NTT Basic Research Laboratories

Annual Report 2022

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 during the last year.

Our laboratories central mission is to promote breakthrough 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, our 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.

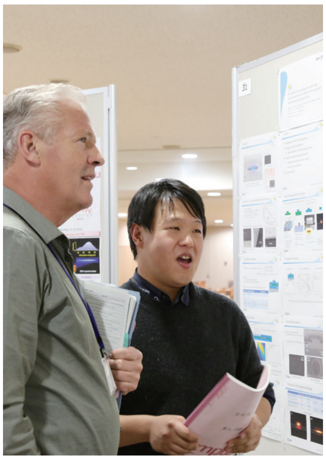
During the coronavirus pandemic, we have been transmitted our research activities and results via networks, but in this "new normal" age, we would like to explore ways to take advantage of the strengths of virtual, online and on-site communication. We are also resuming face-to-face discussions while watching closely to the coronavirus situation.

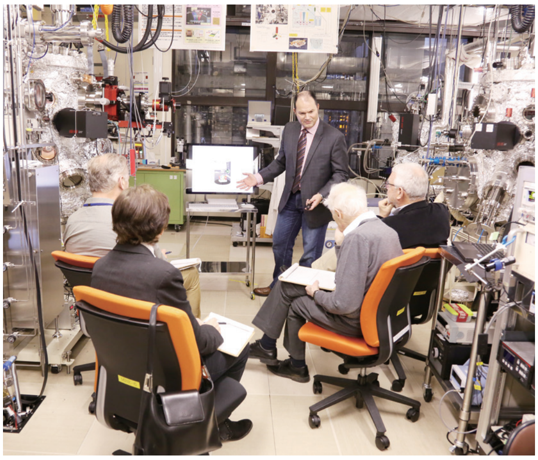
All of these activities enable us to realize our "open door" policy and mission.
Your continued support would be highly appreciated.

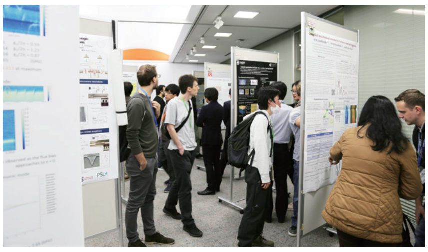
Dr. Kazuhide Kumakura
Director of NTT Basic Research Laboratories,
Nippon Telegraph and Telephone Corporation

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 12th meeting will be held on-site in February, 2023 and we are planning to report 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 science, applied physics, and quantum physics 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. It will be our pleasure to hold this meeting physically in Atsugi for the year 2023.

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 ISNTT2021 virtual format made this extremely difficult to achieve and so the school was postponed. We look forward to resuming the NTT-BRL School in conjunction with the ISNTT to be held onsite in 2023.

Front image:

Optical-to-Electrical Conversion in Graphene

Graphene has attracted significant interest due to its potential to outperform existing semiconductor devices with its high sensitivity and fast electrical response to broadband light. We achieved a breakthrough by developing the world's fastest zero-bias graphene photodetector through the combination of optimized device structure and advanced measurement techniques. As we move forward, we aim to enhance the performance of this device by incorporating a variety of two-dimensional atomic layer materials, thereby unlocking its full potential and breaking conventional limitations.

Organization

NTT Basic Research Laboratories

Director

Kazuhide Kumakura

Research Planning Section

Executive Manager

Katsuya Oguri

Multidisciplinary Materials Design and Science Laboratory

Executive Manager

Hideki Yamamoto

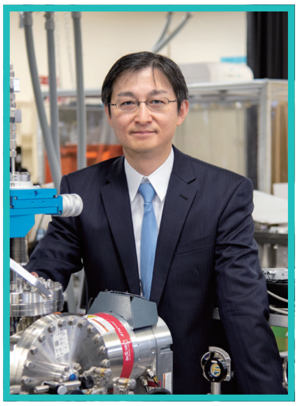
P5

- 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)…98(10)
- Research Associate/Specialist…7
- Joint Researcher…7
- International Interns…19*
- Domestic Interns…18*
- Guest Researchers…2*

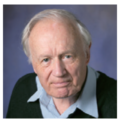
*…Jan. to Dec. 2022 total

As of Dec. 31, 2022

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,USA
Prof. Sir Anthony J. Leggett


Imperial College,UK
Prof. Sir Peter Knight


Université Pierre et Marie Curie,France
Prof. Elisabeth Giacobino


The University of Texas at Austin,USA
Prof. Allan MacDonald

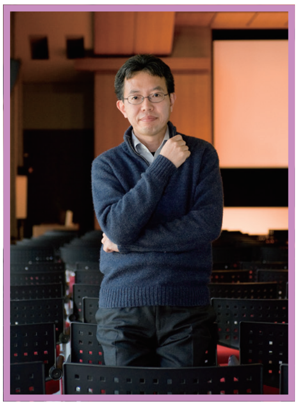

Forschungszentrum Jülich, Germany
Prof. Andreas Offenhäusser


CEA Saclay, France
Prof. Christian Glattli


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

Nanophotonics Center

Project Manager
Masaya Notomi



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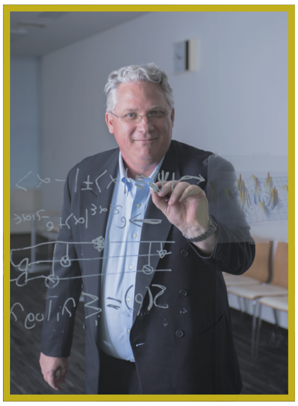
Research Center for Theoretical Quantum Physics

Project Manager
William John Munro



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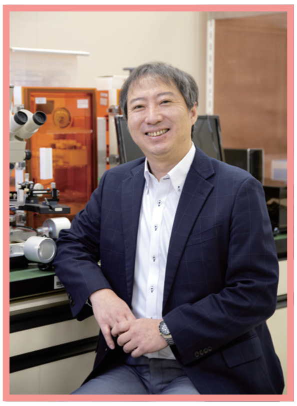
Bio-Medical Informatics Research Center

