KITAKYUSHU SCIENCE AND RESEARCH PARK

Semiconductor-related University Research Seeds

2024

City of Kitakyushu

Kitakyushu Foundation for Advancement of Industry, Science and Technology

Kitakyushu Semiconductor Network

Introduction

Based on the Strategy for Semiconductors and the Digital Industry by the national government, efforts are being made to promote the Japanese semiconductor industry, including establishment of TSMC (semiconductor's global leading company in Taiwan) plant in Kumamoto, as well as strengthening the domestic semiconductor production base. We have also established the Kyushu Semiconductor Human Resources Development Consortium as an organization in the national government, and the Fukuoka Green Device Council in Fukuoka Prefecture for training and securing semiconductor human resources, for strengthening the supply chain, etc.

In light of these trends, the City of Kitakyushu and the Kitakyushu Foundation for Advancement of Industry, Science and Technology have launched the Kitakyushu Semiconductor Network, an initiative to vitalize the semiconductor industry in Kitakyushu area through collaboration among businesses, universities, and national/local governments.

As part of this initiative, we have compiled information on research seeds that researchers involved in the semiconductor-related industries at three universities (the University of Kitakyushu, Kyushu Institute of Technology, and Waseda University) located in the Kitakyushu Science and Research Park, which aims to promote industry-academia collaboration.

Diverse fields are involved in the semiconductor-related industries, and the seeds of the cooperating researchers cover a wide range of technical fields and application fields. The technical fields and the application fields compiled in this report are classified as shown in the table below and displayed on each page. We hope this summary of seeds will help you propel your business development.

Technical fields and application fields

Abbreviation	Technical fields
Mat	Semiconductor materials and functional materials
Des	Semiconductor device design
Waf	Wafer processes
Pac	Packaging
Mou	Circuit board and mounting
Ins	Inspection, measurement, and analysis
Rel	Reliability
Rec	Separation, recovery, recycling, and waste treatment
Con	Signal analysis, signal processing, and control
Oth	Sensors and Others

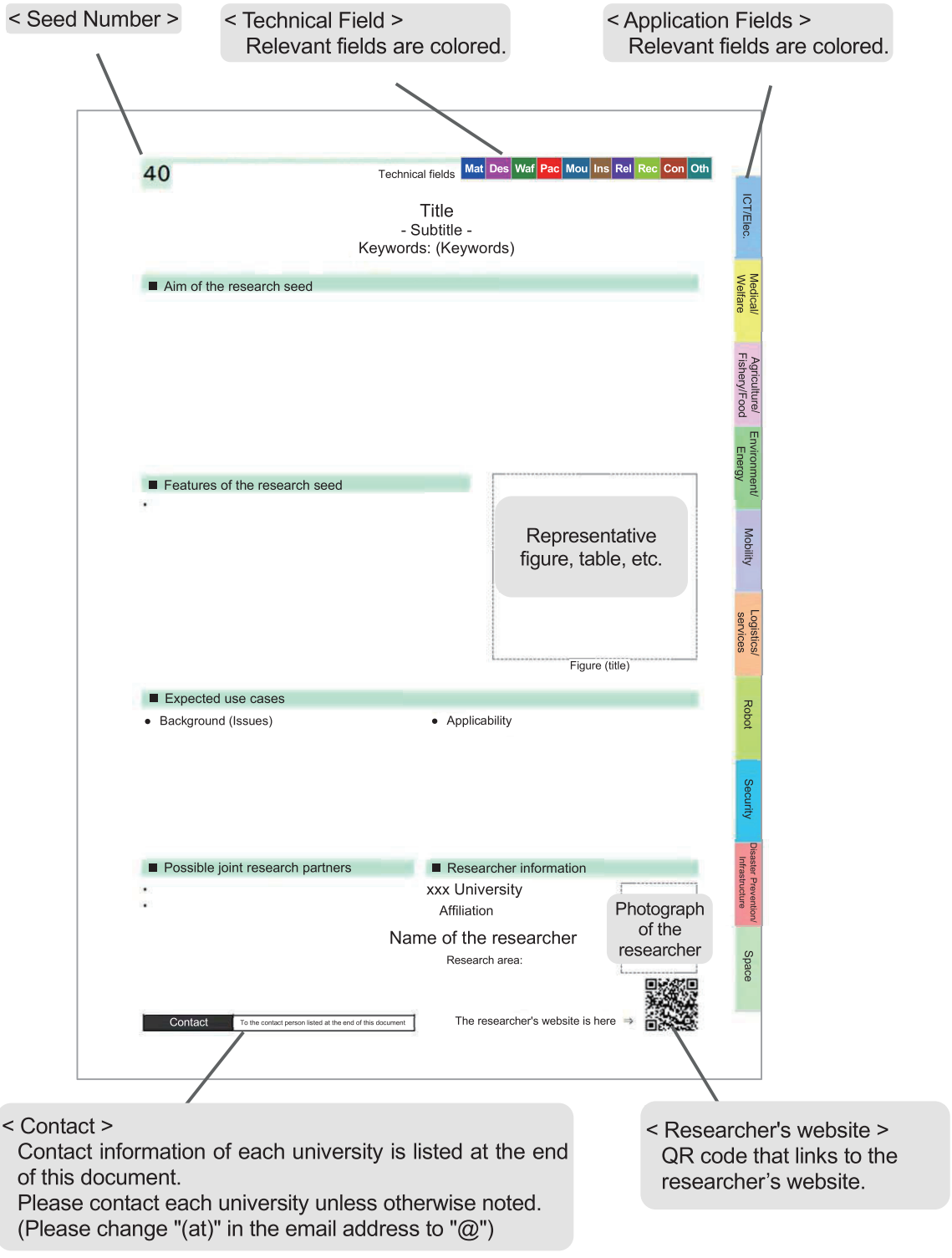
* Shown in upper right of title

Abbreviation	Application fields
ICT/Elec.	Information and Communications Technology (ICT) and electronics industries
Medical/Welfare	Medical service, welfare, and healthcare industries
Agriculture/ Fishery/Food	Agriculture, fisheries, and food industries
Environment/ Energy	Environment and energy industries
Mobility	Land, sea, and air transportation industries
Logistics/services	Logistics and services industries
Robot	Robotics and smart factory industries
Security	Crime prevention and security industries
Disaster Prevention/ Infrastructure	Disaster prevention and social-infrastructure industries
Space	Space industries

* Shown on the left and right edges of each page

Layout of each page

Layout of each page is shown in the figure below.
The seed numbers are listed in the table on the next page.
The technical fields are displayed at the top right of the page, and the application fields are displayed at the left and right edges of the double page spread. Each relevant field is shown in colors while others are greyed out.
For details of each researcher, please check the website of the researcher using the QR code shown on the page.
If you have any questions about the seeds, please contact the university offices listed at the end of this document, unless otherwise specified. (Please change "(at)" in the email address to "@")



List of the research seeds

No	Subject	University	Researcher
1	Development of Brain Function Mimicking Device Using Graphene/Diamond Junction	Waseda University	Kenji Ueda, Professor
2	Semiconductor Laser and Photonic Integrated Circuit Design Technology	Waseda University	Takaaki Kakitsuka, Associate Professor
3	Optimization Method for VLSI Circuit Design	Waseda University	Shinji Kimura, Professor
4	New Sensing Technology Using Point Terahertz Source	Waseda University	Kazunori Serita, Associate Professor
5	Developing the Hardware Development Capabilities with Open Innovation	The University of Kitakyushu	Shigetoshi Nakatake, Professor
6	Low Computational Cost AI for the Edge Computing	Kyushu Institute of Technology	Yuichiro Tanaka, Associate Professor
7	For Online Updates of FPGA Logic and Firmware	The University of Kitakyushu	Susumu Yamazaki, Associate Professor
8	MEMS-based Stiffness/Viscosity Sensors for Microscale Objects	Kyushu Institute of Technology	Momoko Kumemura, Associate Professor
9	Enhancing Medical Treatment and Drug Development through the Fusion of Semiconductor and iPS Cell Technologies	Kyushu Institute of Technology	Takashi Yasuda, Professor
10	Fundamental Technologies for Future Medicine	Waseda University	Jun Kameoka, Professor
11	Advanced Medical Devices Based on Human Body Odors and the Development of Next-Generation Medical Technologies	The University of Kitakyushu	Seung-Woo Lee, Professor
12	Materials, Devices, and Systems For Human and Environmental Applications	Waseda University	Takeo Miyake, Professor
13	Devices Integrating Semiconductor Technologies, Fluid Technologies, and Information Technologies	Waseda University	Kazuma Mawatari, Professor
14	Force Sensors with Variable Sensitivity by Structure Change	Kyushu Institute of Technology	Kazuto Takashima, Associate Professor
15	Mass Production of Sensor Substrates Utilizing MEMS Manufacturing Facilities	The University of Kitakyushu	Takaaki Isoda, Professor
16	Signal Processing and Machine Learning Systems Beyond the Reach of High-speed Internet	The University of Kitakyushu	Susumu Yamazaki, Associate Professor
17	Creation of New Electronic Devices Utilizing the Unique Functions of Diamond	Kyushu Institute of Technology	Akihiko Watanabe, Associate Professor
18	High Temperature Resistant Mounting Technology for SiC Power Devices	Waseda University	Kohei Tatsumi, Professor Emeritus
19	Evaluation Technologies for Semiconductor Device Materials and Processes	Waseda University	Takayoshi Shimura, Professor
20	Compact Power Conversion Circuits for Energy Harvesting	Waseda University	Toru Tanzawa, Professor
21	Micro MEMS Gravimeters in the IoT Era	Waseda University	Tamio Ikehashi, Professor
22	Development of Highly Efficient and Stable Perovskite Solar Cells	Kyushu Institute of Technology	Tingli Ma, Professor
23	Advanced Separation Technologies in Liquid Phase Using Adsorption, Ion Exchange, and Liquid-liquid Extraction	The University of Kitakyushu	Syouhei Nishihama, Professor
24	Separation of Lithium Ions	The University of Kitakyushu	Mitsuharu Terashima, Professor
25	Supply Chain Management through Life Cycle Assessment	The University of Kitakyushu	Toru Matsumoto, Professor
26	Enhancing Power Semiconductor Cooling Performance through Heat and Fluid Flow Optimization	The University of Kitakyushu	Koichi Inoue, Professor
27	1/1000 Reduction in Size and Cost: Intelligent Current Sensor for Electric Power Applications	Kyushu Institute of Technology	Ichiro Omura, Professor
28	Development Environment by FPGA of Motor Drive Control System	Kyushu Institute of Technology	Tsuyoshi Hanamoto, Professor
29	Microwave / Millimeter Wave Integrated Circuit Design Technology for Wireless Communications	Waseda University	Toshihiko Yoshimasu, Professor
30	Innovation in Manufacturing through Optimal Design	Waseda University	Shintaro Yamasaki, Professor
31	Optimization Method for Connecting "Things"	The University of Kitakyushu	Yasuhiro Takashima, Professor
32	Green Computing Materials AI Devices	Kyushu Institute of Technology	Hirofumi Tanaka, Professor
33	Brain-inspired Computer System Embedded in "Things" and Multifaceted Application	Kyushu Institute of Technology	Hakaru Tamukoh, Professor
34	Development of Next-generation Brain-inspired AI Models and LSI Chips / Devices	Kyushu Institute of Technology	Takashi Morie, Specially Appointed Professor
35	Reversible Automation	The University of Kitakyushu	Takeshi Nishida, Professor
36	High-performance, Long-life Machine Learning, Image Processing, and Signal Processing Systems for Space Applications	The University of Kitakyushu	Susumu Yamazaki, Associate Professor

List of Technical Fields

No	Technical fields										Application fields										Page number
	Mat	Des	Waf	Pac	Mou	Ins	Rel	Rec	Con	Oth	ICT/Elec.	Medical/Welfare	Agriculture/ Fishery/Food	Environment/ Energy	Mobility	Logistics/ services	Robot	Security	Disaster Prevention/ Infrastructure	Space	
1	○										●										4
2		○									●										5
3									○		●										6
4						○				○	●	●									7
5		○								○	●	●									8
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7		○			○		○		○		●	●			●			●		●	10
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19	○										●			●							22
20		○									●			●		●			●		23
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22	○					○								●							25
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26		○					○			○				●	●					●	29
27						○	○			○	●			●	●		●	●	●		30
28									○		●				●		●				31
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33		○							○		●						●				36
34		○									●						●				37
35									○	○							●				38
36		○			○		○		○										●	●	39

1

Technical fields: **Mat** | Des | Waf | Pac | Mou | Ins | Rel | Rec | Con | Oth

Development of Brain Function Mimicking Device Using Graphene/Diamond Junction

- Fabrication of Devices with Functions of the Human Brain and Eye -

Keywords: **brain mimicking devices, semiconductors, thin films, electronic materials**

■ Aim of the research seed

In this study, we attempt to develop a device that mimics brain functions based on the unique photoconductive property of a hybrid structure (graphene/diamond junction interface) that combines graphene, a typical carbon material, and a diamond semiconductor, where conductivity of the junction changes with light irradiation and is retained (stored).

In the human brain, synapses, connections between nerve cells, are strengthened according to the importance of information, thereby selecting only important information and enabling efficient processing of information. Similar to the biological synapses, this junction exhibits memory plasticity (short-term to long-term memory change), in which the retention (memory) time of junction conductivity varies greatly depending on the strength of (optical) stimulation, i.e., the number and frequency of irradiated light pulses. This indicates that this junction can be used as a light-controllable artificial synapse. By reproducing brain functions using graphene/diamond junctions with such unique brain-like characteristics (eye (optical sensing) + brain (memory and arithmetic) functions), we will develop brain-function mimicking devices capable of high-speed, high-efficiency image recognition, etc., which is difficult with current devices.

■ Features of the research seed

A feature of this research seed resides in the interfacial carbon structure control technology with our original high quality graphene/diamond junctions, which produces characteristic functions including brain-mimicking optical functions. This technology will lead to the development of unique brain-mimicking visual information processing devices that no other research effort can realize.

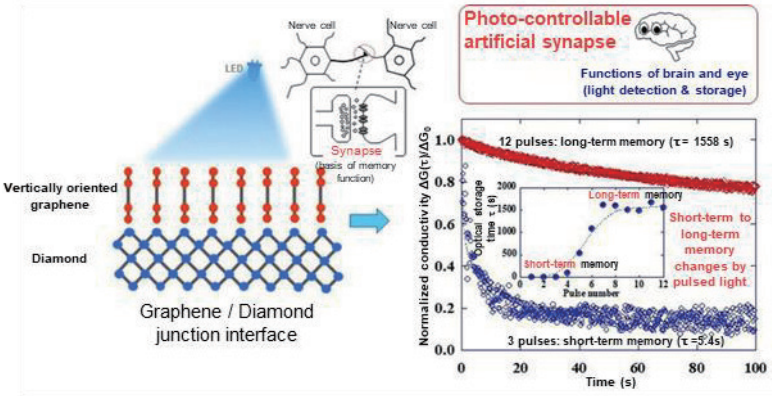

Fig. Unique Photoconductive Properties of Graphene/Diamond Junctions

■ Expected use cases

● **Background (Issues)**

The development of a computing device that functions like a human brain and processes complex information such as images and sounds at high speed and with high efficiency, which is difficult for existing computers, is eagerly awaited, and this device is likely to meet this demand.

● **Applicability**

- Development of brain-mimicking image sensors (image sensors which selectively detect only important (with strong stimulus) image information).
- Application to security cameras (selectively detect and report only suspicious individuals).
- Brain-inspired optical computer

■ Possible joint research partners

- Manufacturers of electrical equipment
- Manufacturers of semiconductor materials and devices
- Manufacturers of information and communications equipment

■ Researcher information

Waseda University
Graduate School of Information, Production and Systems
Kenji Ueda, Professor

Research areas:
Semiconductor materials and devices

The researcher's website is here →

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Technical fields: Mat **Des** Waf Pac Mou Ins Rel Rec Con Oth

Semiconductor Laser and Photonic Integrated Circuit Design Technology

- Virtual Experiments on Optical Devices and Systems -

Keywords: **optical semiconductor, semiconductor laser, photonic integrated circuit**

■ Aim of the research seed

We are engaged in research and development on semiconductor laser design technology. Semiconductor lasers have a wide range of industrial applications including optical communications, medical care, sensors, and processing. This is because compound semiconductors can support a wide range of emission wavelengths, and desired characteristics for the application, such as optical output, spectral width, and modulation bandwidth, can be realized through material and structural design. We, at Waseda University, have developed simulation technology for the emission characteristics of compound semiconductors, as well as for semiconductor lasers and photonic integrated circuits, integrating optical waveguide and optical cavity designs. We are conducting research to improve the performance of infrared light sources for optical communications. We aim to apply this technology to a wide range of applications, from light sources for long-distance optical fiber communications used in backbone networks, to low-power light sources expected to be applied to short-distance optical interconnections between chips, and further to sensing applications.

■ Features of the research seed

By designing epitaxial layers of compound semiconductors such as InP- and GaAs-based materials, we can design light-emitting layers according to the desired operating wavelength. In addition, the laser chip structure is determined by designing an optical waveguide according to the optical output port structure, and by designing a laser cavity integrated with a wavelength-selective filter and a wavelength-selective mirror for wavelength and frequency control. As an example, an optical waveguide cavity structure with a diffraction grating is used to realize lasing frequency stabilization, high-speed modulation, and low-energy operation of a single-mode light source for optical communication in the 1.3-1.55-μm wavelength band.

