Department of Electrical and Electronic Information Engineering

- Electronic Materials
- Electrical Systems
- Integrated Electronics
- Information and Communication Systems

Advanced Materials Science Laboratory

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Key words	Sol-Gel, Mechanical Milling, Anodization, Fuel Cells, All-Solid-State Lithium Ion Batteries, Metal-Air Batteries, Solar Cells, Superhydrophilic/Superhydrophobic, Photocatalyst, Plasmonic Nanoparticles, Multiferroic nanocomposite

We undertake research on manufacture of and applications for functional materials. The materials are prepared by means of sol-gel, ball milling, layer-by-layer assembly, liquid phase shaking, electrophoretic deposition, anodization, etc.

Fig. 1 Photo of electrolyte for fuel cell

Theme 1 ▶ New Generation Fuel Cells

We have developed novel electrolyte composed of phosphoric acid doped polybenzimidazole and inorganic solid acid complex for fuel cells. The inorganic solid acid complex is prepared by ball milling method and the composite electrolyte thus obtained exhibits high thermal stability and high proton conductivity at 100 °C and up. The electrolyte is also mechanically strong and flexible as seen in Fig. 1. The maximum power density at 160 °C and under anhydrous condition is 400 mW cm-2.

Theme 2 ▶ All-Solid-State Li Ion Secondary Battery

We have developed novel synthetic method for a precursor of Li3PS4 solid electrolyte for Li ion secondary battery. The precursor was composed of Li3PS4 and ethyl acetate in a molar ratio of 1 : 2, as determined by thermogravimetric-differential thermal analyses (TG-DTA). Upon drying at 160 °C, the precursor decomposed to form crystalline Li3PS4 with a high ionic conductivity of 3.3 × 10−4 S cm−1 and low activation energy of about 31 kJ mol−1. Fig. 2 shows a scanning electron microscope (SEM) image of Li3PS4 solid electrolyte which is derived from the newly developed precursor.

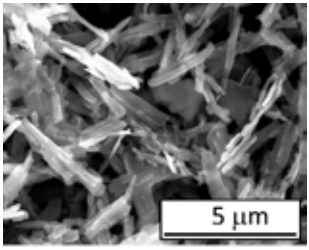

Fig. 2 SEM image of Li3PS4 solid electrolyte derived from the newly developed precursor for Li ion battery

Theme 3 ▶ Plasmonic Nanostructures for Photocatalyst and Solar Cells

We have synthesized several kinds of plasmonic nanostructures composed of noble metal nanoparticles and nano/meso-porous metal oxides prepared by sol-gel, anodization, etc. Fig. 3 shows transmission electron microscope (TEM) images of Au deposited mesoporous SiO2-TiO2. Au was deposited with selected shapes of sphere and rod. These materials show high performance of photocatalysis under sunlight because they absorb the photons very efficiently. Ag-nanoparticle-doped TiO2 was used as photoanode of dye-sensitized solar cells to enhance their power conversion efficiency.

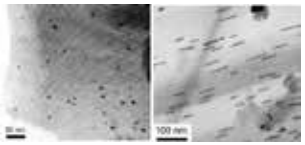

Fig. 3 TEM images of Au nanosphere (left) and Au nanorod (right) deposited mesoporous SiO2-TiO2 photocatalysts

Theme 4 ▶ Multiferroic Nanocomposites for Novel Devices

We have synthesized BaTiO3 (BTO) nanotube arrays by anodization followed by hydrothermal treatment. Figs. 4A and 4B show the top and cross-sectional SEM images of BTO nanotube arrays. The pores of the tubes are filled with CoFe2O4 (CFO) through electro-magneto-phoretic deposition, sol-gel, etc. to obtain multiferroic nanocomposites as shown in Fig. 4C.

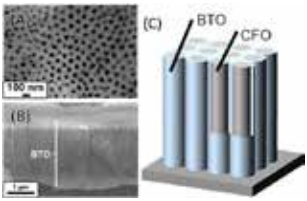

Fig. 2 (A and B) SEM images of BTO nanotube arrays. (C) Illustration of one of the ideal structures of multiferroic nanocomposite.

Spin Electronics Group

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Laboratory URL	http://www.spin.ee.tut.ac.jp/		
Key words	Magnetic material, spin, artificial magnetic lattice, magneto-optical effect, magnetophotonic crystal, photonics, spintronics, magnonics, spin caloritronics, advanced measurement system		

Spin is the origin of ferromagnetism and plays an important role in electrical and electronic information engineering. By controlling the orientation and extent of this spin, it can control various physical quantities such as light, high-frequency electromagnetic waves or ultrasonic, offering attractive functions. We investigate new magnetic materials and devices having specific micro or nano structures called artificial magnetic lattices.

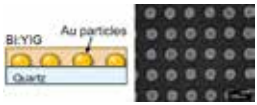
Theme 1 ▶ Spin functional material

We develop magnetophotonic crystals (original to our group) that show enhancement of magneto-optical effects. We also develop new materials with spin functions such as magnetic holograms, multiferroic materials, magnetic domain materials, etc. using sputtering, PLD (Pulsed Laser Deposition), MBE (Molecular Beam Epitaxy), MOD (Metal Organic Decomposition methods.

Magnetophotonic crystals

Theme 2 ▶ Magneto-optical plasmonic structure

In magnetic garnet composite structure with Au particles, which is one of the artificial magnetic lattices, Faraday rotation is enhanced at a wavelength where surface plasmon resonance is excited. Finite-difference time-domain (FDTD) simulation is used to understand phenomena.



Magneto-optical plasmonic structure

Theme 3 ▶ Magnetic hologram memory

A large-capacity holographic data storage system called the collinear system is recognized as a world-first international standard from our research. Currently, we are working to develop high-density holographic data storage systems (multi-volume recording) using optical phase information and rewritable recording systems using polycrystalline spin materials with nanoscale particle size.

Hologram memory system and recorded magnetic information

Theme 4 ▶ Magneto optic special light modulator and 3D display

We develop magneto optic spatial light modulator (MOSLM) using magneto-optical effect with fast switching speed of approximately 10ns per pixel. As an application of the MOSLM, a 3D display can show stereoscopic image having a viewing angle of about 30 degrees in case of the MOSLM with pixel size of 1 μm.

MOSLM and 3D display

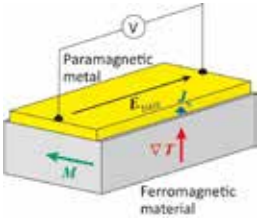
Theme 5 ▶ Spin wave devices

Using magnonic crystal that manipulates spin wave, we develop a new magnonic device for magnetic field sensing with ultra-high sensitivity at room temperature. Furthermore, we develop a new logic device that utilizes spin wave interference in magnetic oxide material.