Project Manager
Hiroshi Nakashima



P11

Research Professors

Sakakibara Heart Institute, Advisor
Prof. Hitonobu Tomoike

Tohoku University
Prof. Masao Morita

University of Toyama
Prof. Kiyoshi Tamaki

Tohoku University, Professor Emeritus
Prof. Junsaku Nitta

Hiroshima University
Prof. Hideki Gotoh

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

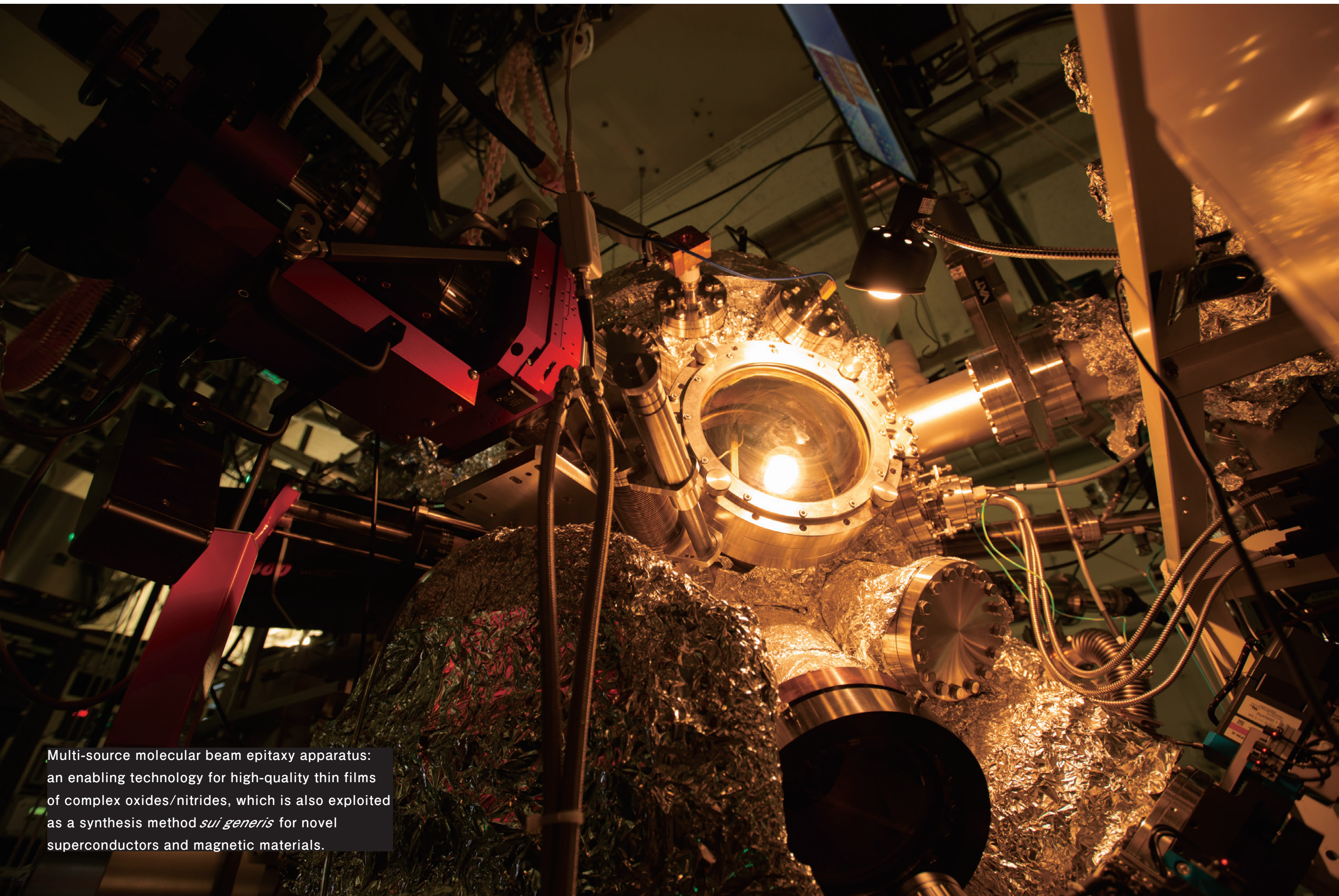
Molecular and Bio Science Research Group

Biocompatible Electrode Materials

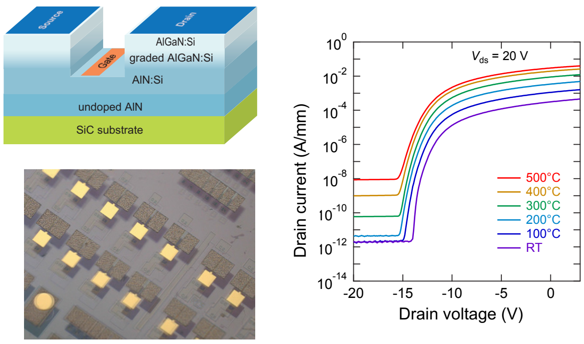
Development and application of bioelectrode materials for measurement of deep biological information

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.

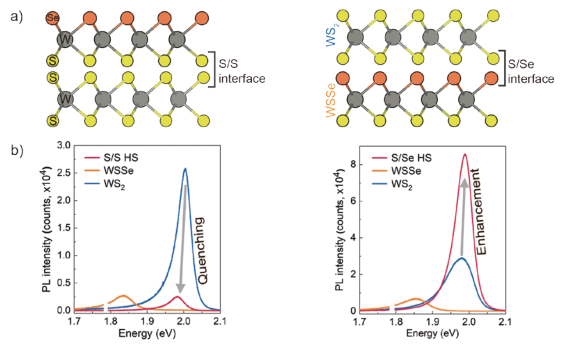


(Left side) Schematic view and optical microscope image of AlN-based transistors.
(Right side) Transfer characteristics at different temperatures from room temperature to 500°C.

World's First Demonstration of Aluminum Nitride-based Transistors

Aluminum nitride (AlN), an ultra-wide bandgap semiconductor, is an attractive material for fabricating low-loss and high-voltage power devices due to its extremely large breakdown field compared with those of conventional semiconductors. We have operated AlN-based transistors for the first time in the world; the key technologies are high-quality AlN crystal growth and good-contact electrode formation. Furthermore, good transistor performance is preserved even at a high temperature of 500°C. Our achievement indicates that AlN-based transistors are promising as next-generation power devices for meeting the ever-increasing demand for operability at high temperatures.

M. Hiroki, Y. Taniyasu, and K. Kumakura, IEEE Electron Device Lett. 43, 350 (2022). Editors' Pick

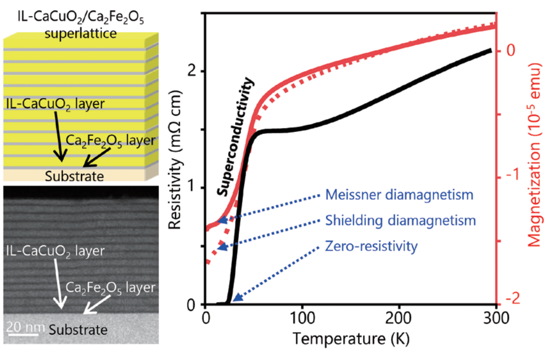


a) Atomic models of heterostructures (HS) with S/S (left) and S/Se (right) interface.
b) Photoluminescence spectra of individual monolayers and HSs.

Manipulation of Optical Properties in Janus WSSe/WS_2 Heterostructures

2D transition metal dichalcogenides (TMDCs) with a TM (e.g., W) layer between top and bottom layers containing different chalcogen atoms (e.g., S in one and Se in the other) are called Janus TMDCs. We developed a growth technology for high-quality Janus TMDCs and fabricated Janus WSSe/WS_2 heterostructures with different stacking orders. Heterostructures with S/S interfaces showed significant photoluminescence (PL) quenching in WS_2. In contrast, PL from WS_2 was enhanced for those with S/Se interfaces. Janus TMDCs provide an additional degree of freedom for manipulating the properties of 2D-material heterostructures.