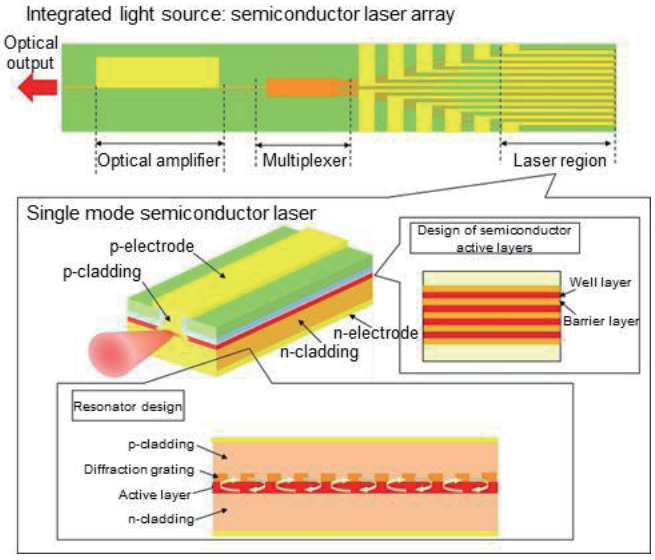

Fig. Structural Design of Optical Semiconductor Integrated Circuit

■ Expected use cases

● **Background (Issues)**

· Performance enhancement of semiconductor lasers: Single-mode lasing, wavelength tunability, high-speed modulation, narrower linewidth, higher output power, etc.

· Active optical integrated circuits: An optical functional device by integrating light source(s), modulator(s), optical amplifier(s), and optical functional element(s) (optical waveguide, multiplexer/demultiplexer, wavelength filter, etc.)

● **Applicability**

· Light source for optical fiber communication

· Light source for sensors (LiDAR, gas detection, medical applications)

■ Possible joint research partners

· Research institutes and manufacturers of optical components

· Research institutes and vendors of optical transmission equipment

· Vendors of optical and electronic circuit simulators

■ Researcher information

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Graduate School of Information, Production and Systems

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Research areas:
Optoelectronics

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3

Technical fields: Mat Des Waf Pac Mou Ins Rel Rec **Con** Oth

Optimization Method for VLSI Circuit Design

- Reduction of VLSI Circuit Area, Calculation Time, and Energy -

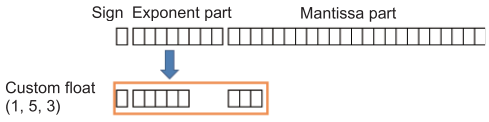
Keywords: **high-level design and verification of VLSI circuits, optimization of arithmetic circuits, approximate calculation, clock gating**

■ Aim of the research seed

Recent advances in high-level synthesis have made it possible to design actual circuits using C and C++ programing language. However, the performance of the resulting circuit depends greatly on how the program is written and on the computing algorithm. Therefore, optimization of the arithmetic circuit and control is performed for an application system such as a convolutional neural network using many arithmetic units to achieve better performance. The number of elements or area, computation time, power or energy consumption are regarded as the performance of a VLSI circuit. Since there are trade-offs between some of the factors, we specifically focus on optimizing power or energy consumption. To be more precise, a data representation method, an operation method, as well as simplification of operation by approximate calculations are introduced. Regarding the power reduction of sequential circuits, clock gating is also applied to stop clock signal supply to registers with optimized selection of an enable signal. Optimum design of a VLSI circuit is implemented to make it a "Green VLSI," especially by reducing the energy consumption, while maintaining the computation accuracy of the whole system.

■ Features of the research seed

This technology is characterized by optimizing the data representation, the computation methods, and the control signal of the clock gating to realize a power-saving and green VLSI circuit. Converting floating point numbers to representations with small bits enables reduction of the memory size and power consumption, and the operation itself becomes simpler while the computation result will be different. Applications such as convolutional neural networks are error tolerant where small changes in the computation results do not affect the final result. Therefore, approximation can be used for the intermediate calculations. Furthermore, the clock gating can stop the output change of the memory elements, input change of the CMOS elements also stops thereby reducing the power consumption.



TOP-5 TEST ERROR UNDER DIFFERENT PRECISIONS

Network	Precision		Accuracy loss
	32 (1-8-23)	9 (1-5-3)	
AlexNet	20.48%	21.00%	0.52%
GoogLeNet	12.57%	12.78%	0.21%
VGG-16	11.16%	11.34%	0.18%
ResNet-50	10.16%	10.58%	0.42%

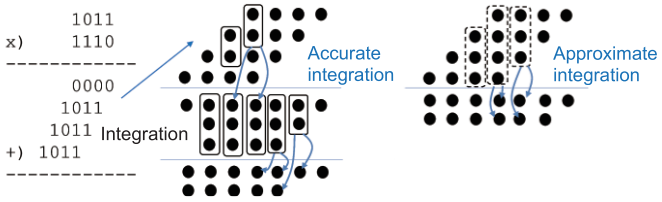


Fig. Optimizing Data Representation and Arithmetic Units

■ Expected use cases

- **Background (Issues)**
  The smaller the energy consumption of the digital electronic circuit, the better. Although large-scale information systems require a design with a high degree of abstraction such as C/C++, power saving functions of current high-level synthesized systems are not sufficient.

- **Applicability**
  It can be applied to power saving for digital control circuits including VLSI circuits obtained by high level synthesis and prototype circuits using FPGA (Field Programmable Gate Array).

■ Possible joint research partners

· Manufacturers of electrical equipment
· Manufacturers of electrical and electronic equipment

■ Researcher information

Waseda University
Graduate School of Information, Production and Systems

Shinji Kimura, Professor

Research areas:
Hardware design and verification

The researcher's website is here →

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Technical fields: Mat Des Waf Pac Mou **Ins** Rel Rec Con **Oth**

New Sensing Technology Using Point Terahertz Source

- Promoting the Use of Terahertz Waves in the Beyond 5G Era -

Keywords: **terahertz, point terahertz source, terahertz sensing, nondestructive evaluation**

■ Aim of the research seed

Terahertz waves refer to electromagnetic waves with frequencies between 0.1 THz and 10 THz or wavelengths between 30 μm and 3 mm. These are electromagnetic waves located between visible light and radio waves and have both properties. Terahertz waves have a small energy of several meV per photon, and are attracting attention as a tool to nondestructively and noninvasively evaluate the properties of various materials ranging from semiconductors to biological tissues through imaging and spectroscopy. In the Beyond 5G era, various services using terahertz waves are expected to become widespread. Accordingly, it will be important to develop devices, sensors, and systems that operate in the terahertz frequency range, as well as to develop sensing technologies using them and integration technologies of the devices. However, there are many problems in making the technology mature enough for applications, including low spatial resolution in measurement, low power, propagation loss in air, and size of the devices. Our research group has solved these problems with technologies to generate small and bright point terahertz sources, and is now developing devices and sensing technologies to make the terahertz technology be widely applied.

■ Features of the research seed

We are developing devices and sensing applications using a very small point terahertz source generated by wavelength conversion from light to terahertz wave. The spot size of the point terahertz source is determined by the wavelength of the excitation laser (several μmφ). As a result, highly sensitive sensing with high-spatial resolution has become possible even for small-sized samples of the micrometer order, which have been difficult to measure with conventional terahertz waves. For example, detection of minute defects in a semiconductor crystal or a disconnection position of metal wiring in an LSI becomes possible. This technology is also applicable to cell scale imaging in biological tissues and label free sensors shown in the right figure, which can detect concentration changes of a very small amount of solution. This technology is also expected to realize terahertz microscopes, and integrated devices when combined with the latest Si technology and data processing technology.

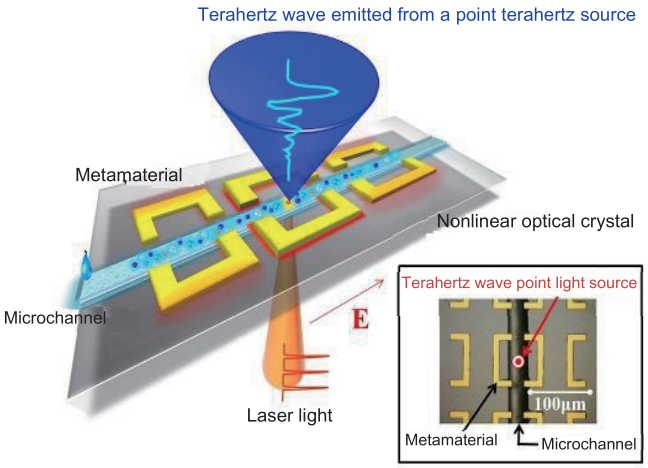

Fig. Example of Sensor Using a Point Terahertz Source

■ Expected use cases

- **Background (Issues)**
  - Semiconductor device manufacturing requires rapid material characterization and defect detection with nondestructive and noncontact techniques.
  - In device development for Beyond 5G, material characterization in the terahertz band is required.
  - In the medical field, label-free testing is required for rapid diagnosis of cancer.
  - Inspection with terahertz waves is one of a nondestructive evaluation technique, but its sensitivity and spatial resolution are poor, and detailed analysis of materials, and integration and miniaturization of devices are difficult. Biometry is also difficult with the terahertz technology due to propagation loss in air and absorption by water.

- **Applicability**
  - Nondestructive and noninvasive evaluation, material characterization in the terahertz band
  - Development of terahertz sensors, terahertz microscopes, and terahertz integrated devices
  - Creation of a new evaluation method using the terahertz data obtained above
  - Promoting the use of terahertz waves in Beyond 5G

■ Possible joint research partners

- All companies related to non-contact and non-destructive evaluation and analysis of semiconductor materials and devices
- All the companies related to biosensors and analyses
- All companies related to medical devices

■ Researcher information

Waseda University
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Research areas:
Terahertz engineering

The researcher's website is here →

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Technical fields: Mat **Des** Waf Pac Mou Ins Rel Rec Con **Oth**

Developing the Hardware Development Capabilities with Open Innovation

- To Facilitate the Creation of Hardware Having New Functions -

Keywords: **open innovation, design systems, functional memory**

■ Aim of the research seed

We are exploring how open innovation can contribute to the semiconductor design. In particular, we are focusing on OpenRAM, a tool that utilizes a general-purpose architecture to realize automatic synthesis of memory blocks. OpenRAM is an open source software tool, and we examined memory synthesis and memory circuit performance when applied to a 0.6 μm CMOS manufacturing process. This identifies the benefits of open source approaches and also the remaining challenges. In addition, future of the R&D is discussed through examples of multifunctional memory development using this tool. This research suggests that open innovation will bring new perspectives and possibilities to the field of semiconductor design.

■ Features of the research seed

OpenRAM provides tools to design and automatically synthesize layouts of memory units with a general purpose architecture that can be adapted to various CMOS manufacturing processes.

- Design and layout synthesis of memory units using 0.6 μm CMOS process
- Identify the benefits and challenges of using open source tools through simulations of functions and performance.
- Use cases of multifunctional memory development with OpenRAM are presented.
- The process from approximate calculation and programmable circuit design to trial manufacturing and verification is relatively easy.
- Issues identified with Process Design Kit (PDK), simulators, and DRC tools
- In the future, we expect to build an environment where full verification is possible only with open source tools.

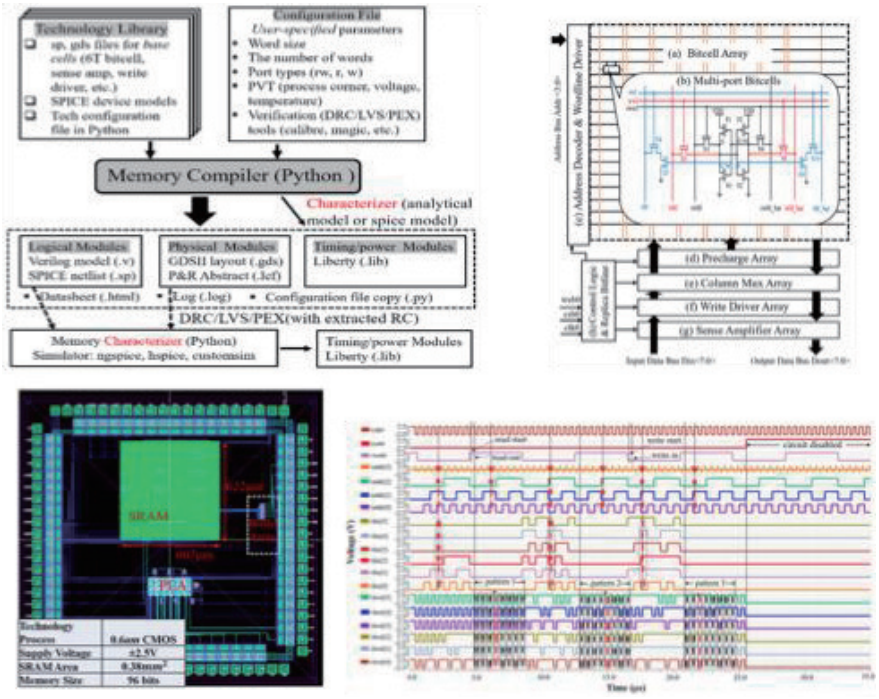

Fig. An Example of Prototype Using OpenRAM

■ Possible joint research partners

- Semiconductor design system developer
- Semiconductor design firms
- Sensor system developers

■ Researcher information

The University of Kitakyushu
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Shigetoshi Nakatake,
Professor

Research areas:
Integrated circuit design technology

The researcher's website is here →

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Technical fields: Mat Des Waf Pac Mou Ins Rel Rec **Con** Oth

Low Computational Cost AI for the Edge Computing

- AI on Edge Devices not only for Inference but also for Training -

Keywords: **embedded systems, reservoir computing, time series signal processing, image processing**

■ Aim of the research seed

Current artificial intelligence (AI) technologies are cloud-oriented, require large amounts of data to learn AI models, and are meant to run on high performance computers consuming large amounts of power, which limits AI implementations on edge devices with limited data, computational resources, and power. In order to solve this problem, we are developing AI technology with low computational cost for learning. This technology can be applied to embedded systems such as automobiles and robots. In particular, if the data handled by AI includes personal information and/or confidential information, infringement of privacy is a concern with cloud AI, while with this technology such concern is no longer a problem since AI processing can be completed within edge devices. Furthermore, because this technology is low in computational cost and relatively easy to implement in hardware, power-saving implementation of AI is possible, and we hope that this research will ultimately lead to the realization of a low-carbon society.

■ Features of the research seed

We build an AI model based on reservoir computing, which is known for its low computational cost for learning. The learning mechanism of the reservoir computing is very simple, and has the advantage of being light in necessary computational resources while it has the disadvantage of low learning freedom. In addition, reservoir computing has low feature extraction capability, which poses problems in application to real problems. In this research, we propose a multi-readout technique to increase the freedom of learning and a technique to extract various features by combining multiple reservoirs with different time constants. These techniques can improve reservoir computing performance while retaining advantages of reservoir computing.

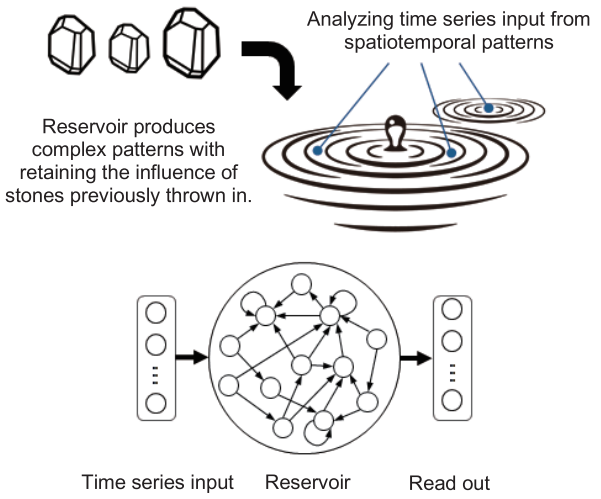

Fig. Reservoir Computing

■ Expected use cases

- **Background (Issues)**
  Cloud computing is utilized to handle the massive computation volume of current AI, but there are cases where sending data to the cloud should be avoided. The ability to complete AI computations at the edge makes it easier to protect data privacy.

- **Applicability**
  Possible applications of this technology are cases where protection of the data privacy is required; some of the examples are data containing confidential corporate information, data containing biological information obtained from wearable devices for healthcare, and moving images in private houses obtained by a surveillance camera.

■ Possible joint research partners

- Automotive (e.g., power-saving AI)
- Robotic-related (e.g., information processing in houses)
- Healthcare-related (e.g., biological information processing)
- Others related to manufacturing (e.g., error detection)

■ Researcher information

Kyushu Institute of Technology
Graduate School of Life Science and Systems Engineering
Yuichiro Tanaka,
Associate Professor

Research areas:
Soft computing

The researcher's website is here →

7

Technical fields: Mat **Des** Waf Pac **Mou** Ins **Rel** Rec **Con** Oth

For Online Updates of FPGA Logic and Firmware

- IoT Framework for Adding Functions and Security Updates -

Keywords: **Over the Air (OTA), partial reconfiguration**

■ Aim of the research seed

In IoT, there is a strong need to add functions to meet user requirements and to update security to withstand cyber attacks. It is desirable that the object of such updates includes not only firmware but also hardware.
What we propose as a research seed here is to make it possible to update not only firmware but also hardware securely Over the Air (OTA) online by using FPGA-based IoT. For that purpose, the system will be duplicated internally for backup while running the other system. The backup system will be updated through OTA before rebooting the system to start up with the updated backup. If the reboot is successful, the backup system will be used for execution replacing the role. If the reboot fails, reboot the system once again with the one previously running to recover. Such mechanism is realized not only with firmware but also with FPGA logic using partial reconfiguration of FPGA.

