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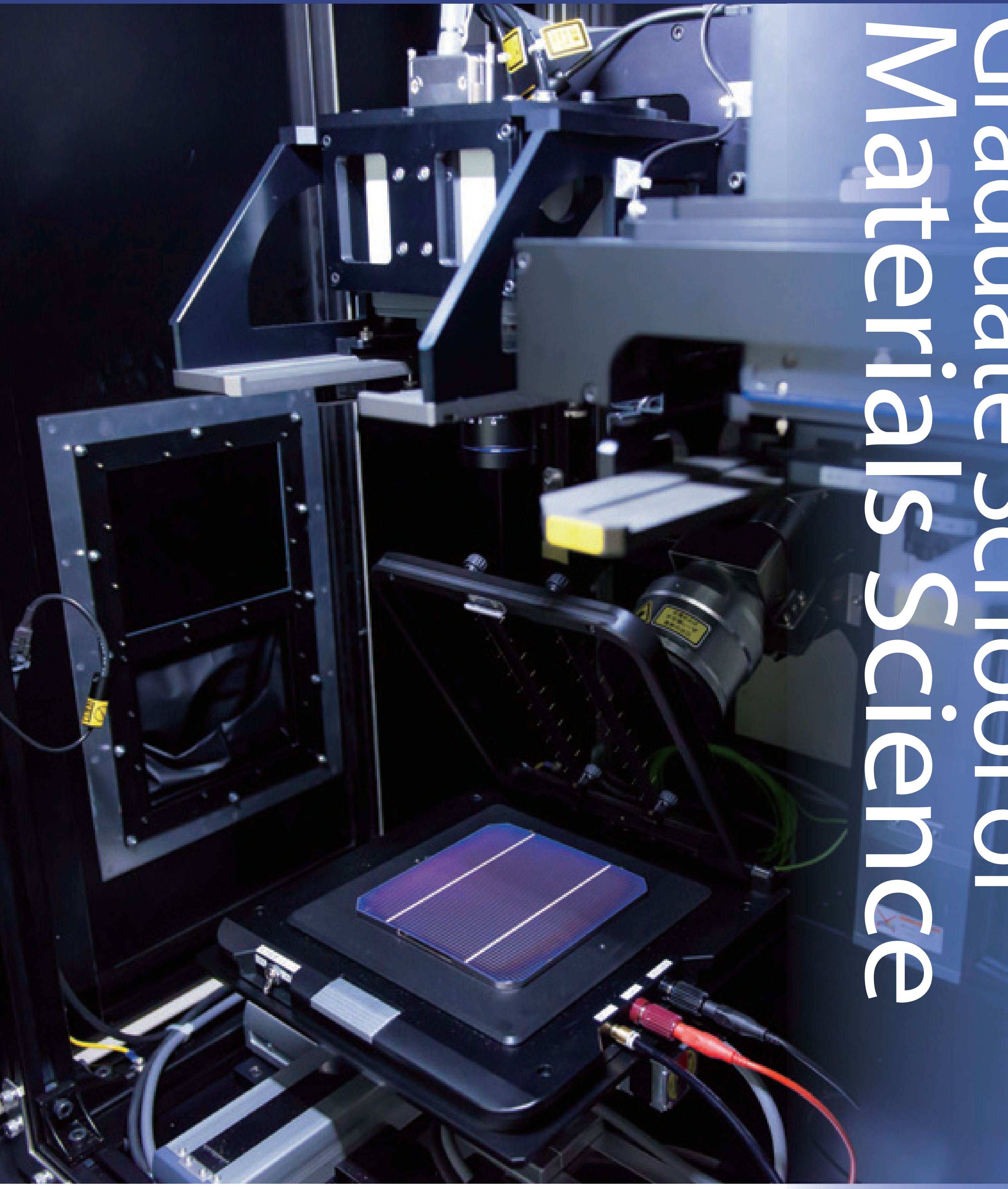
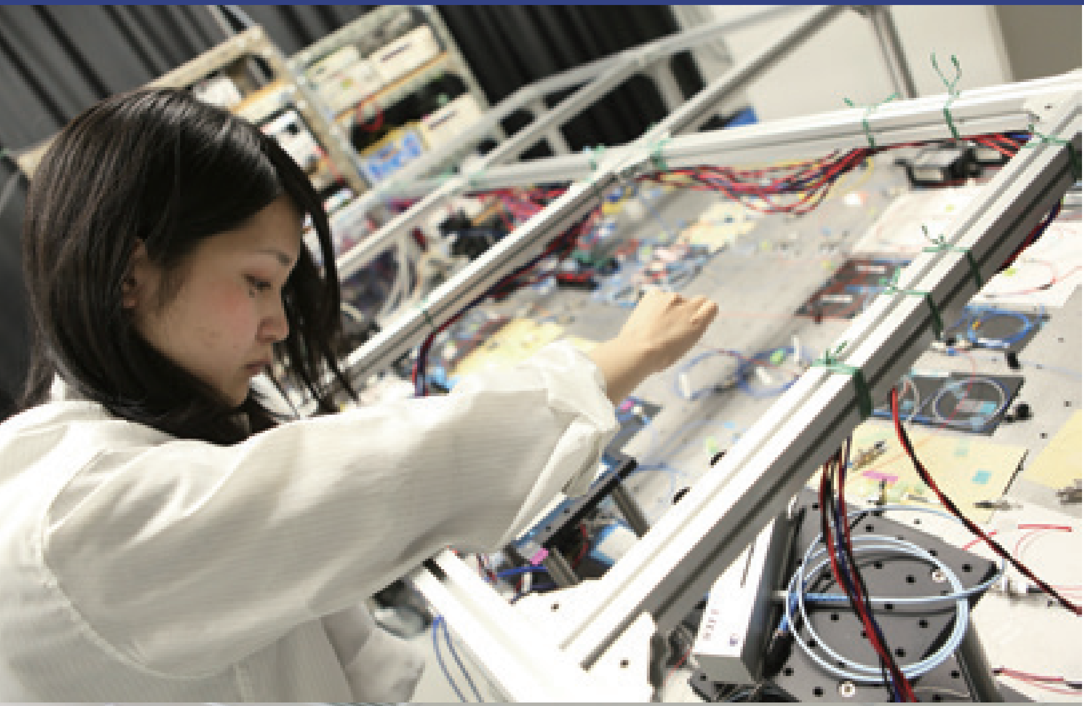
NARA INSTITUTE of
SCIENCE and TECHNOLOGY

2014

Graduate School of Materials Science



Graduate School of Materials Science



CONTENTS

Introduction

to the Graduate School of

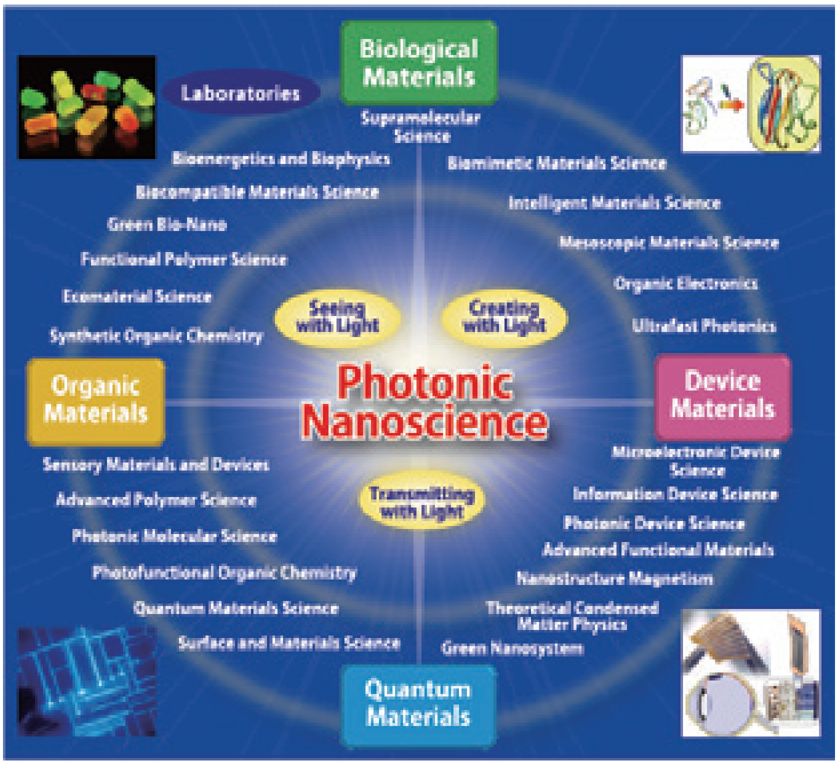
Materials Science

Fully Understanding Materials, Creating New Devices and Functions

Advanced science and technology produce new functional materials and new devices for modern lifestyles. The Graduate School of Materials Science is now strongly promoting ‘photonic nanoscience’ : by using photons ranging from X-ray to microwave, we elucidate novel structures, unique properties, and new device and material functionality at the electron, atomic, and molecular levels. We also conduct total engineering, which involves understanding the interaction of light with matter, designing new functional materials, and developing new devices.

Our research output will contribute to the development of new theory and the discovery of new phenomena, as well as to the creation of new functional materials, new devices, innovative instruments and new techniques in the future.

We systematically educate students who will become excellent leaders in research and development fields in the global society.



Leading research accomplishments supported by an excellent environment

The faculty-to-student ratio in GSMS is extremely high. Furthermore, the internationally renowned and highly active professors in our graduate school are accomplished and receive abundant external research funds, such as Grants-in-Aid for Scientific Research. We offer cutting-edge experimental facilities and a spacious environment that allows all students to focus on their research and studies. The Graduate School of Materials Science includes the Research and Education Center for Materials Science, a common facility on campus that comprehensively supports students' study and research.

Bidirectional industry-academia cooperation program

In addition to fundamental courses in basic research and education in materials science, we also offer industry-academia collaborative courses to develop new materials and new devices. Because researchers from external institutions, including company laboratories, are in charge of collaborative laboratories, students have many opportunities to study practical developments.

Wide-ranging student support systems

More than 60% of students in the master's program and all students in the doctoral program are able to reside in dormitories on campus. Scholarships and research funds are also available. We also provide financial support to all students in the doctoral program and some in the master's program to attend overseas international conferences. We have exchange agreements with many institutions throughout the world, giving students a great opportunity to study abroad.

Research and Education Center for Materials Science

The Center has a number of instruments and cutting-edge facilities operated by many expert technical staff to effectively support the full characterization of new materials, evaluation of novel properties, and nanofabrications. It fully supports education, research and safety management.

In addition to analysis and evaluation of new materials, the Research and Education Center for Materials Science focuses on design and synthesis of new functional materials which may be essential in the areas of modern science and advanced technology, including nanotechnology, biological sciences, information technology, and the environment. This is efficiently achieved by close collaboration between the main and collaborative laboratories at the frontiers of materials science. The Center also has a commission test scheme for non-NAIST researchers who wish to use our analytical facilities.

Graduate School of Materials Science

Laboratories & Faculty

Core Laboratories

Laboratory	Professor	Associate Professor	Assistant Professor
Quantum Materials Science	Hisao Yanagi	Hiroyuki Katsuki	Atsushi Ishizumi, Satoshi Tomita
Surface and Materials Science	Hiroshi Daimon	Ken Hattori	Sakura Takeda
Advanced Polymer Science	Michiya Fujiki		
Photonic Device Science	Jun Ohta	Takashi Tokuda	Kiyotaka Sasagawa, Toshihiko Noda
Information Device Science	Yukiharu Uraoka	Yasuaki Ishikawa	Masahiro Horita, Mutsunori Uenuma
Microelectronic Device Science	Takashi Fuyuki	Hiroshi Yano	Tomoaki Hatayama
Synthetic Organic Chemistry	Kiyomi Kakiuchi	Tsumoru Morimoto	Hiroki Tanimoto, Yasuhiro Nishiyama, Takanobu Jujo
Biomimetic Materials Science	Jun-ichi Kikuchi	Atsushi Ikeda	Kazuma Yasuhara, Keishiro Tahara
Bioenergetics and Biophysics	Mikio Kataoka	Hironari Kamikubo	Yoichi Yamazaki, Mariko Yamaguchi
Supramolecular Science	Shun Hirota	Takashi Matsuo	Satoshi Nagao, Masaru Yamanaka, Hulin Tai
Biocompatible Materials Science	Masao Tanihara	Tsuyoshi Ando	Kayo Terada, Mime Kobayashi
Photonic Molecular Science	Tsuyoshi Kawai	Takuya Nakashima	Junpei Yuasa, Yoshiyuki Nonoguchi
Ultrafast Photonics	Hitoshi Kawaguchi		Takeo Katayama, Kazuhiro Ikeda
Photofunctional Organic Chemistry	Hiroko Yamada	Naoki Aratani	Daiki Kuzuhara, Mitsuharu Suzuki
Nanostructure Magnetism		Nobuyoshi Hosoito	
Theoretical Condensed Matter Physics		Takeshi Inagaki	

Tenure-track Laboratories

Laboratory	Professor	Assistant Professor
Organic Electronics	Masakazu Nakamura	Ryosuke Matsubara, Hirotaka Kojima

Specific Research Laboratories

Laboratory	Associate Professor
Green Nanosystem	Fumihiko Matsui
Green Bio-Nano	Yoichiroh Hosokawa

Collaborative Laboratories

Laboratory	Professor	Associate Professor
Mesoscopic Materials Science (with Panasonic Co, Ltd.)	Ichiro Yamashita, Hideaki Adachi	Shigeo Yoshii
Intelligent Materials Science (with SHARP Corporation)	Akira Takahashi, Makoto Izumi	Noboru Iwata
Functional Polymer Science (with Santen Pharmaceutical Co., Ltd.)	Hiroyuki Aono, Takahiro Honda	Hiroshi Enomoto
Ecomaterial Science (with Research Institute of Innovative Technology for the Earth)	Katsunori Yogo	Teruhiko Kai, Kazuya Goto
Sensory Materials and Devices (with Shimadzu Corporation)	Eiichi Ozeki, Toshiyuki Sato	Takahiro Nishimoto
Advanced Functional Materials (with Osaka Municipal Technical Research Institute)	Yasuyuki Agari Yutaka Fujiwara	Masanari Takahashi

Laboratory Quantum Materials Science

▶ URL: http://mswebs.naist.jp/english/courses/guidance/01.html

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Education and Research Activities in the Laboratory

Electrons, when confined in a nanometer-sized space (1 nanometer = 10^{-9} m), remarkably begin to behave like waves. For example, an organic molecule can be considered as a quantum state in which electrons are confined in a nm space consisting of atoms connected together. Semiconductor nanoparticles show colors different from those of bulk solids due to the quantum size effect. The Quantum Materials Science Laboratory studies molecules, crystals, nanoparticles, and ultrathin films of both organic and inorganic materials, utilizes various optics-based experimental approaches to clarify material properties from the viewpoint of quantum physics, and aims to create new functional materials that can be used in optical information-communication or environment-conscious devices in the future.

