Opening up new horizons with photonics

RIKEN Center for Advanced Photonics (RAP) is helping to realize the dream of making the invisible visible. As one example, stroboscopes, which allow us to see high-speed phenomena by pulsing light in a short duration, cannot catch the movements of molecules or atoms because they simply move too fast. However, thanks to research in photonics, lasers developed to generate pulses at even shorter duration such as $10^{-15}$ second (1 femtosecond) or $10^{-18}$ second (1 attosecond) now allow us to see the movements of electrons in atoms or molecules.

Electron microscopy makes it possible for us to observe objects at extremely high resolution. However, it requires the specimen to be put in a vacuum, making it impossible to see living cells. Using an optical microscope opens up that possibility. It was generally thought that it was impossible to picture objects smaller than half of the wavelength of light in the visible spectrum, but the super-resolution microscopes break this barrier and allow us to access the nanoworld.

We sometimes need to inspect the inner structure of a device or look for contamination in foods without destroying a sample. Terahertz wave makes this possible. The wavelength of terahertz wave is short enough that the "unexplored spectrum of light," is now moving into the application phase thanks to advances in light sources and detectors.

In addition, applications in the field of photonics are expanding in areas such as light wave manipulation with metamaterials, relativistic geodesy using ultraprecision optical lattice clocks, nondestructive inspection of concrete structures with a compact neutron source, all making visible what nobody has ever seen before. Being able to see objects helps us to understand and manipulate them.

The work of the Center for Advanced Photonics focuses not simply on making discoveries that will be recognized by the research community, but rather on contributing to society by developing practical applications of advanced photonics.

Just as our social infrastructure was transformed by the steam engine in the 19th century and by electronics in the 20th century, photonics technology will lead to another transformation of social infrastructure in the current century.

The possibilities opened by photonics are expanding. We are still in the very early stage of this new revolution.

RIKEN Center for Advanced Photonics is committed to expanding the horizons of photon science.

Center Director
Katsumi Midorikawa

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Nonlinear optical process in the XUV region is of paramount importance not only in the field of quantum electronics but also in ultrafast optics. From the viewpoint of quantum electronics, new features of the interaction between intense XUV photons and matter are expected to be revealed through observation of those nonlinear phenomena. On the other hand, those nonlinear processes in the XUV region are indispensable for progress of attosecond science including attosecond atomic/molecular physics and chemistry, because it is very useful for investigating ultrafast phenomena directly in attosecond time scale. Using high harmonic generation by intense femtosecond laser technology, we are pursuing extreme optical science including XUV nonlinear optics and attosecond physics/chemistry.

Expanding the horizon of optical science by attosecond photonics

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Elucidating complex molecular dynamics with femtosecond light

Most of the phenomena in nature are realized by the dynamic behavior of molecules. Among them, chemical reactions are critically important, which dynamically cause the cleavage and formation of chemical bonds and alter the nuclear arrangement within the molecules. Even non-reactive molecules are vibrating, which provides rich information about the molecular properties. Because the timescale of such molecular motion is femtosecond (quadrillionth), femtosecond spectroscopy is essential for elucidating chemical phenomena. Our team investigates the dynamics of molecules from fundamental to complex systems, as well as the molecules in special environments such as interfaces. We extend the frontier of molecular science through the development and use of advanced spectroscopic methods.
Clocks have served as a tool to share time, based on universal periodic phenomena; humankind relied upon the rotation of the earth from antiquity. The radiation from an atom provides us with far more precision than any currently available clock. We experimentally investigate the impact of such relativistic geodesy and new roles for clocks in the future.

**Relativistic Space-Time Engineering with Ultra Precise Atomic Clocks**

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**Towards optoelectronic devices that utilize the quantum nature of electrons and photons**

Advances in device fabrication techniques have enabled integration of individual nanomaterials, where single electrons and single photons could be addressed. We exploit state-of-the-art nanofabrication technologies to develop and engineer optoelectronic devices with novel functionalities that can only be achieved by utilizing the quantum nature of electrons and photons at the nanoscale. We investigate devices that would allow for control over the interactions between electrons and photons at the quantum mechanical level, which would lead to quantum photon sources and optical-to-electrical quantum interfaces.

**Publications**


**Member**

Daichi Kozawa / Shun Fujii / Zhen Li / Daiki Yamashita
Light is a cutting-edge tool for life science research. Development of useful fluorescent probes and the advancement of light microscope technologies have brought us a new world of “live” imaging within a cell. We are developing super-resolution confocal live imaging microscopy (SCLIM) by the combination of a high-speed confocal scanner and a high-sensitivity camera system. With this method we will observe membrane trafficking and organelar dynamics in living cells at high-speed and sub-wavelength space resolution (400) and elucidate underlying molecular mechanisms. We will also try to extend this technology to medical and pharmacological applications.

