FIR UF

Research Center for Development of Far-Infrared Region, University of Fukui

FIR UF
Univ. Fukui

福井大学　遠赤外領域開発研究センター

About FIR UF

Director
Prof. Masahiko Tani

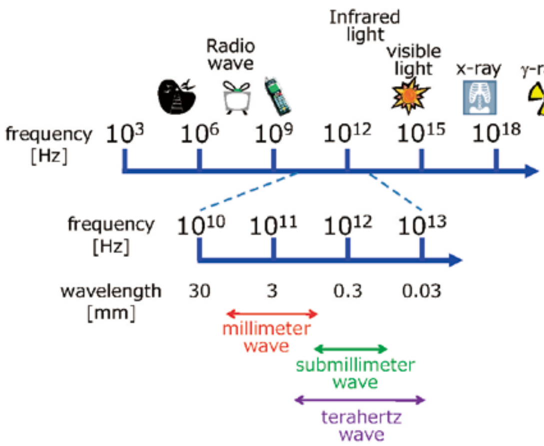
- The Research Center for Development of Far-Infrared Region at the University of Fukui (FIR UF, or FIR Center) is performing research and development in the far-infrared region between radiofrequency waves and visible light using world class gyrotrons, which were originally developed at the FIR UF.
- The FIR UF attracts a great deal of attention owing to its contribution to the global evolution of the research and development in the far-infrared region through the Center's agreements for academic exchanges and memorandums of understanding (MOUs) for collaborations with numerous domestic and overseas institutions.

Overview of FIR UF

The far-infrared (FIR), i.e., terahertz (THz), frequency region is between the radiofrequency (RF) wave region and the infrared light region. The wavelengths of the FIR region range from a few mm to a few tens of micrometers, roughly corresponding to a frequency range of 100 GHz to 10 THz. The electromagnetic (EM) waves in the FIR/THz wave region can propagate in straight lines as light waves and penetrate materials as RF waves. This wavelength region is proving invaluable for many essential 21st-century technologies.

The FIR/THz wave region has long been regarded as an unexplored region because of the lack of powerful sources.Rapid and great progress is expected regarding the FIR region in the very near future. The FIR UF has developed a novel high power far-infrared source "Gyrotron" and is conducting the research and development of new technologies using these world-class machines. The FIR UF is also performing research on THz science, developing novel methods of THz wave generation and new THz spectroscopic techniques. The FIR UF is now a leading research base for FIR/THz waves in Japan.

The FIR UF collaborates with domestic and overseas institutions in worldwide research activities. The center aims to fulfill its role as a world-class base for research on FIR/THz waves. Their research on high-frequency gyrotrons and the development of new FIR/THz spectroscopic techniques attracts considerable attention from around the world.



The electromagnetic spectrum

Research and Development Objectives in FIR UF

To investigate the unexplored region of EM waves

- Further improvement of our high-power FIR/THz-wave-source gyrotrons
- Development of basic technologies in the FIR region, such as high-efficiency power transmission systems and high-sensitivity detectors

To extend research fields with our FIR/THz gyrotrons

- Application of FIR/THz gyrotrons to fundamental physics, materials science, life science, the development of materials with new functions, energy science, and many other fields

To develop novel methods of THz wave generation, detection, and propagation

- THz optical and spectroscopic research using broadband THz waves

To open a new academic field

- Aiming to open a new and interdisciplinary academic field in FIR/THz regions associated with fundamental physics, material science, energy science, life science, etc. using high-power FIR/THz radiation sources

An advanced gyrotron

Chronology of FIR UF

Early 1980's Research for FIR/THz region begins.

1984 Successful oscillations at 70 GHz and 100 GHz by Gyrotron FU I, attracting worldwide attention as a high-frequency gyrotron

1989 Realization of sub-millimeter wave gyrotron at 380 GHz

1991 Gyrotron oscillations at 636 GHz

1992 The Laboratory for Application of Superconducting Magnets is founded in the Faculty of Engineering.

1996 Gyrotron oscillations at 837 GHz

1997 Gyrotron oscillations at 889 GHz (world's highest-frequency gyrotron oscillations)

1999 The FIR Center is founded by the re-organization of the Laboratory for Application of Superconducting Magnets in Faculty of Engineering per the ordinance of the Ministry of Education.