Magnonic device using spin wave

Theme 6 ▶ Spin caloritronics application

Realizing thermoelectric power generation, in addition to exploring raising the performance of thermoelectric materials such as Ca3Co4O9 (Co349), we develop a thermoelectric conversion module. Using the recently discovered spin Seebeck effect, we develop a spin control device based on heat and new thermoelectric power generation module.



Spin Seebeck effect

Theme 7 ▶ Advanced measurement technology

We develop new advanced measurement technologies: optical and magneto-optical confocal microscopy, computer tomography, scanning near field microscopy, etc. for the magnetic, optical, electrical and structural properties,

Processing and Instrumental Mechanics Laboratory

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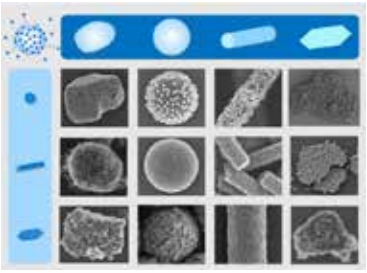
Key words	Nano-composite, functional / structural ceramics, composite particles, discrete element method, finite element method, nano-indentation, superplastic deformation

To further advance various electronic devices, it is essential to develop materials with properties that surpass existing ones. Up to now, as a method to both improve the properties and to innovate new ones, our laboratory has proposed a novel nanocomposites fabrication technique that can be used to obtain optimal microstructural design using attractive electrostatic force, and the properties improvement of the nanocomposite in mechanical, heat and electrical properties have been investigated. Additionally, as it is imperative to establish technologies that can universally and scientifically perform evaluative analysis of the newly-developed materials' properties, establishment of evaluation technology is also carried out.

Theme 1 ▶ Nanostructure controlled functional ceramic composite materials

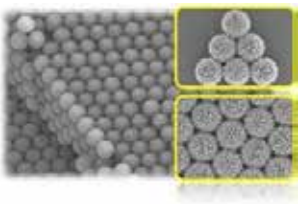
By controlling the microstructural morphology, the mechanical and functional properties of composite materials, such as strength and fracture toughness, etc., can be enhanced. However, by using conventional mechanical powder mixing method, desired properties could not be achieved due to the inhomogeneous mixing. In this study, various types of functional composites fabrication are investigated and developed using novel nano-assembly technique.



Composite materials via proposed technique

Theme 2 ▶ Development of functional composite particles

In this study, novel preparation of functional composite particles via electrostatic adsorption technique is investigated. Various types of composite particles with varying shape can be obtained using nano-sized materials such as adsorption of carbon nanotube onto a particle matrix. This technique would be useful for application in electrochemistry, high efficiency catalysts as well as optoelectronic devices.

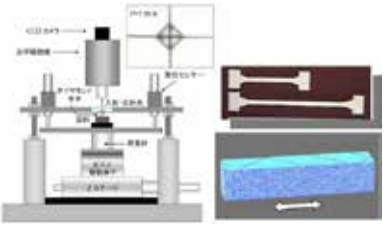


Ordered structure of functional composite particles

Theme 3 ▶ Deformation and flow of advanced materials

This project focus on the investigation of deformation and flow of polycrystalline materials (commonly ceramics) at not only room temperature but also high temperatures. A novel testing procedure and theoretical analysis which includes computer simulation are proposed in this study.

a. Mechanical property analysis of thin films by nano-indentation technique.
b. Surface mechanical property evaluation by scratch test
c. Superplastic deformation of nanostructured materials



Evaluation techniques in our laboratory

Electroanalytical Chemistry Laboratory

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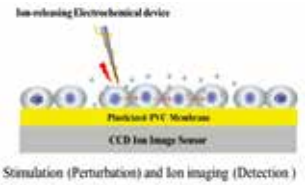
Key words	Ion sensor, ion imaging, electrochemical device, chemical stimulation, polyelectrolyte, chemical observation, living cells and tissue, bio-friendly system

Our laboratory researches micro electrochemical devices and array type ion image sensors, and investigates the application of polyelectrolytes for electrochemical devices. The aim and concept is to fabricate a bio-friendly system for chemical observation of cells and tissues.

Theme 1 ▶ Development of Micro Electrochemical Devices to Release Ions

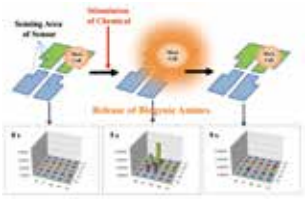
Living action of cells and tissues is due to a conversion and/or a transfer of chemical substances. In order to analyze the action of a tissues, controlled techniques is required; only a cell is stimulated in local, and then the change of chemical substances by the stimulation transfer is monitored. We are developing micro ion-release electrochemical devices to the chemical stimuli. The electrochemical ion-release device is an important tool to stimulate a cell chemically without other effects.



bio-friendly system
An electrochemical system observes living cells by a chemical stimulation.

Theme 2 ▶ Development of Electrochemical Ion Image Sensor

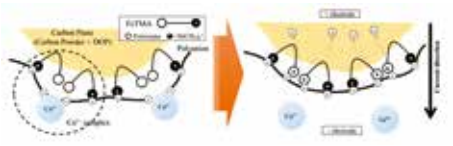
Ion selective electrodes (ISE) and semiconductor ion sensors (ISFET/CCD ion sensor) can measure a specific ion immediately. We have developed ISEs for polyelectrolytes and non-ionic chemicals that had been regarded as difficulty of its detection from Nernst equation. Recently, using a CCD-type ion image sensor that was developed by Professor Sawada in TUT, we are developing chemical imaging of several metal ions and biologically-important organic ions. The image sensors can monitor living cells and tissues non-invasively.



mast cell stimulation
The ion image sensor monitors the concentration change of biogenic amines released from mast cells by a chemical stimulation. 3D images show each sensor response around a mast cell stimulated.

Theme 3 ▶ Application of polyelectrolytes

Polyelectrolytes act as substances with unique functions. We had developed analytical methods for various synthetic and natural polyelectrolytes (chitosan, heparin, chondroitin sulfate, and polyhexanide hydrochloride, etc.) using titration, electrochemical analysis (voltammetry and potentiometry), and capillary electrophoresis. In addition the reaction of polyelectrolyte with proteins has been analyzed. Now, we develop electrochemical devices using polyelectrolytes.



polyelectrolyte ternary complex
A polyelectrolyte ternary complex releases calcium ion by electrolysis.