■ Features of the research seed

This research seed has the following features:
- Firmware can be securely updated online.
- If the update fails, restart automatically with the last version that was previously available.
- In the near future, the hardware (FPGA logic) will also be studied for secure online updates.

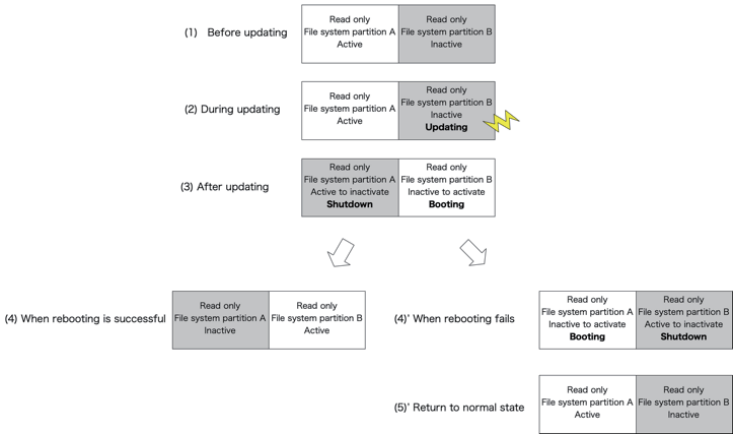

Fig. Updating Process

■ Expected use cases

● Background (Issues)

Can be used by system developers including:
- Developing new IoT services,
- Receiving many requests for additional functions, and
- Having a hard time with security updates.

● Applicability

The following applications are possible:
- Provision of IoT as a subscription service,
- Agile development combined with CI/CD,
- Development with highly productive high-level languages, and
- Products with long lifetimes, such as spacecraft.

■ Possible joint research partners

- Companies developing new IoT services
- Companies dealing with IoT with frequent addition of functions
- Companies operating IoT with stringent security requirements
- Companies requiring hardware updates
- Developers of software-defined satellites
- Companies looking to adopt agile software development

■ Researcher information

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Research areas:
Software and logic circuit design

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The researcher's website is here →

8

Technical fields: Mat Des Waf Pac Mou **Ins** Rel Rec Con **Oth**

MEMS-based Stiffness/Viscosity Sensors for Microscale Objects

Keywords: **MEMS, mechanical characterization of materials in microscale, manipulation of micro-scale object**

■ Aim of the research seed

MEMS is an electrically driven micro-structure mainly made of silicon, and its application as a sensor extends to industries utilizing its driving structure and electrical characteristics. One of the features is that the fine structure of several μm can be made by micromachining.
MEMS tweezers developed and studied in our laboratory are used to capture and characterize biological samples such as DNA (with around 10 μm) and cells. Sensing, trapping, and transporting minute substances can also be applied to evaluating micro-particles produced by organic synthesis. In the conventional method, the physical parameters of micro-particles are analyzed with a large number of samples to obtain average values. However, the MEMS tweezers are an effective measurement tool when the characterization of individual samples is required.

■ Features of the research seed

The MEMS tweezers consist of a pair of probes, an actuator, and a displacement sensor. The device can trap several to several tens of μm micro-objects between the probes. Monitoring the resonant frequency of the probe, we estimate the trapped material's stiffness and viscosity based on the spring-mass-damper model.
With an XYZ linear stage where the MEMS tweezers are mounted, the micro-object can be transported and placed elsewhere.

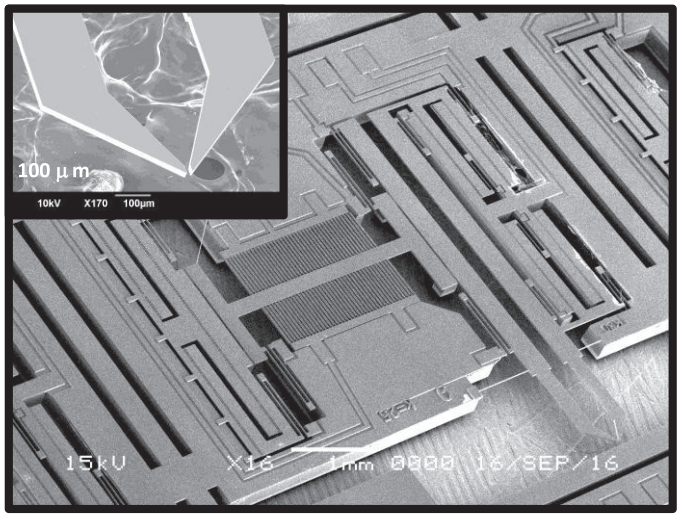

Fig. MEMS tweezers. The left top is a blowup of probes to trap micro-objects

■ Expected use cases

- **Background (Issues)**
  Currently, there are few methods to individually measure the physical properties of minute elastic bodies of several to several tens of μm.

- **Applicability**
  · Evaluation of mechanical properties (hardness and viscoelasticity) of minute synthetic compounds is possible.
  · Minute objects can be placed at a desired position.

■ Possible joint research partners

· Manufacturers for polymer material synthesis
· Cosmetics manufacturers
· Other companies that require mechanical characterization and manipulation of microscale elastic materials

■ Researcher information

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Bio-MEMS

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9

Technical fields: Mat Des Waf Pac Mou Ins Rel Rec Con **Oth**

Enhancing Medical Treatment and Drug Development through the Fusion of Semiconductor and iPS Cell Technologies

- Development of Neural Cell Analysis Technology Using Bio-MEMS -

Keywords: **MEMS, porous membrane, microelectrode array, nerve cell, iPS cell**

■ Aim of the research seed

By combining MEMS (Micro Electro Mechanical Systems) technology, where micro-sized mechanical structures are fabricated by semiconductor processing technology, with cell culture and analysis technology, we will create device technologies that contribute to the fields of medical treatment and drug development. In particular, we are aiming to realize devices that can elucidate the pathogenesis of Alzheimer's disease, epilepsy, and other neurological diseases as well as evaluate the efficacy and safety of drugs for these diseases. To achieve this goal, we will reconstruct nerve tissues in vitro on devices, and create culture environments on the devices that mimic in vivo conditions to enable the nerve tissues on the devices to function as in vivo. We will also build a technology to measure the electrical responses of nerve tissues to drug stimulation using microelectrode arrays formed on the devices. The use of neural tissues derived from human iPS cells makes it possible to perform human-targeted analyses on devices and can be widely used as an alternative to animal testing, which has become difficult to carry out from ethical grounds. Our technology also has the potential to create a new market for the semiconductor industry, which can have an extremely high social ripple effect.

■ Features of the research seed

We have developed a device technology that enables co-culture of neurons and astrocytes (cells connecting neurons and cerebral blood vessels) back-to-back on a transparent SiN porous membrane of approximately 1 μm in thickness. Through the numerous microholes of several μm in diameter opened in the membrane, sufficient material transport is carried out between both cells, allowing both cells to express their original functions and maintain their physiological activities over a long period of time. In addition, using a microelectrode array formed on one side of the membrane, the electrical signals of neurons can be measured noninvasively and simultaneously at multiple points in isolation from astrocytes. By exchanging the cells on both sides of the membrane, it is possible to analyze the signal of dysfunctional astrocytes, which have attracted much attention as one of the causes of neurological diseases.

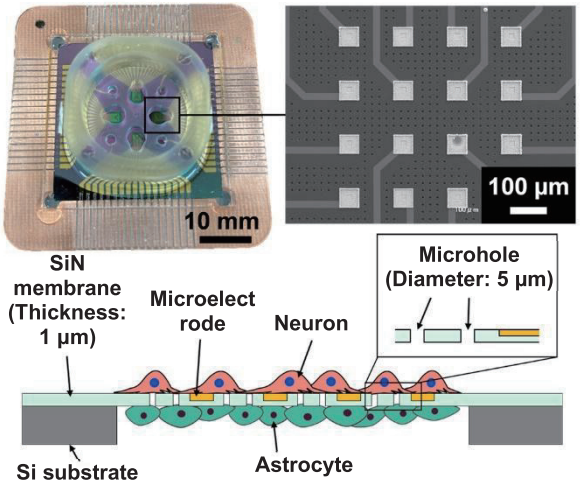

Fig. Photograph of a microelectrode array (top) and a schematic diagram of co-culture back-to-back on a SiN porous membrane (bottom)

■ Expected use cases

- **Background (Issues)**
  For the development of innovative treatments for intractable neurological diseases and the creation of highly effective therapeutic drugs, there is a strong need for device technology that can reconstruct human neural tissue in vitro that can express functions equivalent to those in vivo, and analyze the electrical signals it generates.

- **Applicability**
  By culturing neurons and astrocytes, which are produced from human iPS cells derived from patients with neurological diseases, on this device and analyzing their drug responses, it is possible to apply the device to basic research to elucidate the pathogenic mechanisms of neurological diseases and drug discovery research to evaluate the efficacy and safety of drugs for neurological diseases.

■ Possible joint research partners

- Semiconductor manufacturers capable of developing mass-production technology for devices
- Manufacturers of culturing and measuring equipment capable of developing device peripherals
- Medical institutions and pharmaceutical companies that can use the device in disease mechanism analysis and drug efficacy evaluation

■ Researcher information

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Technical fields: Mat Des Waf Pac Mou Ins Rel Rec Con **Oth**

Fundamental Technologies for Future Medicine

- Real-time Monitoring of Biomarkers -

Keywords: **biosensors, IOMT, Deep Learning**

■ Aim of the research seed

We are conducting a comprehensive study on the Internet of Medical Things (IOMT). The IOMT platform consists of three independent technologies: wearable biosensing devices, internet communication systems, and cloud data processing. Biosensing devices include blood glucose sensors, blood pressure sensors, and biomarker sensors. We are engaged in research and development on biosensors that can continuously measure blood glucose levels at low cost and with high accuracy. We use smartphones, RFIDs, and/or Raspberry Pis as the internet communication systems to continuously acquire bio-information and transmit it to the cloud via the Internet, and optimization of the information communication process to the cloud is studied in this respect. Cloud data processing is used to make a final decision based on the acquired successive bio-information. Machine learning and deep learning programs as well as optimization of feature selection are studied with the data processing to make proper decisions. Continuous bio-information enables comprehensive diagnosis and early detection of diseases, which ultimately leads to a reduction in medical costs.

■ Features of the research seed

The most important challenge today is the development of affordable, reproducible, and reliable wearable biosensors. Communication technology, cloud technology, etc. have been developed extensively, and integration with biosensors is becoming possible. In my group, we are developing three types of biosensors: implantable biosensors, epidermal biosensors, and microneedle type interstitial skin fluid sensors; and researching continuous detection of pH, biomarkers, and ions using the biosensors. Continuous detection of bioinformation is a field that has not been studied until now, and the data will enable prediction of disease progression, and early detection and management of disease.

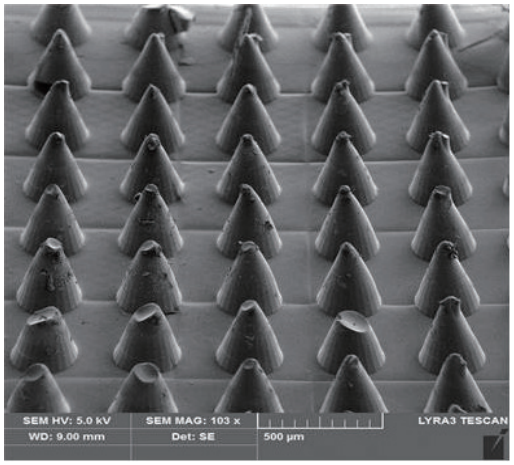

Fig. SEM Image of Hydrogel Microneedle Sensors

■ Expected use cases

● **Background (Issues)**

Due to the immaturity of sensor technologies, continuous detection of biometric information has not been studied. However, it has been shown that changes in biometric information (changes in continuous data) can be used for diagnosis, early detection, and prediction of disease. Therefore, the development of sufficiently reliable biosensors is urgently anticipated.

● **Applicability**

· Early detection and prevention of chronic diseases
· Early prediction of infectious diseases
· Relief of menopausal symptoms
· Diagnosis of depression, etc.

■ Possible joint research partners

· Medical institutions
· Mobile phone operators

■ Researcher information

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Technical fields: Mat Des Waf Pac Mou **Ins** Rel Rec Con **Oth**

Advanced Medical Devices Based on Human Body Odors and the Development of Next-Generation Medical Technologies

- Challenges in Non-invasive Cancer Diagnosis Using Volatile Metabolite Disease Markers -

Keywords: **odors, volatile metabolites, disease markers, gas sensors**

■ Aim of the research seed

Early detection of disease is an important national health care issue that is essential for reducing mortality and ensuring effective treatment in the early stages of the disease. To establish innovative medical technologies that promote early detection and effective treatment of diseases, especially cancer, we aim to develop non-invasive and less burdensome medical technologies utilizing derived from volatile organic compounds (VOCs), which are responsible for odors and are present in body fluids such as saliva and urine, and breath. For instance, exhaled breath contains hundreds or more volatile metabolites that can be precisely analyzed to identify disease-related biomarkers. This research aims to uncover molecular information that strongly correlates with diseases through qualitative and quantitative analysis of low molecular weight volatile compounds produced by the human body, and to develop detection devices for highly sensitive and accurate detection of these molecules. In the future, applications to IoT, robotics, and AI industries utilizing advanced devices like the intelligent artificial nose (e-nose) are feasible.

■ Features of the research seed

Over the past 50 years, numerous biomarkers have been discovered, but most are proteins or genes found in blood, making testing painful and invasive. They are used as supplements to cancer therapy, rather than for screening. Volatile compounds, which are the source of odors, are end metabolites reflecting genetic information, and are of great academic and industrial significance as effective sources of information for comprehensively understanding diseases, including cancer. Recently, we discovered distinct odor groups, such as “newly produced,” “increased or decreased,” and “disappeared” groups, based on the profiles of volatile metabolites present in body fluids. We have also developed new medical technology that detects and diagnoses diseases easily, quickly, and non-invasively. Currently, several dozen disease markers in saliva and urine have been successfully identified, which accelerates the practical application of this technology.

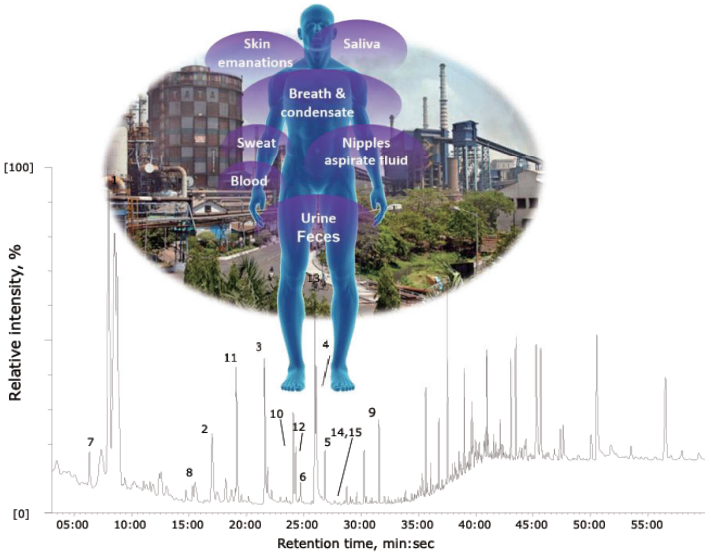

Fig. Volatile Metabolites Emitted from the Human Body

■ Expected use cases

- **Background (Issues)**
  Even in Japan, a country with a long life expectancy, cancer has been the leading cause of death for over 30 years, affecting more than one million people annually, with annual deaths exceeding 370,000. Cancer treatment costs more than 5 trillion yen per year, making early detection a crucial medical issue, also in terms of reducing medical costs.

- **Applicability**
  - Provision of medical services for the prevention and “very” early detection of cancer
  - Development of new medical devices utilizing molecular information from volatile disease markers and the establishment of cancer diagnosis technology
  - Creation of new academic fields based on collaboration between medicine and engineering

■ Possible joint research partners

- Companies interested in medical device development
- Companies experienced in the development of measuring and analytical instruments
- Companies interested in odor (gas) analysis
- Companies interested in developing odor robots
- Product and manufacturing environment analysis, etc.

■ Researcher information

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Material chemistry
Sensor engineering

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12

Technical fields: **Mat** Des Waf Pac **Mou** **Ins** Rel Rec **Con** **Oth**

Materials, Devices, and Systems For Human and Environmental Applications

Keywords: **electroless/electrolytic plating, bioelectrochemistry, semiconductor microfabrication, biological devices, wireless circuits**

■ Aim of the research seed

The Miyake Laboratory at Waseda University conducts a wide range of research activities, from basic science to applied engineering, aimed at developing novel materials, devices, and systems used at device/biological interfaces. Through the development of smart contact lenses that measure intraocular pressure and glucose levels, we are working on prototypes for the early prevention of glaucoma and diabetic retinopathy, the number one and number two leading causes of blindness respectively. In parallel, we develop nano-injector system for cellular manipulation in regenerative medicine.

Our core technologies for this interdisciplinary research include electrochemistry and microfabrication technologies such as electroless and electroplating. Based on these technologies, we have been working on new process development by integrating semiconductor engineering. With expertise in electronics, we are also working on new materials and circuit designs to realize analog and digital circuits on biological surfaces, aiming to discover innovative research seeds for the society of 10 to 20 years in the future. In particular, we are pioneering the field of bioiontronics – centered on ionic and biological signals-which has been difficult to achieve using conventional bioelectronics based on electronic signals. Our ongoing efforts are focused on generating research outcomes that not only surprise the world but also serve as foundations for next-generation technologies.

