TOHOKU UNIVERSITY

Frontier Research in Duo

Frontier Research in Duo (FRiD)

Message

Modern society faces unprecedented changes due to the progress of globalization and accelerated advances in science and technology. In this dynamic situation, a shift of priorities is occurring in academic fields. In addition, with regard to global collaboration framework programs such as EU Horizon 2020, Horizon Europe, etc., and academic discourse at national level regarding quantum technologies, AI, biotechnology, etc., joint projects are being carried out on a greater scale than before, and research aimed to solve social issues (e.g. SDGs) and high-risk, high-impact research programs for future creation of new academic value (e.g. Moonshot) is being conducted.

This program is based on the university's academic diversity and international achievements, and it challenges us to be pioneers in world-leading research and emerging/interdisciplinary research based on the free and original ideas of ambitious researchers.

It is undeniable that the spread of the COVID-19 pandemic has had an impact on our research activities. It is precisely because of times like these that we are taking advantage of online and other resources to develop new research methods for the new normal era. We will carry out our research activities in a relentless manner.

Executive Vice President
(for Research)
Organization Director,
Organization for
Advanced Studies

Motoko Kotani

Contents

Eligible research

A research project that meets both of the following conditions is eligible for application:

1. A research project that drives forward pioneering/interdisciplinary research in a cross-sectoral collaboration
2. A research project whose topic will potentially become a trend in 10 to 15 years, or which is at an initial stage for the creation of an emerging idea.

Research group

The research group must be composed of two or three core researchers belonging to different departments.
The research group must partner with an overseas research institution(s) as a research collaborator(s).

Research period

5 years

Financial Support

Research expenses of 5 to 10 million yen per fiscal year.

Challenge to pioneer in world-leading research

In December 2019, Tohoku University adopted 9 aspiring research projects that challenge the creation of new research area.

Research Projects

- ▶ Development of innovative imaging system for sulfur respiration in humans
- ▶ Homeostatic control through the regulation of commensal bacteria by specific neurons
- ▶ Bio-iontronics Engineering Based on Soft Moist Electrode Technologies
- ▶ Plasma Agriculture -Sustainable Farm Realized by Functional Nitrogen-
- ▶ Realization of Helical -Spintronics
- ▶ Development of Tohoku Univ. Biosatellite Cube (TU BioCube) for Investigation of Life Support Mechanisms in Space Environment
- ▶ Quantum Sensing: From Materials to Universe
- ▶ Multi-Sensory Flexible Skin
- ▶ Understanding the Cultural Process of Sustainable Society for over 10,000 years

Development of innovative imaging system for sulfur respiration in humans

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Prof. Takakazu Nakabayashi

Overseas Research Institution Partners

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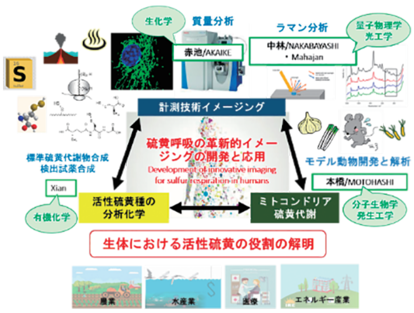
United Kingdom, University of Southampton Prof. Sumeet Mahajan



Reactive sulfur species, abundant in vivo, play an essential role in energy metabolism in mitochondria. Recent establishment of quantification methods for reactive sulfur species using mass spectroscopy has revealed a large amount of reactive sulfur species such as cysteine persulfide, glutathione persulfide, and hydrogen persulfide, which has opened up a new era of life science, because various biological processes are re-evaluated based on the versatile and diverse functions of reactive sulfur species.

A striking example is that mitochondrial sulfur metabolism has been found essential for the efficient generation of proton gradient, resulting in the efficient production of ATP, which has never been described in the biochemistry textbook. This and other discoveries related to the sulfur biology are expected to be further evolved, if simple and easy as well as non-invasive and non - destructive measurement system is invented based on Raman spectrometry. The outcome of our research will have great impacts on a wide range of life science, including clinical medicine, pharmaceutical sciences, development of medical devices, drug development, renovation in agriculture and marine industry, and creation of functional supplements for disease prevention.