Clean Energy Conversion Laboratory

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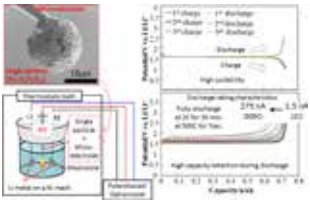
Key words	Lithium-ion batteries, Multivalent ion batteries, All-solid-state batteries, Battery materials, measurement

In order to provide integrated solutions to resource energy and environmental issues and meet societal demands such as for diversification, low environmental impact and decentralization of power sources in the desired ubiquitous network clean energy society, long life secondary batteries and high efficiency fuel cells with low environmental load and high energy density are essential. R&D on new materials, processes and evaluation technologies that will be the foundation of these power sources will become more and more important in the future. This laboratory is broadly deploying R&D that contributes to high safety, low cost, high performance and high reliability of electrochemical energy conversion devices, while looking to their use in clean vehicles such as electric and fuel cell vehicles and the renewable energy generation field.

Theme 1 ▶ Research for next-generation high-performance secondary batteries

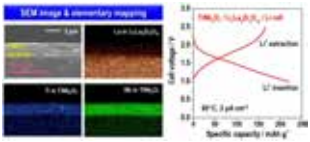
We are putting our attention on environmentally friendly, low cost electrode materials, making clear the material physico-chemical properties, battery operating conditions and various reaction process correlations that occur within batteries such as charge transfers, mass transfers and side reactions. We are also conducting research to improve the performance of lithium-ion batteries by clarifying battery reaction mechanisms. We are also working on research for new battery types such as multivalent ion batteries.



Charge-discharge property of new battery material using single particle measurement system.

Theme 2 ▶ Research for oxide-based all-solid-state battery

All-solid-state lithium-ion batteries, using nonflammable inorganic solid Li-ion conductor as an electrolyte, is expected as one of the next generation energy storage devices, because its safety and reliability are much superior to present lithium ion batteries with flammable organic carbonate liquid electrolyte. However, development of solid electrolytes with both high ionic conductivity and minimizing interfacial resistance between solid electrolyte and electrodes are critical issues to be solved. In our laboratory, oxide solid electrolyte with high ionic conductivity and chemical stability against electrode materials are developed. In addition, aerosol deposition (AD) method, which is polycrystalline ceramic film formation process under room temperature, is applied for novel fabrication process of all-solid-state batteries.



Film electrode formed on oxide solid electrolyte by AD (left) and its charge and discharge property (right).

Theme 3 ▶ Research of new measurement technologies for batteries

There is a trend for lithium-ion batteries to be used in more large scale applications, but fires or explosions may occur if a fault occurs due to the high energy density, and together with recent large-scale recalls, the battery safety has become an issue for society. In this research, we develop battery measurement technologies to detect problems in the production and use of batteries in advance and that can non-destructively identify battery degradation causes.

Plasma Energy System Laboratory

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Laboratory URL	http:// www.pes.ee.tut.ac.jp
Key words	Vacuum plasma, atmospheric-pressure plasma, diamond-like carbon, eco-energy, nanocarbon, energy devices

Theme 1 ▶ Effective utilization of renewable energy and eco-energy

Securing sufficient energy and protection of the global environment are important issues for human. In order to deal with these issues, we are working on research to effectively utilize clean energy (solar energy and wind energy) from the Sun that is the enormous plasma and eco-energy (cogeneration) from energy recovery system such as exhaust heat utilization.

(1) Eco-energy system design and its high-efficiency operation
(2) Utilization and application of weather measurements and solar panel systems
(3) Energy environment control on the cultivation of plants

Solar panels of TUT

Theme 2 ▶ Development of apparatus using generation and control of plasma and its applications for industrial use

We have investigated generation and control technologies of vacuum arc plasma that generates high-energy ions and atmospheric-pressure plasma that generates chemical active radicals. Especially, we have developed apparatuses and processes aimed at industrial use.

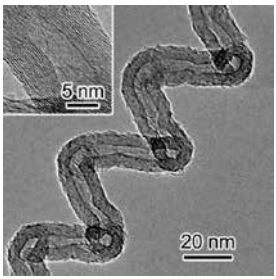
(1) High-performance filtered arc deposition apparatus based on electromagnetic field control and its process development
(2) Composition control and quality analysis of diamond-like carbon (DLC) film
(3) Development of vacuum and atmospheric-pressure plasma apparatuses, and its application to surface treatment by physical vapor deposition and chemical vapor deposition (PVD/CVD) processes
(4) Development of forming, shaping and removing processes for functional protective films

Apparatus for generating high-purity carbon plasma beam

Theme 3 ▶ Nanocarbon synthesis and its application development

We have synthesized nanocarbons using a thermal chemical vapor deposition (CVD) method. We have developed nanocarbons for applications such as energy devices for eco-energy systems, electronic devices, and hydrogen generation system.

(1) Synthesis of helical carbon nanofibers using a catalytic CVD method
(2) Development of direct methanol fuel cells using nanocarbons
(3) Development of super capacitors using nanocarbons
(4) Development of field electron emission sources using fibrous nanocarbons
(5) Development of solar cells using nanocarbons



Transmission electron micrograph of carbon nano-coil

Dielectrics and Electrical Insulation System Laboratory

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Key words	High voltage, insulation diagnosis, ageing, functional insulating material, Ultrasonic microscope, biological tissue, acoustic impedance		

To ensure safety and reliability of power equipment and electronic devices, it is important to select the dielectric and insulating materials suitable for the equipment. In addition, it is also necessary to clarify the cause of failure or to estimate the replacement timing of the equipment. We are developing new measurement and diagnosis techniques based on electrical engineering and clarify the high electric field phenomenon of the dielectric and insulating material. In addition, we apply the developed techniques to fields for medicine, environmental technique, automobile, steel, food, and material.

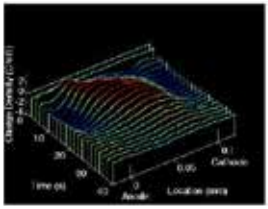
Theme 1 ▶ Diagnosis techniques for industrial use

Replacement timing of deteriorated electrical equipment is important. If it is too early, the replacement cost will increase. On the contrary, if it is too late, it will lead to accident. To prevent the accidents, we develop new techniques for detecting minute signals emitted with degradation. The main research are as follows.

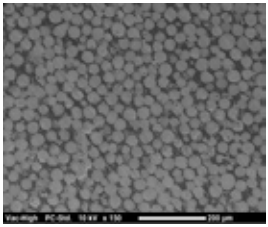
① An electrification in materials is significantly distorts the internal electric field and it may lead to dielectric breakdown. By using ultrasonic technique, the internal charge density distribution can be measured by applying a very high voltage. The technique is highly appreciated in the field of high voltage power transmission.

② Partial discharge (PD) may occur due to the electric field concentration in the electrical insulation parts of power equipment and continuous PD occurrence may lead to dielectric degradation and finally breakdown. PD detection using an antenna method has often advantage. We clarify the relationship between PD phenomena and radiation electromagnetic waves.