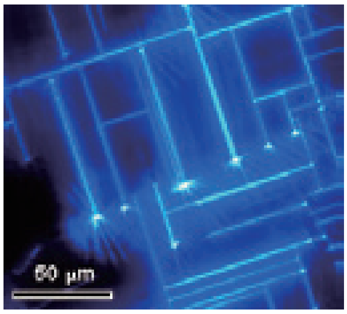

Fig.1 Molecular crystal-based organic laser

Fig.2 Crystal growth of p-H_2

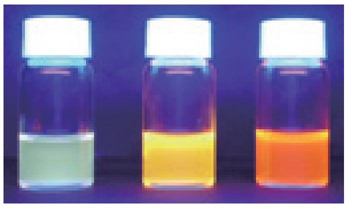

Fig.3 Luminescence from impurity-doped semiconductor nanoparticles

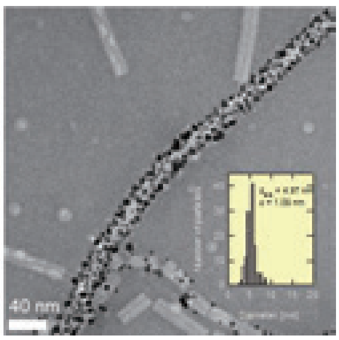

Fig.4 TMV/gold nanoparticle complexes

Research Themes

1. Molecular electronics and photonics

By controlling molecular alignment and crystal growth, we are aiming to realize organic lasers and efficient organic solar cells.

2. Coherent control in molecular crystals

We are attempting to control and observe quantum coherence in molecular crystals of p-H_2 and organic semiconductors by using ultrafast laser spectroscopy.

3. Photo-physical properties of nanostructured materials

We are working on the optical functionality of nanostructured materials such as environment-conscious nanoparticles and impurity-doped nanoparticles.

4. Metamaterial photonics

By assigning distinct functions to different artificial units much smaller than the wavelengths of light, we are attempting to create artificial materials (metamaterials) mimicking an intriguing property for light.

Recent Research Papers and Achievements

1. H. Mizuno, U Haku, Y. Marutani, A. Ishizumi, H. Yanagi, F. Sasaki, and S. Hotta, *Adv. Mater.* **24** 5744 (2012).
2. H. Goto, H. Katsuki, H. Ibrahim, H. Chiba, and K. Ohmori, *Nature Phys*. **7** 383 (2011).
3. A. Ishizumi, S. Fujita, and H. Yanagi, *Opt. Mater*. **33** 1116 (2011).
4. S. Tomita, Y. Kosaka, H. Yanagi, and K. Sawada, *Phys. Rev.* B **87** 041404(R) (2013).

Laboratory Surface and Materials Science

▶ URL: http://mswebs.naist.jp/english/courses/guidance/02.html

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Education and Research Activities in the Laboratory

1. Research purpose and target

All materials, when smaller than one nanometer in size, begin to exhibit different properties from those under normal conditions as exemplified by iron and gold: iron becomes nonmagnetic, while gold becomes highly reactive. These materials are the new microscopic materials essential for resource-saving, energy-saving, element strategy, and nanotechnology. They can be manufactured and analyzed on the surface of a solid at the atomic and electronic level. The Surface and Materials Science Laboratory studies atomic and electronic structures of surface and nanomaterials using unique approaches such as a two-dimensional photoelectron spectrometer, aiming to clarify the physical properties of nanomaterials and to create new functions from the atomic and electronic viewpoint. Our research targets include superstructures on semiconductor surfaces, magnetic thin-films, as well as organic and biological molecule adsorbing surfaces vital to catalysis and molecular electronics. All measurements are made in the largest ultra-high vacuum system in the world.

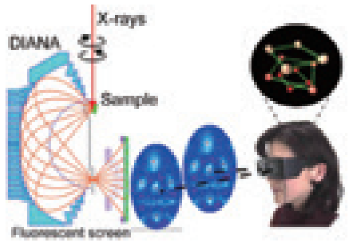

Fig.1 Stereoscopic view of atomic arrangement through our two-dimensional photoelectron analyzer (DIANA) used as an atomic stereo-microscope

2. Educational policy

We provide education not only on experiments but also on what is important as a researcher and a professional engineer, including having an active attitude toward obtaining knowledge through research, originality training, acquisition of technical skills to enhance laboratory techniques (such as shop practice, machine control, and data analysis), and cooperation with laboratory members. Students are expected to improve or create apparatuses before graduation. It is important for students to not only learn how to think systematically through seminars or lecturing in turn, but also to have contact with external researchers as well as the regular educational staff in the laboratory. We conduct joint research with several external research institutions including the synchrotron radiation facilities of SPring-8 and the Ritsumeikan University SR Center, and actively dispatch our students overseas.

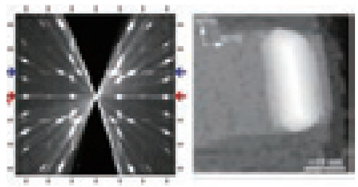

Fig.2 STM image and 3D reciprocal-lattice map of a 3D elongated island of α-FeSi2(110) on Si(001)

Research Themes

1. Atomic structural analysis by stereoscopic viewing, RHEED, STM, Photoelectron Diffraction/Holography
2. Electronic energy bands on surface and their modification by electric field and strain
3. Atomic analysis of surface molecular reactions
4. Surface nanomaterials physical property analysis
5. New analyzers development

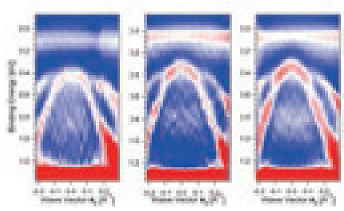

Fig.3 Strain effect on Si band structure

Recent Research Papers and Achievements

1. F. Matsui, R. Ishii, H. Matsuda, M. Morita, S. Kitagawa, T. Matsushita, S. Koh, and H. Daimon, "Characterizing Edge and Stacking Structures of Exfoliated Graphene by Photoelectron Diffraction", *Jpn. J. Appl. Phys.* **52** No.11, Issue 1(5pages), November (2013) .
2. M. Someta, K. Maetani, K. Hattori, and H. Daimon, "Phase discrimination of iron-silicides on Si(001) surfaces by three-dimensional reciprocal-lattice mapping", *Surf. Sci.* **604** 21-26 (2010) .

Laboratory

Advanced Polymer Science

▶ URL: http://mswebs.naist.jp/english/courses/guidance/04.html

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Education and Research Activities in the Laboratory

The Advanced Polymer Science Laboratory is devoted to proposing new ideas and new concepts, aimed at the design of novel photophysical properties and polymeric materials. The specific items are as follows:

1. Research outline

Generation, amplification, inversion and transcription of helix structures by chemical and physical origin

2. One-pot synthesis, green-sustainable process, renewable bioresource-oriented processes of functional polymers and hybridized materials

3. Education in the laboratory

We aim to foster capable researchers and engineers who will work in the area of polymer-related science and technology through leading-edge research activities in relation to the design, synthesis, analysis, and function of polymers. We focus on educating students to think independently about new concepts and propose new ideas through daily interaction, as well as in seminars and meetings hosted by related academic communities.

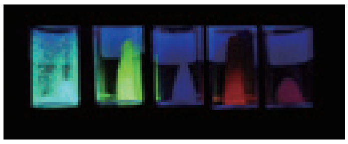

Fig1. Zero-step room-temperature synthesis of full-visible photoluminescent polymer particles

Research Themes

1. Mirror symmetry breaking at polyatomic systems and the origin of life on earth
2. Detection of weak and ultraweak interactions
3. Light-emitting polymeric materials using zero-step synthesis
4. Liquid-phase physisorption of π-conjugated polymers at inorganic/polymer interfaces

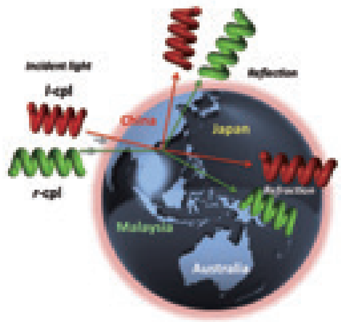

Fig2. International students and collaboration with us

Recent Research Papers and Achievements

1. Y. Nakano, F. Ichiyanagi, M. Naito, Y. Yang and M. Fujiki, "Chiroptical generation and inversion during the mirror-symmetry-breaking aggregation of dialkylpolysilanes due to limonene chirality", *Chem. Commun.* **48** 6636 (2012) [highlighted as cover page].
2. M. Fujiki, Y. Fujimoto, A. Saxena, T. Kawabe and G. Kwak, "Air-stable poly(3,3,3-trifluoropropylsilyne) homo- and copolymers", *Polym. Chem.* **3** 3256 (2012) [highlighted as cover page].
3. M. Fujiki, A. J. Jalilah, N. Suzuki, M. Taguchi, W. Zhang, M. M. Abdellatif and K. Nomura, "Chiral optofluidics: Gigantic circularly polarized light enhancement of all-trans-poly(9,9-di-n-octylfluorene-2,7-vinylene) during mirror-symmetry-breaking aggregation by optically tuning fluidic media", *RSC Adv.* **2** 6663 (2012).

Laboratory Photonic Device Science

▶ URL: http://mswebs.naist.jp/english/courses/guidance/05.html




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Education and Research Activities in the Laboratory

1. Laboratory outline

The Photonic Device Science Laboratory researches and develops new optical functionality-based material science and device function creation for fast, flexible processing of image information that promises to play a leading role in an advanced information society and a “super aging society.” Specifically, we work on applying photonic LSI technology which integrates semiconductor circuit technology and photonic technology toward bio and medical field applications as shown in Fig.1. Our typical research fields include bio-medical photonic LSIs and artificial vision devices.

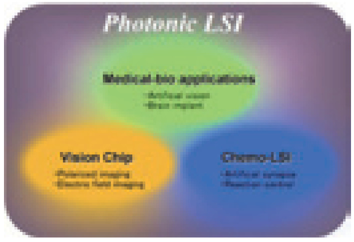

Fig.1 Research fields of Photonic Device Science Lab

2. Research activity and policy

We actively advance joint studies with different research fields because our research subjects necessitate interdisciplinary research activities. For example, we are conducting joint research on artificial vision with the Department of Ophthalmology of Osaka University Graduate School of Medicine and an ophthalmologic apparatus manufacturer. Furthermore, we are conducting joint research on bio-medical photonic LSIs with the Functional Neuroscience Laboratory of the Graduate School of Biological Sciences at NAIST and the Kinki University Hospital Department of Neurosurgery.

Fig.2 Retinal prosthesis device

3. Education

Almost all students in the laboratory are requested to work on research subjects in different fields. We provide introductory seminars, study meetings, and many opportunities to interact with researchers within and outside the university so that they can pursue their research smoothly and widen their research perspectives.