■ Features of the research seed

Currently, as shown in the figure on the right, our research is focused on a resonant coupling circuit—a wireless power transfer and sensing system—based on a novel principle utilizing parity-time (PT) symmetry. A key feature of this circuit is its ability to dramatically amplify sensor sensitivity—by several tens to several thousand times—through the combination of a negative resistance element on the detector side and a conventional resonant circuit with a variable resistor on the sensor side. This enables highly sensitive wireless measurements. In parallel, we are developing a composite nanotube thin film by integrating electrochemical plating with microfabrication technologies. This film allows for efficient intracellular delivery and extraction of substances from a wide range of cells, including microorganisms and plant cells.

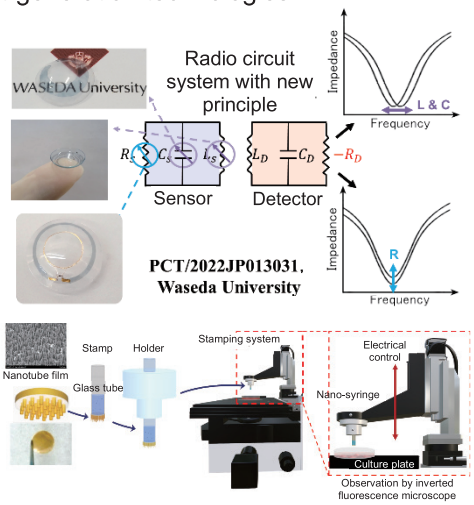

Fig. Miyake Laboratory's Seed Technology (non-restricted items only)

■ Expected use cases

- **Background (Issues)**
  - Wireless measurement is difficult even though we have suitable sensor elements.
  - Having trouble with the performance of wireless measurement because the sensor is embedded in the body or because of materials with dielectric loss.
  - Having trouble introducing substances into or extracting substances from living organisms.

  etc.

- **Applicability**
  - Wearable device
  - Smart contact lens
  - Smart Cell (synthetic biology, regenerative medicine, and agricultural applications)
  - Biomanufacturing
  - Implanted device

■ Possible joint research partners

- Universities and companies that can undertake the production of prototype resonant circuits with sensors and resonant circuits with negative resistance elements
- Universities and companies wishing to introduce substances into or extract substances from cells
- We can also work with those who are having trouble developing device elements for use in living organisms, plants, and things.

■ Researcher information

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Takeo Miyake, Professor

Research areas:
Bioiontronics

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Technical fields: **Mat** Des Waf Pac Mou Ins Rel Rec Con **Oth**

Devices Integrating Semiconductor Technologies, Fluid Technologies, and Information Technologies

- Fluidic IoT in Chemistry and Biosensing -

Keywords: **semiconductor processing technology, micro-nanofluid devices, measurement analysis and diagnostics**

■ Aim of the research seed

Chemical and biological information (environment, health, infectious diseases, biotechnology, food, fisheries, etc.) are important for people, but it is currently difficult to obtain such sophisticated chemical information easily. Therefore, we aim to realize a device with which anyone can access advanced chemical information by designing and systematizing a unique micro-nanofluid device, integrating it with information technology and IoT, and making it suitable for social implementation.
In addition, as a basic technology, we will use the devices to solve the important academic research themes on life science, semiconductors, and chemistry, such as how much water behaves as a normal liquid when space size is reduced, and how water in a small space differs from bulk water.

■ Features of the research seed

1) Channel processing technology for Micro-nanofluid
2) Low temperature substrate bonding technology
3) Ultra-sensitive laser detection technique for concentration of liquid in microspaces
4) Femto / atto liter liquid control technology
5) Application to devices
6) Systemization

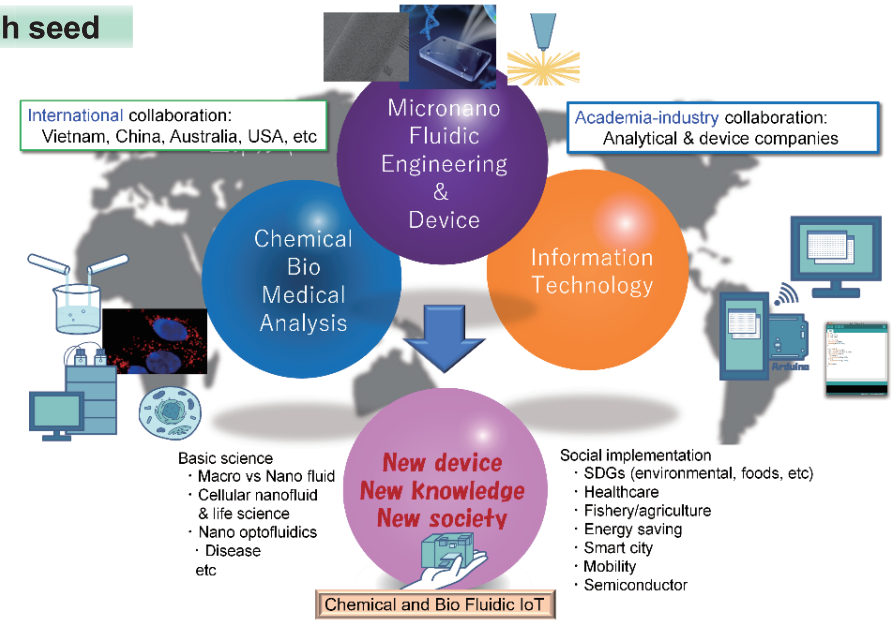

Fig. Outline of the Research

■ Expected use cases

● **Background (Issues)**
· Current chemical and bio analysis equipment is large, expensive, and inadequate for on-site and consumer applications
· Although there are no tools to measure the behavior of liquids in ultra-small spaces and knowledge of it is very little, it is an important academic area for semiconductor etching and cleaning, and life science, and others.

● **Applicability**
· On-site chemical and biosensing
· Home healthcare (combined with AI)
· Ultra-sensitive medical diagnosis
· Real-time virus detection
· Application as an academic tool in the field of liquids in ultrasmall spaces

■ Possible joint research partners

· Chemical and bio instrumentation and analysis
· Semiconductor processing
· Medical diagnosis

■ Researcher information

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Research areas:
Micro-nano device

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14

Technical fields: Mat Des Waf Pac Mou **Ins** **Rel** Rec Con **Oth**

Force Sensors with Variable Sensitivity by Structure Change

- Measurement Range and Sensitivity Can Be Changed According to Usage Conditions -

Keywords: **force sensor, shape memory polymer, shape memory alloy**

■ Aim of the research seed

In recent years, robots have been used widely in fields such as nursing care and welfare, and the force sensors built into robots are required to function in various environments. However, for conventional force sensors, since the amount of deformation applied to the sensor material (strained body) is read by a strain gauge or the like (For example, figure (a)), the measurement range and sensitivity are determined by the sensor material and cannot be changed.

Sensors in this research seed can respond to various situations without replacing the sensor, and, therefore, it can be used in and commercialized for a wide range of applications including production equipment in various factories, measuring devices in research facilities, load cells, and arms of nursing care and welfare robots.

The proposed method can be applied not only to simple single-axis force sensors, but also to six-axis force sensors, torque sensors, and acceleration sensors.

■ Features of the research seed

In this research seed (Japanese Patent Application 2022-027370), we propose a force sensor that can change the measurement range and sensitivity by changing the structure according to the environment. That is, the relationship between the detected strain and force is changed by changing the structure (For example, figure (a) → figure (b)). Since it is necessary to restore the initial structure after the structural change, a shape memory material is used as the sensor material (strained body).

We have developed robots that can freely switch between the flexible / multiple degree of freedom soft robots, and the accurate / highly rigid metal robots conventionally used in factories by using shape memory polymers, etc. This research seed is one of those technologies.

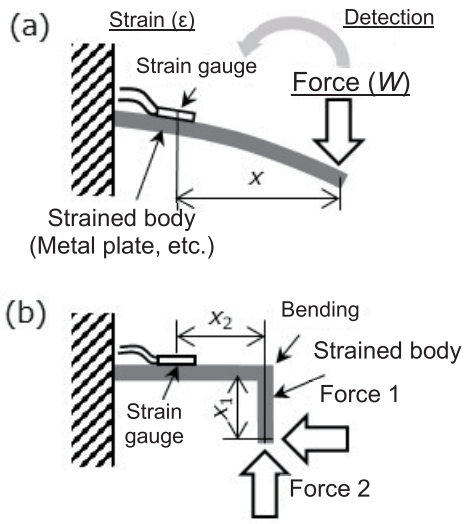

Fig. Structure before and after Sensor Deformation

■ Expected use cases

- **Background (Issues)**
  For conventional force sensors, the measurement ranges and sensitivities are determined by the sensor material and size, and cannot be changed. Therefore, it is necessary to replace the sensor according to the use conditions, and there are problems of labor and cost for preparing different kinds of sensors.

- **Applicability**
  Applications are expected to include production equipment in various factories, measuring devices in research facilities, load cells, and arms for nursing and welfare robots. It is also useful in the case of objects such as food, agricultural products including fruits, as well as people, for which force exerted when touching should be carefully controlled.

■ Possible joint research partners

· Since it can be used in various environments such as factories, and homes, etc., joint research is possible with different companies in a wide range of fields including measurement equipment manufacturers.

■ Researcher information

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Research areas:
Flexible sensor / actuator

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Technical fields: Mat Des Waf Pac Mou Ins Rel Rec Con **Oth**

Mass Production of Sensor Substrates Utilizing MEMS Manufacturing Facilities

- Aiming for Practical Implementation of Home Medical Sensors That Can Be Used Anytime, Anywhere, and by Anybody -

Keywords: **MEMS, sensors, bio, medical**

■ Aim of the research seed

At present, various types of sensors are installed in automobiles, mobile devices, home appliances, as well as some social infrastructure, and are contributing significantly to the sophistication of functions. In recent years, development for IoT (Internet of things) technology that collects information by connecting signals from these sensors to the Internet wirelessly has begun. The realization of IoT makes it possible to remotely exchange data with a wide variety of devices and also control them. Furthermore, it is expected that AI will analyze the huge amount of collected big data to make it possible to predict various phenomena with high accuracy. In particular, biosensors are characterized by their ability to detect chemical changes in substances and living organisms. For this reason, it is expected to be used for preventive medicine and home medical care by collecting in vivo information of people to remotely diagnose health conditions and detect signs of disease. The key to the practical implementation of portable sensors that can be used anytime, anywhere, and by anybody is to provide disposable sensor substrates with high processing accuracy at low prices. We are using MEMS manufacturing facilities to mass-produce disposable sensor substrates and developing elemental technologies to process them into biosensors.

■ Features of the research seed

Sensor substrates are manufactured by fabricating electrode patterns on substrates using semiconductor manufacturing technology (MEMS). Next, a resin layer is provided to construct a detection unit for mounting antibodies, etc. It is then diced into chips. Mass production methods for products with high detection sensitivity and precision are based on a variety of knowhow including base materials, electrode shapes, and resin lamination methods. In addition, bio-derived materials such as enzymes and antibodies are mounted to realize functions as a biosensor. Antibodies, mounting method, and detection method are selected according to the target to be detected. We have intellectual property for these methods.

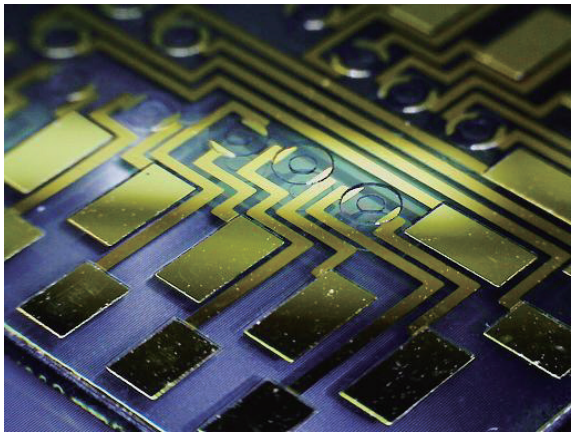

Fig. Example of a Prototype Biosensor Substrate*
(Antibody is mounted on the position indicated by circles.)
Base Material: Au/Cr/Glass, Surface Layer: SU8
*Made by Rika Sato, 2022 Graduate School Graduates

■ Expected use cases

- **Background (Issues)**
  Biosensors are produced by mounting biological materials such as enzymes and antibodies on substrates mass-produced by MEMS technology. Compared with conventional equipment, it can be made smaller and inspection of blood samples with very small amount is possible. On the other hand, repeated usage like a temperature sensor is not possible. Disposable type is necessary to maintain reliability.

- **Applicability**
  Many different proteins are created inside the body, and the amount changes before and after a disease. For example, with cancer, certain proteins are produced depending on where the cancer is generated, and their levels increase in the blood. Sensor substrates mass-produced using MEMS technology are suitable for such inspections because of their excellent processing accuracy and durability.

■ Possible joint research partners

- Sensor substrates: Semiconductor and electronic component manufacturers
- Substrate processing: Chemical and reagent manufacturers
- Measurement system: IT and manufacturers of electrical equipment
- Commercialization: Manufacturers of testing equipment, pharmaceuticals, food products, cosmetics, etc.

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■ Researcher information

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Research areas:
Biosensor engineering
Biomaterial chemistry

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16

Technical fields: Mat **Des** Waf Pac **Mou** Ins **Rel** Rec **Con** Oth

Signal Processing and Machine Learning Systems Beyond the Reach of High-speed Internet

- Edge Servers Compatible with Network Disruptions in Underground and Tunnel Environments, Etc. -

Keywords: **edge computing, network bandwidth saving, communication loss, signal processing, machine learning**

■ Aim of the research seed

This research seed aims to meet the needs for advanced signal processing and machine learning in environments where high-speed Internet cannot reach, network bandwidth is narrow, or networks may be disrupted such as underground or in a tunnel.
For example, the work robot (YAOKI of Daimon Co., Ltd.) that inspects inside of a tube as shown in the figure, can be implemented with our research seed as follows: The tube is photographed with a camera while illuminated by an LED light; and when radio waves reach it, the operator can remotely control the robot while checking the camera image. When communication by radio waves is disconnected, the robot continues to photograph and record, making autonomous decisions each time it moves, and when communication by the radio waves resumes, the recorded video is transmitted.

■ Features of the research seed

This research seed has the following features:
- Ability to perform following advanced machine learning and signal processing in environments with low network bandwidth or network disruption
- Image labeling and classification
- Generating images from text/images from image
- Object recognition
- Text-to-speech/speech recognition
- Translation
- Real-time signal processing

■ Expected use cases

● Background (Issues)
Can be used by system developers in the following situation:
- Must handle narrow network bandwidth/disruption of network communication,
- Want to implement advanced signal processing and machine learning, and
- Burst send the data when network communication is restored.

● Applicability
The following applications are possible:
- Underground and tunnel environments/inside pipes
- Underwater vehicles (moving vehicle going through heavy rain or snowstorm)
- Space environment
- Self-driving car
- More advanced functionality with multiple parallel processors

■ Possible joint research partners

- Civil engineering and construction
- Piping Inspection/Waterworks Bureau/Power Company/Gas Company
- Space equipment industry
- Automotive industry
- Underwater machinery industry

■ Researcher information

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17

Technical fields: **Mat** Des Waf Pac Mou Ins **Rel** Rec Con **Oth**

Creation of New Electronic Devices Utilizing the Unique Functions of Diamond

- Application to High-performance Power Devices and Devices for Extreme Environments -

Keywords: **diamond, power semiconductors, extreme environment devices, biological sensors**

■ Aim of the research seed

The aim of this research is to create new electronic devices that utilize the unique functions of diamond.
Diamond is the hardest material, has a low coefficient of thermal expansion, is corrosion-resistant, and is inert to chemical substances. In addition, it is recognized as the ultimate power semiconductor material because of its high thermal conductivity and wide band gap. In addition, it has unique characteristics such that it is highly biocompatible because the constituent element is carbon; its hydrogen terminated surface shows negative electron affinity; and it shows superconductivity when highly boron doping. From these characteristics, it is expected to be applied not only to power semiconductors, but also to chemical electrodes, biological sensors, ultra-small electron emission sources, and heat sinks. New electronic devices are created by combining these unique diamond functions with surface modification, microfabrication and device processes.

■ Features of the research seed

Currently, our research focuses on power semiconductor applications.