③ It is big issue that continuous PD occurs locally in solid dielectric material. Local dendritic path grows and branch into hollow channels (Electrical Tree) may arise. The electric tree is also one of the causes of degradation. We clarify the occurrence and propagation mechanism for the electrical tree.



Charge movement in polymer



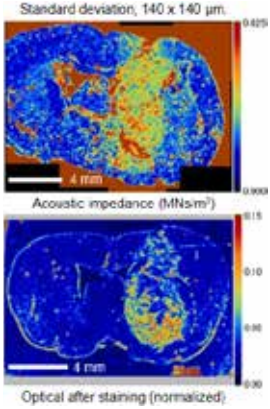
Composite insulation materials

Theme 2 ▶ Development of functional composite insulation materials

The thermal conductive plate in devices like power module for an automobile requires materials with higher thermal conductivity and acceptable electric breakdown strength. By using electrostatic adsorption method, it can design optimal microstructures of filler and matrix polymer. We are developing thermal conductive composite insulating materials with a good balance of acceptable breakdown strength and higher thermal conductivity.

Theme 3 ▶ Ultrasonic techniques for medical use

We are developing an ultrasonic microscope that can image local acoustic impedance of a biological tissue. It can observe without introducing any contamination to the tissue, and without staining the tissue. At this moment we can observe live cultured cells as well as cross section of tissue. Its resolution is as good as several micrometers.



Ultrasonic techniques for medical use

Integrated Biosensor and MEMS Group

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Key words	Smart sensors, CMOS, silicon devices, MEMS/NEMS, RF devices, nanodevices, agricultural sensors, biosensors, gas sensors

Our group studies sensors and micro/nano devices based on LSI and MEMS technologies. The application of the devices covers various fields that include life science, environment, healthcare, etc. We work on creating world's first novel devices from scratch —from design to evaluation— by fully utilizing the LSI/MEMS fabrication facility to contribute to solving issues in such fields.

Theme 1 ▶ Intelligent biosensors

We are researching creative biosensor devices that combine integrated-circuit technology (CMOS and CCD image sensor technology), MEMS and bio-chemical technology. In particular, we are researching and developing image sensors (Fig.1) that can detect various ions from DNA and biological substances and visualize their 2-dimensional distribution and concentration. Further, based on this technology combined with enzymatic reaction, we are developing biomolecule sensors that can detect only specific substances (glucose, etc.). We are also researching on multimodal sensors that can detect various biomolecules, fluorescence, and force at the same time as pH.

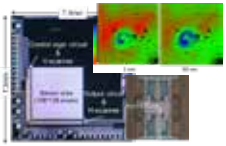


Fig.1

Theme 2 ▶ Filter-free fluorescence image sensor

We develop novel Si-based fluorescence image sensors aiming for the applications including point of care testing (POCT) and micro-total analysis systems (μ-TAS) (Fig. 2). The devices do not require any optical filters, which enable a miniature and simple detection system compared with conventional fluorescence microscopy. Further, they realize simultaneous detection of more than two fluorescence with different wave lengths. We both design and fabricate the devices for further improvement in their performance.

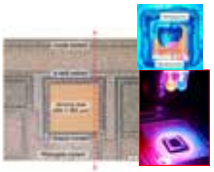


Fig.2

Theme 3 ▶ Ion and force image sensors

Ion and force image sensors can record the change of ion concentration and force distribution in solution (Fig. 3). The sensor consists of CMOS integrated readout circuits and arrayed pairs of an Ion-sensitive FET (ISFET) and a piezoelectric oxide semiconductor FET (POSFET). The recorded images by the sensor will be able to provide a comprehensive analysis of extracellular metabolisms, such as cell immigration and biochemical communications.

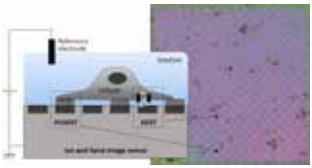


Fig.3

Theme 4 ▶ Intelligent Bio-MEMS devices

We develop sensors that can detect biomarkers that are the diagnostic indices of various diseases quickly and accurately from one drop of blood or urine, aiming to realize rapid onsite diagnosis for simple examination and first aid of illnesses in the home. We are reducing the size and adding multiple elements to sensors that fuse optical MEMS (microelectromechanical systems) and integrated circuit technology, aiming for exhaustive disease diagnosis by the detection of multiple biomarkers (Fig. 4).

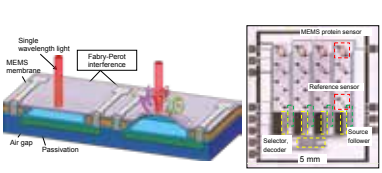


Fig.4

Theme 5 ▶ Variable plasmonic metamaterials

We fabricate metal periodic nanostructures at the same dimensions as light wavelengths, and develop artificial optical materials and plasmonic metamaterials with optical properties that do not exist in the natural world. We embed nanostructures in polymer thin films, aiming to create display elements and electronic skins that can be pasted on that to freely change their coloring using micro-actuator technology (Fig. 5).

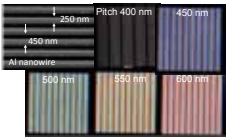


Fig.5

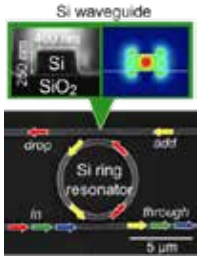
Integrated Photonic Device Group

Staff	• Professor **Ishikawa, Yasuhiko** (E-mail：ishikawa@ee.tut.ac.jp) • Research Associate **Sotto, Moïse**
Laboratory URL	http://int.ee.tut.ac.jp/photon
Key words	Silicon Photonics, Photonic Devices, Integration, Optical Communications/ Interconnects, Germanium, Epitaxial Growth, Optical Waveguides, Multiplexers/ Demultiplexers, Photodetectors, Optical Modulators, Lasers

Si photonics is a technology to fabricate and integrate ultrasmall photonic devices on a Si chip using LSI processes. Such integrated photonic devices are strongly required for low-power and high-capacity information transmission. Based on the state-of-the-art SiGe epitaxial growth technology, high-performance active photonic devices operating at the near-infrared communication wavelengths (1.3–1.6 μm) are integrated on a Si chip with passive photonic devices such as optical waveguides and optical filters.

Theme 1 ▶ Si-based Waveguides

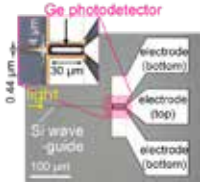
Si/Si nitride waveguides enable light propagation on a Si chip for high-capacity optical communications (wavelength: 1.3 - 1.6 μm) as well as optical interconnections in high-performance LSIs such as AI chips. SOI (Si-on-insulator) wafers have been used, while a technology has to be developed using standard bulk Si wafers toward mass productions.