Research Themes

1. Bio-medical photonic materials and devices
2. Micro-chemical photonic devices
3. Advanced image sensors and their application systems

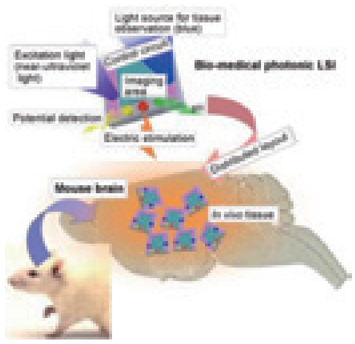

Fig.3 Brain implantable micro imager

Recent Research Papers and Achievements

1. J. Ohta, T. Kobayashi, T. Noda, K. Sasagawa, T. Tokuda, “CMOS Imaging Devices for Biomedical Applications” (invited), *IEICE Trans. Commun.* **E94-B(9)** 2454-2460 (2011).
2. T. Noda, K. Sasagawa, T. Tokuda, Y. Terasawa, H. Tashiro, H. Kanda, T. Fujikado, J. Ohta, “A Smart Electrode Array Device with CMOS Multi-Chip Architecture for Neural Interface”, *Electronics Letters* **48(21)** 1328-1329 (2012).
3. T. Kobayashi, M. Motoyama, H. Masuda, Y. Ohta, M. Haruta, T. Noda, K. Sasagawa, T. Tokuda, H. Tamura, Y. Ishikawa, S. Shiosaka, J. Ohta, “Novel implantable imaging system for enabling simultaneous multiplanar and multipoint analysis for fluorescence potentiometry in the visual cortex”, *Biosensors and Bioelectronics* **38(1)** 321-330 (2012).

Laboratory Information Device Science

▶ URL: http://mswebs.naist.jp/english/courses/guidance/06.html




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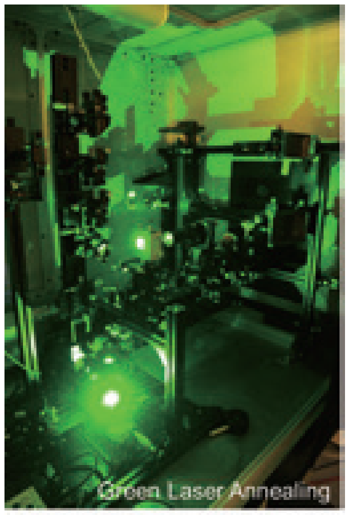
Education and Research Activities in the Laboratory

Many daily necessities around us, such as TVs, personal computers, and mobile phones, are composed of silicon-based semiconductor devices. The Information Device Science Laboratory conducts research on the information function devices that will support the next-generation information society. Our research features the introduction of various new materials on silicon substrates, our own unique designs, and production of semiconductor devices that make the best use of their features. Thus, we are working on producing semiconductor devices with innovative functions on the basis of skilled manufacturing.

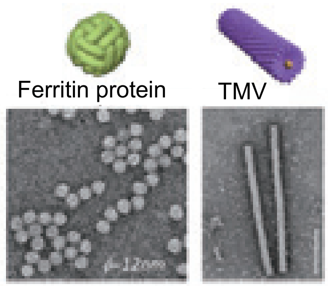


Research Themes

1. Next-generation high-tech information terminals
2. LSIs with new functions based on biological supramolecules
3. Printed/flexible displays using wide band gap materials
4. Printing technology for energy harvesting devices (solar cell, thermo-electric devices)
5. Emerging devices (Graphene transistors, power devices based on GaN)

Recent Research Papers and Achievements

1. M. Uenuma, B. Zheng, K. Kawano, M. Horita, Y. Ishikawa, I. Yamashita, and Y. Uraoka, “Guided Filament Formation in NiO-Resistive Random Access Memory by Embedding Gold Nanoparticles”, *Appl. Phys. Lett.* **100(8)** 083105 (2012).
2. Y. Kawamura, M. Tani, N. Hattori, N. Miyatake, M. Horita, Y. Ishikawa, and Y. Uraoka, “Low-Temperature-Processed Zinc Oxide Thin-Film Transistors Fabricated by Plasma-Assisted Atomic Layer Deposition”, *Jpn. J. Appl. Phys.* **51** 02BF04 (2012).
3. M. Fujii, Y. Ishikawa, M. Horita, and Y. Uraoka, “Unique Phenomenon in Degradation of Amorphous In_2O_3-Ga_2O_3-ZnO Thin-Film Transistors under Dynamic Stress”, *Appl. Phys. Express* **4** 104103 (2011).
4. K. Ohara, B. Zheng, M. Uenuma, Y. Ishikawa, K. Shiba, I. Yamashita, and Y. Uraoka, “Three-Dimensional Nanodot-Type Floating Gate Memory Fabricated by Bio-Layer-by-Layer Method”, *Appl. Phys. Express* **4** 085004 (2011).



Bio-nano-materials for functional devices

Laboratory

Microelectronic Device Science

▶ URL: http://mswebs.naist.jp/english/courses/guidance/07.html



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Education and Research Activities in the Laboratory

'Clean energy creation and efficient energy use' are both important issues to be solved for the realization of a low-carbon society. As a basic device for the infrastructure component, 'Energy electronic devices' need to be developed. In our laboratory, we address silicon (Si) semiconductors and wide-gap semiconductor silicon carbide (SiC), and carry out education and research from basics to applications in the following strategic areas:

1. Creation of new electronic materials with novel microscopic structures controlled at the atomic level

2. Observation and control of functional quantum effect properties

3. Energy electronic device development such as solar cells and power devices

Fig.1 Solar power generation system : the most promising source of clean energy

Research Themes

1. Fabrication and characterization of semiconductor microscopic structures with quantum properties and their functionalization
2. Three-dimensional analysis of photovoltaics and development of novel fabrication processes to realize high-efficiency silicon solar cells
3. Crystal growth of wide-gap semiconductor silicon carbide (SiC) and development of ultra-low-loss power devices

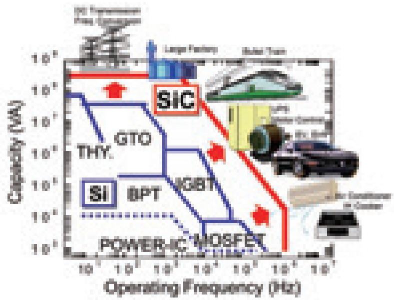

Fig.2 Application areas of SiC power devices

Recent Research Papers and Achievements

1. Publications
・K. Hirata, T. Saitoh, A. Ogane, E. Sugimura, and T. Fuyuki, "Selective Emitter Formation by Laser Doping for Phosphorous-Doped n-Type Silicon Solar Cells", *Appl. Phys. Express.* **5(1)** 016501/1-3 (2012).
・D. Okamoto, H. Yano, K. Hirata, T. Hatayama, and T. Fuyuki, "Improved Inversion Channel Mobility in 4H-SiC MOSFETs on Si-face Utilizing Phosphorus-Doped Gate Oxide", *IEEE Electron Device Lett.* **31(7)** 710-712 (2010).

2. Invited Talks
・H. Yano, T. Hatayama, and T. Fuyuki, "$POCl_3$ Annealing as a New Method for Improving 4H-SiC MOS Device Performance", PRiME 2012, Honolulu (HI, USA), #2548, 2012/10/10.
・T. Fuyuki and A.Tani, "Photographic Diagnosis of Crystalline Silicon Solar Cells by Electroluminescence", 2010 SEM Annual Conference, Indianapolis (IN, USA), 2012/7/7-9.

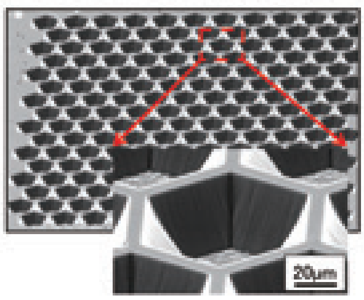

Fig.3 Fabrication of SiC microstructure

Laboratory

Synthetic Organic Chemistry

▶ URL: http://mswebs.naist.jp/english/courses/guidance/08.html


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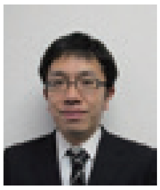
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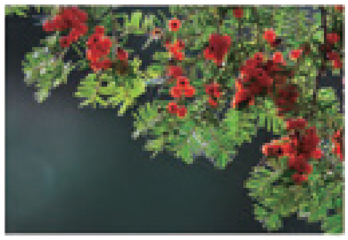
Education and Research Activities in the Laboratory

The Synthetic Organic Chemistry Laboratory develops students' abilities to (1) understand research background, (2) make rational and subjective research plans, and (3) consider and conclude obtained results accurately (deep insight into the truth) through the study on organic synthesis. Thereby, we aim to develop human resources with broad perspectives, adaptability, and creativity, all of which are essential for researchers. We also encourage students to present their research in various meetings and symposia to enhance presentation skills.



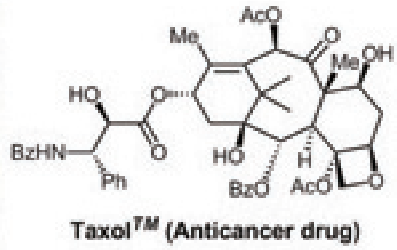


Fig.1

Research Themes

Research in our laboratory focuses on photochemistry, natural product chemistry, and organometallic chemistry towards organic synthesis. We are interested in developing novel photochemical and catalytic reactions to synthesize compounds of interest to the pharmaceutical industry. We are also interested in the synthesis of natural products and functional organic materials utilizing our methods. Our current research themes are the following:

1. New methodologies for the synthesis of various functional polycyclic organic compounds, such as biologically active compounds and functional organic materials (Fig.1)

2. Asymmetric photoreactions and devising a new microreactor system using a capillary reactor for organic synthesis (Fig.2)

3. New environmentally-friendly green organic synthesis processes using organometallic catalysts (Fig.3)

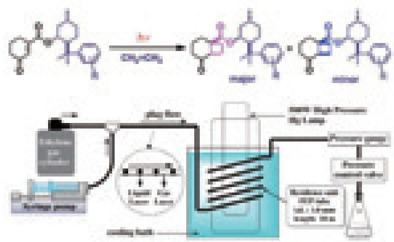


Fig.2

Recent Research Papers and Achievements

1. K. Hayashi, H. Tanimoto, H. Zhang, T. Morimoto, Y. Nishiyama, and K. Kakiuchi, "Efficient Synthesis of α,β-Unsaturated Alkylimines Performed with Allyl Cations and Azides: Applications to the Synthesis of an Ant Venom Alkaloid", *Org. Lett.* **14(22)** 5728-5731 (2012).
2. K. Terao, Y. Nishiyama, H. Tanimoto, T. Morimoto, M. Oelgemöller, and K. Kakiuchi, "Diastereoselective [2+2] Photocycloaddition of a chiral Cyclohexenone with Ethylene in a Continuous Flow Microcapillary Reactor," *J. Flow Chem.* **2(3)** 73-76 (2012).
3. M. Fujioka, T. Morimoto, T. Tsumagari, H. Tanimoto, Y. Nishiyama, and K. Kakiuchi, "Rh(I)-Catalyzed Asymmetric Synthesis of 3-Substituted Isoindolinones through CO Gas-Free Aminocarbonylation", *J. Org. Chem.* **77(6)** 2911-2923 (2012).

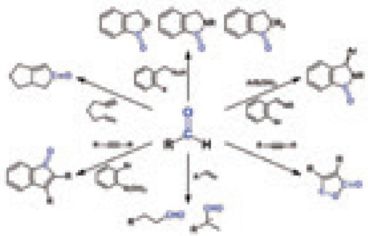


Fig.3

Laboratory Biomimetic Materials Science

▶ URL: http://mswebs.naist.jp/english/courses/guidance/09.html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Education and Research Activities in the Laboratory

The Biomimetic Materials Science Laboratory is developing seeds that promise to take a leading role in bio-nano science and information technology through learning from biological systems and developing new molecular materials and systems that exceed original biological systems.

Research Themes

1. Cerasome as a new bio-nano material

Cerasome, a new nanocapsule, has been developed by applying a ceramic coating to only a single atomic layer on the surface of an artificial cell membrane, and are exploring its possibility as a bio-nano material (Fig.1). For example, we utilize the high structure stability of cerasome to establish artificial multicell systems, magnetically manipulate artificial cells, and develop highly efficient gene transfer methods.

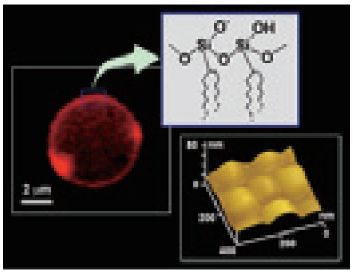
Fig.1

2. Molecule-based next-generation information and telecommunications systems

Biological systems have wireless, nano-scale information processing systems. Thus, we learn from biological systems how to create artificial cells that incorporate enzymes and receptors and to develop nano-devices that can process information on light, heat, or ions. Furthermore, these nano-devices are organized and coordinated organically to develop "molecular communication," a molecule-based information and communications system for the future (Fig.2).

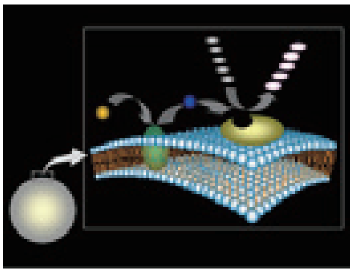
Fig.2

3. Production of molecular devices made of fullerene and carbon nano tubes

We produce fullerene C60 solubilized on an artificial cell membrane and carbon nanotubes made of complex macromolecular or supramolecular compounds (Fig.3). Their optical characteristics are used to study the application of various molecular devices such as cell activated devices, photoelectric conversion elements, and sensors.