Latest research results

A novel role of reactive sulfur species in protein quality control (01.08.2020 Press Release)

We have found that persulfidation of protein cysteine residues by reactive persulfide species protects proteins from irreversible dysfunction. This study elucidates a new redox mechanism in which reactive persulfide species prevents protein deterioration, and is a breakthrough discovery in biochemistry, cell biology, redox biology, etc. This discovery will contribute to the prevention of aging in human, the establishment of healthy longevity, and the development of diagnosis and prophylactic treatments for various diseases related to oxidative stress, such as respiratory and heat diseases and cancer.

The results of this research were published on January 1, 2020 in the journal Science Advances.

Homeostatic control through the regulation of commensal bacteria by specific neurons

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Prof. **Shoichiro Kurata**

Co-PI
Graduate School of Life Sciences
Prof. **Hiromu Tanimoto**

Co-PI
Graduate School of Agricultural Science
Prof. **Haruki Kitazawa**

Overseas Research Institution Partners
Germany, University of Cologne, Prof. **Kei Ito**

"The mind controls the body". As expressed in this proverb, the close connection between the nervous system and the immune system has been inferred. The relationship between immune responses and nervous system has, however, remained unexplored since Metalnikov's initial experiments in 1924.The PA identified neurons controlling intestinal flora, which is essential for host homeostasis. In this study, the three research groups of this university are fused to reveal the control mechanisms of the homeostasis by the neurons. The study will creates new research areas in control of immunity by nervous system.

Latest research results

To determine the structure of the neural circuit responsible for immune regulation, we screened the JaneliaGAL4 lines created by the "FlyLight" project, and identified a line (49171 line) out of 291 lines in which neural inhibition reduced resistance to Gram-negative and Gram-positive bacterial infections. Moreover, to elucidate how the neurons regulate intestinal immunity and maintain homeostasis, we performed a comprehensive analysis of gene expression in the intestinal tract dependent on the neurons. 1139 genes were identified, supporting, in terms of gene expression, that NP3253 neurons regulate gut microbiota.

Bio-iontronics Engineering Based on Soft Moist Electrode Technologies

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Co-PI
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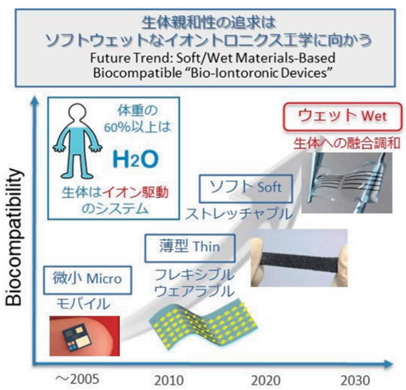
Prof. **Atsuhiro Nakagawa**

Co-PI
Graduate School of Biomedical Engineering
Prof. **Tetsu Tanaka**

Overseas Research Institution Partners
United States, UCLA Prof. **Ali Khademhosseini**
Sweden, Linköping University Prof. **Magnus Berggren**
China, Peking University Assoc. Prof. **Xiaojie Duan** etc.

The conventional metal-silicon devices (hard, dry, electronic) and biological systems (soft, wet, ionic) are essentially different. In order to eliminate this mismatching and create truly biocompatible medical devices, new field of "bio-iontronic engineering" using soft/wet materials should be established. This project is for realizing the hydrogel-based biocompatible devices that can be powered by enzyme reactions (biological power generation), which will be one of the research trend in 15 years. We will challenge to realize such "all-organic bio-iontronic devices" by collaboration of researchers in different fields (engineering, medical engineering, medicine) and the relating world's top runners.



Latest research results

Totally Organic Bio-Iontophoresis Patch "Commercialization starts from a standard model through flexible customizations" (01.29.2020 Press Release)

We have developed a skin patch BIPP® with an enzyme-based bio-power generation mechanism in cooperation with Sun Arrow Co., Ltd. This totally organic iontophoresis patch, which induces a small electric current to the skin, is the platform of various medical and cosmetic devices including the transdermal drug dosing patch. This research has been published (on line) in J. Phys. Energy on Sep. 15.