Si optical waveguides and ring resonators

Theme 2 ▶ Ge-on-Si Photodetectors

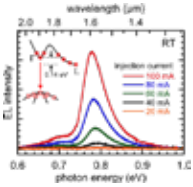
Photodetectors are inevitably necessary to convert optical signals to electrical ones for the processing with LSIs. Ge, a group-IV semiconductor similar to Si, has a good compatibility with Si processing technology. Integrated photodetectors of high-quality Ge epitaxial layer have been realized, while higher-frequency operation remains as an important issue.



Ge photodetector integrated with Si optical waveguides

Theme 3 ▶ Novel Ge-on-Si Devices

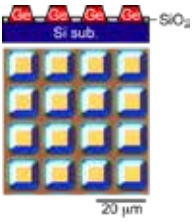
Ge is an indirect bandgap semiconductor, while theoretical investigations have shown that excellent optical properties, similar to direct semiconductors, can be obtained applying the band engineering. Novel photonic devices are under investigations such as optical intensity/phase modulators and light emitters (particularly, lasers).



Electroluminescence from Ge

Theme 4 ▶ Near-infrared Imaging

Near-infrared Ge detectors are applicable to image sensors in addition to optical communications. Near-infrared light tends to penetrate into materials as well as human bodies, indicating applications to see-through image sensors.



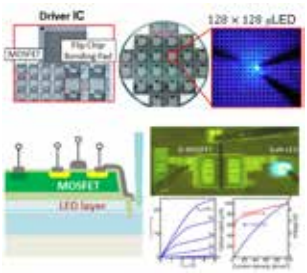
Arrayed Ge mesa structure selectively grown on Si

Opto-Electronic Group

Staff	• Professor **Wakahara, Akihiro** (E-mail：wakahara@ee.tut.ac.jp) • Associate Professor **Sekiguchi, Hiroto** (E-mail：sekiguchi@ee.tut.ac.jp) • Assistant Professor **Yamane, Keisuke** (E-mail：yamane@ee.tut.ac.jp)
Laboratory URL	http://www.int.ee.tut.ac.jp
Key words	Micro-Display, Solar Cell, Thermal Stable LD, Crystal Growth (III-V-N on Si, GaN), OEIC

Theme 1 ▶ Development of Monolithic Opto-Electronic Integrated Circuit

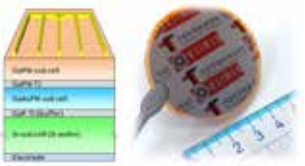
In the last decade, the significance of heterogeneous integration devices/systems has been progressively increasing because of the anticipated limit on further miniaturization of Si-based LSIs, and GaN-based materials are understandably one of the candidates for that component. In Particular, the heterogeneous integration technique on the Si-CMOS platform is an important topic for a breakthrough to POST-CMOS technology. In this subject, a monolithic integration process of Si-MOSFET and GaN-μLED using Si/SiO2/GaN-LED wafer has been developed. The n-channel MOSFETs (nMOSFETs) and μLED are successfully fabricated as a top-Si layer and GaN-LED layer respectively using a CMOS process line.



Opto-Electronic Integrated Circuit using GaN-LED and Si-LSI

Theme 2 ▶ Development of Monolithic III-V-N/Si Multi-Junction Solar Cell

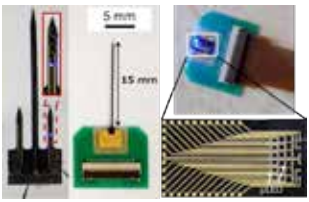
Integration of high-quality III-V compounds on Si substrates are of importance for a wide variety of light emitting/absorbing device applications while it allows significant saving of substrates. The monolithic integration approach using lattice-matched III-V/Si hetero-epitaxy enables a simple fabrication process of dislocation-free device structures on entire Si substrates. In this subject, we propose a GaPN/ GaAsPN/Si multi-junction structure in which lattice constants for all layers are matched to a Si bottom cell for highly efficient and cost effective solar cells.



Monolithic III-V-N/Si Multi-Junction Solar Cell

Theme 3 ▶ Development of micro-LED neural probe for optogenetic stimulation

Optogenetics, in which neural activity can be selectively manipulated by light, is a new technology that has attracted in neuroscience in recent years. Although optical fibers are generally used for optical stimulation, they restrict the free moving of experimental animals because they are connected to the animals. A MicroLED device is one of candidates for achieving optical stimulation under free movement because it can be controlled by wireless. Furthermore, multipoint stimulation can be achieved by arranging a plurality of micro LEDs in one probe, which can clarify how neural network works. In this subject, we have been developed a novel MicroLEDs tool for Optogenetics to understand brain function.



MicroLED tool for bioscience

Kawano Research Group

Staff	• Associate Professor **Kawano, Takeshi**
Laboratory URL	http://www.int.ee.tut.ac.jp/icg/member/~takekawano
Key words	microscale device, nanoscale device MOSFET, MEMS, flexible device, stretchable device, neural recording/stimulation, neuron/cell, brain

Theme 1 ▶ Microneedle-electrode array device

"The brain is an extremely complex system." Microfabricated silicon needle-electrode devices were expected to be an innovation that records and analyzes the electrical activities of the microscale neuronal circuits in the brain. We have developed the world's smallest 5-μm-diameter low-invasive needle electrodes for the brain. Their electrode device reduces the total invasiveness to brain tissue in vivo and realizes stable neural recordings, thus enhancing opportunities for needle-electrode device technology in neurophysiology.

Recent papers:

Sawahata, H. et al. Single 5 μm diameter needle electrode block modules for unit recordings in vivo. Sci. Rep. 6, 35806 (2016).
Fujishiro, A., et al. In vivo neuronal action potential recordings via three-dimensional microscale needle-electrode arrays. Sci. Rep. 4, 4868 (2014).

Theme 2 ▶ Nanoneedle-electrode array device

For acquiring a large amplitude and a high quality of neuronal signals, intracellular recording is a powerful methodology compared to extracellular recording to measure the voltage or current across the cell membranes. We have developed an intracellular recording device, which has >100-μm-long three-dimensional nanoscale-tipped microneedle-electrodes. The nanoelectrode, whose size is longer than the conventional intracellular nanoelectrode (< 10-μm long), has the potential to be used in cells that are deep within a tissue, such as cells in brain slices or brain in vivo, thus accelerating the understanding of the brain.