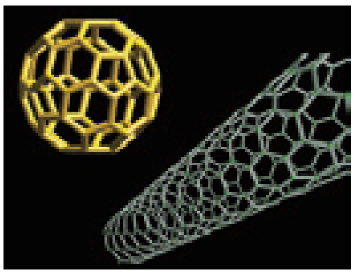
Fig.3

Recent Research Papers and Achievements

1. J. Kikuchi and K. Yasuhara, "Cerasomes: A New Family of Artificial Cell Membranes with Ceramic Surface", in "*Advances in Biomimetics*", A. George, ed., InTech, Rijeka **231-250** (2011).
2. M. Mukai, K. Maruo, Y. Sasaki, and J. Kikuchi, "Intermolecular Communication on a Liposomal Membrane. Enzymatic Amplification of a Photonic Signal with Gemini Peptide Lipid as a Membrane-bound Artificial Receptor", *Chem. Eur. J.* **18** 3258-3263 (2012).
3. A. Ikeda, M. Mori, K. Kiguchi, K. Yasuhara, J. Kikuchi, K. Nobusawa, M. Akiyama, M. Hashizume, T. Ogawa, and T. Takeya, "Advantages and Potential of Lipid-Membrane-Incorporating Fullerenes Prepared by the Fullerene-Exchange Method", *Chem Asian J.* **7** 605-613 (2012).

Laboratory Bioenergetics and Biophysics

▶ URL: http://mswebs.naist.jp/english/courses/guidance/10.html




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Education and Research Activities in the Laboratory

All proteins are synthesized according to genetic information. Since genetic information only includes amino acid sequences, all the information necessary for proteins to fulfill their functions, the design principle of proteins, must be coded into amino acid sequences. Recently, it has been clarified that Alzheimer's disease is caused by abnormally folded proteins. Thus, understanding the design principle of proteins has become a critical issue not only in the field of protein science but also in cell biology, pathology, and drug discovery. Our ultimate research objective is to clarify the design principle of proteins, so that we can establish the discipline of "protein design engineering" which will help to create artificial proteins with new functions.

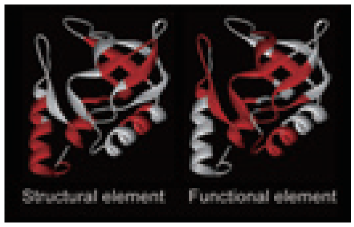

Fig.1 Identification of regions important to structure and function

Research Themes

1. Establishment of protein design engineering

To clarify the design principle of proteins, we devised approaches called systematic alanine insertion mutation analysis, and successfully extracted the structure and function information coded on amino-acid sequences (Fig.1). We are planning to utilize this information in designing artificial proteins.

2. Intra-protein information transmission

Externally stimulated information passes through protein molecules, changing the structural state of the proteins and causing the expression of their functions. The structural changes are closely coupled with proton transfers within protein molecules. In that sense, proteins are considered as protonics devices. Recently, we utilized high-resolution neutron structural analysis jointly with X-ray structural analysis, successfully observing hydrogen atoms in the protonics device (Fig.2). Based on the results, we are now proposing a new mechanism of the intra-protein information transmission of protonics devices.

3. Inter-protein information transmission

Protein molecules repeatedly associate and dissociate with each other, thereby expressing advanced functions. We are working on the mechanism of association and dissociation among proteins, aiming to elucidate the intercellular information transmission mechanism.

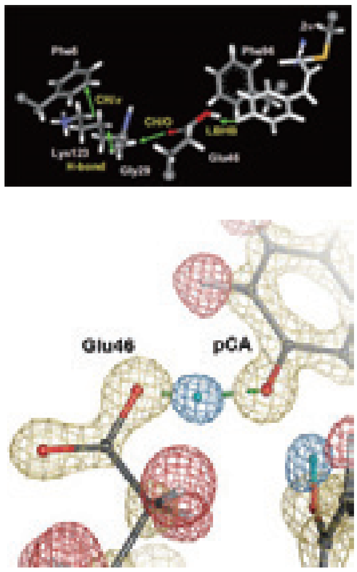

Fig.2 Intramolecular information transmission through various hydrogen bonds

Recent Research Papers and Achievements

1. F. Schotte, H. S. Cho, V. R. I. Kaila, H. Kamikubo, N. Dashdorj, E. R. Henry, T. J. Graber, R. Henning, M. Wulff, G. Hummer, M. Kataoka and P. A. Anfinrud, "Watching a signaling protein function in real time via 100-ps time-resolved Laue crystallography", *Proc. Natl. Acad. Sci. USA* **109** 19256-19261 (2012).
2. R. Shiba, M. Umeyama, S. Tsukasa, H. Kamikubo, Y. Yamazaki, M. Yamaguchi, M. Iwakura and M. Kataoka, "Systematic alanine insertion reveals the essential regions that encode structure formation and activity of dihydrofolate reductase", *BIOPHYSICS* **7** 1-10 (2011).
3. S. Yamaguchi, H. Kamikubo, K. Kurihara, R. Kuroki, N. Niimura, N. Shimizu, Y. Yamazaki and M. Kataoka, "Low barrier hydrogen bond in photo active yellow protein", *Proc. Natl. Acad. Sci. USA* **106** 440-444 (2009).

Laboratory Supramolecular Science

▶ URL: http://mswebs.naist.jp/english/courses/guidance/11.html

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Education and Research Activities in the Laboratory

In living organisms, a variety of biomolecules such as proteins, DNA, and sugars form unique supramolecular assemblies to maintain bio-functions. Based on chemical knowledge of the functions and structures of these bio-supramolecules at molecular level, our laboratory focuses on elucidation of the function mechanisms and design/applications of bio-supramolecules using various spectroscopic analysis methods, protein engineering techniques, and organic syntheses.

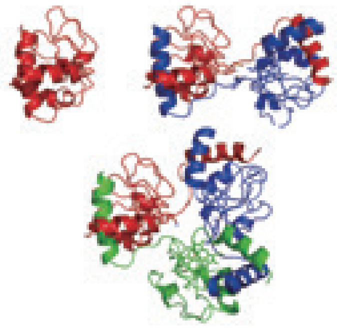

Fig.1 Elucidated structures of cytochrome *c* supramolecules

Research Themes

1. New bio-supramolecules creation

We develop new protein supramolecules and polymers for functional biomaterials based on a new concept in which a protein molecule is used as a structural unit (Fig.1).

2. Creation of photo-reactive proteins, peptides, and metal complexes

We design photo-controlled systems using proteins and metal complexes (*e.g.* binuclear complexes with an azobenzene linker for a reversible on-off controlled DNA cleavage, Fig.2). These systems are attracting attention in the biotechnology and pharmaceutical science fields due to their potential application for gene manipulation and cancer treatments.

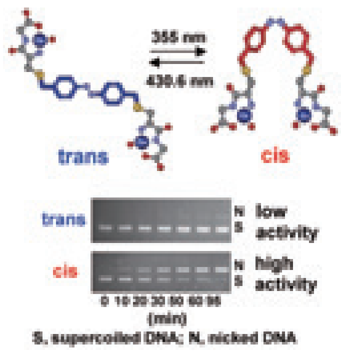

Fig.2 Photo-controlled DNA cleavage by metal complex-conjugated azobenzene

3. Elucidation and inhibition of protein denaturation processes

Accumulation of proteins with unusual structures in tissues causes various diseases such as Alzheimer's disease, Parkinson's disease, and mad cow disease (Conformation diseases). We investigate denaturation of these proteins at the molecular level and develop strategies to inhibit this denaturation.

4. Elucidation of enzyme reaction mechanisms and functional analysis of physiologically active molecules for medicinal chemistry

To understand and regulate the extraordinary efficiency of bioreactions, we study the functional expression mechanism of physiologically active small molecules from the perspective of medicinal chemistry.

5. Functional protein creation through synthetic chemistry approaches

We precisely design organometallic complex-containing proteins, thereby creating "molecular design-based functional biomolecules" with unique functions. This strategy uses the advantage of the complementarity of synthetic chemistry and biochemical approaches, in combination with genetic engineering methods (Fig.3).

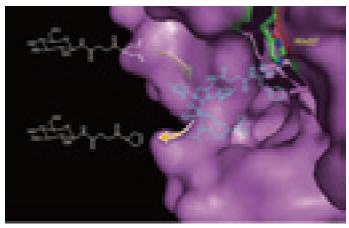

Fig.3 Olefin metathesis in protein matrix

Recent Research Papers and Achievements

1. S. Hirota, Y. Hattori, S. Nagao, M. Taketa, H. Komori, H. Kamikubo, Z. Wang, I. Takahashi, S. Negi, Y. Sugiura, M. Kataoka, Y. Higuchi, "Cytochrome *c* polymerization by successive domain swapping at the C-terminal helix", *Proc. Natl. Acad. Sci. USA* **107** 12854-12859 (2010).
2. T. Matsuo, C. Imai, T. Yoshida, T. Saito, T. Hayashi, S. Hirota, "Creation of an artificial metalloprotein with a Hoveyda-Grubbs catalyst moiety through the intrinsic inhibition mechanism of α-chymotrypsin", *Chem. Commun.* **48** 1662-1664 (2012).

Laboratory

Biocompatible Materials Science

▶ URL: http://mswebs.naist.jp/english/courses/guidance/12.html




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Education and Research Activities in the Laboratory

The Biocompatible Materials Science Laboratory analyzes the interactions between living organisms and materials at the molecular level to elucidate biocompatibility mechanisms, applying the findings to the development of materials for regenerative medicine such as those for nerves, blood vessels, bones, and skin, as well as the development of new treatments, drugs, and drug delivery systems (DDS). In the laboratory, we offer study meetings once a week on subjects in the fields of chemistry, organic chemistry, biochemistry, instrumental analysis, and polymer science so that students can learn and conduct research in a wide range of areas. We take advantage of knowledge and technology in various academic disciplines including organic chemistry, inorganic chemistry, polymer science, molecular biology, medicine, and pharmaceutical sciences, thus conducting molecular design and evaluation of new materials. Furthermore, we conduct weekly journal meetings, monthly report meetings, and interim report meetings twice a year. Through these research and educational activities, we aim to foster researchers who can play leading roles in the field of functional materials.

Fig.1

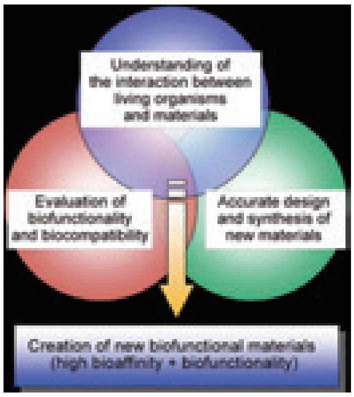

Fig.2

Research Themes

Based on the analysis of biocompatibility mechanisms, we are developing materials for regenerative medicine, as well as developing the new treatments, drugs, and drug delivery systems (DDS) listed. Specifically, we are advancing our research in the following fields: the elucidation of biocompatibility mechanisms, the design and creation of materials that support tissue engineering and regenerative medicine, and the development of a synthetic vector for gene therapy. For the elucidation of biocompatibility mechanisms, the interactions between biological (genes, proteins, cells, tissues, and individual organisms) and synthetic materials are analyzed at the molecular level. The discoveries and basic knowledge obtained are utilized for designing new materials. For example, we are developing innovative antithrombogenic materials that make possible small-bore artificial blood vessels that could not have been achieved by conventional technology.

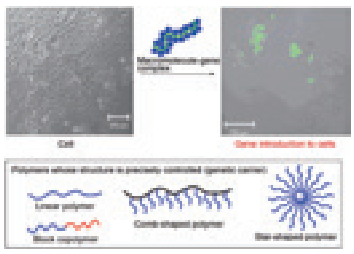

Fig.3

Recent Research Papers and Achievements

1. A. Kusumaatmaja, T. Ando, K. Terada, S. Hirohara, T. Nakashima, T. Kawai, T. Terashima, M. Tanihara, "Synthesis and photoproperties of Eu(III)-bearing star polymers as luminescent materials.", *J Polym Sci Part A: Polym Chem* **51(12)** 2527-2535 (2013).
2. Y. Shibasaki, S. Hirohara, K. Terada, T. Ando, M. Tanihara, "Collagen-like Polypeptide Poly(Pro-Hyp-Gly) Conjugated with Gly-Arg-Gly-Asp-Ser and Pro-His-Ser-Arg-Asn Peptides Enhances Cell Adhesion, Migration, and Stratification.", *Biopolymers* **96(3)** 302-315 (2011).

Laboratory

Photonic Molecular Science

▶ URL: http://mswebs.naist.jp/english/courses/guidance/13.html




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Education and Research Activities in the Laboratory

Research activity of this laboratory is focused on "Photonic Molecular Science", a new research field covering molecules, polymers, coordination compounds and low-dimensional nano-materials with advanced photo-functionality. We accept students who have been educated in related fields such as chemistry, applied physics, material science and electronic engineering in domestic and overseas universities. Students are trained in organic and inorganic syntheses and their characterization methods, which are essential for developing future advanced materials and devices with photo-functionality. We welcome ambitious students who have high motivation, flexibility, and positive attitudes to address new scientific challenges while taking advantage of their educational backgrounds and scientific interests in materials science.