· Synthesis of diamond thin films
  Synthesis of single crystal diamond and various doping techniques

· Diamond device process
  Semiconductor processes and microfabrication

· Surface modification
  Modification of surface properties such as hydrogen termination and oxygen termination

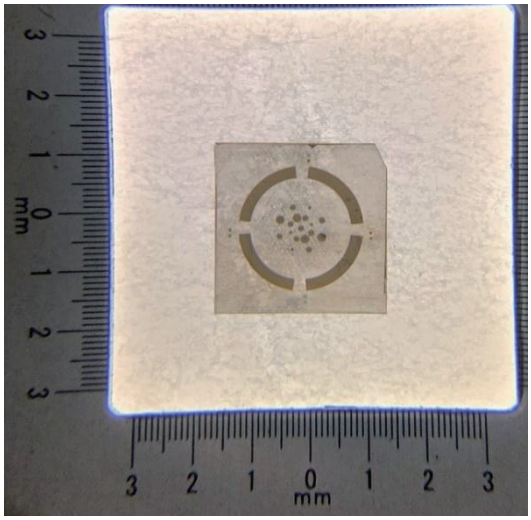

Fig. Diamond pin diode

■ Expected use cases

● **Background (Issues)**
· Power semiconductors (research in progress)
· Small electron sources
· Heat dissipation of electronic devices
· Substrate for various sensors

● **Applicability**
· Power devices with ultra-high breakdown voltage
· Miniaturization of power devices
· Devices for extreme environment
· Biosensors

■ Possible joint research partners

· Semiconductor manufacturers
· Semiconductor user companies

■ Researcher information

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Semiconductor device

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18

Technical fields: **Mat** Des Waf **Pac** **Mou** Ins Rel Rec Con Oth

High Temperature Resistant Mounting Technology for SiC Power Devices

- Micro-Al/Nano-Ni (MANN) High Temperature Resistant Interconnection Technology -

Keywords: **high temperature resistant bonding agent, alternative to solder material, SiC power device mounting, stress relaxation type bonding structure**

■ Aim of the research seed

SiC power semiconductors, which have attracted attention as energy-saving devices, have begun to be used in electric vehicles, etc., and their practical application is rapidly progressing. Since wide band gap semiconductors such as SiC can be used at high temperatures, it has been desired to use a new high melting point material for connections in place of the conventionally widely used mounting connection material such as solder. Silver nanoparticle bonding can be sintered for connection at a relatively low temperatures, and after sintering, it has a melting point of the bulk material and has high heat resistance, which enables the practical application of the material. However, nanometallic materials have poor ductility and high hardness after sintering, so the reliability against thermal stress is not sufficient. Control of void formation during sintering is also a problem especially for large area applications. In order to solve these problems, a composite paste consisting of 75vol%Al (micro size) particles and 25vol%Ni (nano-size) particles was developed. Its target is application to chip bonding materials, heat sink bonding materials, etc. of power devices as high-heat-resistant bonding materials to replace solder and nano-Ag materials. (Patents: Japan [6384894, 6384895, 6061427, 7198479], USA [US9960140B, US11810885], etc.)

■ Features of the research seed

Ni particles smaller than 100 nm in diameter starts sintering at temperatures lower than 300°C. However, as with nano-Ag material, the application as a bonding material has problems of high hardness and inclusion of voids after sintering. In this study, we succeeded in suppressing the formation of large voids by giving deformability to the sintered layer and by forming a lattice of Al particles by mixing micro-sized Al particles. It was also found out that nano Ni particles can be firmly bonded to Al in air. A characteristic bonding mechanism is developed by forming a thin composite oxide film at the interface. [Right figure (a) Schematic diagram of application to die bonding, (b) Stress/strain curve during shear test, and (c) SEM cross-sectional image of bond layer.

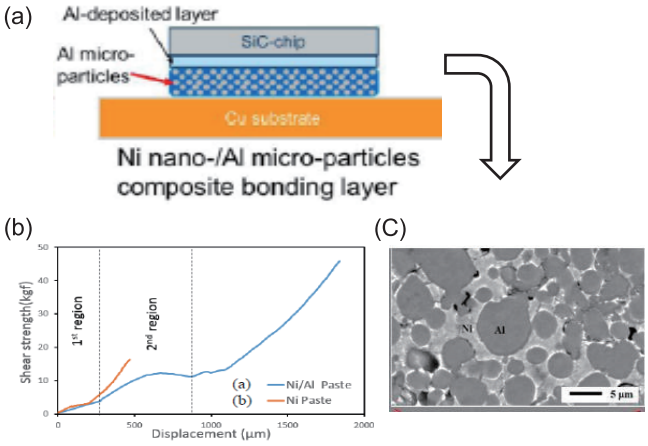

Fig. High Heat-resistant Bonding by MANN Composite Paste

■ Expected use cases

- **Background (Issues)**
  As the current density of power devices increases, operation temperature becomes higher, and at the same time, fatigue degradation of mounting materials due to thermal cycling becomes a problem. An alternative to low melting point solder material is required, and efforts to shift to various high melting point materials have been examined, but problems remain in cost, reliability, etc.

- **Applicability**
  This technology is superior not only as a bonding material for power devices requiring high heat resistance because it can reduce thermal stress, suppress gas voids, and provide stronger bonding in air, but also as an electrode bonding material for solar cell interconnectors requiring high corrosion resistance. The benefit of cost reduction against Ag nanomaterials is also large.

■ Possible joint research partners

- Companies related to power devices and power modules
- Companies related to electric and hybrid vehicles
- Nanopaste bonding materials manufacturers
- Semiconductor packaging and equipment companies
- Solar cell companies

■ Researcher information

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Material interconnection

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Technical fields: **Mat** | Des | Waf | Pac | Mou | Ins | Rel | Rec | Con | Oth

Evaluation Technologies for Semiconductor Device Materials and Processes

- Support for Material Search, Equipment Development, and Introduction of New Processes -

Keywords: **semiconductor device prototyping, MOS interface, defect evaluation, synchrotron radiation measurement**

■ Aim of the research seed

Semiconductor devices are fabricated from substrate materials such as silicon wafers through various processes including cleaning, thin film formation, lithography, heat treatment, and ion implantation. The development of these materials and processes covers a wide range of targets, including not only improving the performance of electronic devices, such as improving integration and reducing power consumption, but also reducing costs, reducing environmental impact, substituting rare materials, and responding to political risks. However, the development of new materials, new processes, and new equipment poses a variety of challenges, including technical issues as well as environmental and regulatory issues, supply chain issues, and market acceptance, making it difficult to make expensive capital investments from the beginning of the development. Although thorough preliminary research and detailed evaluation of the prototype are important to mitigate these risks, there is a tendency to avoid novel materials and processes for existing prototyping lines. It is also difficult to demonstrate the inherent superiority of new materials and processes under normal process conditions. We aim to support the development of new technologies for advancement of the entire semiconductor industry, such as new materials and processes, through device prototyping and evaluation using our shared facilities effectively as well as our knowledge of material science and process engineering.

■ Features of the research seed

We can demonstrate the superiority of our newly introduced technology by prototyping semiconductor devices and measuring their electrical characteristics, such as current, voltage, resistance, and capacitance. In addition, advanced measurement technologies such as X-ray photoelectron spectroscopy and nano-X-ray diffractometry are utilized with an extremely high level of expertise to evaluate the chemical composition, potential distribution, and crystal defects of semiconductor surfaces and interfaces, thereby identifying impurities and dipoles generated during the manufacturing process. Examining and combining both the electrical and physical characteristics at the process design stage of the prototyping enables optimization of the process, unlocking the true potential of the new technology.

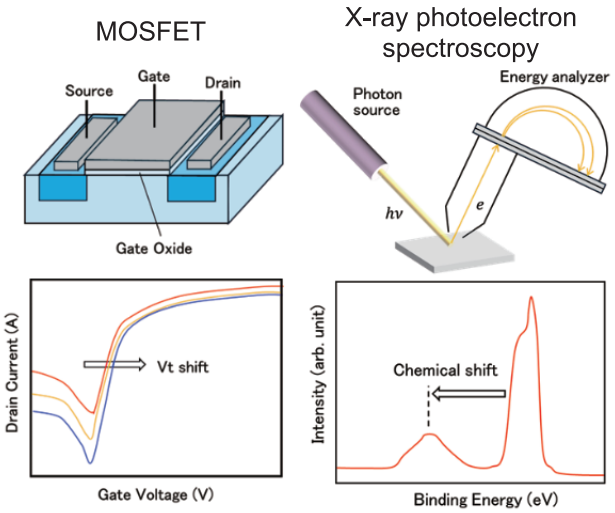

Fig. Electrical Characterization and Advanced Measurement Technology

■ Expected use cases

- **Background (Issues)**
  - Evaluation of defects associated with larger wafer diameters
  - Search for epitaxial thin film formation conditions
  - Evaluation of surface defects associated with surface polishing
  - Evaluation of interface defects of gate insulator
  - Evaluation of surface damage layer due to etching
  - Evaluation of impurity diffusion by heat treatment process
- **Applicability**
  - Development of crystal growth equipment
  - Introduction of new film deposition equipment
  - Development of environmentally friendly polishing equipment
  - Development of new process gases
  - Development of ultra-high temperature heat treatment furnace

■ Possible joint research partners

- Wafer manufacturers
- Film deposition equipment manufacturers
- Etching equipment manufacturers
- Wafer processing equipment manufacturers
- Heat treatment equipment manufacturers
- Cleaning equipment manufacturers

■ Researcher information

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Semiconductor device material

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Technical fields: Mat **Des** Waf Pac Mou Ins Rel Rec Con Oth

Compact Power Conversion Circuits for Energy Harvesting

- Toward Battery Replacement-Free Using Environmental Energy -

Keywords: **energy harvesting, environmental energy, IoT, power conversion circuit, battery**

■ Aim of the research seed

Internet of Things (IoT) that autonomously collects information by attaching sensors and information communication circuits to every object is attracting much attention as a way to improve efficiency of agriculture, manufacturing, and commerce, as well as to respond to social changes, e.g., aging and population decline. Batteries are required when installing IoT devices at places without a commercial power source. If the battery needs to be replaced every few years after installation, manual labor is required every time for the replacement and the replaced battery must be disposed of. The European Battery Regulation was developed to reduce the amount of waste batteries. Battery-free and maintenance-free operation of the IoT devices are becoming important to save manpower and reduce the amount of battery waste. For this reason, research and development of energy transducers and power conversion circuits for IoT devices have been active.

The aims of our research are miniaturization and efficiency improvement for power conversion circuits that bridge various energy transducers (AC/DC output, output voltage of several hundreds of mV to several tens of V) and various IoT devices (operating voltage of 1.8 V to 5 V, average current consumption of several tens of μW to several of mW).

■ Features of the research seed

The figure shows an example of developed power conversion circuits. The ideas of miniaturizing the circuits have been verified.

In the future, it will be important to find a means to determine the best combination of energy transducers and power conversion circuits to realize compact and low cost solutions required when the specifications of IoT devices and available environmental energy are given, and to find an efficient method to design the power conversion circuits.

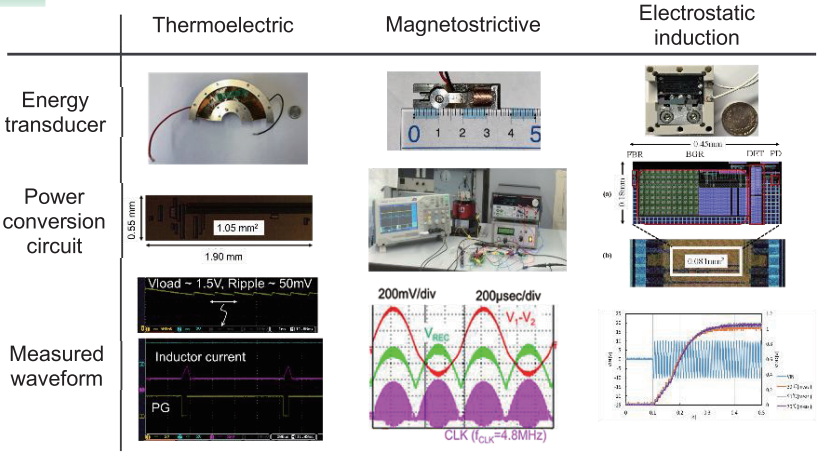

Fig. Developed Power Conversion Circuit

■ Expected use cases

- **Background (Issues)**
  - An application with which replacement of batteries needs be avoided for at least ten years after the installation while actual replacement frequency is much higher
  - Applications where sensor replacement is dangerous
  - Applications where sensor replacement is virtually impossible

- **Applicability**
  - Anomaly detection of social infrastructure such as tunnels and bridges
  - Detection of abnormalities in chemical plants, power plants, etc.
  - Detection of abnormal water levels and flow rates of rivers, sewers, etc.
  - Smart Agriculture (visualization of solar radiation, conditions of soil and fertilizer, temperature, etc.)
  - Watching over elderly people living along
  - Healthcare, logistics, manufacturing, transportation, and space

■ Possible joint research partners

- Companies and universities developing environmental power generation devices
- IoT system integrators
- Companies specializing in the design of integrated circuits for IoT
- Dedicated manufacturers providing circuit IP

■ Researcher information

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21

Technical fields: Mat Des Waf Pac Mou Ins Rel Rec Con Oth

Micro MEMS Gravimeters in the IoT Era

- Seismometers, Altimeters and Drone-based Underground Cavity Detection -

Keywords: **MEMS, accelerometer, gravimeter, seismometer, altimeter**

■ Aim of the research seed

Gravimeters are sensors that measure the gravitational force acting on a mass. Although they were developed in the 1930s and have a long history, their applications have been limited due to their heavy weight, bulky size, and high cost. MEMS gravimeters, fabricated using micro-electro-mechanical systems (MEMS) technology, are compact, lightweight, and low-cost, making them suitable for IoT applications. They also have the potential to revolutionize the field. For example, a MEMS gravimeter can be mounted on a drone to detect underground cavities by measuring minute changes in gravity. In environmental technology, it can be used to identify sites suitable for geothermal power generation. Additionally, it can play a role in CO2 monitoring for Carbon Capture and Storage (CCS) projects. In disaster prevention and mitigation, MEMS gravimeters can be used for volcanic activity monitoring, water level measurement, and the detection of long-period earthquakes. Their applications also extend to gravity-based altimeters, which, unlike barometric altimeters, are unaffected by atmospheric pressure.

■ Features of the research seed

A MEMS gravimeter is a type of accelerometer and consists of a spring-mass system. Despite the small mass resulting from miniaturization, the use of an extremely weak spring enables measurable displacement of the mass in response to slight changes in gravity. This weak spring is formed by combining a mechanical spring with a positive spring constant (k_m) and an electrostatic spring with a negative spring constant (k_e). Thanks to the voltage tunability of k_e, the total spring constant can be maintained at a constant value. The device is fabricated by etching a silicon layer through the wafer. Its manufacturing is carried out in a cleanroom at the Kyushu Institute of Technology, while evaluation and implementation are conducted at the Kitakyushu Foundation for the Advancement of Industry, Science and Technology.

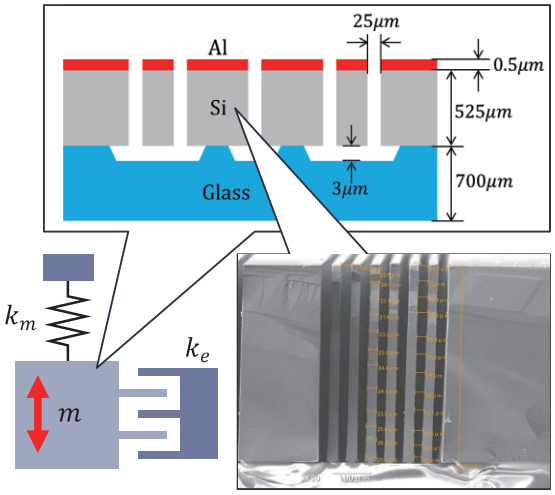

Fig. Structure of Spring Mass System of the MEMS

■ Expected use cases

- **Background (Issues)**
  Conventional gravimeters are heavy, bulky, and expensive. Compact, lightweight, and low-cost MEMS gravimeters make them suitable for IoT applications where many sensors are used. It can be used not only as a small seismometer that can detect long-period vibrations, but also as an altimeter, a vibrometer, and a tilt sensor.

- **Applicability**
  - Underground exploration and resource exploration
  - CO_2 monitoring at CCS
  - Volcanic activity monitoring and water level measurement
  - Small seismometers
  - Small vibrometers capable of detecting low frequency vibration
  - Altimeters, inclination sensors

■ Possible joint research partners

- Companies related to sensors
- Companies related to semiconductors
- Companies related to IoT technologies
- Companies related to environmental technologies
- Companies related to disaster prevention technologies

■ Researcher information

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MEMS

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22

Technical fields: **Mat** Des Waf Pac Mou **Ins** Rel Rec Con Oth

Development of Highly Efficient and Stable Perovskite Solar Cells

- Next Generation Flexible Photoelectric Conversion Device -

Keywords: **organic/inorganic semiconductors, solar cells, flexible, high efficiency, electrode materials**

■ Aim of the research seed

Halide perovskite solar cell is a kind of organic semiconductor solar cell. The mobility of charge in the crystal is as high as that of silicon, and the efficiency is as high as that of silicon solar cells. The advantage over a silicon solar cell is the perovskite solar cells can be fabricated on a plastic substrate at low temperature and with lightweight flexible properties. The perovskite solar cells can be installed on the roofs, walls and windows of a building in any shape, which is impossible with heavy silicon solar cells. However, the application of the halide perovskite solar cells has been limtied because they contain lead metal ions. Our goal is to develop lead-free, environmentally friendly halide perovskite solar cells with high efficiency and high stability.
We also aim to develop high-capacity secondary batteries using nanomaterials. Our goal is to contribute to the realization of a carbon-neutral society through the development of solar cells, secondary batteries, and fuel cells.

■ Features of the research seed

The equipment that we have is as follows:
- Equipment for nanomaterial synthesis and evaluation,
- Equipment for manufacturing and evaluating solar cells,
- Equipment for manufacturing and evaluation of fuel cells and secondary batteries.