2005 World's first gyrotron oscillations exceeding 1 THz (1013 GHz)

2006 The Cryogenic Laboratory is functionally integrated into the FIR Center.

2008 Research for THz science begins.

2011 Joint research scheme, open to public, begins.

2013 Research for FIR/THz region in University of Fukui is designated by the Ministry of Education as one of the research topics that must be performed intensively.

Gyrotron FU I

Displayed in the entrance hall of FIR UF building

Research organization

- Director: Prof. Masahiko Tani
- Vice Director: Prof. Seitaro Mitsudo
- Research Supervisor: Prof. Teruo Saito
- Supervisor of International Cooperation: Prof. Toshitaka Idehara

Research groups of FIR UF

Attach the domain name "u-fukui.ac.jp", after "@" of the following to form the full e-mail addresses.

Core research group 1. Development of fundamental far-infrared technologies

Prof. Teruo Saito, Associate Prof. Yoshinori Tatematsu.
Postdoctoral fellows: Dr. Yusuke Yamaguchi, Dr. Eduard M. Khutoryan

- Development of high-power far-infrared radiation sources
- Research into the high-efficiency, high-stability, and high-frequency operation of gyrotrons

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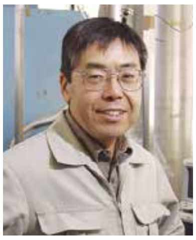


Core research group 2. Applications of THz technologies for research in materials science and sensing

Prof. Masahiko Tani, Associate Prof. Kohji Yamamoto.
Postdoctoral fellows: Dr. Atsushi Iwamae, Dr. Gudrun Niehues, Dr. Stefan Funkner

- Development and application of novel THz-wave emitters and detectors
- THz optical and spectroscopic research using broadband THz waves
- Time-domain coherent anti-Stokes Raman scattering (CARS) spectroscopy in the THz region

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Core research group 3. Development of new technologies in the far-infrared region

Prof. Isamu Ogawa

- Further improvements in the gyrotron performance for application as a high-power far-infrared radiation source
- Development of high-performance transmission lines for wider application of the gyrotrons

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Core research group 4. Low-temperature and condensed-matter physics in the far-infrared region

Prof. Seitaro Mitsudo, Associate Prof. Yutaka Fujii

- Electron spin resonance spectroscopy in the submillimeter-wave region
- Millimeter- and submillimeter-wave material processing
- Development and application of dynamic nuclear polarization-enhanced nuclear magnetic resonance (DNP-NMR)

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yfujii@


Research organization

International cooperative research group 1. Development of high-power THz-wave technologies

Prof. Toshitaka Idehara

- Development of high-power THz-wave radiation sources: the Gyrotron FU CW Series
- Development of new THz technologies through international collaborations

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Visiting professor's group 1. Far-infrared spectroscopy and its applications

Prof. Seizi Nishizawa, Prof. Shintaro Ishiyama, Prof. Yoshiaki Tsunawaki, Associate Prof. Mitsuru Toda

- Applications of high-power THz waves
- Development and applications of novel THz time-domain spectroscopy (TDS)

Visiting professor's group 2. Development of far-infrared devices

Prof. M.Petelin, Prof. G.N.C.Santos, Prof. H.Aripin, Prof. V.N.Manuilov

- Development of submillimeter-wave gyrotrons for materials processing
- Computer simulation for the design of gyro devices

Cooperative research group 1. Material physics in the far-infrared region

Prof. Hikomitsu Kikuchi, Prof. Kazutoshi Fukui

- Electron spin resonance (ESR) spectroscopy in the submillimeter wavelength range
- Studies of the optical properties of nitride semiconductors using broadband spectroscopy in the far infrared to vacuum ultraviolet range