Plasma Agriculture -Sustainable Farm Realized by Functional Nitrogen-

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Graduate School of Engineering
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Co-PI
Graduate School of Agricultural Science
Prof. Hideki Takahashi

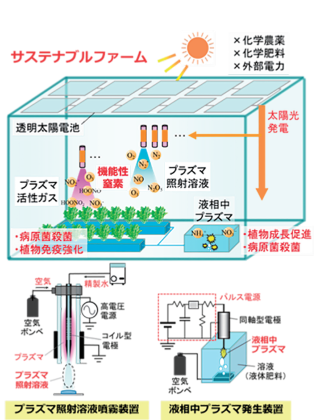
Co-PI
Graduate School of Life Sciences
Prof. Atsushi Higashitani

Overseas Research Institution Partners

United States, University of Minnesota — Prof. Peter Bruggeman

United States, Old Dominion University — Prof. Michael Kong

In this research project, in order to establish a controlled and stable food production environment, we propose a system that realizes increase in food production using atmospheric pressure plasmas inducing bactericidal action, plant immunity enhancement, and plant growth promotion. The key components, which are responsible for these biological effects, are unstable reactive nitrogen species, which are synthesized from inexpensive air and water through the plasma reactors.These short-lived nitrogen compounds contributing to the functionalization of plants are defined as “functional nitrogen”. The main purpose of this research project is to synthesize and control the novel functional nitrogen using the plasmas and to clarify the mechanism of their actions on plants. On the other hand, the functional nitrogen and some by-products may damage plant cells, and the second purpose of this research project is to elucidate the mechanism of this “cell damage” and to find out how to overcome it. The final goal is to demonstrate a "sustainable farm" that grows plants with functional nitrogen without using conventional chemical pesticides and chemical fertilizers by exploring novel functional nitrogen and plasma-controlled synthesis of them.



Latest research results

Asahi Shimbun's speech site "Ronza" published, "Plasma is used for agriculture to create a sustainable food production system -a new basis for global focus, reduction of chemical pesticides and fertilizers-” on May 26, 2020. Furthermore, in the "Sendai Business World“, an information magazine on the Sendai economic zone, an article titled "Adding Value to Strawberries with Plasma-Experiments in Yamamoto Town, Sustainable Agriculture" was published in September 2020.

Realization of Helical-Spintronics

PI
Graduate School of Engineering
Assoc. Prof. Makoto Kohda

Co-PI
RIEC
Assist. Prof. Shun Kanai

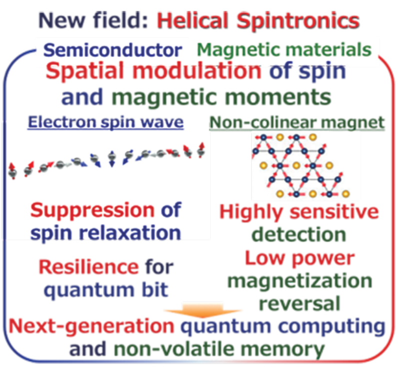
Overseas Research Institution Partners

United States, The University of Chicago — Prof. David Awschalom

New Zealand, Victoria University of Wellington — Dr. Michael Kammermeier

By focusing on spatial structure on electron spins as well as local magnetic moments in nanometer scale, we will investigate the fundamental technologies for next-generation non-volatile memories and quantum information processing, based on the dynamics of helical spin texture and non-colinear magnetic structures. By understanding the physics of spatial spin/magnetic structures both in semiconductors and ferromagnetic metals, we will establish new field, a so called “Helical-Spintronics”.

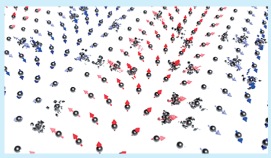
We will tackle this new field of Helical-Spintronics with two young scientist (Kohda/Kanai) and two collaborators in overseas who are in the front runners in the field of Spintronics and quantum information technology.



Latest research results

Spin, Spin, Spin: Researchers Enhance Electron Spin Longevity through International Collaboration (06.16.2020 Press Release)

The electron spin wave is a new carrier for information processing. An international collaboration with Victoria University of Wellington (New Zeeland) has now developed a way to extend and stabilize the lifetime of the electron’s spin wave to more effectively carry information.



