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, relativistic geodesy using ultraprecise 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

Extreme Photonics Research Group

- Attosecond Science Research Team
  Team Leader Katsumi Midorikawa
- Ultrafast Spectroscopy Research Team
  Team Leader Tahei Tahara
- Space-Time Engineering Research Team
  Team Leader Hideyoshi Katori
- Quantum Optoelectronics Research Team
  Team Leader Yuichiro Kato
- Ultrafast Coherent Soft X-ray Photonics Research Team
  Team Leader Eiji J. Takahashi
- Ultrafast Electron Beam Science RIKEN Hakubi Research Team
  RIKEN Hakubi Team Leader Yuya Morimoto

Subwavelength Photonics Research Group

- Live Cell Super-Resolution Imaging Research Team
  Team Leader Akihiko Nakano
- Biotechnological Optics Research Team
  Team Leader Atsushi Miyawaki
- Image Processing Research Team
  Team Leader Hideto Yokota
- Innovative Photon Manipulation Research Team
  Team Leader Takao Tanaka
- Advanced Laser Processing Research Team
  Team Leader Koji Sugiuira

Terahertz-wave Research Group

- Tera-Photonics Research Team
  Team Leader Hiroaki Minamide
- Terahertz Sensing and Imaging Research Team
  Team Leader Chikko Otsuki
- Terahertz Quantum Device Research Team
  Team Leader Hidetoshi Katori

Advanced Photonics Technology Development Group

- Photonics Control Technology Team
  Team Leader Satoshi Wada
- Ultrahigh Precision Optics Technology Team
  Team Leader Yutaka Yamagata
- Neutron Beam Technology Team
  Team Leader Yoshie Otake
- Advanced Manufacturing Support Team
  Team Leader Yutaka Yamagata

Office of the Center Director
Director Akihiko Nakano
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 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 ultrashort 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

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 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 ultrashort 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.

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.
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 fully utilize the novel time resource provided by such clocks. For example, a transportable ultraprecise atomic clock, which may be taken out into the field, will function as a gravitational potential meter. We experimentally investigate the impact of such relativistic geodesy and new roles for clocks in the future.

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 new 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.
Creating novel ultrafast soft x-ray sources using the extreme nature of laser

Laser is the ultimate light source created by mankind, and it has become an indispensable tool for our social life. In this laboratory, our main goal is to create an unexplored ultrafast laser by using the extreme nature of laser such as ultrashort pulse, super broadband, high power, and so on. Specifically, we are developing a high-power a few-cycle laser source, and using it to develop novel laser source with full coherence in the soft x-ray region and a pulse width of attosecond region. We extend the frontier of laser science through the development of novel laser sources.

Space-time imaging of the initial steps of chemical reactions with ultrafast electron beams

Electron beams are used for examples in electron microscopy and electron-beam lithography, where high spatial resolution is required. By using state-of-the-art laser and electron-beam technologies, we control the temporal structure of an electron beam with ultimate attosecond resolution and apply the controlled electron beams for imaging and controlling ultrafast chemical reactions. We explore the atomic-scale dynamics of electrons in a material which is the initial step of most photochemical reactions.
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 (40) and elucidate underlying molecular mechanisms. We will also try to extend this technology to medical and pharmacological applications.

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 (40) 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 cap, gliding down in a microtubule like a roller coaster, pushing our ways through a jungle 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.

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 cap, gliding down in a microtubule like a roller coaster, pushing our ways through a jungle 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.

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 cap, gliding down in a microtubule like a roller coaster, pushing our ways through a jungle 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.
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

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 nanofabrication 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 aluminum 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) demonstrates color palette covering a broad gamut of colors.

Lightwave manipulation by subwavelength structures


Image Processing Cloud

Colors created by metamaterial absorber that consists of subwavelength aluminum structure.
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).

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). 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, bioschips, micromachines, etc.

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

Our team develops state-of-the-art frequency-tunable THz-wave sources which exploit new THz-wave application fields. A nonlinear optical process is utilized for realizing the THz-wave source which lights up the THz-wave gray zone, and our original design and method will be demonstrated. We develop THz sources with high output, wide tunability, high stability and narrow linewidth.

Leading Terahertz science & applications with innovative Tera-photonics technology

Our team develops state-of-the-art frequency-tunable THz-wave sources which exploit new THz-wave application fields. A nonlinear optical process is utilized for realizing the THz-wave source which lights up the THz-wave gray zone, and our original design and method will be demonstrated. We develop THz sources with high output, wide tunability, high stability and narrow linewidth. Active collaboration with both internal and external research groups is carried out for exploring new applications by development of instrument combined with new THz-wave sources. Advanced THz-wave technologies are also being developed in cooperation with industry to establish practical THz-wave sources and technologies in the world.