U. Erkılıç, S. Wang, Y. Sekine, and Y. Taniyasu, Appl. Phys. Lett. 121, 113102 (2022).

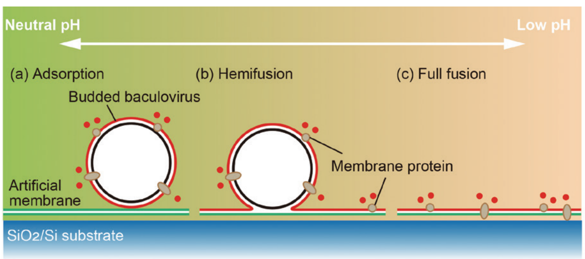


(Left) Schematic (top) and cross-sectional electron microscope image (bottom) of IL-$CaCuO_2$/$Ca_2Fe_2O_5$ superlattice.
(Right) Superconducting properties of IL-$CaCuO_2$/$Ca_2Fe_2O_5$ superlattice.

Design and Creation of New Cuprate Superconductor Composed of Artificial Superlattices

There have been only a few examples of novel cuprate superconductors created by means of artificial superlattices. Typically, such structural complexity arises from the fact that the superlattices are made of materials with different crystal structures. Our custom-designed molecular beam epitaxy apparatus, which is combined of a high-precision flux-rate control system and an elemental source sequencing, is a key for such new superlattice superconductors. Actually, we have prepared high-quality superlattices composed of $CaCuO_2$ and $Ca_2Fe_2O_5$ and found that this new superlattice is a superconductor. This discovery holds promise for the creation of further new superconductors using our approach.

A. Ikeda, Y. Krockenberger, Y. Taniyasu, and H. Yamamoto, ACS Appl. Electron. Mater. 4, 2672 (2022).



pH dependence of budded baculoviruses fusion to artificial membranes.
(a) adsorption, (b) hemifusion, and (c) full fusion.

Incorporation of Membrane Proteins into Artificial Lipid Bilayers by using Budded Baculovirus

Artificial bilayer lipid membranes (artificial membranes) have been used to evaluate functions of lipids and membrane proteins. However, efficient introduction of membrane proteins into artificial membranes had been a challenge. We found that budded baculoviruses can be fused to an artificial membrane formed on a silicon substrate efficiently under low pH conditions. This finding enabled us to introduce membrane proteins into the artificial membrane.

A. Oshima, K. Nakanishi, N. Kasai, H. Nakashima, K. Tsumoto, and K. Sumitomo, Langmuir 38, 5464 (2022).

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

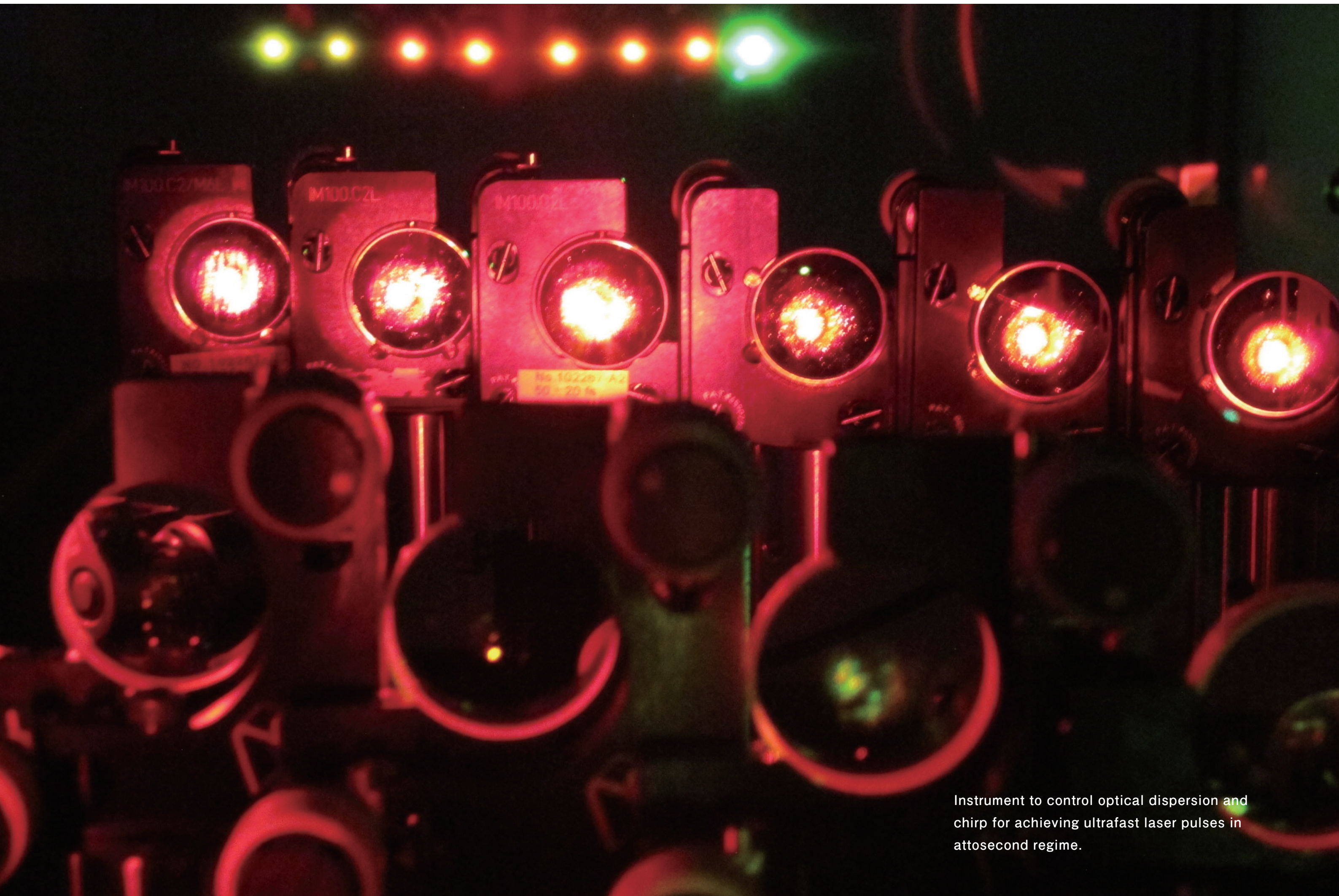
Nano-scale Physics in Optically-active Materials

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

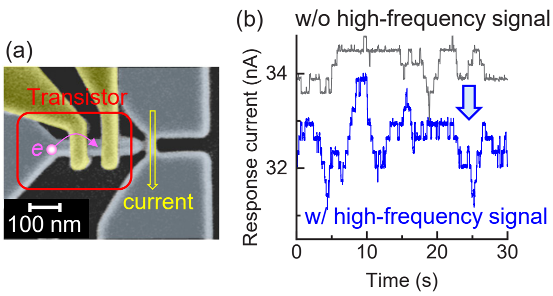
Photonic Nano-Structure Research Group

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) Scanning electron microscope of the single electron device.
(b) Response current by the AC signal.

