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. Terahertz wave, which has been called 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, environmental monitoring using fluorescent proteins, relativistic geodesy using ultraprecision optical lattice clocks, 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
Attosecond Science Research Team

Team Leader Katsumi Midorikawa

Expanding the horizon of optical science by attosecond photonics

Nonlinear optical process in the XUV region is of paramount importance not only in the field of quantum electronic but also in ultrafast optics. From the viewpoint of quantum electronics, new features of the interaction between intense XUV photons and materials 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.

- Keywords
  - Attosecond Science, Ultrafast Lasers, Strong Field Physics, High Harmonic Generation, Multiphoton Microscopy

- Publications

- Member
  - Tohru Kobayashi / Yutaka Nagata / Yasuo Nabekawa / Eiji Takahash / Tomoya Okino / Hikaru Kuramochi / Yu-Chieh Lin / Kunihiko Ishii / Satoshi Nihonyanagi / Pardeep Kumar

Ultrafast Spectroscopy Research Team

Team Leader Tahei Tahara

Catching nuclear motion of reacting molecules using a-hundred-trillionth pulses

One of the frontiers of science today is to elucidate the molecular mechanisms that enable complex molecular systems to realize high efficiencies, and to utilize the obtained knowledge for creating new functions. For achieving this goal, it is critically important to elucidate fundamental molecular processes comprehensively, from simple molecules in solutions to complex molecules in heterogeneous environments, on the time scales ranging from femtoseconds to seconds. We developed advanced ultrafast and nonlinear spectroscopies based on the “extreme” optical technology, and carry out the most advanced spectroscopic studies for observing and controlling reactions and functions of complex molecular systems. For example, we have developed femtosecond time-resolved impulsive stimulated Raman spectroscopy, and achieved femtosecond tracking of structural evolution of proteins for revealing the earliest process to trigger the biological functions.

- Keywords
  - Ultrafast spectroscopy, Nonlinear spectroscopy, Single-molecule spectroscopy, Dynamics, Interface

- Publications

- Member
  - Kunihiko Ishii / Satoshi Nihonyanagi / Hitkuru Kuramochi / Ahmed Mohammed / Pardeep Kumar
Space-Time Engineering Research Team

Team Leader Hidetoshi Katori D.Eng.

Relativistic Space-Time Engineering with Ultra Precise Atomic Clocks

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 accurate periodicity. The state-of-the-art atomic clocks sense the relativistic space-time curved by gravity, which reveal the difficulty of sharing time with others. Moreover, such clocks may be used to investigate the constancy of fundamental constants, where the foundation of the atomic clocks is anchored.

Optical lattice clocks raised the possibility of ultra-stable and accurate timekeeping by applying the "magic wavelength" protocol on optical lattices. Since the proposal of the scheme in 2001, the optical lattice clocks are being developed by more than 20 groups in the world, and the clocks are surpassing the uncertainty of the current SI second, becoming one of the most promising candidates for the future redefinition of the second.

Our team develops highly precise and transportable optical lattice clocks capable of long time operation by introducing advanced techniques in the field of atomic physics and quantum optics; we thus explore applications of "space-time engineering" 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.

Quantum Optoelectronics Research Team

Team Leader Yuichiro Kato Ph.D.

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.

Remote frequency comparison of optical lattice clocks between RIKEN and the University of Tokyo (UTokyo) reveals their different tick rates as predicted by general relativity.

Scanning electron micrograph of a suspended carbon nanotube field effect transistor.
Observe nano-scale activities within a living cell by sub-wavelength high-speed imaging

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 (4D) 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 photochromism, in experimentation. Cruising inside cells in a super-micro corps, gliding down in a microtubule like a roller coaster, pushing our ways through a jumble of chromatin 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.

Cultured HeLa cells expressing the photoconvertible fluorescent protein, Kaede. Before (left) and after (right) multiple, local irradiation of violet laser light, green-to-red color conversion occurred in the cytosol or nucleus of targeted cells.
Image processing research for scientific information

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.

Colors created by subwavelength metal structure

Innovative Photon Manipulation Research Team intensively studies novel photon manipulation technologies using knowledge and experiences obtained from the researchers on light wave interaction with subwavelength fine fabrication systems. These photon manipulation technologies will be applied for three-dimensional nanofabrication apparatus, intended for researchers both inside and outside RIKEN.
Advanced Laser Processing Research Team

Team Leader: Koji Sugioka

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<td>Femtosecond laser, Laser processing, Micro/nanofabrication, 3D fabrication, BioChip</td>
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<td>Kotaro Ohashi / Dongzhi Zhang / Daniele Serien / Yasutaka Harada / Seisuke Nakashima / Felix Sima / Yang Liu</td>
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Creation of 3D functional micro and nano structures by femtosecond laser

The high peak intensity of femtosecond laser allows nonlinear multiphoton absorption to be induced in transparent materials. More interestingly, a focused femtosecond laser beam can deposit localized energy by nonlinear absorption in transparent materials to process the materials in a three-dimensional (3D) manner. Our team takes advantages of this feature to integrate 3D complex polymer structures with micro and nano feature sizes into 3D glass microfluidic structures. This novel technique termed “femtosecond laser ship-in-a-bottle 3D integration” can create highly functional biochips that perform mixing, separation, reaction and analysis of biochemical materials in parallel with high speed and high sensitivity. The fabricated biochips are being applied to researches on early detection and inspection of disease, elucidation of the mechanism of disease progression and function of a single cell, etc.