Materials and device technology:
- Several types of highly stable lead-free perovskites
- High-performance inorganic semiconductor materials that can be fabricated at low temperatures
- Carbon electrode having high performance and high stability
- High-performance photoelectric conversion devices
- Fabrication technologies of flexible photoelectric conversion devices

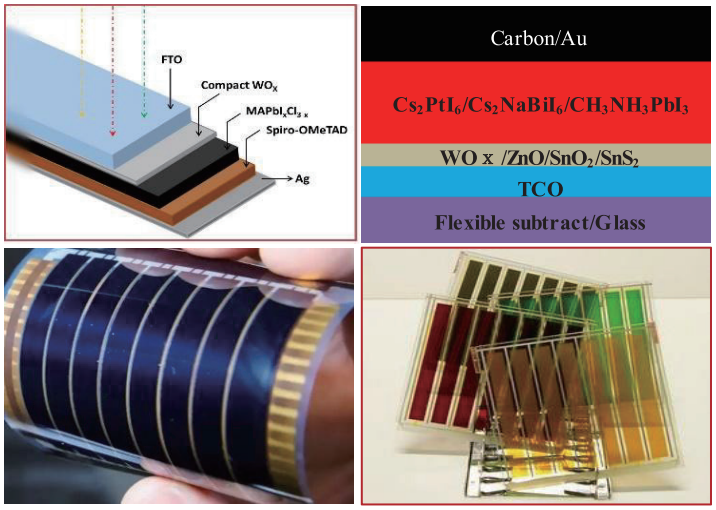

Fig. Developed Photoelectric Device

■ Expected use cases

● **Background (Issues)**
To use solar energy effectively, low-cost, highly efficient, and high stablility solar cells and low-cost, large-capacity, and highly-durable secondary cells are required, but there are no materials or device that satisfy these requirements.
We will solve the problem by proposing new materials and new device structures.

● **Applicability**
- Perovskite solar cells
- Perovskite photodetectors
- Fuel cells
- Solid electrolyte
- Solid state sodium ion batteries
- Solid state lithium ion batteries

■ Possible joint research partners

- Solar cell companies
- Companies related to materials development
- Companies related to electronics and sensors
- Electric vehicle companies
- Fuel cell manufacturers

■ Researcher information

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Research areas:
Development of organic and inorganic semiconductor materials

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Technical fields: Mat Des Waf Pac Mou Ins Rel **Rec** Con Oth

Advanced Separation Technologies in Liquid Phase Using Adsorption, Ion Exchange, and Liquid-liquid Extraction

- Separation Technologies for Wastewater Treatment and Recovery of Valuable Metal Resources -

Keywords: **adsorption, ion exchange, liquid-liquid extraction, separation technology**

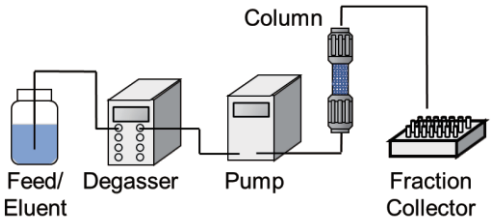
■ Aim of the research seed

Separation technologies for removal of toxic substances contained in wastewater and for recovery of valuable metal resources in waste, for the semiconductor and chemical industries, are investigated. The adsorption/ion exchange method is highly suitable as an end of pipe separation technology in factories because continuous operation using columns is possible. In addition, valuable metal resources in waste can be recovered with high efficiency and with high purity by using the adsorption/ion exchange method or the liquid-liquid extraction method following leaching using mineral acid.
In our laboratory, the adsorption/ion exchange method or the liquid-liquid extraction method is selected depending on the target substance, and comprehensive research from development of a separation agent with high separation performance, quantitative evaluation of separation performance, development of a separation process using a column adsorption or a mixer-settler, is conducted for practical applications.

■ Features of the research seed

· Adsorption/ion exchange method:
Development of adsorbents, evaluation of separation performance, and development of a separation process by a column adsorption system are carried out comprehensively.

· Liquid-liquid extraction method:
Evaluation of extraction performance and separation process by mixer-settler equipment are carried out comprehensively.



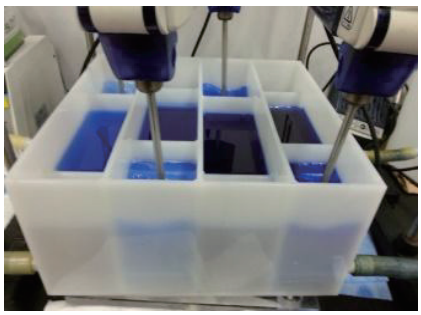


Fig. (Top) Column Adsorption System
(Bottom) Mixer Settler Apparatus

■ Expected use cases

● **Background (Issues)**
Separation technologies for materials in the liquid phase (water and organic solvent) are investigated. For the removal of hazardous substances in wastewater and the separation and recovery of valuable resources in waste, appropriate separation systems are designed according to the composition and quantity

● **Applicability**
· Treatment of wastewater containing TMAH in the semiconductor industry
· Treatment of acid-containing wastewater in chemical polishing
· Separation and recovery of valuable metal resources from waste and wastewater

■ Possible joint research partners

· Semiconductor manufacturers
· Manufacturers in the chemical industry
· Recycling business operators

■ Researcher information

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Research areas:
Separation engineering
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Separation of Lithium Ions

- Improve Recovery Efficiency by Membrane Separation Technology -

Keywords: **nanofiltration, NF membrane, multivalent ions**

■ Aim of the research seed

Lithium (Li) is one of the elements used in automotive lithium-ion batteries (LIB), and its demand has been increasing rapidly with the recent spread of electric vehicles. Extraction from salt lakes, which are the main source of Li at present, has a problem that lakes with large amounts of Li yield are limited. Therefore, as a new means to secure Li resources, it is required to create a technology to efficiently recover Li from waste LIB, which is expected to be generated in large quantities for the future. At present, a solvent extraction method has been established for the recovery of Co and Ni, and is practically applied. On the other hand, in the case of recovering Li from residual liquid after solvent extraction, multi-step purification is required due to the high impurity level, which poses challenges of lower purity and lower recovery rates. We applied a membrane separation process using an NF membrane before solvent extraction. An NF membrane is a membrane element capable of removing medium to high molecular weight organics smaller than 2 nm in solution. Because you can charge the membrane surface, separation of low-valent ions, which can penetrate the charged membrane, and divalent ions, which can be removed by the charged membrane, is possible, allowing operation at lower energy than RO membranes. Separation of Li^+ ions from multivalent ions such as Co^{2+} and Ni^{2+} in advance is possible with this NF membrane, which enables efficient purification of Li, thereby realizing high purity and high recovery rates.

■ Features of the research seed

To confirm separation performance of the NF membrane, a liquid mixture containing monovalent and polyvalent ions was used to measure the removal rate of the NF membrane. $MgCl_2$ and LiCl simulated water (Li^+, Mg^{2+} 2000 mg/L) was used to carry out the separation experiment using equipment having NF membrane. The operating conditions were pressure of 0.6 MPa, flow rate of 125 L/h, and membrane area of 0.05 m^2. The duration of the experiment was about 8 minutes. The membrane permeation flux J_w was calculated. Solution analysis was also carried out for three kinds of water: simulated raw water, NF membrane filtered water, and NF membrane concentrated water. Removal rates of Mg^{2+} and Li^+ were calculated from the results. The experimental results showed that the removal rate of Mg^{2+} was 70% and that of Li^+ was 14%.

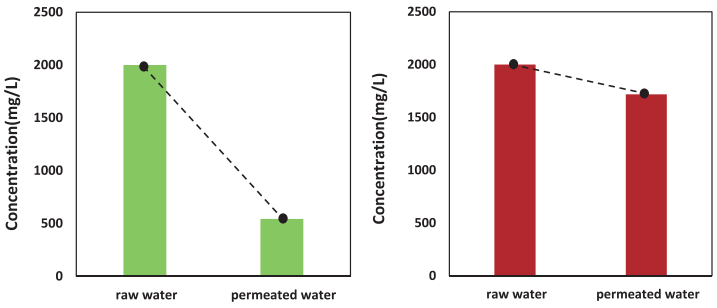

Figure 1: Concentration of Mg2+ in raw water and permeated water

Figure 2: Concentration of Li+ in raw water and permeated water

Fig. Results of Li^+ and Mg^{2+} Concentrations in Raw and Permeated Water

■ Expected use cases

- **Background (Issues)**
  The NF membrane had a problem that the performance deteriorates due to acid. However, it is expected that this new foreign-made NF membrane will be utilized, which has a dense pore structure of 1 nm or less with ion selectivity about 1.5 times higher than others leveraging recent DX technology.

- **Applicability**
  The acid-resistant NF membrane unit enables extraction under acidic conditions, and is expected to be applied to highly efficient recovery of precious metals, not only Li^+, with the solvent extraction method.

■ Possible joint research partners

· Nonferrous metals, materials
· Water treatment
· Waste recycling

■ Researcher information

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Water treatment

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25

Technical fields: Mat **Des** Waf Pac Mou Ins Rel **Rec** Con Oth

Supply Chain Management through Life Cycle Assessment

- Contribute to Carbon Neutrality -

Keywords: **LCA, carbon footprint, Scope 3**

■ Aim of the research seed

I am studying visualization techniques of the environmental load by life cycle assessment. The life cycle includes mining of raw materials; manufacturing of materials, parts, and products; consumption of the product; disposal and recycling of the product; and transportation of goods, etc. between each process step. By evaluating CO2 emissions from all of these processes, carbon neutrality measures for semiconductor-related industries will be examined. The basic method is the Life Cycle Assessment (LCA), but its applications include Carbon Footprint (CFP), Greenhouse Gas (GHG) emissions of organizations, and supply chain emissions (Scope 3). In addition, as environmental loads other than CO2, the environmental footprint (water, resources, etc.) are also a research object.

A method to ensure the traceability of substances and materials using information systems is also a research subject. This approach enables supply chain management, environmental assessment, optimization, etc.

■ Features of the research seed

In this research, minimization of environmental load generated through supply chains will be examined. Evaluation not only of upstream but also downstream of the process, i.e., reuse and recycling of process waste and post-use products, is also an important subject of our research.

I am working with researchers specializing in information engineering on data management through supply chains and optimization based on it.

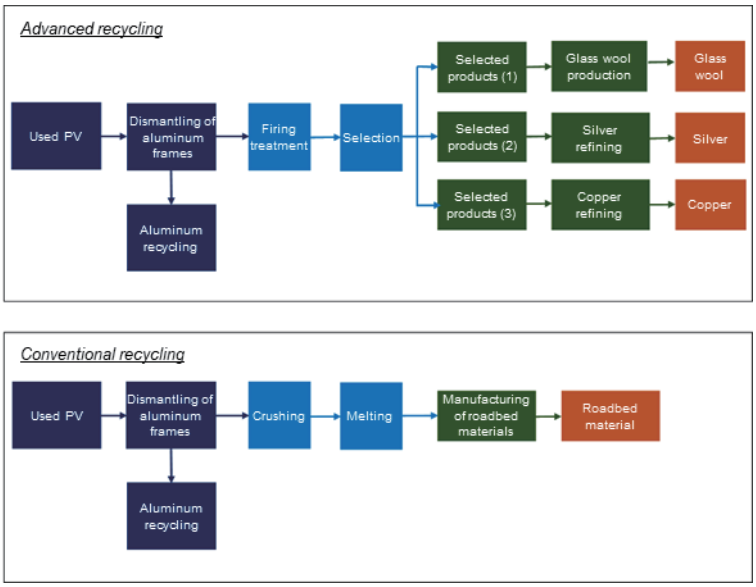

Fig. Example of Evaluation of Solar Panel Recycling

■ Expected use cases

- **Background (Issues)**
  The demand for suppliers to decarbonize business operations is growing day by day, and it is essential for companies to take measures to visualize and then minimize the carbon footprint to ensure their competitiveness. In recent years, ESG investment, especially green investment, has been expanding, and there is a great demand for non-financial information disclosure.

- **Applicability**
  In Europe, there is a movement to start Digital Product Passport (DPP) from in-vehicle batteries. The system is expected to expand to other products in the near future, prompting Japan to take urgent action. This research can be applied to development of a Japanese system of DPP.

■ Possible joint research partners

· Semiconductor manufacturers
· Manufacturers of products using semiconductors
· Recycling business operators
· System integrators

■ Researcher information

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Resource recycling
Energy management

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Technical fields: Mat **Des** Waf Pac Mou Ins **Rel** Rec Con **Oth**

Enhancing Power Semiconductor Cooling Performance through Heat and Fluid Flow Optimization

Keyword: **electronics cooling, liquid cooling, boiling cooling, pin-fin heat sink**

■ Aim of the research seed

With the progress of power electronics technology, it is expected that electronic power devices will become more powerful and compact. Since electric power consumed in the electronic devices is converted into heat, a high-performance cooling technology with a high heat flux is indispensable to operate devices, including semiconductor devices, in an appropriate temperature range to ensure reliability. This laboratory is working on the following research subjects on various cooling technologies including space applications:

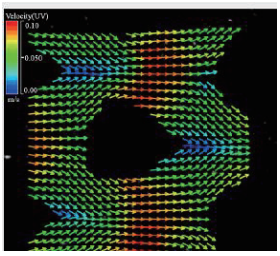
(1) Multi-objective optimization of liquid-cooled pin fin heat sink
(2) Enhance cooling performance of liquid cooled cold plates
(3) Flow boiling in mini-channels
(4) Boiling two-phase flow under microgravity

■ Features of the research seed

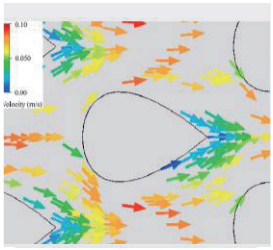
In this laboratory, we are working on experimental elucidation of physical phenomena and various application technologies based on it. Main research examples are as follows:

(1) Cooling device optimization utilizing both working fluid flow visualization experiments and thermo-fluid computer simulation,
(2) Multi-objective optimal design of cooling devices with both heat transfer performance and fluid flow performance as the objective functions,
(3) Elucidation of flow boiling in surface tension driven flow field (microgravity, small flow channels) with the aim of establishing high heat flux cooling technology applicable to various electronic equipment including space applications.

External view of airfoil pin fin heat sink



PIV visualization experiment



CFD analysis

Fig. Airfoil Pin Fin Heat Sink

■ Expected use cases

● **Background (Issues)**

To realize rapid enhancement in performance of various electronic devices, such as those for electric mobility, high-power electronic devices, e.g., solar panels and wind power generators, high-performance computer servers, and electronic devices for space applications, it is important to ensure the normal operation and reliability of semiconductor devices, and it is essential to improve the performance of high-heat-flux cooling technology in confined spaces.

● **Applicability**

- Electric mobility for automobiles, ships and aircraft
- Large-scale electric power management systems including renewable power generation equipment such as solar panels and wind power generators, and regulating capability of time-varying power generation equipment
- Various power electronics devices including ones for space applications
- High-performance computer servers for data centers

■ Possible joint research partners

- Manufacturers of power electronics devices
- Manufacturers of electric transport equipment
- Companies related to renewable energy generation such as solar and wind power
- Manufacturers of power devices
- Manufacturers of satellites, spacecrafts, other space applications
- Manufacturers of data centers and other large computer systems

■ Researcher information

The University of Kitakyushu

Faculty of Environmental Engineering

Koichi Inoue, Professor

Research areas:
Thermo-fluid engineering
Heat transfer engineering

The researcher's website is here →

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27

Technical fields: Mat Des Waf Pac Mou **Ins** **Rel** Rec Con **Oth**

1/1000 Reduction in Size and Cost: Intelligent Current Sensor for Electric Power Applications

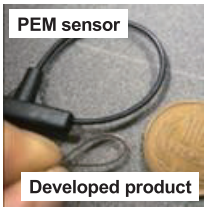
- Ultra-lightweight, Compact, and Low-cost Current Sensor for Condition Monitoring -

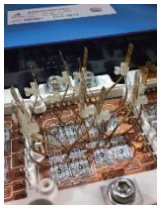
Keywords: **micro current sensor, Rogowski coil, IGBT module, power electronics**

■ Aim of the research seed

IoT platforms have been deployed in companies, factories, and in transportation, creating an infrastructure that collects massive amounts of data in real time, enabling equipment degradation monitoring using AI. For example, failure of platform doors of a railway has a great impact on society. Prediction of such failures and taking preventive measures become possible by monitoring the deterioration of motors that drive platform doors. As shown in this example, in the future, the deterioration monitoring function is expected to be introduced to an enormous number of small motors and electric actuators for safety and security. To meet such demand, we would like to provide an inexpensive and ultra-compact monitoring environment (observation and measurement) for measuring the driving current of motors and actuators, thereby contributing to the safety and security of society.

- Can be applied to various shapes and sizes
- Disposable use of sensors
- Built-in use in equipment and systems





■ Features of the research seed

We have developed a new concept of current sensors by signal processing IC technology and integration on a printed circuit board. A special print pattern and unique signal processing technology reduce the size and cost by 1/1000. It covers a wide current range from less than 1 A to more than 1000 A and a frequency range from DC to 100 MHz. It is expected to be applied to various power electronics devices such as power semiconductors used in electric vehicles and photovoltaic power generation and integration on printed circuit boards of switching power supplies for servers. Another feature of this system is that it is possible to add functions to carry out fault diagnosis with software by developing an algorithm in addition to current detection.

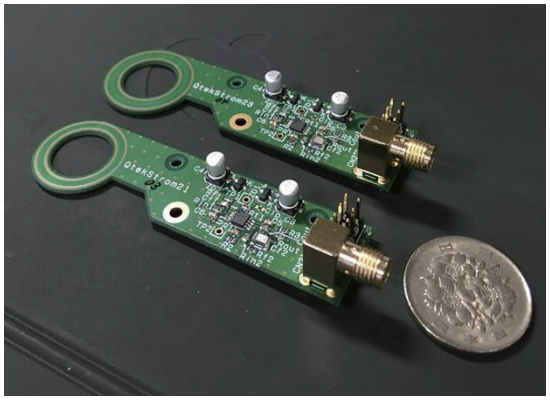


Fig. Current Sensor with Latest Ultra-small Amplifier

■ Expected use cases

● **Background (Issues)**

Although it is desired to introduce deterioration monitoring systems for motors around us to support our daily life by improving safety and convenience, such massive deployment has not been realized yet due to the cost and size.