Single-electron Devices for Detecting High-frequency Signals Beyond the RC Time Constant

Single electron devices that can control the motion of individual electrons are promising for data processing utilizing single electrons as bits of information. However, since the devices are on the nanometer scale, their resistance is large and their operation speed is not fast. We succeeded in enabling a silicon transistor with a unique structure to respond signals faster than the speed determined by the resistance. This is due to the nonlinear electrical characteristics of the transistor, in which leakage current is suppressed to the theoretical limit. Such a fast-signal response would enable the transistor to function as a sensor detecting high-frequency signals.

K. Nishiguchi, A. Fujiwara, and K. Chida, 35th International Microprocesses and Nanotechnology Conference

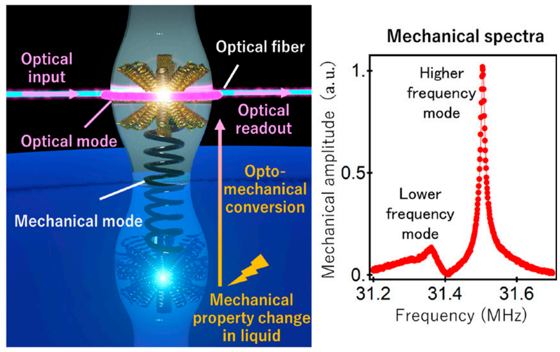
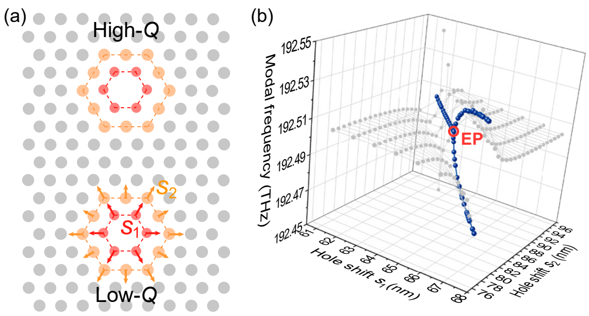


Figure: Conceptual illustration of liquid probing with an optomechanical device (left). and mechanical vibration spectra in liquid (right).

Highly Sensitive Liquid Probing Using an Optomechanical Device

In-liquid measurement technology using mechanical devices can be used to detect fine particles and evaluate the viscoelasticity of liquids. However, drastic improvements in the spatial resolution and detection sensitivity of devices have been a challenge. We have devised a new sensing method using optomechanical devices consisting of hair-sized glass wires that use light to probe the mechanical vibration characteristics of liquids with ultrahigh sensitivity. This technique has achieved picogram-level mass detection sensitivity (equivalent to a single bacterium) and is capable of local characterizing phase-separated liquids. It is expected to be used in a wide range of fields, including ultra-sensitive chemical and biosensors and rheological applications.

M. Asano, H. Yamaguchi, and H. Okamoto, Sci. Adv. 8, eabq2502 (2022).

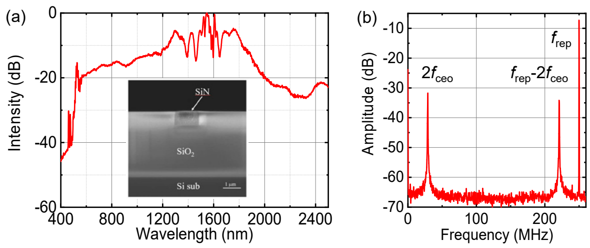


(a) Our coupled photonic crystal nanocavities. The resonance frequency and radiation loss of the lower cavity are varied by controlling the two hole shift parameters s_1 and s_2.
(b) Frequencies of the two eigenmodes dependent on s_1 and s_2. Blue symbols indicate the system with a symmetry based on the contrast of loss. The red circle marks the EP.

Radiation-Induced Exceptional Point of Coupled Photonic Crystal Nanocavities

Coupled cavities with a contrast of their on-site optical gain (stimulated emission) and loss (absorption and radiation) can have a peculiar degeneracy in their eigenmodes called an exceptional point (EP). Optical systems with EPs exhibit unconventional phenomena such as directional responses, circularly polarized radiation, and enhanced emission. We showed theoretically that we can obtain an EP in coupled silicon photonic crystal nanocavities with contrasting radiation losses. This design does not need any amplifying and absorbing media or carrier excitation. Our work paves the way for the application of EPs in photonic devices without external control of electrical or optical pumping of their active carriers.

K. Takata, N. Roberts, A. Shinya, and M. Notomi, Phys. Rev. A 105, 013523 (2022).



(a) Spectrum of supercontinuum light.
(b) Carrier-envelope offset signal by *f*-3*f* self-referencing interferometry.

Frequency Stabilization of an Optical Frequency Comb with a Single SiN Waveguide

In order to use the optical frequency comb outside the laboratory, a compact and frequency-stabilized optical frequency comb light source is required. By designing the dispersion of the SiN waveguide and optimizing the width and length of the waveguide, we succeeded in generating ultra-wideband supercontinuum light from 400 to 2500 nm and stabilizing the carrier-envelope offset frequency with *f*-3*f* self-referencing interferometry. We believe that this method, which enables frequency stabilization with a single optical element, is a promising compact optical frequency comb light source.

A. Ishizawa, K. Kawashima, R. Kou, X. Xu, T. Tsuchizawa, T. Aihara, K. Yoshida, T. Nishikawa, K. Hitachi, G. Cong, N. Yamamoto, K. Yamada, and K. Oguri, Optics Express 30 (4) 5265 (2022).