Recent papers:

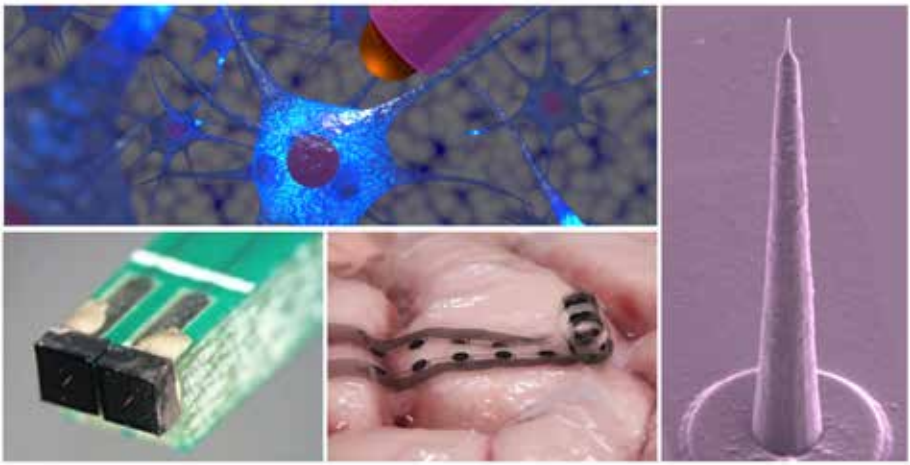
Kubota, Y. et al. Long nanoneedle-electrode devices for extracellular and intracellular recording in vivo. Sensors Actuators B. Chem. in press.
Kubota, Y. et al. Nanoscale-tipped high-aspect-ratio vertical microneedle electrodes for intracellular recordings. Small 12, 2846–2853 (2016).

Theme 3 ▶ Flexible, stretchable, and deformable device

Electrocorticographic (ECoG) recordings are a low invasive way to record the neuronal activities from cortical surfaces and are used in medical applications such as diagnostics of diseases. Common issue of state-of-the-art flexible ECoG devices that are thin and a large area, is addressing difficulties during device placement. We have proposed a way to overcome this by facilitating an actuating film based on a curled film. However, the curled film is flattened when the film comes in contact with a brain surface due to the surface tension between the film and the brain-surface.

Recent paper:

Yamagiwa, S., Ishida, M. & Kawano, T. Self-curling and -sticking flexible substrate for ECoG electrode array. Proc. IEEE Int. Conf. Micro Electro Mech. Syst. 480–483 (2013).



Developed neuronal recording micro/nanodevices: extracellular micro-scale needle-electrode (lower left), flexible ECoG microelectrode (lower center) and intracellular nano-scale needle electrode (right).

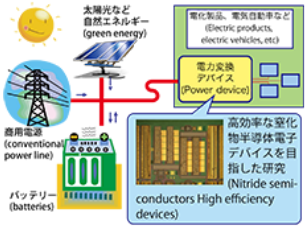
Applied Physical Properties and Process Laboratory

Staff	• Professor **Okada, Hiroshi** (E-mail : okada@las.tut.ac.jp)
Laboratory URL	http://www.int.ee.tut.ac.jp/oeg
Key words	Electron device, compound semiconductor, GaN, harsh environment electronics, power electronics, nano materials

Our interest is a development of novel electron devices beyond the present microelectronics by using compound semiconductors such as gallium nitride (GaN). Towards integrated device/system for power electronics and harsh environment electronics, device fabrication technologies are also investigated using clean room facility.

Theme 1 ▶ High performance electron device based-on nitride semiconductors

So far, semiconductor devices are regarded as components for "low power electronics." However, recent advances in technology for GaN-related materials open up a new field of “heavy electronics” or “power electronics,” where high voltages beyond 100 V are controlled in higher temperature environments. These advances are promising for compact and high efficiency systems which are indispensable for hybrid vehicles and electric vehicles. Realization of high tolerance devices for use in harsh environments is also expected. In this laboratory, we focus on power electronics and electronics for harsh environments, and investigations are made to develop advanced semiconductor devices based on nitride semiconductors and nano materials.



Power electronics for daily life.

Theme 2 ▶ Investigation of novel electron device by heterogeneous integration

Nitride semiconductors possess relatively wide band gap energy and chemically stable nature. These properties are suitable for operations of electron devices made with nitride semiconductors in tough environment such as in high temperatures nearby the engine in vehicles, irradiation environment in space, and so on. Novel sensors and electronic devices can be expected by hybriding nitride semiconductors and other characteristic materials or nano structures including well developed silicon circuits. These unique integrated devices are expected to enhance the field of engineering since these are useful to detect physical information in harsh environment.

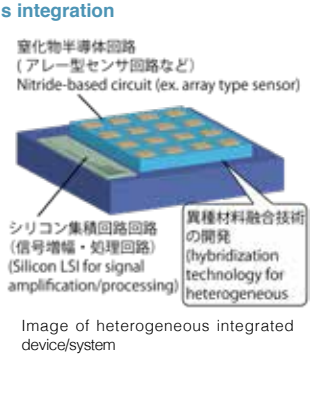


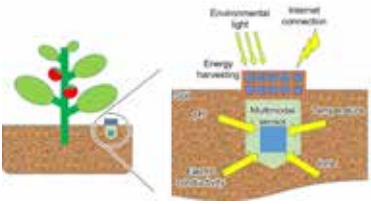
Image of heterogeneous integrated device/system

Integrated Sensing System Laboratory

Staff	• Associate Professor **Noda, Toshihiko** (E-mail：info-bio@int.ee.tut.ac.jp)
Laboratory URL	http://int.ee.tut.ac.jp/bio/en/
Key words	CMOS, MEMS, Multimodal sensing, Intelligent sensors, Agricultural sensors, Packaging technology

Our research interests are focused on smart sensing systems based on CMOS/MEMS technology. Multimodal sensing systems integrated with different kind of sensors such as physical sensors, chemical sensors, and biosensors, attract attention as a key element of new generation society based on IoT and big data analysis. This concept is proposed in the 5th Science and Technology Basic Plan of Japan as “Society 5.0”. In our laboratory, design and fabrication technologies of the multi-modal sensors are studied. Novel application of sensors in the harsh environment that can be realized using robust packaging technology is also investigated.

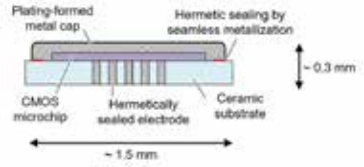
Theme 1 ▶ Agricultural sensors



Agricultural multimodal sensor

Multi-modal sensing become an important technology in the field of smart agriculture typified as the plant factory. In the case of hydroponics, feed-back control of components of nutrient solution is necessary based on multi-element detection of nutrients. The temperature of nutrient solution and the amount of dissolved oxygen also have a big influence on the growth of fruit and vegetables. Similarly in the soil cultivation, there are many items related to growth, which are nutrients, moisture content, pH, and temperature in the soil. In recent years, there are attempts to measure these items to optimally control the growth of plants and maximize the productivity of crops. Since each item is not independent but mutually related, it is necessary to comprehensively measure a plurality of items simultaneously and perform big data analysis in order to optimize growth conditions. In this laboratory, we are studying sensing devices and systems that measure and visualize the important items, which are nutrients, moisture content, and distribution of various ions for example, by a multimodal measurement. This makes it possible to accurately grasp the information of the rhizosphere, which plays an important role in plant growth, and contributes to an increase in yield.