● **Applicability**

- Power conditioner
- Electric and hybrid vehicles
- ICT servers, power supplies for railway vehicles, etc.
  - Application at high temperature of 250°C with polyimide material
  - Can be attached to and detached from the measurement amplifier with a microconnector
  - Integration into equipment and systems, disposable use

■ Possible joint research partners

Companies that are deploying IoT services, factory engineering companies, companies that can handle IoT infrastructure, e.g., motor manufacturers and electrical component manufacturers, measuring instrument manufacturers, building and railway automatic door maintenance companies, etc.

■ Researcher information

Kyushu Institute of Technology

Graduate School of Life Science and Systems Engineering

Ichiro Omura, Professor

Research areas:
Power semiconductor

The researcher's website is here →

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28

Technical fields: Mat Des Waf Pac Mou Ins Rel Rec **Con** Oth

Development Environment by FPGA of Motor Drive Control System

- High-efficiency, High-precision Speed Control -

Keywords: **PMSM, FPGA, Encoder-less**

■ Aim of the research seed

Along with the improvement of maximum rated voltage and switching speed of power semiconductor devices, high performance and high accuracy control are required for inverters that generate arbitrary AC output waveforms from commercial power sources or DC power sources. On the other hand, new structures and circuits are considered and proposed for motors, for example, multiple stator windings and multi-phase windings. To realize like these motor controls, developing a control system for a power converter to control an increasing number of power semiconductor devices at high speed and with high accuracy as well as a complex control theory are necessary.

In this study, to construct a control development environment including a high-precision real-time execution model of motors is proposed. Here, a highly functional FPGA (Field Programmable Gate Array) with a built-in CPU circuit is used, and a real-time execution model of the motor control system at the gate pulse level is integrated on the same chip to realize a hardware/software integrated control system that can improve the efficiency of the development period.

■ Features of the research seed

Since the control system is created with a highly functional FPGA, flexible design of the inverter output is possible and easy to change numbers of current measurements. In addition, the development environment is used High Level Synthesis (HLS) for the hardware part of the FPGA, and the user interface is implemented using a CPU with a built-in chip, which enables implementation in a short period of time, and it is possible to construct a flexible control system including the development environment.

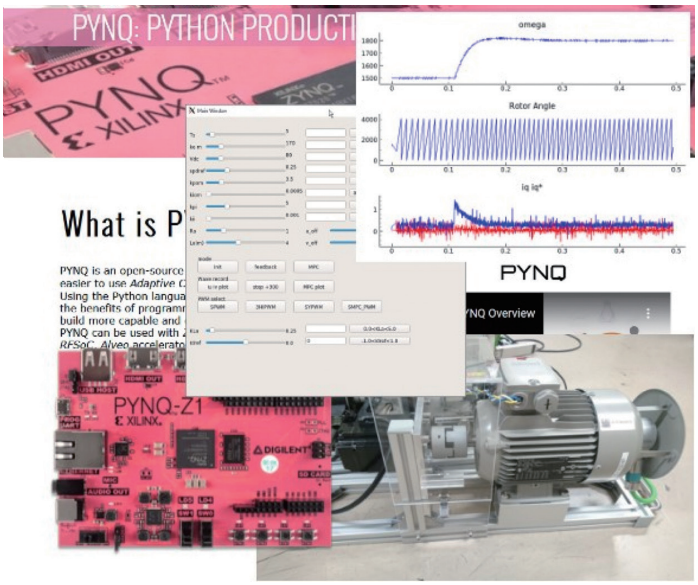

Fig. An Image of Development Environment

■ Expected use cases

- **Background (Issues)**
  It is expected to be used for the development of equipment that requires motor drive control. Developing the interface circuit depending on the detection signal is required. If the control system becomes complicated, capacity of the FPGA may become a restriction.

- **Applicability**
  Inverters and converters are used in various devices such as automotive equipment, industrial equipment, and home appliances. Applications to these fields where rapid prototyping is required to realize higher functions are possible.

■ Possible joint research partners

· Electronics companies
· Companies related to automobiles

■ Researcher information

Kyushu Institute of Technology
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Tsuyoshi Hanamoto,
Professor

Research areas:
Power electronics

The researcher's website is here →

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29

Technical fields: Mat **Des** Waf Pac Mou Ins Rel Rec Con Oth

Microwave / Millimeter Wave Integrated Circuit Design Technology for Wireless Communications

Keyword: **Power Amplifier, Oscillator, Switch, Low noise amplifier, Mixer**

■ Aim of the research seed

We are studying to improve the performance of RFICs using silicon and compound semiconductors for higher speed and lower power consumption (higher efficiency) of wireless communications using microwaves and millimeter-waves.
The actual research items are as follows:

1) highly linearity, and highly efficient Power Amplifiers
2) Wideband, low phase noise, low power consumption Voltage Controlled Oscillators
3) Low noise, highly linear, low power consumption Low Noise Amplifiers
4) Highly linear, low power consumption Switch IC
5) Highly linear, low power consumption Mixer IC

We are studying integrated circuit design technology to realize the above. Operating frequencies in this study are mainly from 2 GHz to 100 GHz.

■ Features of the research seed

Conventionally, linearity and efficiency of a Power Amplifier is a trade-off. To overcome the issue, we proposed new bias circuits and load circuits, and confirmed their effectiveness through chip measurement. This bias circuit adaptively controls the bias condition of the MOSFET for amplification according to the input power, and simultaneously improves linearity and efficiency. The fabricated chip has achieved a linear output power of 21 dBm and a power added efficiency of 42.5% at 25 GHz.
Concept of this bias circuit is also applied to Voltage Controlled Oscillator, Low Noise Amplifier and Mixer to achieve low power consumption.

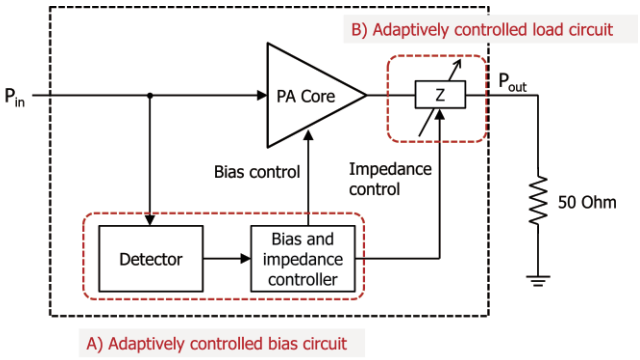

Fig. Architecture of the Power Amplifier

■ Expected use cases

- **Background (Issues)**
  Modulated signals with high peak factors such as 256QAM are used with 5G. Radio equipment is required to modulate and demodulate this signal with high linearity and low power consumption. Therefore, the Power Amplifier must be highly linear and efficient.

- **Applicability**
  Future 6G and WLANs will require even higher transmission speeds and lower power consumption. Using frequencies above 100 GHz is being examined for improvement of transmission speed, and we believe that the circuit technology studied in our laboratory can be applied.

■ Possible joint research partners

· Telecommunication equipment manufacturers

■ Researcher information

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Toshihiko Yoshimasu,
Professor

Research areas:
RFIC

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30

Technical fields: Mat | Des | Waf | Pac | **Mou** | Ins | Rel | Rec | Con | Oth

Innovation in Manufacturing through Optimal Design

- Creation of Optimal Solutions that Exceed the Limits of Designer's thinking ability -

Keywords: **optimum design, structural optimization, electromagnetic devices, automotive components**

■ Aim of the research seed

Simply speaking, optimal design is an attempt to mathematically formulate three factors: design variables that are variable factors in design, the objective function corresponding to a performance index to be maximized, and constraints to be satisfied, and to obtain a design solution that maximizes the objective function while satisfying the constraints, i.e., an optimal solution, based on mathematics. While competition among companies is very intense nowadays, optimal design in the sense that the optimal solution is rationally obtained based on mathematics rather than the designer's intuition or experience, has the potential to bring innovation to manufacturing. In particular, in the design of various functional structures, it is becoming more obvious that due to the high degree of design freedom, optimal design can provide a unique optimum structure that exceeds the limits of the designer's thinking ability. Our research group puts optimal design as a central research theme, is engaged in basic research on the theme, and applies it to engineering research in a broad sense for electromagnetic devices, automotive components, etc.

■ Features of the research seed

A feature of optimal design is that it has a wide range of applications. Our research group is working on optimal design of various functional structures, including lightweight, highly-rigid structures that rigidly support various loads, radiators with high heat transfer efficiency, electrolyte channels for large scale storage batteries with high energy generation efficiency; and permanent magnet synchronous motors with high torque output. The figure on the right shows a type of electromagnetic device called a noise filter, which is used to eliminate high frequency noise in electrical systems. Conductor layout design for noise filters is difficult even for experienced designers, but our group has succeeded in semi-automatically obtaining the optimal conductor layout by optimal design.

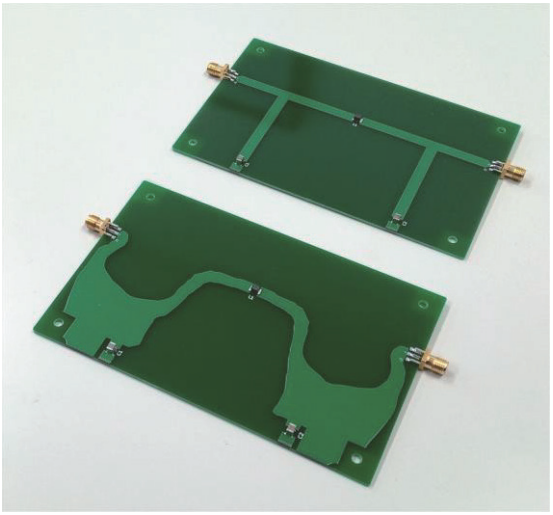

Fig. Optimal Design of Conductor Layout
(front: optimal layout, back: general layout)

■ Expected use cases

- **Background (Issues)**
  Optimal design is translated to a purely mathematical problem when it is formulated as an optimization problem. The problem will then be solved by various mathematical programming . This higher level abstraction based on mathematics is the background of its wide applications.
- **Applicability**
  As mentioned above, optimal design has a wide range of applications and is expected to be used in product design for various functional components such as electromagnetic devices and automotive components.

■ Possible joint research partners

· Companies in general that handle various functional structures such as electromagnetic devices and automotive components

■ Researcher information

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Professor

Research areas:
Optimal design

The researcher's website is here →

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31

Technical fields: Mat **Des** Waf Pac **Mou** Ins Rel Rec Con Oth

Optimization Method for Connecting "Things"

- Optimizing How Information, Logistics, and Operations Are Connected -

Keywords: **routing problems, optimization methods, integer linear programming, metaheuristic**

■ Aim of the research seed

In daily life, there are countless situations where things need to be connected. Examples include the selection of transportation means, the construction of networks, and the scheduling of tasks. This research seed formulates these issues as optimization problems, extracting the constraints and defining solutions that meet the needs. The optimization methods are then selected according to the conditions required by the problem.

■ Features of the research seed

In this research seed, not only formulation but also optimization methods can be selected flexibly according to the situation. For example, if the problem size is not very large and solution quality is crucial, integer linear programming can be employed. On the other hand, if solution time is more important than solution quality, metaheuristic programming can be employed. The research experience we are engaged in on optimization provides us with a multitude of alternatives.

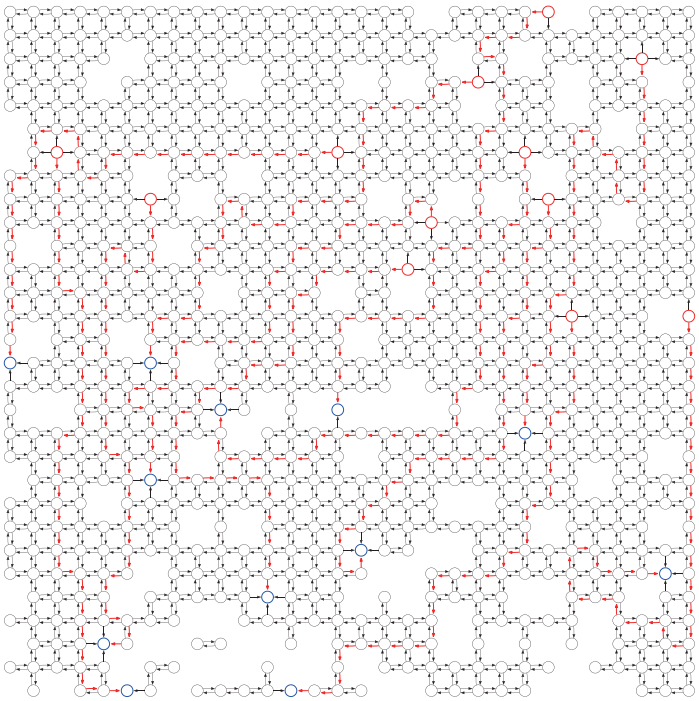

Fig. Example of Wiring Problem for 800 Points (difference of 12 pieces from red circle to blue circle is the minimum difference in length/It takes about 10 minutes on a normal PC.)

■ Expected use cases

- **Background (Issues)**
  There are many situations where things need to be coordinated. Normally, methods based on experience are used to deal with such situations. We present formulation of a problem and its solution.

- **Applicability**
  Possible applications include the following area, but not limited:
  · Wire routing,
  · Distribution plan optimization,
  · Scheduling such as shift determinations, etc.

■ Possible joint research partners

· Circuit layout design
· Logistics
· Manufacturing

■ Researcher information

The University of Kitakyushu
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Yasuhiro Takashima,
Professor

Research areas:
Combinatorial optimization

The researcher's website is here →

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32

Technical fields: **Mat** **Des** **Waf** Pac **Mou** Ins Rel Rec Con **Oth**

Green Computing Materials AI Devices

- Establishment of Highly Efficient AI computing device -

Keywords: **random network, nonlinear, physical reservoir computing, material intelligence**

■ Aim of the research seed

We intend to drive a paradigm shift in next-generation AI systems by combining nanomaterial science, integrated circuits, and information science. So far, we have succeeded in developing a material reservoir device with expanding charge information by introducing redox reactions as chemical dynamics. Based on these results, we aim to build a foundation for more efficient AI hardware by connecting nanomaterials with CMOS integrated circuits. Additionally, we are constantly considering a paradigm shift to a highly efficient AI system mostly driven by edge terminals that learns according to the environment and performs unique operations by reducing the power consumption of rapidly increasing AI systems to the limit to realize a system that is vastly more energy efficient than the current leading AI chips.

■ Features of the research seed

We are promoting the development of a in-materio physical reservoir computing system, a type of brain-inspired AI, by controlling a random network structure of nanomaterials. By successfully controlling the charge information in the material and combining it with the already developed CMOS AI hardware, we aim to achieve a super energy saving of the current AI chips. We are conducting comprehensive R&D activities from development of a Material AI device with novel principles, circuit integration to implementation to robots.

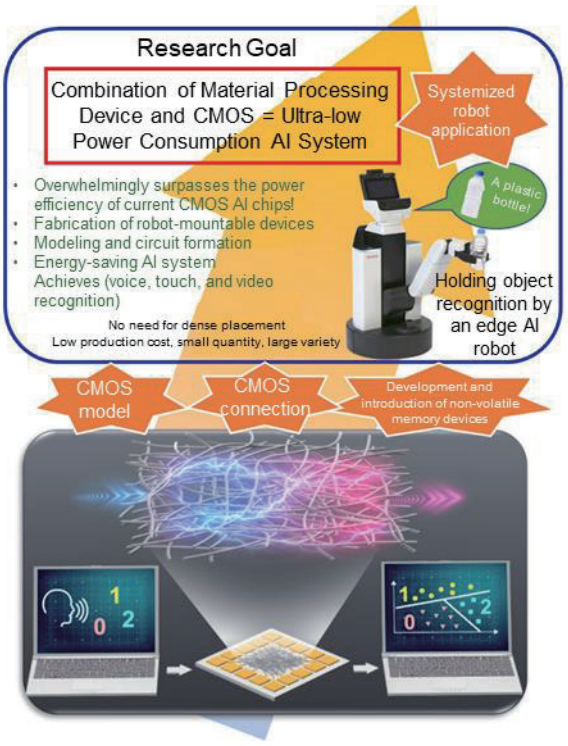

Fig. Random Network Reservoir with Dynamics and Its Applications

■ Expected use cases

● **Background (Issues)**

(i) Performance Enhancement of AI Devices by CMOS Connection of Nanomaterial Brain-inspired AI System
(ii) Development of Nanostructured Nonvolatile Analog Memory Devices
(iii) Development of Neuromorphic AI Models and Integrated Circuits
(iv) Systematization of Analog AI Chips for Edge Applications and Application to Robotics

● **Applicability**

· Edge AI computing
· Autonomous robots (recognition of holding objects, image recognition, voice recognition, etc.)
· Low power consumption AI system

■ Possible joint research partners

· Manufacturers of electrical equipment
· Semiconductor manufacturers (foundry/design)

■ Researcher information

Kyushu Institute of Technology
Graduate School of Life Science and Systems Engineering
Hirofumi Tanaka,
Professor
Director of Research Center for Neuromorphic AI Hardware

Research areas:
Materials AI devices

The researcher's website is here →

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33

Technical fields: Mat **Des** Waf Pac Mou Ins Rel Rec **Con** Oth

Brain-inspired Computer System Embedded in "Things" and Multifaceted Application

- Aiming to Realize Edge AI Systems Through Integrated Research into Circuits, Theory, and Applications -

Keywords: **brain-inspired artificial intelligence, FPGA, digital circuits, reservoir computing, home service robots**

■ Aim of the research seed

Toward the Realization of Future Brain-inspired Computer Systems and Robotic Applications

1. New computer architecture combining hardware, software, and network (circuit)
2. Deep learning and brain-inspired artificial intelligence algorithms suitable for hardware (theory)
3. Implementing brain-inspired artificial intelligence for home service robots and **"Everything"** (application)

By combining the three pillars shown above, we aim to build an "**Edge-oriented Brain-inspired Computer System**" that implements artificial intelligence into all objects, and to apply it to a wide range of applications. Through this research seed, we aim to realize edge AI systems that support Japan's key industries such as automobiles and robots.