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

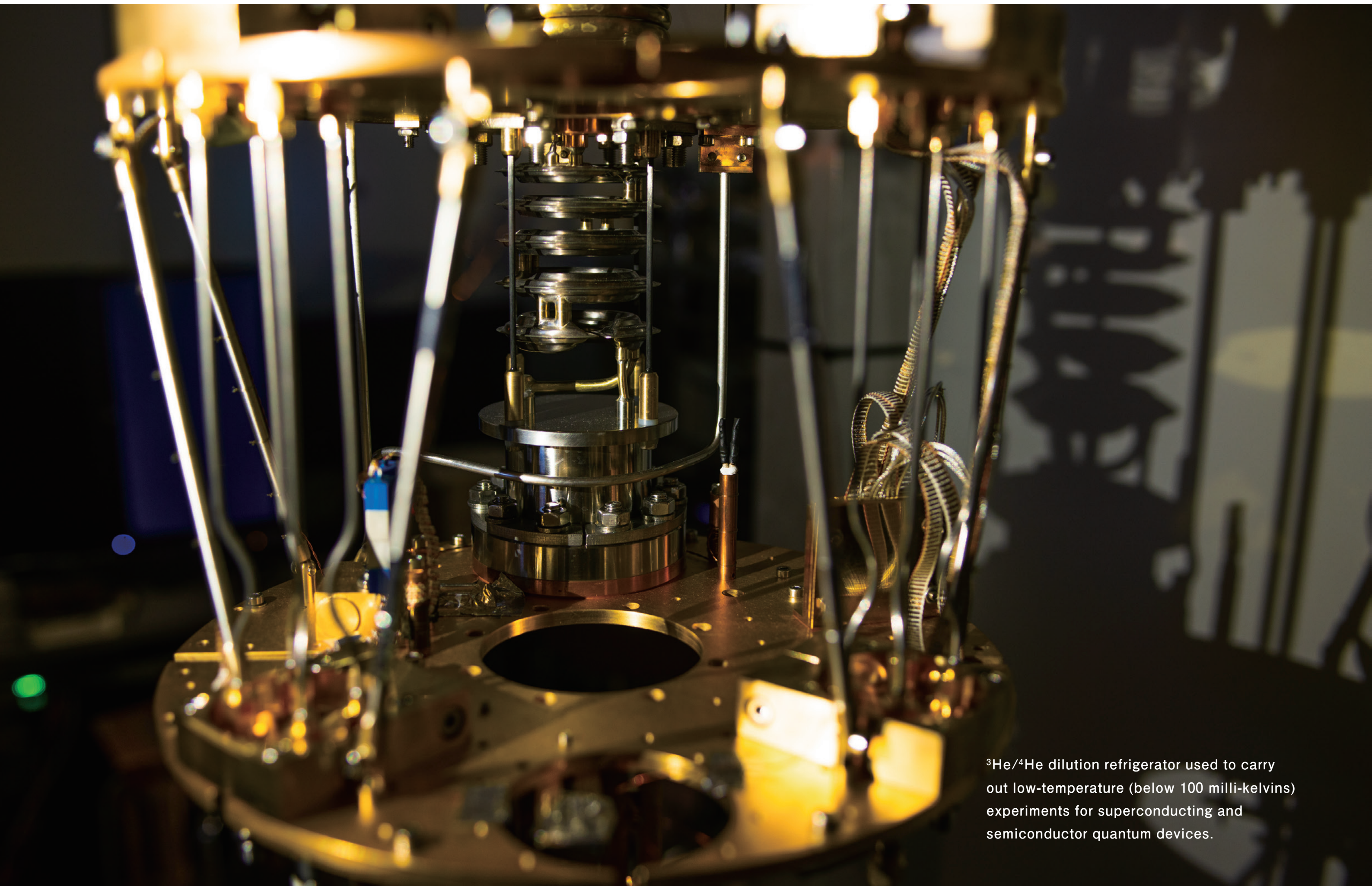
Quantum Solid State Physics Group

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

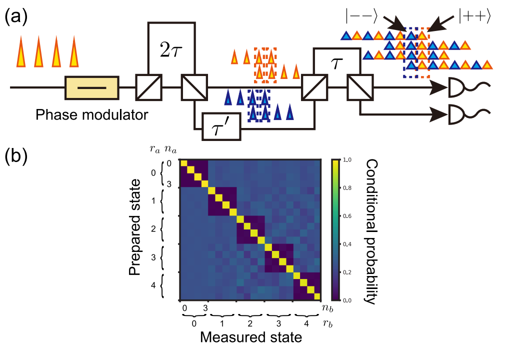
Unconventional charge and spin transport phenomena in quantum devices

Fast Coherent Carrier Dynamics in Electronic Devices

Information processing with coherent electron motion



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

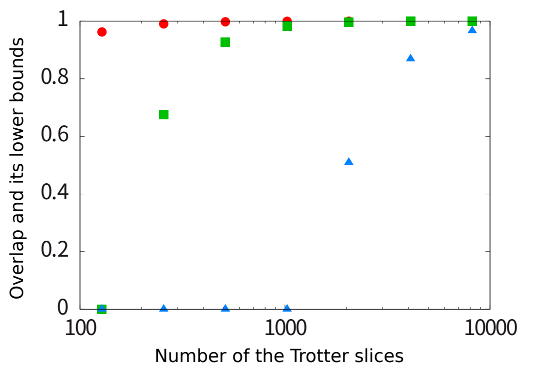


(a) A part of the measurement device for a four-dimensional time-bin state.
(b) Conditional measurement probability distribution for the prepared and measured states.

Scalable Preparation and Measurement of d-dimensional Time-bin States in (d+1) Mutually Unbiased Bases

A high-dimensional quantum key distribution (QKD) can increase communication speeds by embedding multiple values in a single photon. For a d-dimensional time-bin quantum state, we devised a scalable implementation of (d+1) mutually unbiased bases, with which we can improve the robustness against communication errors. We observed acceptably low symbol error rates for d-dimensional QKD. Our results constitute a basic element of an advanced secure communication system.

T. Ikuta, S. Akibue, Y. Yonezu, T. Honjo, H. Takesue, and K. Inoue, Phys. Rev. Research 4, L042007 (2022).

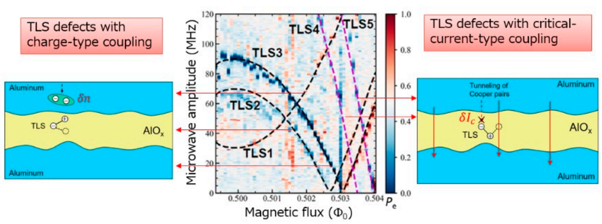


Overlap between true dynamics and simulated dynamics (red circles), our lower bound (green squares), and conventional lower bound (blue triangles).

State-dependent Error Bound for Digital Quantum Simulation of Driven Systems

Digital quantum simulation is a promising application of quantum computers. In such a simulation, a time-evolution operator is decomposed into simulatable quantum gate operations. However, this decomposition causes some errors. To evaluate these errors, we derived a lower bound for the overlap between the true dynamics and the simulated dynamics. Moreover, we also extended our formalism to digital quantum simulation on NISQ computers.

T. Hatomura, Phys. Rev. A 105, L050601 (2022).

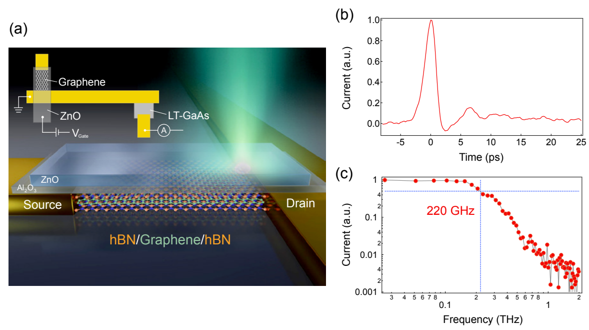


Spectrum of TLS defects (center). The types of defects can be identified by their slopes. (left) Schematic illustration of TLS defects with the charge-type interaction. (right) Schematic illustration of TLS defects with the critical-current-type interaction.