Theme 2 ▶ Packaging technology



Miniaturized packaging technology for harsh environment

In social implementing the multimodal sensors and expanding its application range, it is necessary to operate the sensor stably for a long time even in harsh environments. For example, in the case of sensors for agriculture, sensors are used in the water and soil. Therefore it is required to withstand external stress such as water infiltration, water absorption, electrode corrosion, and mechanical force. In the case of biomedical applications, it is also required to be minimally invasive, non-toxic, and flexible. Unless these requirements are satisfied, even a sensor having excellent measurement capability cannot be put into practical use. Our laboratory is working on development of a packaging technology concurrently with the sensor development. In accordance with various requirements of each application, we are working on the development of element technologies for realizing ultra-small packages as well as optimum shapes and materials of the packages. As an alternative to a conventional packaging technology which was based on the assembly of individual parts, we are working on a chip level package by introducing thick-film forming technologies such as a plating technology used in the CMOS/MEMS technology. Sophisticated packages that are compact and flexible and can operate stably for a long time even under the harsh environments can be achieved by a combination of these technologies.

Wave Engineering Laboratory

Staff	• Professor **Ohira, Takashi** (E-mail：ohira@tut.jp) • Research Assistant **Abe, Shinji** (E-mail：abe@ee.tut.ac.jp)
Laboratory URL	http:// www.comm.ee.tut.ac.jp
Key words	Electrified road electric cars, underwater wireless power transmission, communication for high-frequency filters, battery-less sensor systems, non-linear device measuring instruments, DOA finders, wireless secret key sharing, wireless power transfer, drone

The wireless technology makes us free from the confines due to wires. In addition to the current information transmission systems for broadcasting and communication, prospective applications are emerging if we can exploit the wireless technology for energy transfer. Our laboratory is engaged in research and education covering a wide scope from creating basic theories to pragmatic system development. Graduated students are expected to be a professional engineer who contributes to the global society by the sophisticated wireless technology.

Theme 1 ▶ Electrified roadway, Future vehicle city

We propose a new concept of electric motor vehicle named EVER, which can continuously run on electrified roadways without consuming charged onboard energy. This technology simultaneously overcomes four major problems: weight, cost, charging time, and cruising range of battery-based EVs. To develop this technology, we focus on the wheels of the vehicle to pick up high-frequency energy from a feeder line buried under the road surface. The line is excited with high frequency while the EV is running, the energy propagates on the line, goes through the wheel, and finally reaches the motor. This technology will contribute to mass deployment of EVs replacing fossil-fuel engines, and to the ecological world with minimum CO2 emission.

Custom Computing Systems Laboratory

Staff	• Professor **Ichikawa, Shuichi** (E-mail : ichikawa@tut.jp)
Laboratory URL	http://www.ccs.ee.tut.ac.jp/ich/index.html.en.latin1
Key words	Special-purpose Computing Circuits, FPGA Applications, Computer Security, Parallel Processing, High-performance Computing, Embedded Systems

Our laboratory deals with a wide range of research from software to hardware based around “high-speed processing.” We explore the methods to improve performance using dedicated circuits (in hardware themes), and using parallel and distributed processing (in software themes). We are also promoting research on information security and computer security, whose importance has been increasing in recent years.

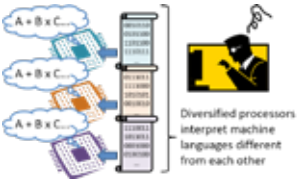
Theme 1 ▶ Reconfigurable logic circuits and special-purpose computation circuits

Field Programmable Gate Array (FPGA) is a kind of reconfigurable logic devices in which the internal logic circuit can be arbitrarily rewritten. We design, implement, and evaluate dedicated circuits for various applications, which range from academic to practical. We design the dedicated circuits in Hardware Description Language (HDL), implement circuits using CAD software, and evaluate their performance on FPGA boards. For an example, we have implemented hard-wired sequence control circuits by translating PLC (Programmable Logic Controller) software into HDL description. One of the proposed circuits achieved 8,050 times higher performance than the equivalent software implementation on a PLC. In addition, we are working on data-dependent hardware that makes circuits smaller and faster by fixing a part of input as constant. This idea corresponds to “partial evaluation” or “specialization” in software.

A demonstration version of control machinery using FPGA.

Theme 2 ▶ Information security and computer security

We utilize FPGAs to implement and evaluate components for secure systems such as encryption circuits and random number generation circuits. We are also studying secure processors which incorporate the features to protect software. One of our research on secure processors is based on diversification. The reason why a computer virus spreads and infects many computers is that their processors interpret the same machine language. If they interpret different machine languages, malicious software for a specific processor will no longer affect the other processors. The concept of such diversified processors can be compared to the myth of the Tower of Babel. FPGA technologies are well suited to this diversification technology. We apply our idea to the soft processors written in HDL to demonstrate the practicality of diversified processors.



The concept of diversified processors

Theme 3 ▶ Parallel processing technology

In recent parallel processing, the performance of each processing element may differ widely. For a simple example, different kinds of personal computers may be used in a PC cluster. We are studying the load balancing techniques for such heterogeneous systems to derive their maximal performance automatically. We are also working on optimized application software mainly for embedded systems. The target applications include, for example, scientific computation, image processing, and positioning systems.

Load balancing on a heterogeneous cluster system.

Wireless Networks Laboratory

Staff	• Professor **Uehara, Hideyuki** (E-mail：uehara@tut.jp) • Assistant Professor **Miyaji, Yuichi** (E-mail：miyaji@ee.tut.ac.jp)
Laboratory URL	http://www.comm.ee.tut.ac.jp/
Key words	Wireless access controls, wireless multi-hop communications, sensor and ad-hoc networks, array signal processing

Wireless systems hide limitless possibilities that can enrich our lives, as said by the father of wireless communications, Guglielmo Marconi, “It is dangerous to put limits on wireless.” We are aiming to realize new communication networks through wireless access and multi-hop communications, based on communications theory, network architecture and signal processing. Specifically, we undertake research on access control for effectively sharing limited radio resources, network control for cooperative connections and signal processing for high quality communications, for distributed autonomous systems such as sensor and ad hoc networks.