Bioimaging Technologies by use of glowing proteins

We label a fluorescent probe on a specific region of a biological molecule and bring it back into a cell. We can then visualize how the biological molecule behaves in response to external stimulation. Since fluorescence is a physical phenomenon, we can extract various kinds of information by making full use of its characteristics. For example, the excited energy of a fluorescent molecule donor transfers to an acceptor relative to the distance and orientation between the two fluorophores. This phenomenon can be used to identify interaction between biological molecules or structural change in biological molecules. Besides, we can apply all other characteristics of fluorescence, such as polarization, quenching, photobleaching, photoconversion, and photochronism, in experimentation. Cruising inside cells in a super-micro corp, gliding down in a microtubule like a rollercoaster, pushing our ways through a jangle of chromatins while hoisting a flag of nuclear localization signal -- we are reminded to retain a playful and adventurous perspective at all times. What matters is mobilizing all capabilities of science and giving full play to our imagination.

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Our goal is to develop original RIKEN data processing technology and multidimensional measurement technology in order to contribute to understanding biological phenomena. We are especially contributing to the fields of mathematical biology, bio-medical simulations as well as medical diagnostic and treatment technology by researching and developing new data and image processing technologies and establishing new tools for quantification of biological phenomena, intended for researchers both inside and outside RIKEN.

Image processing research for scientific information

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Lightweight manipulation by subwavelength structures

Our team intensively studies novel photon manipulation technologies using knowledge and experiences obtained from the researches on light wave interaction with sub-wavelength fine structures. These photon manipulation technologies will be applied for three-dimensional nano fabrication systems, ultra-high sensitive molecular sensing devices, and so on. Figure (a) shows a scanning electron microscope image of RIKEN’s logo consists of a sub-wavelength aluminium structure, which absorbs light of certain wavelength determined by its size and shape. Figure (b) shows an observed image of the RIKEN’s logo under white light illumination. Figure (c) shows a demonstrated color palette covering a broad gamut of colors.
Our research team is developing advanced laser processing techniques which realize low environmental load, high quality, high efficiency fabrication of materials. In particular, by using femtosecond lasers, novel material processing techniques including 3D fabrication, surface nanostructuring, novel nanomaterial synthesis, and tailored beam processing are developed, which are applied for fabrication of functional micro/nanodevices. As one of examples of the 3D fabrication, our team successfully created a 3D complex shape of pure protein such as bovine serum albumin (BSA).

Furthermore, enhanced green fluorescent protein and enhanced blue fluorescent protein were formed on a single substrate to realize a two-color fluorescence image exhibiting a RIKEN logo. The 3D proteinaceous micro and nanostructures fabricated by this technique will offer many applications including cell culture, tissue engineering, biochips, micromachines, etc.

Femtosecond Laser 3D Micro/Nanofabrication: Creation of 3D Structures Made of Pure Protein

Our research team is developing advanced laser processing techniques which realize low environmental load, high quality, high efficiency fabrication of materials. In particular, by using femtosecond lasers, novel material processing techniques including 3D fabrication, surface nanostructuring, novel nanomaterial synthesis, and tailored beam processing are developed, which are applied for fabrication of functional micro/nanodevices. As one of examples of the 3D fabrication, our team successfully created a 3D complex shape of pure protein such as bovine serum albumin (BSA).

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Terahertz Sensing and Imaging Research Team

Team Leader: Chiko Otani  |  D.Sci

**Fields**

Interdisciplinary science and engineering, Engineering, Space Science, Molecular Biology / Genetics, Chemistry

**Keywords**

Terahertz science, Terahertz spectroscopy, Terahertz imaging, Terahertz control, Superconducting detector

**Publications**


**Member**

Masatsugu Yamashita / Hiromichi Hoshina / Yoshizaki Sasaki / Javier Miguel Hernandez / Mingzi Chen / Yoysaihi / Rosalena Irma Alip

**Terahertz Sensing, Imaging, and Applications**

Terahertz (THz) wave has the unique characteristics such as the transparency to many soft materials and their spectral absorption features. These characteristics can be utilized for many applications in various scientific and industrial fields. In this team, we are developing novel technology, science and applications in THz sensing and imaging. Especially, we have promoted the research of THz spectroscopy of macromolecules, the challenge to the control of molecular structures and functions by the strong THz fields, and the development of high-sensitivity imaging detectors for the CNB polarization measurements as well as the collaborative research and development for its practical applications.

Development of compact and portable terahertz laser source

Terahertz light having both the transparency of radio wave and the high resolution of light is expected to be used in a wide range of application fields as a light source for various perspective and nondestructive inspections. We are developing THz-QCL (terahertz quantum-cascade laser), which is expected to be a very compact, portable, high power terahertz light source. Through the introduction of a new quantum subband structure and/or nitride semiconductors, THz-QCL aiming for implementation in society is being developed by performing room temperature oscillation and enlarging the operating frequency region which has been impossible so far. By developing the next generation compact terahertz imaging devices, we would like to contribute to the realization of a prosperous society in the near future.