■ Features of the research seed

- We aim to realize edge AI systems through **research combining the fields of circuits, theory, and applications**.
- Our advantages consist in **digital circuit design (logic circuit design)**. Achievements include CNN and reservoir computing circuits realized with FPGAs.
- **We are focusing on applications.** We have a track record of integrating FPGAs with the Robot Operating System, which is the de facto standard in the robotics industry, as well as applying the system to robots and autonomous driving.
- **Awarded the most prestigious awards in the three fields.** The ISCAS Best Live Demo Award (circuit), the IJCNN Best Paper Award (theory), five-time champion of the World Robotics Competition (application), and many others.

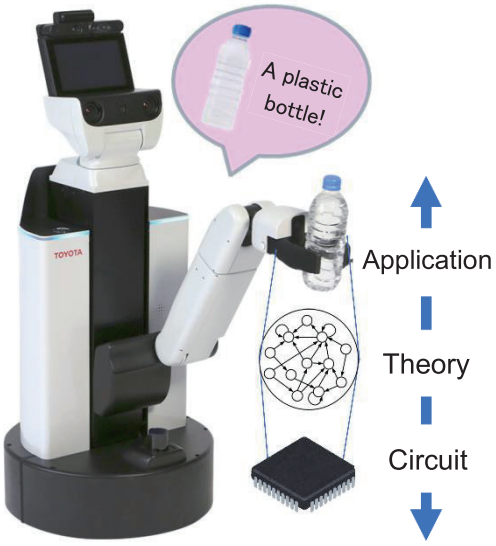

Fig. Example of Robot Object Recognition by Reservoir Chip

■ Expected use cases

- **Background (Issues)**
  Miniaturization, higher speed, and lower power consumption are necessary to realize AI that operates inside objects such as robots. Research and development that deals with theory and circuit architecture from an application aspect are also required. We are also focusing on developing a new research area through collaboration with nanomaterial researchers, which greatly transcends fields.

- **Applicability**
  Sophistication and lower power consumption of edge systems such as robots.
  Examples include implementations of FPGA in CNN, reservoir, Visual SLAM, etc.; and applications to anomaly detection, hammering inspection, model predictive control, image and speech recognition, home service robots, industrial robots, and autonomous driving.

■ Possible joint research partners

- Companies who understand the importance of edge AI systems and are interested in AI circuitry and AI utilization

■ Researcher information

Kyushu Institute of Technology
Graduate School of Life Science and Systems Engineering
Hakaru Tamukoh,
Professor

Research areas:
Brain-inspired computer system

The researcher's website is here →
(Search with "tamukoh lab"!)

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Technical fields: Mat **Des** Waf Pac Mou Ins Rel Rec Con Oth

Development of Next-generation Brain-inspired AI Models and LSI Chips / Devices

- Realizing High-efficiency Edge AI and Bringing AI Closer to Human Beings -

Keywords: **brain-inspired AI, reservoir computation, integrated circuits**

■ Aim of the research seed

Focusing on activities under the NEDO-commissioned project the "Project for Innovative AI Chip and Next-generation Computing Technology Development," we are collaborating with companies and universities involved in the project to develop ultra-low-power hardware for edge AI, research AI processing models as the background of the development, and apply the system to various applications. Current deep learning-based artificial intelligence technology uses a large amount of data and requires a large amount of hardware resources to realize high-precision intelligent information processing. In reality, however, data as well as resources are often insufficient, and the performance of current AI cannot be fully demonstrated. On the other hand, AI training is usually performed mainly in the cloud, but the importance of edge processing has been recognized in recent years, and edge AI technology has been actively developed. Under such circumstances, our group is developing an AI processing model that enables advanced intelligent processing even with a small amount of data and limited hardware resources, and its integrated circuit implementation (FPGA, ASIC) including device technology. Our goal is to develop various applications and promote social implementation.

■ Features of the research seed

The reservoir computing model is adopted as an AI processing model that does not require large amounts of data and hardware resources. Even though it is a simple recursive neural network, this model exhibits high performance in nonlinear processing and time series information processing. We are implementing the system with reconfigurable digital integrated circuit (FPGA), which can be developed in a short period of time, and developing dedicated time-domain analog integrated circuits (ASIC) capable of ultra-low power consumption operation. We are developing a technology to supply inexpensive hardware to the market with the mature CMOS technology with embedded flash memory.

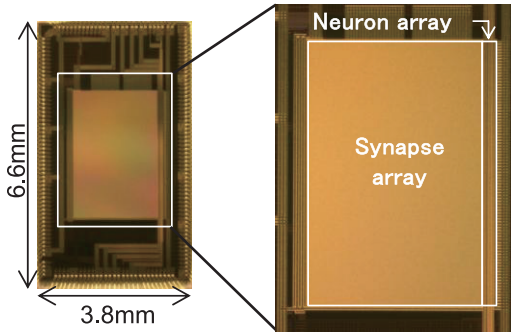

Fig. Reservoir Chip Designed and Fabricated Using CMOS Technology

■ Expected use cases

- **Background (Issues)**
  We want to respond to the demand for solving problems by simply installing inexpensive dedicated hardware - without advanced knowledge - in factories, distribution centers, nursing care facilities, etc., where labor saving and efficiency improvement can be expected using autonomous robots, or where incorporation of edge AI processing for IoT is anticipated.

- **Applicability**
  Service robots for nursing care, monitoring, and home use; transport robots within factories; intelligent navigation devices for autonomous machines such as drones; signal processing units for IoT devices; environmental monitoring devices; anomaly detection devices, etc.

■ Possible joint research partners

- Manufacturers and application companies of robots, drones, etc.
- AI-related information processing companies
- Companies related to IoT technologies
- Semiconductor integrated circuit design companies and manufacturers

■ Researcher information

Kyushu Institute of Technology
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Takashi Morie,
Specially Appointed Professor

Research areas:
Brain-inspired integrated systems

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35

Technical fields: Mat Des Waf Pac Mou Ins Rel Rec **Con** **Oth**

Reversible Automation

- Relocatable Robot Operation Technology -

Keywords: **relocation of industrial robots, sensor systems, wireless robot devices**

■ Aim of the research seed

When automating a manufacturing site, SMEs must consider not only the initial installation cost but also various running costs, such as electricity, maintenance for the automatic machines, and personnel and training costs for operators, in addition to initial installation costs. In a multi-product production process, consideration must be given to the production stoppage period and adjustment person-hours required for process changes when changing product types. Under these circumstances, it is important to reduce the cost and effort required for process changes for automating the multi-product manufacturing processes. In the medium to long term, a seamless transition from manual work to automation is desirable. We are proposing Reversible Automation (RA) that enables rapid replacement of workers and machines according to the process.
RA requires robots that can be quickly readjusted after rearrangement and adapt to changes in the environment. The robot also needs to be safe without a safety fence. Other important features include compactness, quick restart from an abnormal outage, and as few cables as possible.

■ Features of the research seed

The ease of relocation with RA makes it easier to consider the introduction of robots in advance, thus reducing the initial person-hours and costs. It also contributes to improving business continuity by allowing relocation of automatic machines according to changes in employee work patterns and working hours. Sophistication of RA technology is also useful for shortening the introduction period of automatic machines and other measures realized by automation such as mass production and labor saving.
On the other hand, there are several new technological elements that must be developed from an RA perspective. Our research focuses on the development of essential technologies, including: collaborative robots, grippers, three-dimensional measurement, motion planning, and risk assessment.

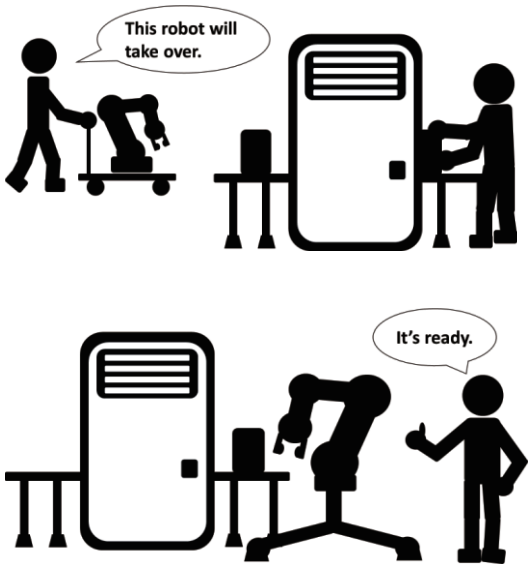

Fig. Reversible Automation Allows Humans and Robots to Work on Shifts

■ Expected use cases

- **Background (Issues)**
  Small and medium businesses that are considering automation due to labor shortages or business continuity may plan to deploy robots, but cost analysis often reveals that installation and operational expenses make such investment unprofitable. There are many manufacturing sites where permanent automation is difficult.

- **Applicability**
  If a robot system that is easy to move or relocate allows "spot automation," automation of part of a task or automation only for a certain period of time, It can help address workforce illness or enable night-time production. Additionally, production resilience will be improved dramatically.

■ Possible joint research partners

· Robot system integrators
· Robot manufacturers
· SMEs engaged in manufacturing
· Manufacturers promoting robot DX

■ Researcher information

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Research areas:
Control, robotics, and measurement

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Technical fields: Mat **Des** Waf Pac **Mou** Ins **Rel** Rec **Con** Oth

High-performance, Long-life Machine Learning, Image Processing, and Signal Processing Systems for Space Applications

- Enables Online Updates of FPGA Logic and Software -

Keywords: **Software defined satellites, for moon and Mars exploration, for deep space, improve productivity, update functions**

■ Aim of the research seed

In this research seed, we propose a system that can update functions as needed during a long-term mission in space. It also uses a higher-level programming language that is simpler than C and better suited to developing web applications and the IoT to achieve higher productivity. Furthermore, it can perform advanced machine learning, image processing, and signal processing required for recent systems used in space applications.
We can assume high-speed internet on the ground, but not in space. This technology seed is intended for use in an environment where network disruption may occur.
FPGAs are increasingly being used to realize advanced functionality in space. Since TSMC's move to Kumamoto, the semiconductor industry has boomed rapidly, making it difficult for emerging space equipment companies to recruit semiconductor engineers capable of designing FPGA logic. This technology seed also solves this problem by developing the FPGA logic to realize an application as software rather than directly designing it.

■ Features of the research seed

This research seed has the following features:
- Can perform updates of functions as needed to support long-term space missions
- Uses a higher-level language that is simpler than C and is also better suited to developing web applications and IoT
- Can perform advanced machine learning, image processing, and signal processing
- Can be used during network disruptions
- Does not directly design the FPGA logic that implements the application

■ Expected use cases

● Background (Issues)
Can be leveraged by companies such as:
- Companies in the space equipment industry/considering entering the space equipment industry,
- Companies that want to develop a space instrument that can carry out long-term space missions,
- Companies that want to improve system productivity.

● Applicability
The following applications are possible:
- Advanced machine learning, image processing, and signal processing
- Application to network disruption environments
- Distributed processing

■ Possible joint research partners

- Space equipment industry
- Especially for disaster prevention

■ Researcher information

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Susumu Yamazaki,
Associate Professor

Research areas:
Software and logic circuit design

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The researcher's website is here →

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For inquiries regarding this collection of seeds as a whole, please contact the Kitakyushu Foundation for Advancement of Industry, Science and Technology <FAIS> Semiconductor Industry Support Center.

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June 2024
Kitakyushu Semiconductor Network
Future Industry Promotion Division, Industry and Economics Bureau, City of Kitakyushu
Kitakyushu Foundation for Advancement of Industry, Science and Technology <FAIS>

Overview of the Kitakyushu Semiconductor Network

1. Purpose

Purpose of the network is to revitalize the semiconductor related industries in the City of Kitakyushu area through commitment that leads to expansion of transactions of participating companies, development and securing of human resources, etc., in cooperation with national and prefectural governments, thereby promoting the semiconductor related industries of the area.

2. Date of Establishment

July 20, 2022

3. Participating companies

Members companies: 46
Supporting members: 18 companies and 1 organization (as of March 2024)

4. Observer

The Kyushu Bureau of Economy, Trade and Industry; Fukuoka Prefecture; the Kyushu Semiconductor & Digital Innovation Association; the Kitakyushu Chamber of Commerce and Industry; the University of Kitakyushu; the Kyushu Institute of Technology; Waseda University; the Nishinippon Institute of Technology; Kyushu Polytechnic College; the National Institute of Technology, Kitakyushu College

Three main components of the business

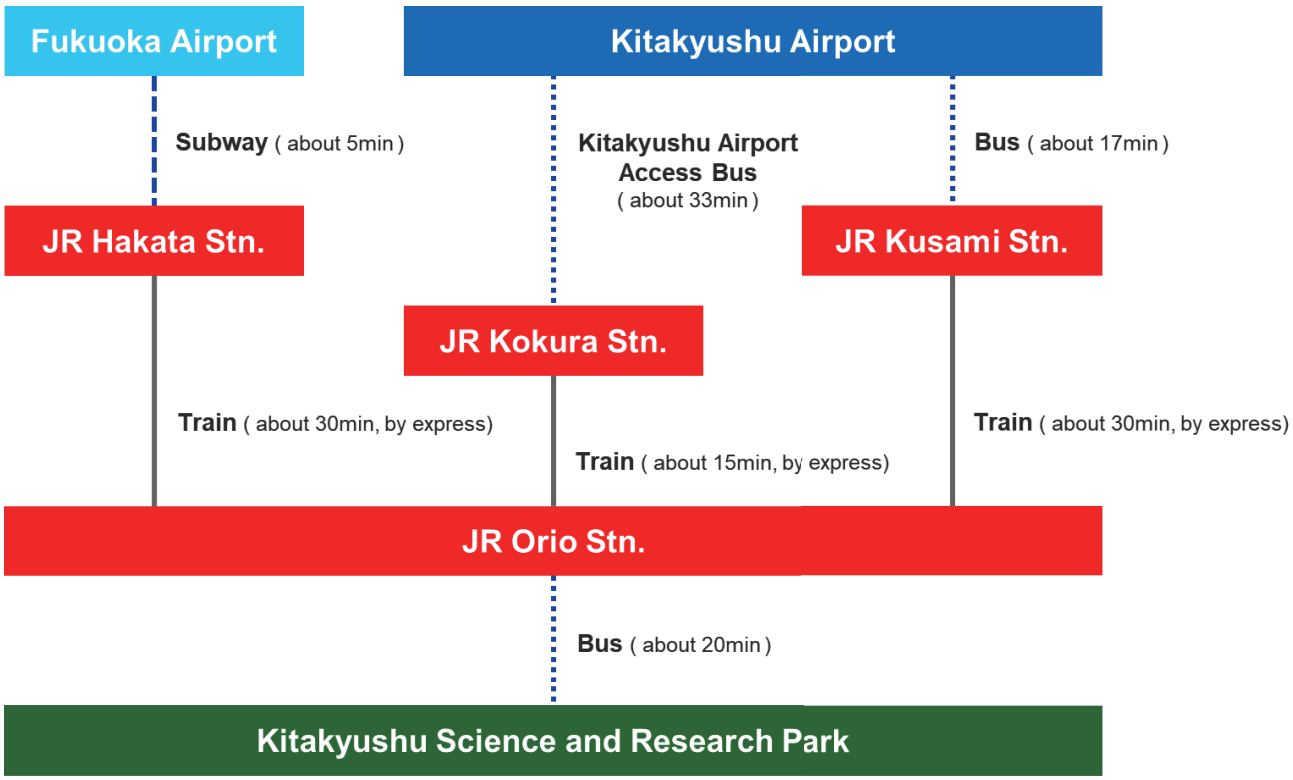
Developing and securing human resources in semiconductor-related industries	Cultivation of sales channels and promotion of inter-company exchanges	Support for technology and R&D
· Promote opportunities for personnel with practical skills/knowledges and students to find suitable positions · Provide basic education to learn about semiconductors from scratch	· Create opportunities to contact semiconductor manufacturers as a customer · Promotion of exchanges information/personnel between companies and provision of various information	· Support for industry-academia collaboration and inter-company collaboration · Introduction of subsidies for semiconductor-related development

Supply of advanced human resources	Expansion of local business	Revitalization of local universities
Development of engineers in the local companies	Advertisement of the City of Kitakyushu area	External financing

Revitalization of semiconductor-related industries in the City of Kitakyushu area

- Advancement and revitalization of local semiconductor companies
- Attracting semiconductor-related companies and research institutes
- Creation of new jobs

Access to the Kitakyushu Science and Research Park



Campus map of the Kitakyushu Science and Research Park