Theme 1 ▶ Wireless Networks

In wireless networks, especially distributed autonomous networks such as sensor and ad hoc networks, it is crucial to keep connectivity high for delivering more data with low latency, and also to save energy for longer time operation. We are aiming to design and build medium access control and topology control protocols so as to utilize and manage wireless resources efficiently for the use of the emerging IoT or trillion sensors universe.

Cluster formation for wireless sensor networks.

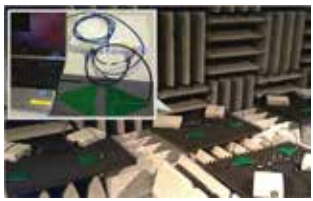
Theme 2 ▶ Sensing Systems

A sensor which converts physical quantities to electrical signals can be a sensing system and create new services when a lot of sensors are assembling together and connecting each other, besides having processing and communication functions. We are aiming to develop new sensing systems exploiting radio wave propagation characteristics such as localization for mobile objects including sensors and persons, and also for resonator’s location estimation in wireless multi-hop power transfer systems.

Location estimation for wireless multi-hop power transfer systems.

Theme 3 ▶ Full Duplex Multi-hop Communications

Communication traffic is rapidly growing as widely spreading wireless tools and sensors, which causes wireless resources a critical shortage. In-band full duplex communications can double the capacity in principle than half duplex communications used in current wireless LAN etc., however it must suppress self-interference. In addition, no protocols have been designed for multi-hop communications. We are aiming to develop a self-interference canceler and access protocol for in-band full duplex multi-hop communication systems that can efficiently utilize wireless resources by spatial-temporal control.



Wireless multi-hop communication testbed using two directional transceivers.

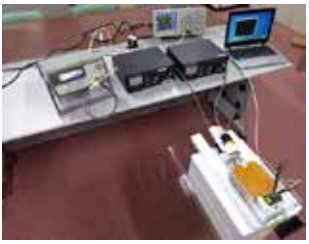
Electromagnetic Wave Engineering Laboratory

Staff	• Associate Professor **Tamura, Masaya** (E-mail：tamura@ee.tut.ac.jp)
Laboratory URL	http://www.comm.ee.tut.ac.jp/em/index.html
Key words	Microwave circuit, RF circuit, wireless power transfer, underwater wireless power transfer, high-frequency filters for communication, battery-less sensor systems, wireless harness

Our daily lives are surrounded by electromagnetic wave. It includes not only radio wave utilized in the data transmission but also heat radiation from our body and sunlight. We are widely conducting basic & applied researches with the aim of social contribution using the electromagnetic field.

Theme 1 ▶ Underwater wireless power transfer

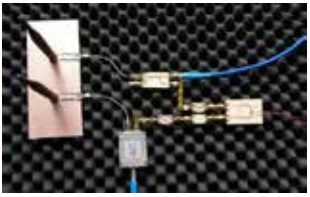
Autonomous underwater vehicles are desired to charge battery and communicate information under water in order to improve operation efficiency. We have an ambitious goal of developing the wireless power and data transfer system for operation underwater, focusing on the capacitive coupling with a simple structure and low leakage of field. So as to require a high power charging in this case, we are also investigating an elucidation of high-frequency property in fresh water and seawater.



Underwater wireless power and data transfer systems.

Theme 2 ▶ Next-Generation Wireless RF Circuits

Various methods in order to achieve high-speed and large-capacity wireless communications are developed such as Massive-MIMO, In-band full-duplex, and OAM. We aim to develop the RF circuits that are key technologies to realize these methods. As we image the application to a wide target range from portable devices to base station in small cell, we are developing value-added solutions such as high tunability and high power capability corresponding to the targets.



RF front-end circuit for in-band full duplex.

Theme 3 ▶ Wireless Harness

Numerous sensors are installed in various facilities and equipment for the purpose to support safe and secure life. In particular, power supply by wireless power transfer is expected for the sensors in dangerous places such as infrastructures in factory and power plant. We are developing a unique system with the pseudo-shielded space, which makes it possible to confine the electromagnetic field in the space and communicate with the sensors outside the space.

Cavity resonance enabled wireless power transfer systems.

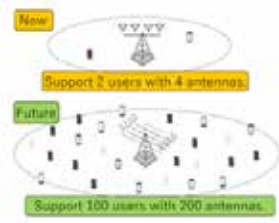
Communications and Signal Processing Laboratory

Staff	• Associate Professor **Takeuchi, Keigo** (E-mail：takeuchi@ee.tut.ac.jp)
Laboratory URL	http://comm.ee.tut.ac.jp/csp/en/
Key words	Massive MIMO, compressed sensing, belief propagation, spatial modulation, energy efficiency, multiuser decoding, spatial coupling

For future wireless communications, groundbreaking schemes are needed to satisfy high performance requirements. In order to realize such a paradigm shift in the field of communications, an interdisciplinary point of view is important in our research. One sometimes recognizes that a problem is essentially the same as a problem that has been already solved in another research field, while there is no superficial relationship between the two problems. Our goal is to realize novel communication schemes by applying such achievements from other fields to the field of communications. Also, we are aiming to deliver our achievements on communications to different research fields in order to contribute to academic and industrial progress in a wide range of fields including communications.

Theme 1 ▶ Massive MIMO

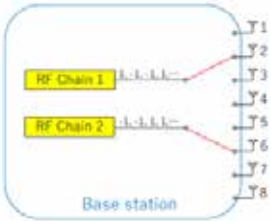
Multiple-input multiple-output (MIMO) systems are wireless communication systems that use multiple transmit and receive antennas for information transmission. In massive MIMO systems, base stations equip a large number of antennas to support many users simultaneously. Conventional receivers cannot be used to process all user signals jointly and efficiently. In our laboratory, we are aiming to construct efficient reception schemes for massive MIMO on the basis of an iterative method called belief propagation and of its modification proposed in the field of compressed sensing.



Massive MIMO

Theme 2 ▶ Spatial Modulation

The signals 1, -1, or 0 (no transmission) are transmitted in spatial modulation, while 1 or -1 is sent in conventional modulation. Since information is conveyed by signal 0 (no transmission), spatial modulation is an energy-efficient transmission scheme. A problem is an efficient blind estimation of the positions at which signals 0 have been sent. In our laboratory, we utilize a similarity between the problem and that considered in the field of compressed sensing to construct efficient reception schemes.



Spatial modulation

Theme 3 ▶ Multiuser Decoding

Decoding and multiuser detection have been separately developed in coding theory and communication theory, respectively. In multiuser decoding, on the basis of a combination of the two fields, joint detection and decoding are performed to realize a significant improvement in decoding performance. In our laboratory, we are aiming at improving the performance of multiuser decoding by applying spatial coupling, which was an idea to improve the performance of belief-propagation-based decoding up to the optimal performance.