Detection of Two-level System Defects in Superconducting Qubits

A critical problem with superconducting quantum computers is the rapid loss of quantum information due to the interaction between a qubit and its noisy environment. One of the main noise sources associated with superconducting qubits is atomic-scale two-level system (TLS) defects located inside oxide layers formed on the top of superconducting materials. We developed a novel microwave technique that allows us to identify the particular type of TLS defect. The approach complements methods for the characterization of other types of noise in superconducting qubits and will enable further improvements in the performance of superconducting quantum processors.

L. V. Abdurakhimov, I. Mahboob, H. Toida, K. Kakuyanagi, Y. Matsuzaki, and S. Saito, PRX Quant. 3, 040332 (2022).



(a) Schematic of graphene photodetector. The inset shows the entire device structure. (b) Waveform of photocurrent.
(c) Fourier spectrum of (b) showing 3 dB bandwidth of 220 GHz.

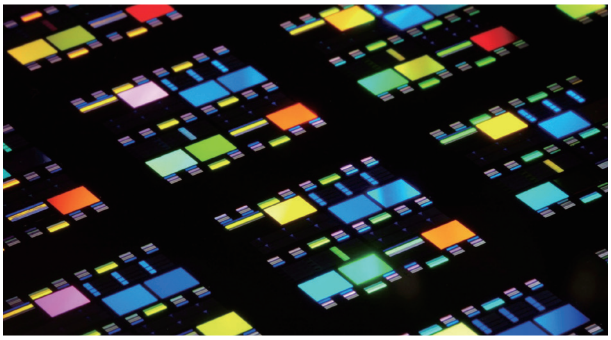
Ultrafast Optical-to-electrical Conversion in Graphene

Graphene photodetectors are promising next-generation devices that have the potential to be highly sensitive and fast in their response to broadband light. However, until now, their demonstrated operation speed at zero bias has been hindered by factors such as the device structure and measurement equipment. By overcoming these limitations, we achieved an operation speed of 220 GHz and clarified the operating principle of graphene photodetectors. This breakthrough provides useful design guidelines for maximizing the performance of these devices.

K. Yoshioka, T. Wakamura, M. Hashisaka, K. Watanabe, T. Taniguchi, and N. Kumada, Nat. Photonics 16, 718 (2022).

Nanophotonics Center

Nanophotonics Center



Overview

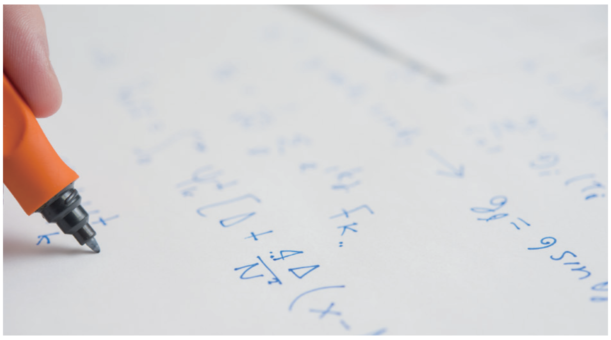
The Nanophotonics Center was established in April 2012 and is composed of several groups involved in nanophotonics research at NTT Basic Research Laboratories and NTT Device Technology Laboratories. We are conducting studies of photonic crystals to reduce the footprint and energy consumption of various 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.

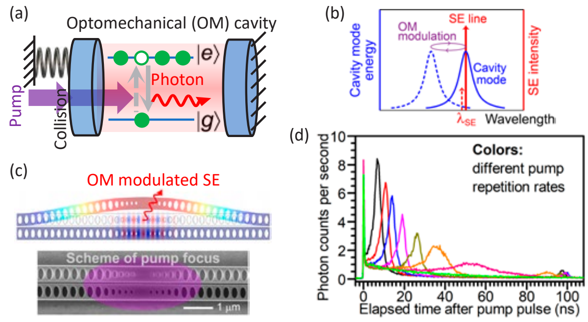
Research Themes

- **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**

Dynamic Modulation of Spontaneous Emission with Optomechanical Hybrid Cavity Quantum Electrodynamics System

We have demonstrated a novel optomechanical cavity quantum electrodynamics (QED) system in which optical transition, optical resonance, and mechanical resonance are strongly coupled. Our device consists of copper-doped Si double nanobeam photonic crystals, which function as a strongly-coupled hybrid resonator with a high-Q optical cavity and a high-Q mechanical cavity. When the system was excited by repetitive laser pulses, we demonstrated dynamic modulation of the spontaneous emission rate induced by the mechanical resonance tuning. This phenomenon means that we can dynamically control the cavity QED effect, in which spontaneous emission is enhanced by optical resonance, via mechanical oscillation, thereby paving the way to novel hybrid quantum systems.

F. Tian, H. Sumikura, E. Kuramochi, M. Takiguchi, M. Ono, A. Shinya, and M. Notomi, Optica 9, 309 (2022).

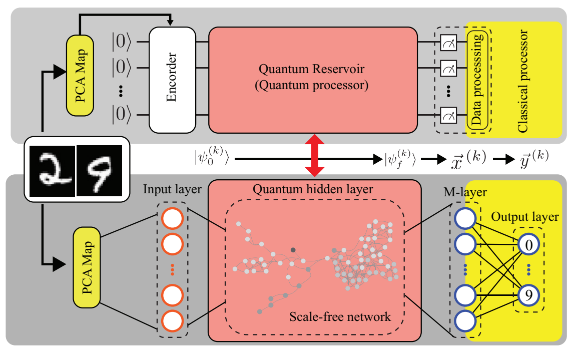


(a)Schematicdiagramofahybridizedoptomechanicalcavity-QEDsystem.
(b)Spectralillustrationofthedynamicsofthehybridsystem.
(c)Practicalconfigurationoftheoptomechanicalcavity(upper:opticalandmechanicalresonancemodes;lower:SEMimage).
(d)Experimentalresultsofdynamicallyenhancedspontaneousemission.

Quantum Extreme Reservoir Computation

Today's NISQ processors have allowed us to enter an era where tasks can be performed that are hard to achieve on supercomputers. However, the tasks that have been performed so far are quite abstract and not so practical. Here, we introduce a resource-efficient quantum neural network model with a focus on the role of the feature space the quantum processors can give for classification tasks. We show how complex scale-free networks generated in a discrete-time crystal model can provide a feature space with distinct quantum advantage. Importantly, our model does not require optimization of the quantum processor to the particular classification task.