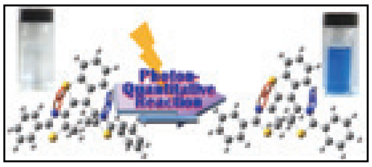

Fig.1 Schematic illustration for photoisomerization reactions of our unique photochromic molecule, which exhibits photoreaction with quantum yield of unity, a "photon-quantitative reaction"

Research Themes

Molecular- and nanoparticle-based devices are candidates for active elements in future information science and technology for communication, memory, sensing and display. Our research interests are focused on new photo-functional molecular and nano-scale materials which actively interact with photons. Our research subjects include photo-responsive molecules (Fig.1), π-conjugated molecules, nanoparticles and nanowires (Fig.2), intelligent fluorescence sensors (Fig.3), nanocarbons, and circularly polarized light-emitting materials.

Fig.2 Flexible thermoelectric sheet based on p-type and n-type carbon nanotubes

Recent Research Papers and Achievements

1. T. Nakashima, Y. Kajiki, S. Fukumoto, M. Taguchi, S. Nagao, S. Hirota, T. Kawai, "Efficient Oxidative Cycloreversion Reaction of Photochromic Dithiazolylthiazole", *J. Am. Chem. Soc.* **134** 19877-19883 (2012).
2. S. Fukumoto, T. Nakashima, T. Kawai, "Photon-Quantitative Reaction of a Dithiazolylarylene in Solution", *Angew. Chem. Int. Ed.* **50** 1565-1568 (2011).
3. J. Yuasa, T. Ohno, K. Miyata, H. Tsumatori, Y. Hasegawa, T. Kawai, "Noncovalent Ligand-to-Ligand Interactions Alter Sense of Optical Chirality in Luminescent Tris(β-diketonate) Lanthanide(III) Complexes Containing a Chiral Bis(oxazolinyl) Pyridine Ligand", *J. Am. Chem. Soc.* **133** 9892-9902 (2011).
4. Y. Nonoguchi, T. Nakashima, A. Tanaka, K. Miyabayashi, M. Miyake, T. Kawai, "Oligomerization of Cadmium Chalcogenide Nanocrystals into CdTe-Containing Superlattice Chains", *Chem. Commun.* **47** 11270-11272 (2011).

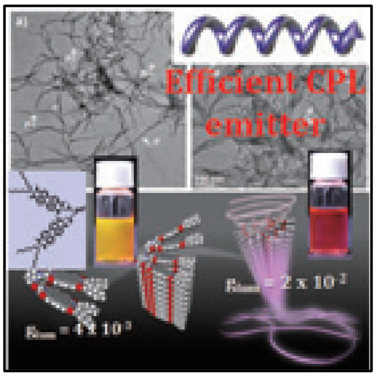

Fig.3 Efficient emission of circularly polarized luminescence from chiral molecules and their use for sensing bio-related compounds are studied.

Laboratory

Ultrafast Photonics

(Material function analysis and evaluation)

▶URL: http://mswebs.naist.jp/english/courses/guidance/14.html



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Education and Research Activities in the Laboratory

1. Educational goal

We foster engineers and researchers who will be able to take leading roles in next-generation photonics and electronics through experimental and theoretical research activities in ultrafast photonics. In our laboratory, we determine research themes in consideration of the interests of individual students and conduct training with an emphasis on experimental work on "device fabrication" and "measurement and evaluation." Students are required to understand the research themes and their backgrounds, and to use laboratory equipment with an understanding of their operating principles so that they can learn the skills required of independent engineers or researchers. Furthermore, we provide guidance about experimental condition setting and logical consideration for experimental results, thus helping them cultivate their technical insight.

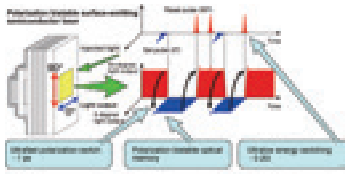

Fig.1

2. Research activities, policy and targets

In our laboratory, we advance research on nano-scale semiconductor optoelectronic devices and their applications to photonic networks (future optical communication networks) with a focus on experiments under the keyword of "ultrafast". We also conduct research on new optical devices for future signal processing technologies such as quantum computers and quantum information and communication technology.

Fig.2

Research Themes

1. Fabrication of new types of vertical-cavity surface-emitting lasers (VCSELs) and their applications to optical signal processing (Fig.1 and 2)
2. High-index-contrast subwavelength grating (HCG) VCSELs and its application to on-chip optical signal processing (Fig.3)
3. New spin controlled semiconductor optical device research (Fig.4)

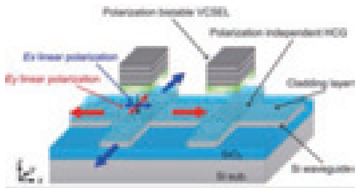

Fig.3

Recent Research Papers and Achievements

1. N. Yokota, Y. Tsunemi, K. Ikeda, and H. Kawaguchi, "Pump probe measurement of electron spin relaxation time in (110)-oriented GaAs/AlGaAs multiple quantum well microposts", *Appl. Phys. Express* **5** 122401 (2012).
2. K. Ikeda, K. Takeuchi, K. Takayose, I-S. Chung, J. Mørk, and H. Kawaguchi, "Polarization-independent high-index contrast grating and its fabrication tolerances", *Appl. Opt.* **52** 1049-1053 (2013).
3. T. Katayama, T. Okamoto, and H. Kawaguchi, "All-optical header recognition and packet switching using polarization bistable VCSEL", *IEEE Photon. Technol. Lett.* **25** 802-805 (2013).

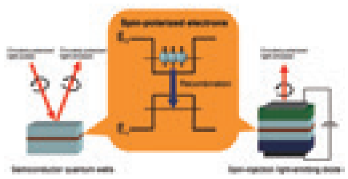

Fig.4

Laboratory

Photofunctional Organic Chemistry

▶ URL: http://mswebs.naist.jp/english/courses/guidance/24.html

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Education and Research Activities in the Laboratory

The Photofunctional Organic Chemistry Laboratory was established on January 1, 2011. We focus on the synthetic and structural studies of aromatic compounds and the development of functional dyes and organic electronic materials in view of their application to organic devices such as organic thin-film solar cells.

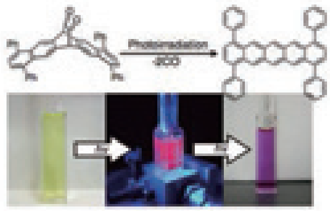

Fig.1

Research Themes

1. Development of new functional acenes

Acenes typified by pentacene are known as excellent organic semiconductor materials. Aiming to achieve organic semiconductor materials that can be produced through solution processes, we use various techniques such as the precursor method and the substituent introduction method to develop new materials (Fig.1).

2. Development of new porphyrinoids

Porphyrins are cyclic tetrapyrroles contained in photosynthetic reaction centers or hemes, and are widely used as in-vivo or functional materials. We are developing new porphyrinoids, which are their analog, and studying the structure and electronic characteristics of these materials, thereby developing new functional materials such as organic electronic materials or catalysts (Fig.2, Fig.3).

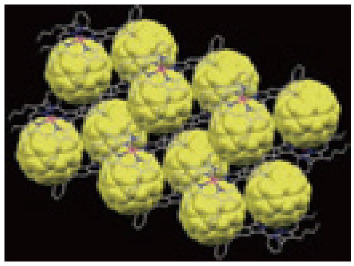

Fig.2

3. Creation of unique carbon frameworks with remarkable optical properties

We also develop synthetic methods of various polyaromatic hydrocarbons. These compounds have near-infrared absorption properties and strong light emission.

4. Development of organic thin-film solar cells

We conduct joint research with research teams specializing in supramolecules, organic electronic devices, and molecular spectroscopy to develop coating-type low molecule-based thin-film solar cells.

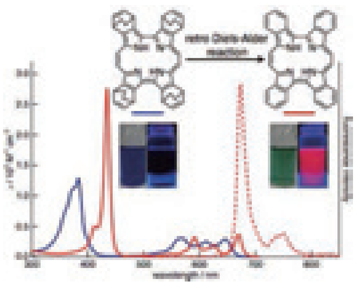

Fig.3

Recent Research Papers and Achievements

1. D. Kuzuhara, Y. Sakakibara, S. Mori, T. Okujima, H. Uno, H. Yamada, "Thiatriphyrin(2.1.1): A Core-Modified Contracted Porphyrin", *Angew. Chem. Int. Ed.* **52** 3360-3363 (2013).
2. H. Yamada, C. Ohashi, T. Aotake, S. Katsuta, Y. Honsho, H. Kawano, T. Okujima, H. Uno, N. Ono, S. Seki, K. Nakayama, "FET performance and substitution effect on 2, 6-dithienylanthracence devices prepared by photo-irradiation of their diketone precursors", *Chem Commun.* **48** 11136-11138 (2012).

Laboratory

Nanostructure Magnetism

(Material functional analysis & evaluation)

▶ URL: http://mswebs.naist.jp/english/courses/guidance/15.html

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Education and Research Activities in the Laboratory

In the Nanostructure Magnetism Laboratory, we use the vacuum deposition method and sputtering to produce metallic magnetic thin and multilayer films, and conduct basic research on magnetic phenomena specific to nanostructure thin films and the relationship between the structure of thin films and magnetism. The laboratory is characterized by research on "nanostructure magnetism" with synchrotron radiation X-rays. We are developing an X-ray magnetic scattering technique that enables element-specific magnetic structure analysis through the improvement of measuring methods, sensitivity enhancement and analysis precision.

Magnetic thin films and multilayer films with modulated structures on the nanoscale can produce various magnetic structures and magnetization processes because of the effects of the magnetic anisotropy in the individual magnetic layers, as well as direct or indirect exchange coupling between the magnetic layers. Thus, we elucidate element-specific magnetic structures and vector magnetization processes by resonant X-ray magnetic scattering techniques, and reveal the appearance mechanism of magnetic functionalities. In spin electronics, which is recently attracting attention, "magnetism in nonmagnetic layers" or "magnetism of conduction electrons" is related to the appearance of functionalities. The resonant X-ray magnetic scattering allows us to study the magnetism in nonmagnetic layers without being affected by the magnetism in ferromagnetic layers. We take advantage of these characteristics to advance our research on conduction electrons magnetism.

In our laboratory, based on the specialized knowledge and experimental technology of solid state physics, especially on magnetism, obtained from the above studies, we, for educational purposes, cultivate human resources with the ability to discover problems, search for solutions, discuss issues logically, give presentations on research results, and demonstrate their ability in companies, universities, and research institutions after graduation.

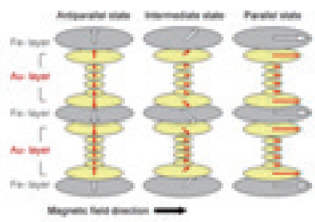

Fig.1 Magnetic field dependence of the magnetic structure induced in the Au layers of an Fe/Au multilayer film

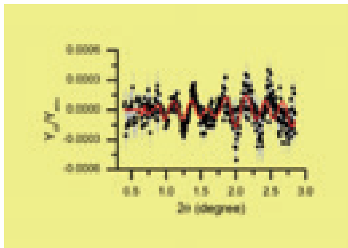

Fig.2 Magnetic scattering profile generated by uncompensated magnetization induced in the antiferromagnetic MnIr layer of an exchange bias film (Ir L3 absorption edge)

Research Themes

1. The induced magnetic structure and magnetization process for the conduction electrons in nonmagnetic layers of the magnetic/nonmagnetic multilayer film that produces oscillatory interlayer exchange coupling or giant magnetoresistance effect

2. Vector magnetization processes caused by direct and indirect exchange coupling and magnetic anisotropy

3. The exchange bias effect mechanisms

Recent Research Papers and Achievements

1. N. Hosoito, K. Kodama, R. Yamagishi, "Au Spin Polarization Induced in an Fe/Au(001) Multilayer with Interlayer Exchange Coupling from the X-ray Energy Dependence of Resonant X-ray Magnetic Scattering at the Au L3 Absorption Edge", *J. Phys. Soc. Jpn.* **81** 064713-1-5(2012).

Laboratory

Theoretical Condensed Matter Physics

▶ URL: http://mswebs.naist.jp/english/courses/guidance/27.html

Assoc. Prof.
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Education and Research Activities in the Laboratory

1. Laboratory Profile

The aim of our laboratory is to theoretically elucidate optical properties of semiconductors. In particular, we are currently studying the many-body effect in optically excited semiconductors.

2. Education

In addition to daily research guidance toward the completion of academic dissertations, we provide seminars on electromagnetics, quantum mechanics, and statistical mechanics to students who missed the opportunity to study these subjects. We aim to not only foster students with excellent presentation skills, but also cultivate a sense of responsibility, of mission, and of achievement through writing papers and giving presentations at conferences.