Well - defined rotation of spin orientation called electron spin wave

Development of Tohoku Univ. Biosatellite Cube (TU BioCube) for Investigation of Life Support Mechanisms in Space Environment

PI

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Assoc. Prof. **Jun Hidema**

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Assoc. Prof.
Toshinori Kuwahara

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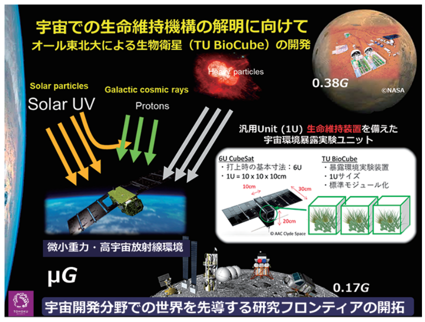
Graduate School of Science
Prof. **Yasumasa Kasaba**

Overseas Research Institution Partners

United States, Ohio Wesleyan University — Prof. **Chris Wolverton**

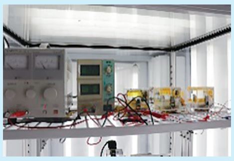
Germany, University of Stuttgart — Dr. **Michael Lengowski**

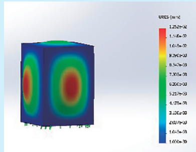
The purpose of this project is to develop the word's first "Biosatellite Cube (Tohoku Univ. Biosatellite Cube [TU BioCube])", which is the space radiation including UV radiation exposure apparatus capable of controlled life support, based on the versatile 1U (10 cm x 10 cm x 10 cm) CubeSat. The developing of TU BioCube makes it possible to perform the world's first experiment that can estimate the effect of space environment on organisms (plants). In addition, in near future, the developing TU BioCube will absolutely become pioneering and essential study to create basis of space habitation. This study can not only promote the technology of plant cultivation in space but also apply to space habitation for animal, space medicine, and basic biological science. Furthermore, this study will be expected to applicate for space engineering and material engineering fields in terms of constructing lifemaintaining system.



Latest research results

The concept study and basic design of TU BioCube have been conducted with members of the space life science research community, JAXA, and multiple companies / manufacturers. Especially, we are focusing on the main elemental technology development items, "Cube basic structure", "pressure control system", "temperature control system", "sunlight transmission window", "biological culture vessel system", "monitoring sensor system", and "biological experiment system".





Quantum Sensing: From Materials to Universe

PI

AIMR & Purdue
Prof. **Yong P. Chen**

Co-PI

RIEC & EE
Assoc. Prof.
Tomohiro Otsuka

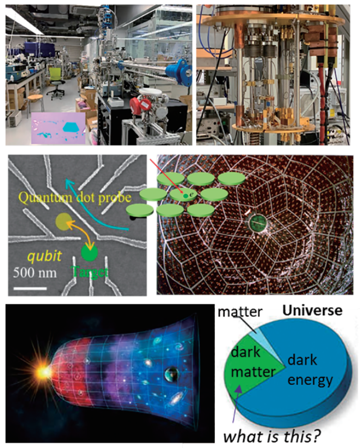
Co-PI

RCNS & PHYS
Prof. **Kunio Inoue**

Overseas Research Institution Partners

United States, Purdue University — Assoc. Prof. **Rafael Lang**; Assist. Prof. **Pramey Upadhyaya**

Quantum science and technology promise revolutionary advances in many aspects of human life in future. One major focus in this area has been quantum computing based on quantum bits (qubits). However, developing a practical quantum computer with a large number of qubits remains very challenging. One reason is that qubits can be very sensitive to perturbations in the environment. On the other hand, such sensitivity can also be harnessed to turn qubits (even just a small number of them) into powerful "quantum sensors". Such quantum sensing could offer a more near-term quantum technology (compared to quantum computing) with many useful applications. In this project, we will study quantum sensors --- particularly those based on quantum dots (a platform for qubits), and explore their applications in both materials research (e.g., sensitive measurements of electric and magnetic properties) as well as high energy physics and cosmology (e.g., radiation detection, neutrino research, searching for dark matter and fundamental particles important to understand the universe). The project will bring together researchers from diverse disciplines-ranging from materials science, spintronics to high energy physics-from Tohoku university as well as our overseas partner institution (Purdue University in USA), to develop key scientific capabilities and collaborations to pursue world-leading quantum sensing research.



Latest research results

We have used NV centers as room temperature quantum sensors to study magnetic materials and phenomena including magnetic switching, fluctuations and magnons. We have started constructing new experimental setups to measure semiconductor quantum dots based quantum sensors and 2D/topological quantum materials and effects of radiation in dilution refrigerators.