A. Sakurai, M. P. Estarellas, W. J. Munro, and K. Nemoto, Phys. Rev. Applied 17, 064044 (2022).

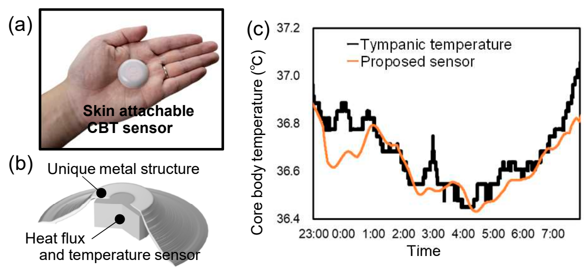


Schematic illustration of the structure of the quantum extreme reservoir computer utilizing both quantum (red) and classical (yellow) data processing. The quantum reservoir is formed using a scale-free networks generated in a discrete-time crystal.

Skin-Attachable Core Body Thermometer for Visualization of the Circadian Rhythm

The temperature of internal organs located deep in the body (core body temperature (CBT)) exhibits a 24-hour rhythm linked with the internal clock of the body. Conducting an orderly life aligned with this internal clock can reduce the risk of mental and physical illness. However, the procedure for monitoring the temperature can be stressful. We addressed this problem by developing a skin-attachable CBT sensor that has a unique structure designed to reduce the effect of ambient convection and thereby reduce the number of errors. We verified the operation of the sensor through numerical calculations and in-vitro experimentation. Then we used it in a visualization of the CBT behavior during sleep.

Y. Tanaka, D. Matsunaga, T. Tajima, and M. Seyama, IEEE Sensors Journal, 21, 16118 (2021).
D. Matsunaga, Y. Tanaka, T. Tajima, and M. Seyama, 44th Annual International Conference of the IEEE Engineering in Medicine & Biology Society (EMBC), 1258 (2022).



(a) Photograph of CBT sensor.
(b) Schematic of internal structure.
(d) Typical CBT behavior during sleep.

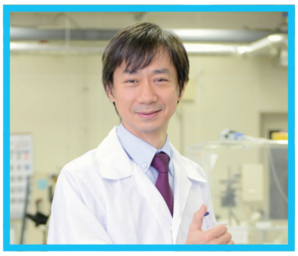
The title of "NTT Fellow" is reserved for our most gifted scientist and engineers whose research and development activities have brought them significant distinction both within NTT and internationally. Our "Fellows" are extremely highly regarded. Next the title of "Senior Distinguished Researcher" is 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, 2022

NTT Fellow

Shingo Tsukada

Medicine, Physiology, Biomedical interface & data analysis



Research Subject

Biological Information Elucidation Using Advanced Medical Materials

Hiroshi Yamaguchi

Quantum and Nano Device Research

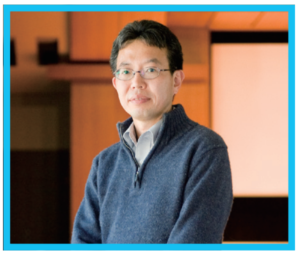
Research Subject

Nano-mechanics in Semiconductors

Senior Distinguished Researcher

Masaya Notomi

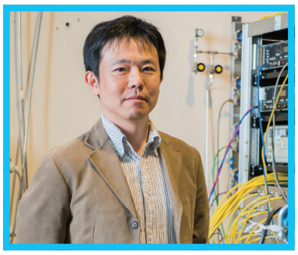
Nanophotonics Center Project Manager



Research Subject

Photon Manipulation in Photonic Nanostructures

Koji Muraki

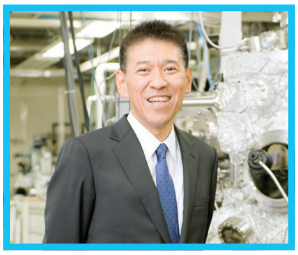


Research Subject

Electron Correlation in Semiconductor Nanostructures

Hideki Yamamoto

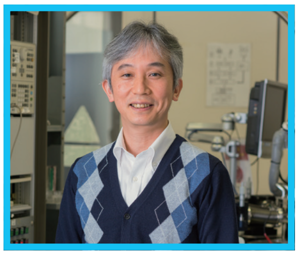
Multidisciplinary Materials Design and Science Laboratory Executive Manager



Research Subject

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

Akira Fujiwara

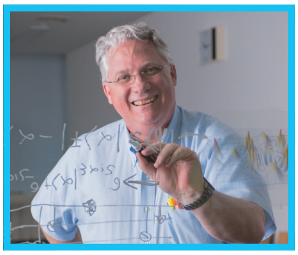


Research Subject

Ultimate Electronics Using Semiconductor Nanostructures

William John Munro

Research Center for Theoretical Quantum Physics Project Manager

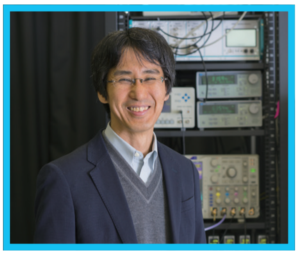


Research Subject

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

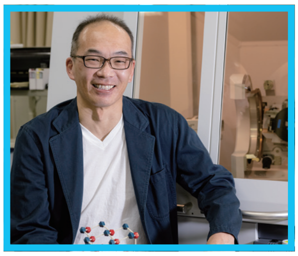
Quantum Optical Physics Research Group Leader

Research Subject

Quantum information technologies based on superconducting quantum circuits

Yoshitaka Taniyasu

Thin-Film Materials Research Group Leader
Low-Dimensional Nanomaterials Research Group Leader