Cooperative research group 2. Applications of far-infrared lasers

Prof. Toshikazu Hori, Prof. Kazuki Kurihara

- Simulation of submillimeter electromagnetic wave propagation
- Development and application of far-infrared molecular lasers

Cooperative research group 3. Materials evaluation in the far-infrared region

Prof. Yoshiro Iwai, Associate Prof. Tomomi Honda

- Mechanical characterization of high-quality ceramics
- Surface characterization of new materials formed using high-power far-infrared technology

Research support organization

- Research advisers: Prof. Fumitaka Horii, Prof. Takao Mizusaki, Prof. Kiyomi Sakai
- Coordinators: Dr. Tasaburo Saji, Dr. La Agusu
- Research support staff: Mr. Shigenobu Arakawa
- Technical staff: Mr. Tomohiro Kanemaki, Mr. Takanobu Yamada, Dr. Takashi Furuya
- Cryogen supply section: Prof. Isamu Ogawa (section head)
- Secretaries: Ms. Miyuki Morito, Ms. Yoriko Kuwashima,
  Division of Research Promotion, Department for Strategic Planning & Promotion

1 Advanced Gyrotron Project

In the FIR UF, on the basis of the achievements of the gyrotron study, a project for the development of advanced gyrotrons has been promoted for application in various studies. Representative results are shown here.

1. Gyrotron with an internal converter, Gyrotron FU CW G Series

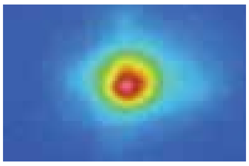
We commenced the development of CW gyrotrons equipped with a converter to produce a Gaussian beam. We can apply these devices in a wide variety of scientific research areas.

Gyrotron FU CW GI

The first gyrotron of this series, which was used for the direct measurement of positronium hyperfine splitting

Gyrotron FU CW GI

- Fundamental harmonics
- Frequency: 203 GHz
- Power: 0.5 kW



Infrared image of the temperature increase caused by the radiation beam from the Gyrotron FU CW GI.

Gyrotron FU CW GIII

Second-harmonic, high-power gyrotron for use as a power source for pulsed ESR

Gyrotron FU CW GIII

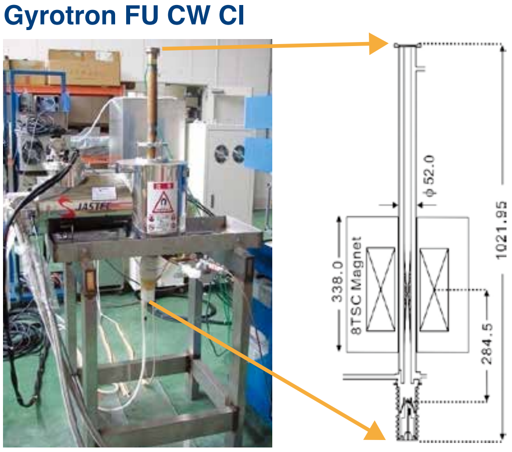
- Second harmonics
- Frequency: 395 GHz
- Power: 0.4 kW

A second-harmonic oscillation efficiency of 4% was realized using a specially designed electron gun. Continuous operation for over ten hours was achieved.

2. Compact gyrotrons - Gyrotron FU CW C Series

Using innovative designs for making gyrotron tubes compact, along with a compact magnet and rack-mounted power supplies, we realized compact gyrotron systems. Each system can be installed within a 3-m^2 floor space and a height of 1.5 m.