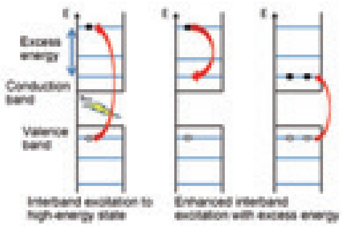

Fig.1 Impact ionization-an example of carrier multiplication

Research Themes

Carrier Multiplication in Semiconductor Nanocrystals

Recently, solar cells have been attracting attention as an environmentally friendly energy source that can contribute to the efficient use of the earth's finite resources because they can directly transform optical energy to electricity. Most current solar cells on the market consist of a single p-n junction and their conversion energy is limited to the Shockley-Quiesser limit, which is about 30%. Carrier multiplication is a phenomenon in which multiple electron-hole pairs are excited from a single photon. This phenomenon is expected to enable the creation of solar cells with an incident photon-to-current efficiency higher than the Shockley-Queisser limit.

In our laboratory, we are theoretically studying carrier multiplication in semiconductor nanocrystals based on the projection operator method in non-equilibrium statistical mechanics.

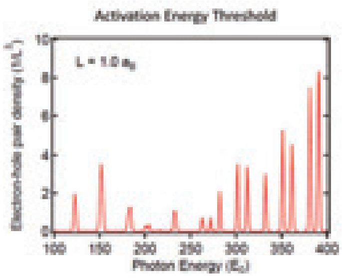

Fig.2 Electron-hole pair density as a function of the excitation light energy. Here, the bandgap energy is set to 100 E_0. E_0 and a_B denote the exciton Rydberg energy and Bohr radius, respectively.

Recent Research Papers and Achievements

Takeshi J. Inagaki, A. Miyake, and M. Aihara, "Ring-Shaped Spatial Photoluminescence Profiles in Two-Dimensional Semiconductors", *J. Phys Soc. Jpn.* **76** November 114705 (2007).

Laboratory

Organic Electronics

▶ URL: http://mswebs.naist.jp/english/courses/guidance/25.html



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Education and Research Activities in the Laboratory

1. Research aims

We carry out our research projects with the slogan "*Electronics on any surface!*" We take advantage of organic conducting materials in view of the sustainability of society, aiming to add unprecedented electronic functions to all aspects of life, including food, shelter, and clothing. We utilize all our knowledge of solid-state physics, material chemistry, and electronic engineering to advance our research covering everything from basic science to applications.

2. Example of research activities

We have developed various unique equipment including an "atomic-force-microscope potentiometry apparatus" that allows us to precisely measure the electric potential distribution on the surface of functional organic materials with very high special resolution (Fig.1). By combining original evaluation methods and synchrotron radiation beam-based structural analyses, we have clarified the hierarchical crystallographic structure of pentacene thin films, a typical material for organic thin-film transistors, as well as the corresponding carrier transportation band-edge structure (Fig.2).

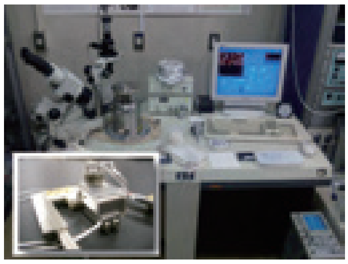

Fig.1 Atomic-force-microscope potentiometry apparatus

3. Educational policy

We select research themes from a wide range of research fields, from basic studies related to materials to practically operable active elements in circuits, depending on the interests and abilities of individual students. In addition, we foster independent thinking and the top-level mindset necessary for researchers through joint research with research institutes in Japan and abroad, as well as presentations at international conferences. Thus, we aim to cultivate researchers who have a broad knowledge of science and a perspective toward industrial applications.

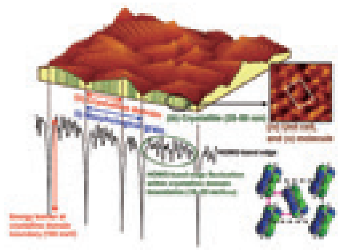

Fig.2 Hierarchical structure of pentacene thin films

Research Themes

1. Elucidation of carrier transport mechanisms in organic semiconductors.
2. Exploration of organic thermoelectric materials toward the realization of flexible thermoelectric conversion devices
3. Basic research on flexible THz imaging devices using organic transistor structures
4. Development of high-brightness organic photovoltaic devices for energy harvesting in room ambient (Fig.3)

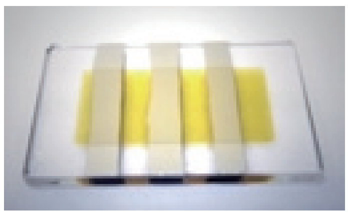

Fig.3 High-brightness organic photovoltaic device

Recent Research Papers and Achievements

1. S.-G. Li et al., "THz-Wave Absorption by Field-Induced Carriers in Pentacene Thin-Film Transistors for THz Imaging Sensors", *Org. Electron.* **14** 1157 (2013).
2. S. Yogev et al., "Fermi Level Pinning by Gap States in Organic Semiconductors", *Phys. Rev. Lett.* **110** 036803 (2013).
3. R. Matsubara et al., "Crystal Order in Pentacene Thin Films Grown on SiO_2 and Its Influence on Electronic Band Structure," *Org. Electron*. **12** 195 (2011).

Laboratory

Green Nanosystem

▶ http://mswebs.naist.jp/english/courses/guidance/gn_fm.html

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Education and Research Activities in the Laboratory

Newly established in 2013 our laboratory investigates nano-scale structures and their properties at the surface based on spectroscopy and diffraction methods.

At the interface where two different materials meet, unique electronic and magnetic phenomena such as photovoltaic and rectification effects appear, owing to structural anisotropy and interface-specific composition. Such nano-scale regions become good active reaction sites for catalysis. We investigate the local electronic properties by a non-destructive, atomic site specific method: photoelectron diffraction spectroscopy. The purpose of our research is to provide useful knowledge for developing and improving new devices for green innovation based on these interface phenomena.

Thanks to many collaborators abroad as well as in Japan, we promote our research using synchrotron facilities. We contribute to the operation of the unique photoelectron diffraction station at SPring-8, Japan. We also have strong ties with the photoelectron diffraction group at Swiss Light Source.

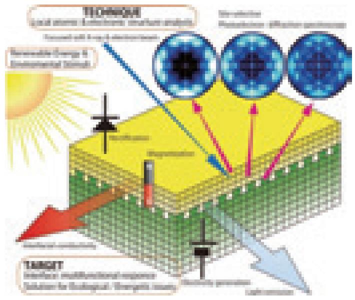

Fig.1 Photoelectron diffraction spectroscopy is our original method. It is a non-destructive local atomic/ electronic structure analysis method for surface and interface.

Research Themes

1. Revealing unique phenomena related to photoelectron diffraction and developing new analysis methods based on such phenomena
2. Construction of a new projection type electron analyzer
3. Atomic level characterization of local structure and properties of functional material interfaces

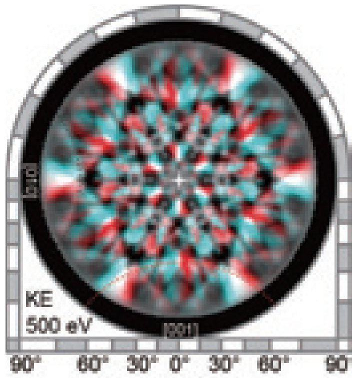

Fig.2 Visualization of graphite atomic arrangement by photoelectron holography

Recent Research Papers and Achievements

1. S. Roth, F. Matsui, T. Greber, J. Osterwalder, "Chemical Vapor Deposition and Characterization of Aligned and Incommensurate Graphene/Hexagonal Boron Nitride Heterostack on Cu(111)", *Nanoletters* **13** 2668 (2013).
2. F. Matsui, T. Matsushita, H. Daimon, "Photoelectron diffraction and holographic reconstruction of graphite", *J. Phys. Soc. Jpn.* **81** 114604 (2012).
3. F. Matsui, M. Hashimoto, T. Matsushita, K. Goto, N. Maejima, H. Matsui, Y. Kato, H. Daimon, "Negative Photoelectron Diffraction Replica in Secondary Electron Angular Distribution", *J. Phys. Soc. Jpn.* **81** 013601 (2012).
4. F. Matsui, N. Nishikayama, N. Maejima, H. Matsui, K. Goto, M. Hashimoto, T. Hatayama, T. Matsushita, Y. Kato, H. Daimon, "Site-Specific Stereograph of SiC(0001) Surface by Inverse Matrix Method", *J. Phys. Soc. Jpn.* **80** 013601 (2011).
5. F. Matsui, T. Matsushita, H. Daimon, "Stereo Atomscope and Diffraction Spectroscopy -- Atomic Site Specific Property Analysis", *J. Electron Spectrsc. Relat. Phenom.* **178-179** 221 (2010).
6. F. Matsui, T. Matsushita, Y. Kato, F. Z. Guo, M. Hashimoto, K. Inaji, H. Daimon, "Atomic-layer resolved magnetic and electronic structure analysis of Ni thin film on a Cu(001) surface by diffraction spectroscopy", *Phys. Rev. Lett.* **100** 207201 (2008).

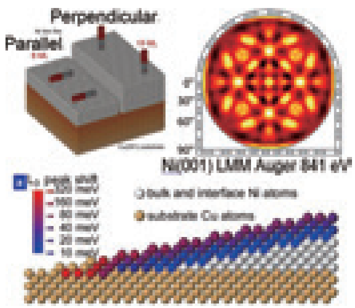

Fig.3 Revealed atomic, electronic and magnetic properties of magnetic thin film for each atomic layer

Laboratory

Green Bio-Nano

▶ URL: http://mswebs.naist.jp/english/courses/guidance/26.html

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Education and Research Activities in the Laboratory

The Green Bio-Nano Laboratory of the Environment Photonics Super Research Group (Group leader: Prof. Tsuyoshi Kawai) is a unit run by Prof. Yoichiroh Hosokawa as the principal investigator (established on April 1, 2011). Prof. Hosokawa takes advantage of laser light to develop new technology for the manipulation and measurement of cells and proteins, and to clarify the interaction between cells or proteins from a new perspective in order to further understand the adaptability and responsiveness of cells and living tissues. These activities aim to open a new field of green innovation. The laboratory fosters human resources who have a broad knowledge of science ranging from physics and chemistry to biology and medicine.

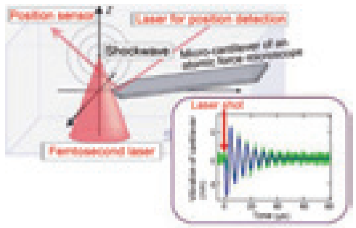

Fig.1 Local force measurement for femtosecond laser impulse utilizing atomic force microscope

Research Themes

1. Exploration of responsiveness of cells and living tissues to environment stress
2. Development of a new measurement method to estimate internal stress in living tissue utilizing ultrashort lasers and atomic force microscopes
3. Exploration of ice formation dynamics triggered by ultrashort laser pulses

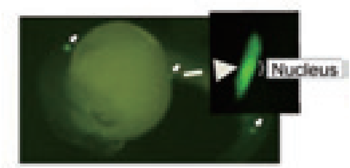

Fig.2 Femtosecond laser photoporation of fluorescence molecules into single cells of zebrafish embryos

Recent Research Papers and Achievements

1. Y. Hosokawa, M. Ohta, A. Ito, and Y. Takaoka, "Photomechanical ablation of biological tissue induced by focused femtosecond laser and its application for acupuncture", *Appl. Phys. A* **110** 613-616 (2013).
2. T. Iino and Y. Hosokawa, "Controllability of Femtosecond Laser-induced Impulse in Water Evaluated by Local Force Measurement System Using Atomic Force Microscopy", *J. Appl. Phys.* **112** 066106 (2012).
3. H. Y. Yoshikawa, Y. Hosokawa, et al., "Spatially precise, soft microseeding of single protein crystals by femtosecond laser ablation", *Cryst. Growth Des.* **12** 4334-4339 (2012).
4. Y. Hosokawa, M. Hagiyama, T. Iino, Y. Murakami, and A. Ito, "Noncontact etimation of intercellular breaking force using a femto-second laser impulse quantified by atomic force microscopy", *Proc. Nat'l Acad. Sci. USA* **108** 1777-1782 (2011).
5. Y. Hosokawa, H. Ochi, T. Iino, A. Hiraoka, and M. Tanaka, "Photoporation of biomolecules into single cells in living vertebrate embryos induced by a femtosecond laser amplifier", *PLoS ONE* **6** e27677 (2011).

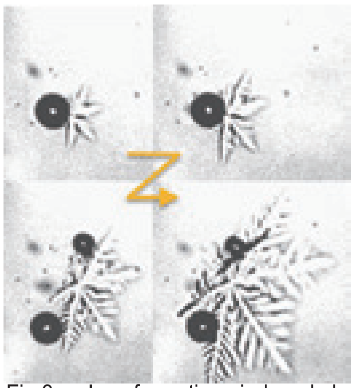

Fig.3 Ice formation induced by femtosecond laser impulse

Collaborative Laboratory

Mesoscopic Materials Science

(with Panasonic Co.,Ltd.)

▶ URL: http://mswebs.naist.jp/english/courses/guidance/17.html

Visiting Prof.
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Education and Research Activities in the Laboratory

We aim to cultivate researchers, who can carry out the integration of biomolecular materials and semiconductor technology research, and who will promote interdisciplinary research and open up new research areas. In the master's program, we first provide students with a basic education in order for them to grasp the reason why our research is necessary for society, and why research on science and technology is essential for the development of humankind. Then, based on this education, students participate in our research activities in the mesoscopic and nano fields, experiencing the joy of new discoveries and skilled manufacturing through experiments. Thus, we nurture researchers who can take on basic responsibilities for the development of new science and technology.