Research Subject

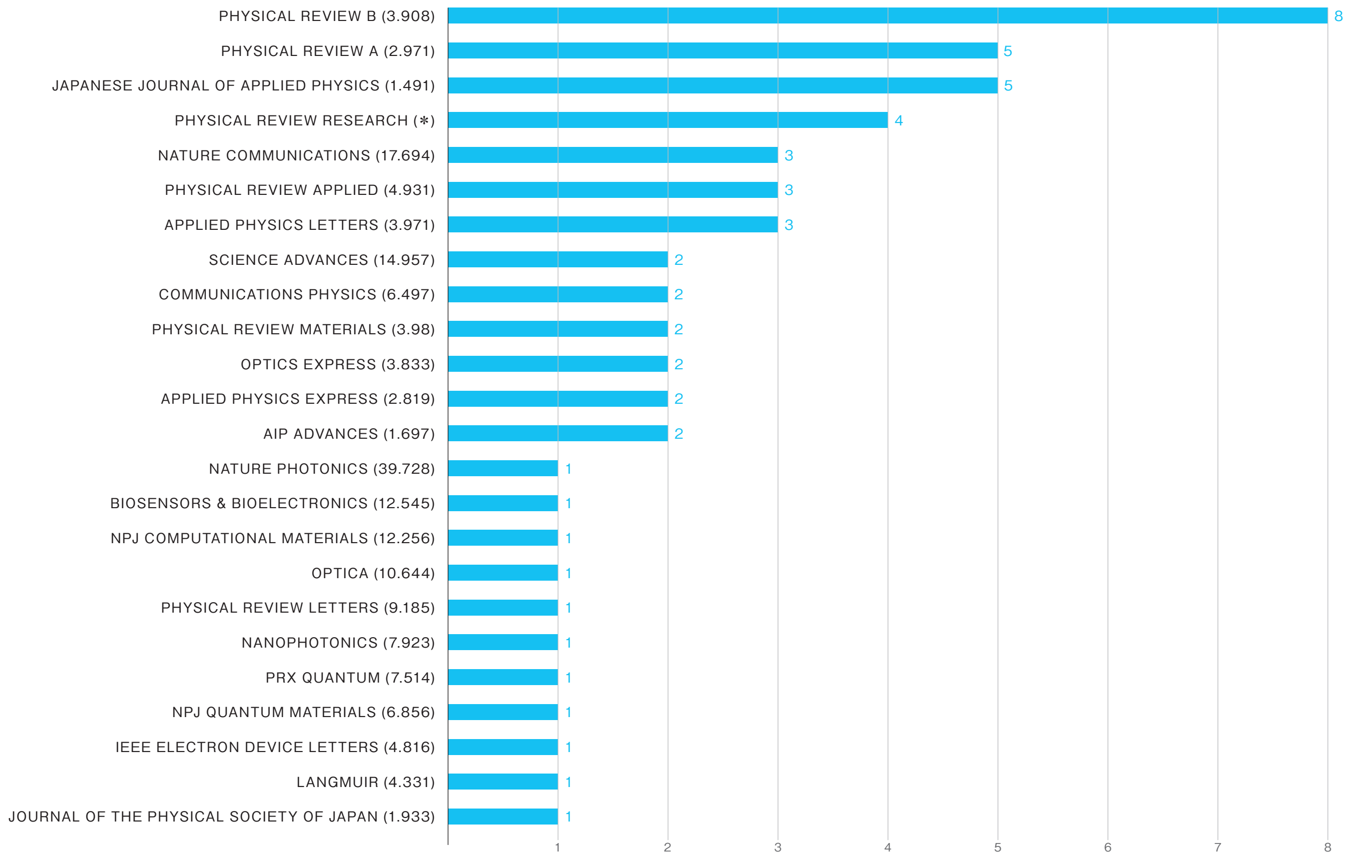
Research on functional materials for green innovation

Distinguished Researcher

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

Publication List

The total number of NTT Basic Research Laboratories papers published in international journals in 2022 is 64 with an average impact factor of 5.905. The 2021 impact factor of those individual journals are shown in ( ).



Number of Presentations

118
(37 Invited talks)

Number of Patents

43

List of Award Winners

The Commendation for Science and Technology by the Minister of Education, Culture, Sports, Science and Technology: Awards for Science and Technology in Research Category
Telecommunication-band Quantum Optics and its Application to Information Processing **Hiroki Takesue**

The Commendation for Science and Technology by the Minister of Education, Culture, Sports, Science and Technology of Japan, The Young Scientists' Prize
Theoretical study of quantum repeaters towards a quantum internet **Koji Azuma**

The 3rd Fumiko Yonezawa Memorial Prize of the Physical Society of Japan
Research on Quantum Transport and Control of Spin-orbit Interaction in Novel Semiconductor Materials **Keiko Takase**

14th Conference on Laser and Electro-Optics Pacific Rim (CLEO Pacific Rim 2022) Best Paper Award
Erbium-doped Rare-Earth Oxide Thin Film Waveguides for Integrated Quantum Photonic Devices
Xuejun Xu, Masaya Hiraishi, Tomohiro Inaba, Tai Tsuchizawa, Atsushi Ishizawa, Haruki Sanada, Takehiko Tawara, Jevon Longdell, Katsuya Oguri, and Hideki Gotoh

18th International Workshop on Nanomechanical Sensing (NMC2022) Best Oral Presentation
An optomechanical prober in liquid with twin microbottle resonators **Motoki Asano**

20th JSAP Photo & Illustration Contest, Excellent Award
Nano-size pencil? **Masato Takiguchi, Sylvain Sergent, Masaya Notomi, Stéphane Vézian, Benjamin Damilano**

NTT Basic Research Laboratories

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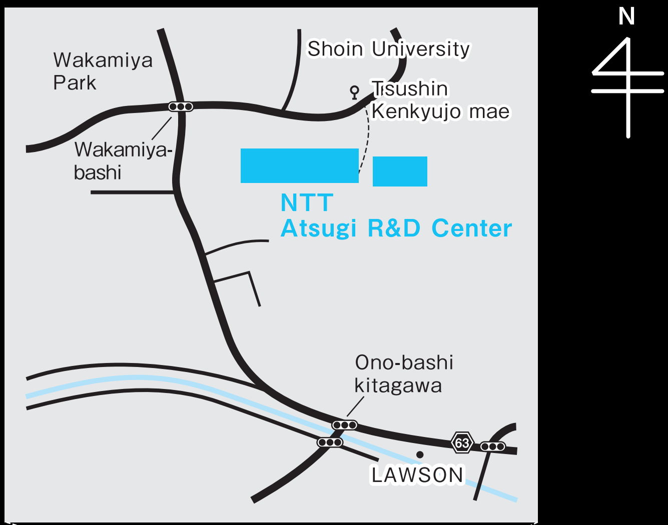

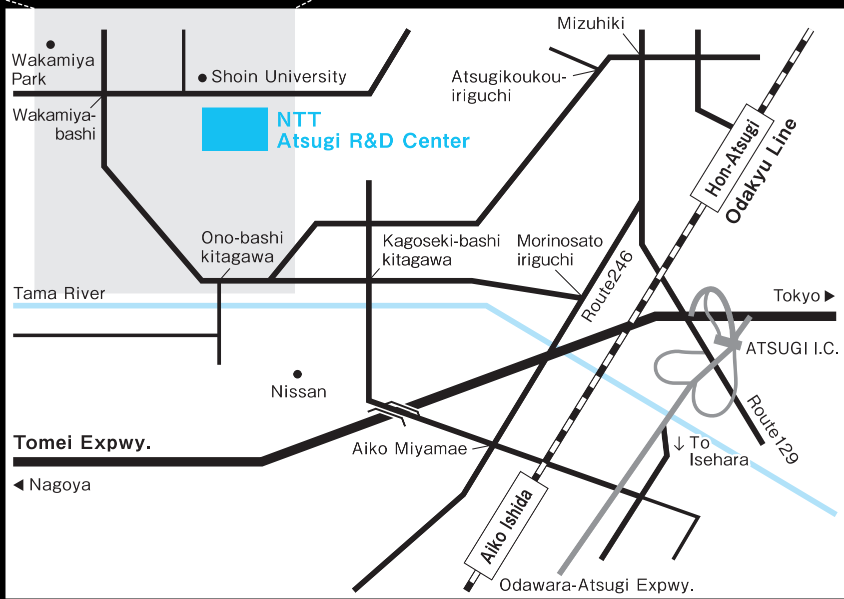

Access

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.