Leading Terahertz science & applications with innovative Tera-photonics technology

Our team develops state-of-the-art frequency-tunable THz-wave sources which exploit new THz-wave application fields. A nonlinear optical process is utilized for realizing the THz-wave source which lights up the THz-wave gray zone, and our original design and method will be demonstrated. We develop THz sources with high output, wide tunability, high stability and narrow linewidth. Active collaboration with both internal and external research groups is carried out for exploring new applications by development of instrument combined with new THz-wave sources. Advanced THz-wave technologies are also being developed in cooperation with industry to establish practical THz-wave sources and technologies in the world.
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 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.

Keywords

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

Publications


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 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.

Keywords

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

Publications


Member

Masatatsu Yamashita / Hirochiku Hoshina / Yoshiki Sasaki / Javier Miguel Hernandez / Mingjo Chen / Yuya Yamada / Rosalena Irima / Akiho Aiji
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 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 maintain social environment that humans can live safely. Moreover, we are investigating fundamental research topics including particle control with high power Lyman α, and development of laser pumped neutron source. New applied researches were performed on the basis of basic research of laser materials, and nonlinear optics.

Development of 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. Development and research 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 immunosassay 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.

Fields

Engineering, Mathematical and physical sciences, Biology / Biochemistry, Agricultural Sciences, Medicine, dentistry, and pharmacy

Keywords

Particle control and measurement, Medical and agricultural measurement, Trace gas measurement, Natural energy, Space applications

Publications


Member

Nobuhito Satoh / Kimito Kase / Tomoki Matsuyama / Takafumi Sassa / Takaya Ogawa / Masato Yamamoto / Katsuhiko Fujii / Kentaro Miyata / Masayuki Maruyama / Koichiro Shirota / Yusuke Tajima / Yoshiyuki Takizawa / Tetsuya Aoyama / Noboru Ebizuka / Hiroyoshi Aoki / Takuya Hosobata / Satoru Egawa / Masahiro Takeda / Yuko Sato

(a) Sodium LIDAR
(b) Coherent Lyman α resonance radiation source for ultra-slow muon generation
(c) Laser inspection of infrastructure by courtesy of Aizu-ku, Pref. and Space Corp.
(d) Application of photonics control technology to plant cultivation

An elliptic neutron focusing mirror with metallic substrate used in J-PARC BL-16(SOFIA)

(a) N-Methoxycarbonyl-2-ethylhexyl-4-nitroaniline crystal
(b) Lithium fluoride bonded to potassium bromide crystal
(c) Lithium fluoride bonded to potassium bromide crystal
(d) Lithium fluoride bonded to potassium bromide crystal

Member

Koshibo Shibata / Yasuaki Tajima / Yoshinobu Takizawa / Tetsuya Anzai / Noboru Ebizuka / Hiyoshi Akou / Takuya Hosobata / Satomi Egawa / Masahiro Takada / Yoko Satoh
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 diffractionmeter for the temperature 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.

### Research and development of compact neutron system for practical use at anytime, anywhere

**Field**
- Physics, Engineering, Interdisciplinary science and engineering

**Keywords**
- Accelerator-based compact neutron system
- Characterization of microstructure and texture evaluation in steels
- Research and development of non-destructive inspection for infrastructures
- Visualization of water and air hole in concrete slabs
- Detection of salt damage in the concrete by prompt-gamma neutron activation analysis

**Publications**

**Member**
- Asoha Taketani / Masato Takamura / Tomohiko Kobayashi / Yuzo Wakabayashi / Makiko Murata / Takaki Takanishi / Kunitoshi Fujita / Chihito Iwamoto / Mingjie Yan / Shota Ikeda / Makoto Fujino / Makoto Goto / Yoshio Matsuzaki / Haruhiko Hashizume

---

### 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.

**Field**
- Engineering, Interdisciplinary science and engineering

**Keywords**
- Production technology, Mechanical machining, Laser machining, CAD/CAM/CAE, 3D printer

**Publications**

**Member**
- Kenji Yamazawa / Shigeru Ikeda / Kei Sunouchi / Takeshi Fujimoto / Masahito Takekawa / Masaharu Watanuki / Juriko Ito