Multi-Sensory Flexible Skin

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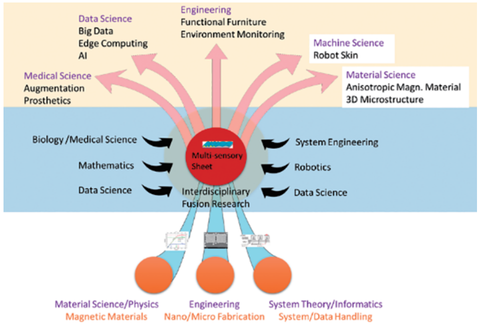
Co-PI
Graduate School of Engineering
Visiting Assoc. Prof.
Masanori Muroyama

Co-PI
IFS
Dr. **Gildas Diguet**

Overseas Research Institution Partners

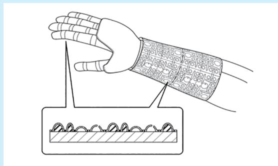
Germany, University Ruhr West Prof. **Ioannis Iossifidis**
Germany, Fraunhofer ENAS Dr. **Mario Baum**

We strife to combine Material Science, Micro-/Nano Sensor Technology, Sensor Network System, Integration of Materials, and Robotics. A bendable, scalable multi-sensory skin will be developed. It has the ability of sensing directional tactile force, magnetic field, pressure, sound, distance, temperature, and heat flux at the same time. It uses the same basic structure and material for all sensory functions. It is expected to open up a large variety of not yet achievable research topics, such as for example safe physical human interaction machines, prosthetics with real sensory experience, human augmentations, remote experience, smart walls and furniture. Each of it could become a hot topic in the future to address pressing challenges in our society.We are sharing a common vision to combine science and engineering as well as fundamental and applied research, leading to new commercialized products and visible improvements to everyday life.



Latest research results

We have developed the basic principles of a wearable sensor system, consisting of 3D-microstructured soft magnetic thin film and microelectronics capable of edge heavy sensing. By using the giant stress impedance effect various environment parameter can be continuously measured in a relatively simple structure and high spatial resolution. The sensor principle has been proven and the wearable sensor system concept has been submitted as patent.
Micromachines, 11, 649 (2020), JP2020-12685



Understanding the Cultural Process of Sustainable Society for over 10,000 years

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Co-PI
Graduate School of
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Prof. **Yasufumi Iryu**

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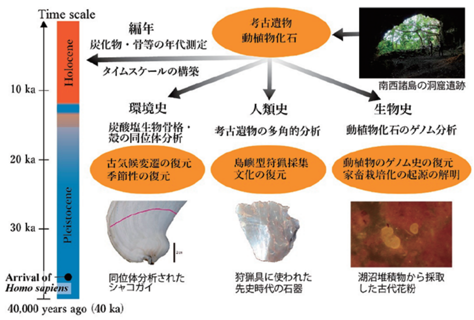
Yoshihisa Suyama

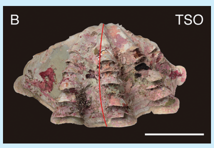
Overseas Research Institution Partners

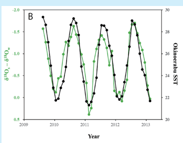
England, University of Oxford Prof. **Tom Higham**

In this project, we try to better understand how the island hunter-gatherer culture has been developed and why they were able to sustain the culture over 10,000 years. We investigate archaeological materials to reveal an island hunter-gatherer culture and analyze carbon and isotope records in shells from prehistoric sties to precisely reconstruct the paleoclimate. We also undertake ancient and present DNA analyses of plant and animal samples to detect the roots of the domestication.
This multidisciplinary approach provides us with an opportunity for elucidating adaption strategy of hunter-gatherers on a small island to the drastic climate changes from the Terminal Pleistocene to the Holocene and their subsistence strategy that allowed them to cohabitate with animals and plants within small island environments.
The findings of this study would contribute to the studies on the human history, but also offer us hints for a sustainable lifestyle in the future.



Latest research results





In this project, we reconstruct paleoenvironment based on geochemical record from tridacnine shells collected from prehistoric sites. For this purpose, we establish a relationship between oxygen isotope ratios of Tridacna squamosa (left photo) shells and seawater temperature (right figure). This tridacnine thermometer allows us to reconstruct past seawater temperature with high accuracy (±<1℃). This study is published online in Paleontological Research.

Frontier Research in Duo (FRiD)

Logo for Frontier Research in Duo

This Program promotes the challenge to pioneering world-leading research and the creation of new research area.
We made “FRiD”, the abbreviation for this program into “brushstroke letters” and dynamically expressed the research project’s challenge to the world.

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