, Akihiko Shinya, Masaya Notomi

JSAP Research Encouragement Award
Electron Paramagnetic Resonance Spectroscopy Using a Single Artificial Atom Communications Physics 2, March 2019, 33 **Hiraku Toida**

JSAP Young Scientist Presentation Award
Novel Superconducting $(CaCuO_2)_n/(Ca_2Fe_2O_5)_m$ Superlattices Prepared by MBE **Ai Ikeda**

JSAP Young Researcher Best Presentation Award
Development of 3D-cultured Neuronal Network in Graphene-based Self-folding Electrode Array **Koji Sakai**

JSAP Young Researcher Best Presentation Award
Quantum Transport Evidence of Weyl Fermions in an Epitaxial Ferromagnetic Oxide **Kosuke Takiguchi**

Society for Chemistry and Micro-Nano Sytems Visual Movie Awards
Construction of Vessel-Like Tissue Using Fluidic Device Based on Hydrogel Film **Riku Takahashi**

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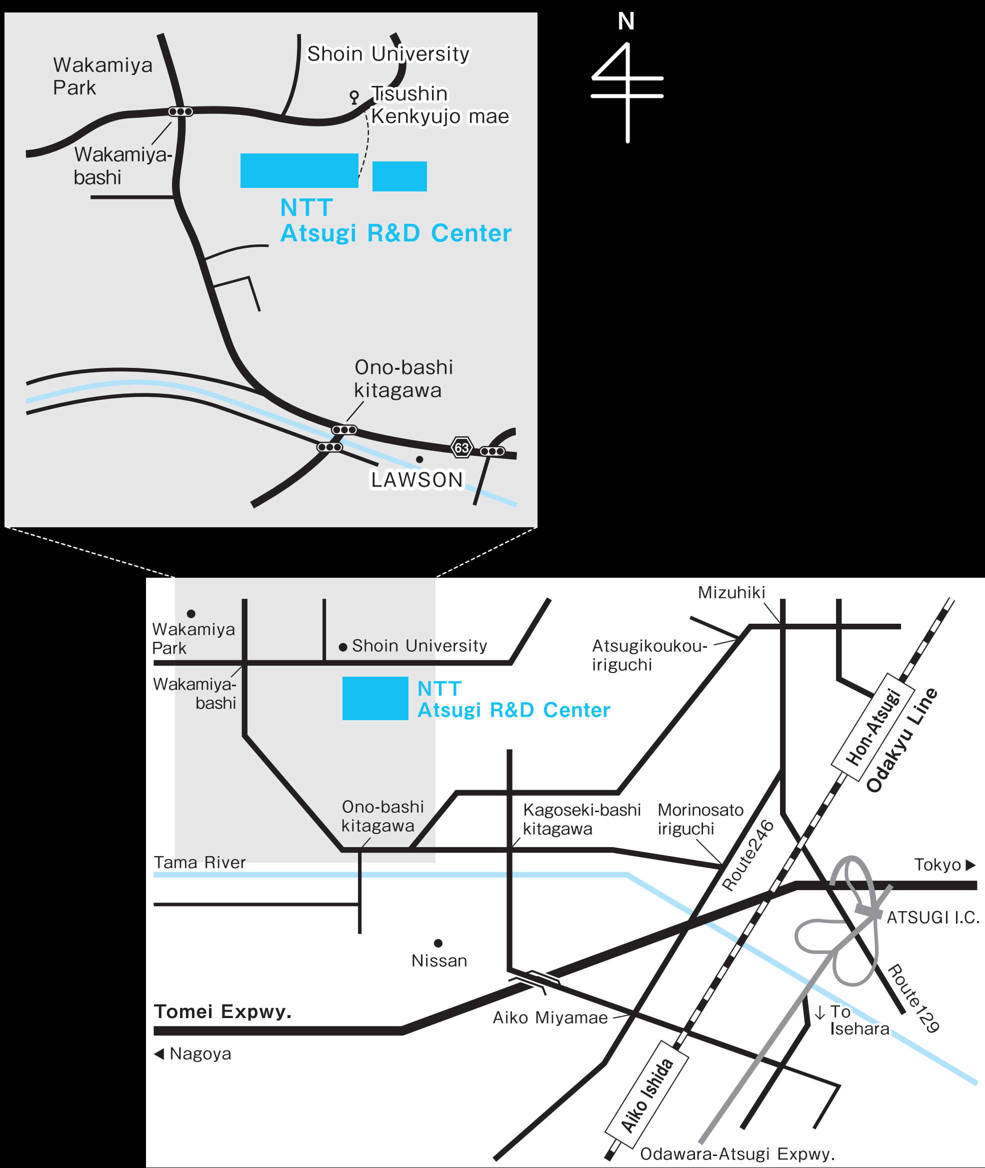

Access

By train and bus

"Aiko-Ishida" station on Odakyu Line (1 hour from Shinjuku by express)
North Exit Bus Depot 4
20 minutes bus ride on "愛17 Morinosato" route; get off at "Tsushin Kenkyujo-mae" bus stop.
20 minutes bus ride on "愛18 Shoin Daigaku" route; get off at "Tsushin Kenkyujo-mae" bus stop.
20 minutes bus ride on "愛19・21 Nissansenshingijyutsukaihatsu center" route; get off at "Tsushin Kenkyujo-mae" bus stop.

"Hon-Atsugi" station on Odakyu Line (1 hour from Shinjuku by express)
East Exit Bus Center Pole 9
30 minutes bus ride on "厚44 Morinosato via Akabane/Takamatsuyama" or
"厚45 Morinosato via Funako/Morinosato-Aoyama" get off at "Tsushin Kenkyujo-mae" bus stop.

By taxi

15 minutes from "Aiko-Ishida" station on Odakyu Line (around 1,500yen) or 20 minutes from "Hon-Atsugi" station on Odakyu Line (around 2,500yen)

By car

20 minutes (5km) drive from Tomei Expwy "Atsugi I.C."; get off the Expwy toward Isehara and turn right at the Taya crossroads.