![Schematic structure and operating properties of terahertz quantum-cascade laser (THz-QCL)](image)

**Keywords**

Terahertz, Quantum cascade lasers, Inter-subband transition, Nitride semiconductors lasers, Molecular beam epitaxy

**Publications**


**Member**

TsungTse Lin / Masafumi Jo / Li Wang / Ke Wang
Phononics Control Technology Team

Team Leader Satoshi Wada Ph.D.

Development of phononics control technology for science and social issues

Our team investigates new optical technologies for solving world-wide environmental and energy problems. We are mainly developing remote-sensing system of poisonous gas, lidar as an atmospheric monitor for high energy cosmic ray observation, and solar-pumped laser for advanced energy source. We are also developing tunable laser-based biosensors for biomedical and agricultural applications. These researches will contribute to build and to maintain social environment that humans can live safely. Moreover, we are investigating fundamental research topics including particle control with high power laser, a coherent source, and development of laser pumped neutron source. New applied researches were performed on the basis of basic research of laser materials, and nonlinear optics.

Keywords
Engineering, Mathematical and physical sciences, Advanced Photonics Technology Development Group

Publications

Member
Norihito Sato / Kiyu Kase / Tomoko Matsuyama / Takaharu Sassa / Takayo Ogawa / Masao Yumoto / Koichiro Shirota / Yusuke Tajima / Tetsuya Aoyama / Noboru Ebizuka / Hiroyoshi Aoki / Takuya Hosobata / Satoru Egawa / Masahiro Takeda / Yuko Sato

(a) Sodium LIBAR
(b) Coherent Lyman-α resonance radiation source for ultra-slow muon generation
(c) Laser inspection of infrastructure by courtesy of Shibaura Inst. and Suez Corp.
(d) Application of phononics control technology to plant cultivation

Ultrahigh Precision Optics Technology Team

Team Leader Yutaka Yamagata D.Eng.

Developing advanced optical components by ultrahigh precision technology

Our team develops advanced ultrahigh-precision/micro fabrication technologies and their application to scientific apparatuses and devices to support advanced scientific research at RIKEN. Research and development plans of our team include the following four topics:
1. Development of ultrahigh-precision optics including design, fabrication, metrology and computational simulation;
2. Development of ultrahigh-precision/micro fabrication technologies;
3. Development of materials and devices for biology or biochemistry such as microfluidic immunoassay devices.

In all R&D topics, our team collaborates with laboratories inside and outside of RIKEN and helps them to construct the most advanced experimental apparatuses, which will lead to innovative scientific research results.

Keywords
Engineering, Interdisciplinary science and engineering

Publications

Member
Koshibe Shinya / Yasuku Taya / Yoshikichi Takizawa / Tetsuya Anzawa / Noboru Ebizuka / Hiroyoshi Aoki / Takaya Hosobata / Satoru Egawa / Masashiro Takakura / Yoko Sato
Research and development of compact neutron system for practical use at anytime, anywhere

RIKEN has developed accelerator-driven compact pulse neutron systems for practical use in industrial applications and non-destructive infrastructure inspection. They are called RIKEN accelerator-driven compact neutron source RANS and RANS-II. RANS has succeeded to develop non-destructive inspection methods with slow and fast neutrons. One is the visualization method of the corrosion and its related water movement of painted steels and the analytical method of the quantitative estimation of the water movement in the painted steels, the other is the neutron engineering diffractometer for the texture evaluation and the austenite volume fraction estimation of iron and steel. The others are the fast neutron imaging applications. Novel scattered neutron imaging method to see through the fracture in the concrete slab has been successfully developed. The compact neutron systems are expected to be widely used on-site.

Example of manufactured parts for scientific apparatus and number of requests

It is inevitably required to devise and/or maintain variety of advanced research instruments and equipments to promote and support laboratories for wide ranges of research fields from fundamental to practical phases. The main duty of our team is to develop those instruments required by researchers, and also this duty should be conducted consequently from concept design to manufacture through detailed design and instrumentation. Our team also deals with improvement and maintenance of working scientific experimental equipments. For these purposes, we are constantly making efforts to improve our design, manufacturing and engineering capabilities for rapid services.

 empirical data on the performance of various materials "

6. Member
- Atsushi Taketani / Masato Takamura / Tomohiko Kobayashi / Yujiro Nakai / Maki Murata / Takeaki Takanashi / Kuntaro Fujita / Chihito Iwamoto / Misao Yano / Shotaro Ikeda / Makoto Fujita / Makoto Goto / Yoshio Matsuoka / Haruhiko Hashizumi

The future imaging of compact neutron non-destructive test system on-site

Examples of manufactured components for scientific apparatus and number of requests in FY2020

- Member
- Kenji Yamasawa / Shigeru Ikeda / Kei Sunouchi / Takashi Fujimoto / Masahiro Takekido / Masaharu Watanuki / Junji Ito