In the doctoral program, we not only provide guidance on specific research themes but also clarify the difference between science and engineering, thus providing students with adequate guidance so that they can, in a balanced manner, utilize both in a scientific mindset, leading to paradigm shifts and engineering knowledge that serves to realize scientific ideas. Thus, we cultivate self-sustaining researchers who will contribute to society. We are now creating the research field of wet nanotechnology, aiming to establish a technique that allows us to produce functional nano structures based on the nano-integration and self-organization of biomolecules and organic molecules in aqueous solutions.

Fig.1

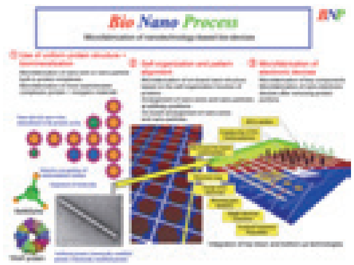

Fig.2

Research Themes

With the specific research theme of wet nanotechnology, we are doing research on the development of nano-devices and nano-processes, where proteins are used as nano-templates and self-assembling nano-blocks. The bio nano process is a device-fabrication process that integrates top-down technology, such as photo lithography, with bottom-up technology, such as biological technology. Proteins are produced from the information stored in DNA with structures of some proteins being identical at the atomic level. They can exhibit their self-organization functions and automatically produce functional structures of dimension 10-100 nm. Furthermore, they can utilize biomineralization to produce semiconductor nanoparticles and nano-wires. Since top-down technology is available for producing microstructures down to 50-nm in size, integration of the two technologies can produce functional structures of about several nanometers in size with high dimensional accuracy on a large scale. This is a typical example of "process integration technology". Our group has fabricated a floating gate memory using a monolayer of nano-dots array made by cage-shaped proteins. This method is now further modified to produce Si nano-disc quantum structures, dye-sensitized solar cells, Si-nanowire bio-sensors, and DNA sequencers.

Recent Research Papers and Achievements

K. Sano, A. Miura, S. Yoshii, M. Okuda, M. Fukuta, Y. Uraoka, T. Fuyuki, I. Yamashita, and K. Shiba,"Nonvolatile Flash Memory Based on Biologically Integrated Hierarchical Nanostructures", *Langmuir* **29(40)**, 12483-12489, (2013).

Collaborative Laboratory

Intelligent Materials Science
(with SHARP Corporation)

▶ URL: http://mswebs.naist.jp/english/courses/guidance/18.html

Visiting Prof.
Akira Takahashi

Visiting Prof.
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Noboru Iwata

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Education and Research Activities in the Laboratory

The Intelligent Materials Science Laboratory has three educational staff members, who independently conduct research on new devices and materials in their own specialized fields, including research on memory devices centered on magnetic and optical materials, materials and application technologies for display devices such as liquid crystal displays (LCDs), and light emitting diodes (LEDs), and devices with nano-sized materials.

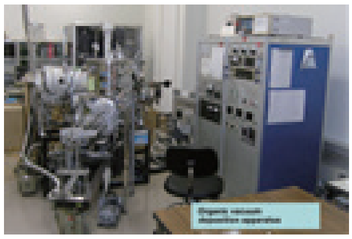

Fig.1

Research Themes

1. Recording materials

Disk type memory such as optical disks is a field where technical improvement is continuously undertaken to increase recording density through material and device development. In this course, new composite materials for recording media and read/write heads are investigated.

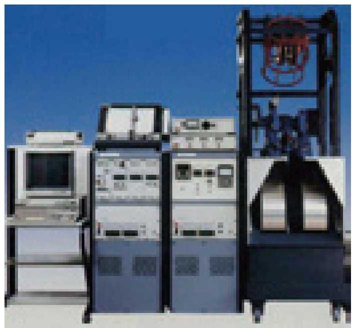

Fig.2

2. Display device materials

Flat panel displays are widely used for flat panel televisions, mobile phones, etc. and their higher resolution, faster response, lower power consumption, etc. is constantly being pursued. This laboratory conducts R&D on materials, devices, mechanical analysis, etc. of liquid crystal displays and light emitting diodes.

3. Nano-sized materials

Electronic characteristics of semiconducting materials are entirely different from bulk materials due to quantum effects when the crystal size is controlled in the microscopic region ranging from atomic to several nanometers.

We study functional materials that sensitively show a macroscopic response to external stimuli such as light, electric fields, or magnetic fields by controlling the electronic level or phase transition.

Recent Research Papers and Achievements

1. Signal equalization and reproduction from amplitude information through the use of the frequency response of an optical disc system

- T. Okumura, T. Numata, J. Akiyama, S. Maeda, T. Yamaguchi, A. Takahashi, “Method for Evaluating Partial Response Maximum Likelihood System Performance Using Sequenced Amplitude Margin”, *Jpn. J. Appl. Phys.* **41** 1783-1784 (2002).

2. Super-resolution reproduction through the use of changes in optical characteristics due to temperature at the absorption edge of zinc oxide

- M. Yamamoto, G. Mori, H. Tajima, N. Takamori, A. Takahashi, “Super-Resolution Optical Disc with High Readout Stability Using Zinc Oxide Thin Film”, *Jpn. J. Appl. Phys.* **43** 4959-4963 (2004).

Collaborative Laboratory

Functional Polymer Science

(with Santen Pharmaceutical Co., Ltd.)

▶ URL: http://mswebs.naist.jp/english/courses/guidance/19.html

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Education and Research Activities in the Laboratory

We cultivate human resources who have the ability to find and solve research challenges, as well as those who can contribute to society through research activities on drug discoveries based on synthetic organic chemistry. We provide research and education, aiming to cultivate human resources who dream of performing skilled manufacturing and spare no effort toward achieving their dreams. Thus, we place emphasis on the understanding of research background and positioning, experimental design and techniques, result analysis, discussion, and how to derive conclusions. We provide guidance to students so that they can acquire basic experimental skills to obtain correct and reliable data and, at the same time, give consideration to health and safety during actual chemical experiments.

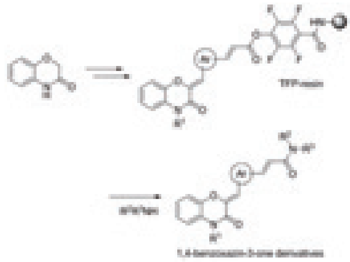


Fig.1 Resin-based solid-phase synthesis

Research Themes

The Functional Polymer Science Laboratory, a collaboration course between Santen Pharmaceutical Co., Ltd. and Nara Institute of Science and Technology, has been conducting research activities since April 2005. Our main research themes are basic synthetic organic chemistry for drug discovery and searching for candidate compounds for developing new medicinal drugs with unique structures. In particular, we are synthesizing and conducting the functional evaluation (screening) of compounds that can inhibit protein kinase, a target of molecularly targeted agents recently attracting increasing attention in various fields. For compound synthesis, we use the reaction of TFP-resin in its solid-phase to study parallel synthesis (1,4-benzoxazin-3-one derivatives) (Fig.1), whereas for drug design, we search for compounds that can secure a three-dimensional stable conformation suitable for active expression when they feature intramolecular nonbonded interaction (nonbonded interaction between hetero atoms such as hydrogen bond, N, O, and S)(Fig.2).

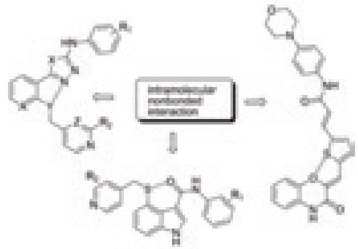


Fig.2 Compounds with kinase-inhibition activity based on intramolecular nonbonded interaction

Recent Research Papers and Achievements

1. Academic conference presentations

- The 25th Medicinal Chemistry Symposium 2006 (Nagoya) (in Japanese).
- The 26th Medicinal Chemistry Symposium 2007 (Sagami-Ohno) (in Japanese).
- The 27th Medicinal Chemistry Symposium 2008 (Osaka) (in Japanese).
- The 39th Congress of Heterocyclic Chemistry 2009(Sendai) (in Japanese).

2. Papers

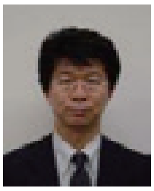
- T. Honda, et al., *Bioorg. Med. Chem. Lett.* **18** 2939 (2008).
- T. Honda, et al., *Bioorg. Med. Chem.* **17** 699 (2009).
- H. Tajima, et al., *Bioorg. Med. Chem. Lett.* **20** 7234 (2010).
- T. Honda, et al., *Bioorg. Med. Chem. Lett.* **21** 1782(2011).

Collaborative Laboratory

Ecomaterial Science

(with Research Institute of Innovative Technology for the Earth)

▶ URL: http://mswebs.naist.jp/english/courses/guidance/20.html



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Education and Research Activities in the Laboratory

The Ecomaterial Science Laboratory, which is staffed by researchers of the Research Institute of Innovative Technology for the Earth (RITE), provides research and education on fundamental technologies (material development, nano-structure control technology) to solve the global warming issue, as well as applied research for practical applications (process development and system design). To reduce carbon dioxide emissions (CO_2 emissions), we are advancing our technology development efforts, focusing on the separation, recovery, and fixation of carbon dioxide in the gas exhausted from large-scale fixed emission sources such as thermal power plants and steel mills. In our laboratory, students can deepen their understanding of social background, causes, and countermeasures concerning global environmental issues, particularly the global warming issue. They can also learn the science of materials that contribute to solving global environmental issues through the development of technologies now underway in RITE, such as separation and recovery techniques for carbon dioxide and hydrogen (H_2), and biomaterial production technology. Furthermore, we provide education that allows students to deepen their technical knowledge in the field of chemistry including physical chemistry, material science, chemical engineering, and organic-inorganic synthesis; view academic disciplines from a wide perspective; and develop the ability to comprehensively understand the connections of their research activities with social phenomena as well as problem solution methodology. We normally provide students with OJT education through the global warming countermeasure technology project now underway in RITE.

Fig.1 Research fields

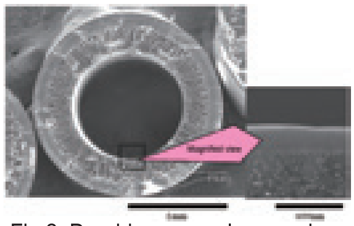

Fig.2 Dendrimer complex membrane

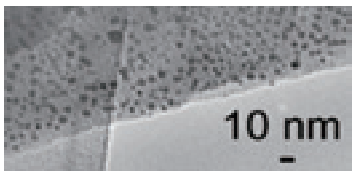

Fig.3 Mesoporous silica membrane

Research Themes

1. **Membrane separation and adsorption separation technology (polymeric membrane, inorganic membrane)**
   Research on various separation membranes (carbon dioxide, hydrogen, and alcohol) with the use of polymeric (dendrimer) and inorganic porous materials (carbon, zeolite, and mesoporous silica)
2. **Biomass utilization technology**
   Research on comprehensive wood-based biomass utilization technology
3. **Carbon dioxide (CO_2) fixation and utilization technology**
   Research on using alkaline-earth metals in iron and steel slag or waste concrete to convert CO_2 into the form of stable carbonate

Recent Research Papers and Achievements

1. K. Nagata, M. Miyamoto, Tsuyoshi Watabe, Y. Fujioka, K.Yogo*, "Preparation of Pore-fill-type Palladium–Porous Alumina Composite Membrane for Hydrogen Separation" *Chem.Lett.* **40(1)** 19-21 (2011).
2. M. Miyamoto, Y. Fujioka, K.Yogo , "Pure Silica CHA Type Zeolite for CO_2 Separation Using Pressure Swing Adsorption at High Pressure", *Journal of Materials Chemistry*. **22(38)** 20186-20189 (2012).

Collaborative Laboratory

Sensory Materials and Devices
(with Shimadzu Corporation)

▶ URL: http://mswebs.naist.jp/english/courses/guidance/21.html



Visiting Prof. Eiichi Ozeki

Visiting Prof. Toshiyuki Sato

Visiting Assoc. Prof. Takahiro Nishimoto

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Education and Research Activities in the Laboratory

We are advancing our research on sensor- and device-related fundamental technologies such as microfabrication. We take advantage of these technologies to conduct research on various devices such as electrophoresis chips, cell culture chips (Fig.1), microreactors, electro-osmotic pumps, and vapor-liquid separation chips. Furthermore, we are also furthering research on molecular imaging technology (Fig.2) and X-ray image sensor systems (Fig.3) to be applied in the medical diagnosis field, as well as working on the integration of these technologies to realize highly functional ultra micro chemical analysis systems (μTAS: Micro Total Analysis Systems).