Cloud-Based Eye Disease Diagnosis Joint Research Team

Team Leader: Masahiro Akiba

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<td>Hideto Yokota / Shin Yoshizawa / Satoko Takeda / Shigeki Kudo / Masahiko Morita / Norio Yasuhisa / Guanghui An / Masami Nakamura</td>
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Development of classification model of eye-disease using machine learning

The joint research team aims to develop the system which enable to detect the early sign of ocular diseases by utilizing the posterior optical coherence tomography (OCT) images and other relevant ophthalmic diagnosis data. By applying the analysis method to the OCT images, disease-related factors and image features are extracted. Machine learning and deep learning methods are adapted so as to utilize even with small amount of clinical data. It is said that the transition from disease treatment (sick care) to screening (health care) are required. Fundus is the only organ from which the blood vessels can be directly observed and eyes are said to be the windows of the body. Studies on the relevance of systemic diseases such as arteriosclerosis, cardiovascular diseases and lifestyle diseases from the fundus are also being conducted. We are constructing an ophthalmic diagnosis support system by utilizing various instrument data, non-structured data, and multi-dimensional data such as 3D structured data as well as its time-series data. This approach can be well suited for screening.

Classification of glaucoma

(a) Automated classified parameters from OCT image,
(b) Quantified most important 9 parameters from OCT data and patient’s background information,
(c) example of results with different glaucoma type.
### Terahertz Sensing and Imaging Research Team

**Team Leader**
Chiko Otani  |  O.Sci.

#### Fields
- Interdisciplinary science and engineering
- Chemistry, Engineering, Molecular Biology / Genetics

#### Keywords
- Terahertz science, Terahertz spectroscopy
- Terahertz imaging, Terahertz control, Superconducting detector

#### Publications

#### Member
Masatomo Yamashita / Hiroki Hoshiba / Satoru Mima / Yoshio Koyama / Shota Yamazaki / Isao Yoshihime
Noriaki Yakeuchi / Shwpo Oguri / Kodai Koyama

#### 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 CMB polarization measurements as well as the collaborative research and development for its practical applications.

#### Figure
[Left] THz and Raman spectra of biodegradable polymer (PHB)
[Right] Structural change by irradiating strong THz radiation

(Left) THz and Raman spectra of biodegradable polymer (PHB)
(Right) Structural change by irradiating strong THz radiation

(top: without irradiation, bottom: with irradiation)
Terahertz Quantum Device Research Team

Team Leader: Hideki Hirayama

- **Fields**: Optical Device Engineering, Quantum Electronics, Semiconductor Physics

- **Keywords**: terahertz, quantum cascade lasers, inter-subband transition, nitride semiconductors, molecular beam epitaxy

- **Publications**

- **Member**
  - Wataru Terashima / Tsung Tse Lin
  - Masayuki Jo / Ke Wang / Li Wang
  - Muhammad Aymal Khan / Sachie Fujikawa

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**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 have 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.

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Photonics Control Technology Team

Team Leader: Satoshi Wada

- **Fields**: Engineering, Mathematical and physical sciences, Biology / Biochemistry, Agricultural Sciences, Medicine, dentistry, and pharmacy

- **Keywords**: Photonics control technology, Medical and agricultural measurement, Trace gas measurement, Natural energy, Space applications

- **Publications**

- **Member**
  - Norihito Saito / Kienmu Kase
  - Tomoki Matsuyama / Takafumi Sassa
  - Takayoshi Ogawa / Masaki Yumoto
  - Takahiro Mitchihara / Katsumi Fuji
  - Loutchev Oleg Anatolievich / Kentaro Mori
  - Takanori Kojima / Takayoshi Ogawa / Miyamoto Kusumi / Yukihiro Maruoka / Taro Fujiwara / Kei Otsuka
  - Masayuki Maruyama / Takeharu Murakami / Taro Fukuyama / Kayo Koike / Takane Kobayashi / Yuichi Komachi
  - Masayuki Maruyama / Takeharu Murakami / Taro Fukuyama / Kayo Koike / Takane Kobayashi / Yuichi Komachi

**Development of photonics 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 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 human can live safely. Moreover, we are investigating fundamental research topics including particle control and measurement of pulsed Lyman-α 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.
Ultrasound Precision Optics Technology Team

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 fabrication technology for soft materials using the electrosprey deposition method; and (4) 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.

Neutron Beam Technology Team

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 RANS2. 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 reflected neutron imaging method to see through the fracture in the concrete slab has been successfully developed. The compact neutron system is expected to be widely used on-site.
Supporting advanced scientific research by manufacturing technology

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 gains 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.

Examples of manufactured components for scientific apparatuses and number of requests in FY2016

Fields
Engineering; Interdisciplinary science and engineering

Keywords
Production technology, mechanical machining, laser machining, CAD/CAM/CAX, 3D printer

Publications