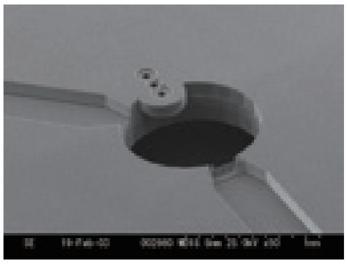

Fig.1 Cell culture chips

Research Themes

Taking advantage of semiconductor manufacturing process technologies to apply micromachining to silicon substrates and glass substrates of sub-micron dimensions, we develop functional devices with one-micron sized three dimensional structures that are used for chemical analysis and chemical manipulation (reaction or extraction).
We also work in the medical diagnosis field, on molecular imaging technology and X-ray imaging systems. We pursue the application of molecular imaging-related technologies such as the molecular design of molecular probes or microreactor based synthetic apparatuses, to the medical diagnosis fields including cancer detection at its very early stage. X-ray imaging systems are an important technology in the medical diagnosis field. We investigate a large area 2D X-ray detector composed of a poly crystalline CdZnTe film, a thin film transistor array and read out electronics.

The following are our laboratory research themes:

1. Microchemical analysis systems
2. Microreactors and micropumps
3. Polymer micelle (lactosome)
4. Probe synthesis systems with microreactors
5. X-ray photoconductor materials: Poly crystalline growth and evaluation
6. X-ray imaging systems

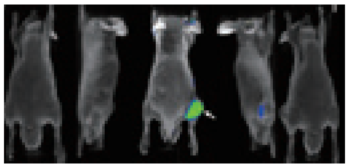

Fig.2 Molecular imaging probe "Lactosome" for cancer
(→ : cancer)

Recent Research Papers and Achievements

1. YG.Yu et.al. ,"The Annealing Effects of Chlorine Doped Polycrystalline CdZnTe Films", The 59th JSAP Spring Meeting, Waseda University, Tokyo, Japan (2012).
2. A. Yoshimatu et.al., "Grain Growth and Characteristics of Chlorine Doped Thick Polycrystalline CdZnTe Films", IEEE 2012 Nuclear Science Symposium, Medical Imaging Conference & Workshop on Room-Temperature Semiconductor X-Ray and Gamma-Ray Detector, Anaheim, California, USA (2012).
3. T. Arai et.al.,"Size Control of the Polymer Micelles in a Micro Flow Channel", The Chemical Society of JAPAN, The 92nd Annual Meeting, Keio University, Kanagawa, JAPAN (2012).
4. T. Hae et al., "Growth and characterization of CdZnTe polycrystalline film for the X-ray flat panel detector", The 60th JSAP Spring Meeting, Kanagawa Institute of Technology, Kanagawa, Japan (2013).
5. T. Okamoto et al., "Deposition of Polycrystalline Cd1-xZnxTe Films on Zn Te/ Graphite and Graphite Substrates by Close-Spaced Sublimation", 16th International Conference on II-VI Compound and Related Materials (II-VI 2013), Shiga. Japan (2013).
6. K. Hayama et al., "Size Control of the Polymer Micelles in a Micro Flow Channel", The Chemical Society of JAPAN, The 93rd Annual Meeting, Ritsumeikan University, Shiga, JAPAN (2013).

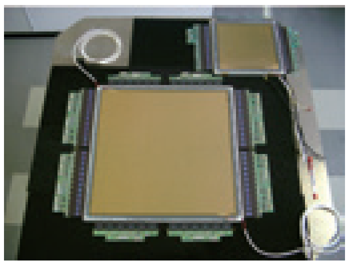

Fig.3 X-ray image sensor for diagnosis

Collaborative Laboratory

Advanced Functional Materials

(with Osaka Municipal Technical Research Institute)

▶ URL: http://mswebs.naist.jp/LABs/omtri/index.html



Visiting Prof. Yasuyuki Agari
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Education and Research Activities in the Laboratory

Polymers, ceramics and metals are materials used widely in industry. Their applications are widespread from structural uses to a variety of functional uses. We are devoted to developing these materials and their nano-composites to be applied in advanced industry. We focus on the nanostructure control of the materials to realize next generation electronic, optical, and energy devices. Another important challenge is the development of environmental-conscious material processing technology. Our laboratory, located in Osaka Municipal Technical Research Institute near the downtown area of Osaka city, conducts intimate collaborations with engineers from private companies to rapidly apply the developed materials to practical devices.

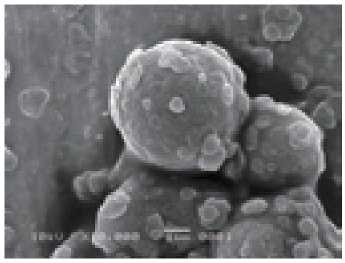


Fig.1 Core-shell particles of phenol resin particles covered with thermal conductive BN nano-particles, which can be made of highly thermal conductive honeycomb structures

Research Themes

1. Transparent and highly thermal emissivitive coating materials and highly thermal conductive materials

Super hybrid materials with nano particles, made up of honeycomb structures with co-continuous phases, have been developed to attain both a high thermal emissivity and light transparency, or highly thermal conductivity (> 20 W/(m K) or 10 W/(m K) with electric insulation).

2. Biomass polymer materials with unique properties

A group of environmental and functional polymer materials, poly(lactic acid), is being developed to obtain mechanical properties comparable to polyethylene, which has good moisture permeability as well as air barrier. As a result, poly (lactic acid) with approximately 1 of Mw/Mn can be synthesized.

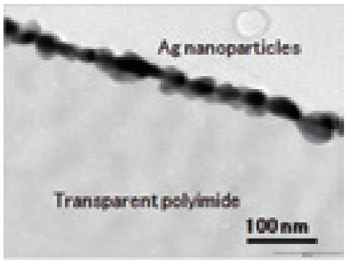


Fig.2 Highly reliable nanostructure for the wiring fabrication on transparent polyimide substrate: nano-interlocked structure of polyimide and Ag nanoparticles is formed at the interface.

3. Highly reliable wiring fabrication on flexible polymer substrates

The core technology to fabricate the wiring pattern is selective polymer metallization using plating. Along with plating technology, nanoparticle fabrication and the surface treatment of polymers are fully used to develop wiring with controlled nanostructures at the metal / polymer interface.

4. Lithium ion batteries fully composed of ceramics

Our research is aimed at the development of the all solid state lithium ion battery with high safety and high rechargeable capacity without liquid leakage. Our approaches to fabricate the lithium ion battery are economic and ecological techniques expected to be used in industry. Core techniques employed are the aerosol deposition method and the spray pyrolysis method.

5. Control of morphology and structure of materials for electric devices

Nano-particles, nano-fibers, nano-rods, and nano-sheets are very important, promising materials for the application of electric devices, energy storage, energy conversion, and medical tools. We prepare a variety of nano-materials such as oxides, sulfides, and nitrides, and we develop new industrial applications.

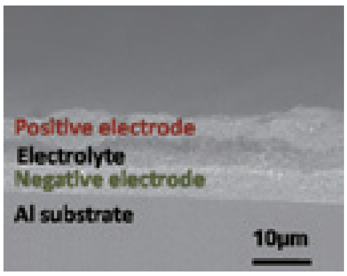


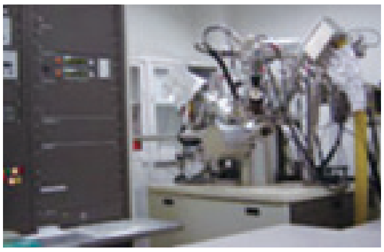
Fig.3 Cross-section of an all solid state lithium ion battery. The layer by layer structure is composed of a positive electrode ($LiFePO_4$), a solid state electrolyte (Li_7SiPO_7), and a negative electrode ($Li_4Ti_5O_{12}$).

Recent Research Papers and Achievements

1. Y. Fujiwara, Y. Kobayashi, N. Higuchi, Y. Hoshiyama, and H. Miyake, "Codeposition Mechanism in Sn/Ag Nanoparticle Composite Plating", *Electrochim. Acta* **89** 623-630 (2013).
2. Y. Agari, H. Hirano, J. Kadota, K. Hasegawa, "Thermal conductivity of boron nitride/phenol resin composite with honeycomb structure", International Conference on Chemical and Molecular Engineering 2012(Zürich).
3. M. Takahashi, J. Tani, H. Kido, A. Hayashi, K. Tadanaga, and M. Tatsumisago, "Thin Film Electrode Materials $Li_4Ti_5O_{12}$ and $LiCoO_2$ Prepared by Spray Pyrolysis Method", 2011 IOP Conf. Ser. Mater. Sci. Eng., 18, 122004.

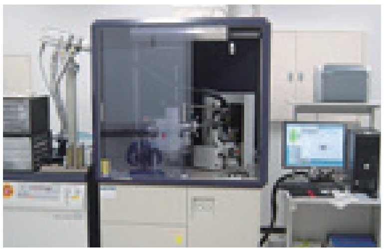
Research Facilities

Transmission
Electron Microscope
(TEM)



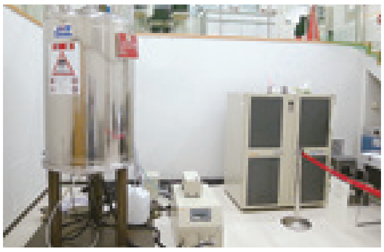
Secondary
Ion Mass Spectrometer
(SIMS)

Small-angle
X-ray scattering
diffractometer
(SAXD)



Wide-angle
X-ray diffractometer
(WAXD)

Single crystal
X-ray diffractometer and
structure analysis system



600MHz Superconductive
NMR spectrometer

500MHz Superconductive
NMR spectrometer

400MHz Superconductive
NMR spectrometer

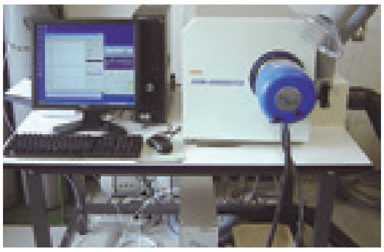
400MHz Solid-state
superconductive
NMR spectrometer

300MHz Superconductive
NMR spectrometer

EI, CI, FAB Mass
spectrometer

ESI/APCI Mass
spectrometer

MALDI-TOF Mass Spectrometer

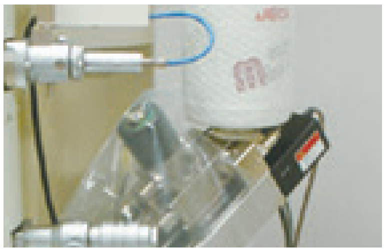


DART Mass Spectrometer

Inductively Coupled Plasma Mass Spectrometer
(ICP-MS)

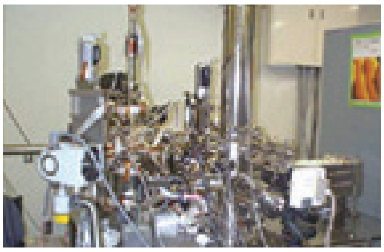
Differential scanning calorimetry/ Thermogravimetry-Differential thermo analyzer
(DSC/TG-DTA)

Field Emission Scanning Electron Microscope
(FE-SEM)



Nanoprobe surface analytical system

X-ray Photoelectron Spectroscope (ESCA, XPS)**/ Auger Electron Spectroscope** (AES)



Scanning Tunneling Microscope
(STM)

Scanning Probe Microscope
(SPM)

Confocal laser microscope

Laser zeta potential analyzer

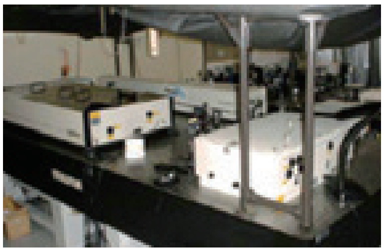
Stylus-type surface profilometer

Spectroscopic ellipsometer

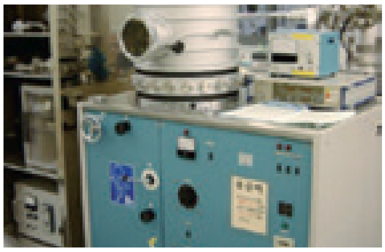
Dynamic Light Scattering spectrometer
(DLS)

Circular Dichroism spectropolarimeter
(CD)

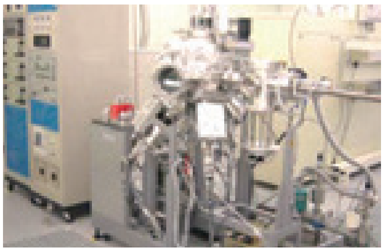
Laser Raman spectrophotometer



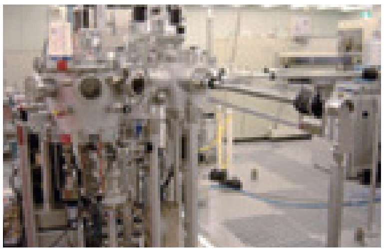
Ultrafast spectroscope using femtosecond laser pulses
(100fs)



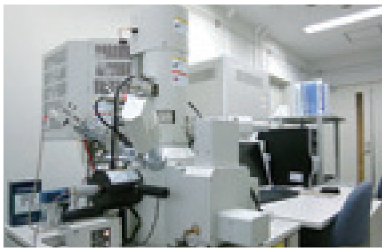
Vacuum vapor deposition apparatus



Oxide complex thin film coating apparatus



High purity metal sputter



Focused Ion Beam fabrication systems
(FIB)

Nano-prober/EBAC

Projection Aligner

Nara Institute of Science and Technology

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