Gyrotron FU CW CI



- Frequency tunability
- Fundamental harmonics: 107–205 GHz, 150–320 W
- Second harmonics: 290–396 GHz, 10–30 W
- Applications: Studies on magnetic resonance and DNP-NMR

Gyrotron FU CW CII

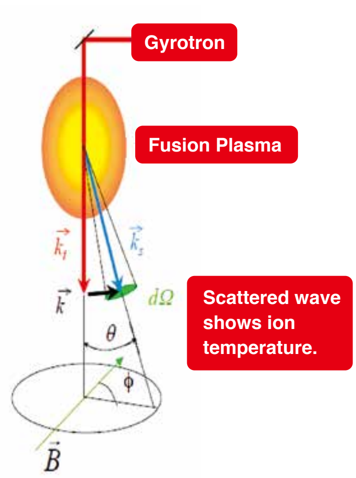
- Frequency fixed
- Fundamental harmonics: 203 GHz, 0.8 kW
- With mode conversion system (Gaussian mode output)
- Applications: Measurement of positronium; operation with rack-mounted power supplies

Operation with rack-mounted power supplies

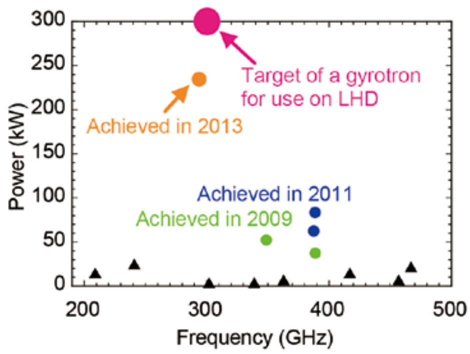
Operation parameters
- Cathode voltage: 20 kV
- Beam current: 300 mA

3. Development of a high-power pulse gyrotron

Using a gyrotron, the ion temperature of a fusion plasma can be measured up to 100 million degrees. For this application, more than 100 kW is required. Following the achievement of the world's highest second-harmonic oscillation, we now aim to realize even higher powers with the fundamental harmonic oscillation.



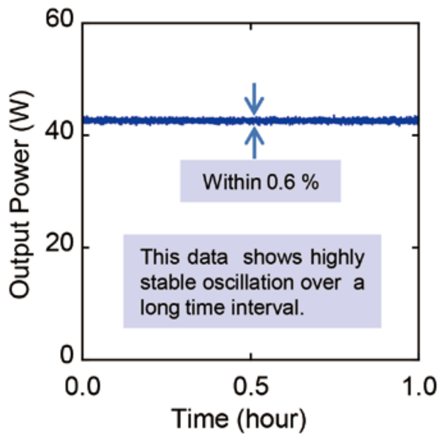
Target power of a high-power gyrotron
The optimum frequency is 300~400 GHz.
A high power exceeding 300 kW is required.



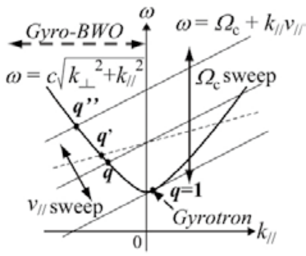
A high-power pulse gyrotron mounted on a 12-T SC magnet is under development for use on LHD in the National Institute for Fusion Science.

4. Stabilization of power

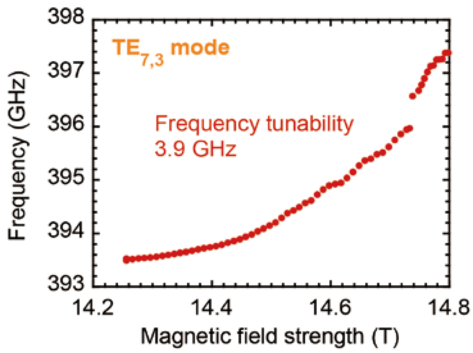
The stabilization of the output power over a long time interval is necessary for the application of the gyrotrons. A highly stable oscillation within a power fluctuation of 0.6% was realized by PID feedback control.



5. Continuous frequency tunability



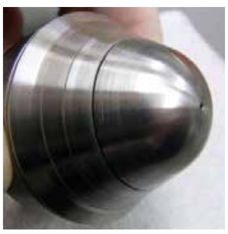
The continuous frequency tunability is very important for the application of the gyrotrons. We realized a 400-GHz-band gyrotron with a frequency tunability greater than 4 GHz using the mechanism of backward wave oscillation.



6. Development of high-performance electron guns

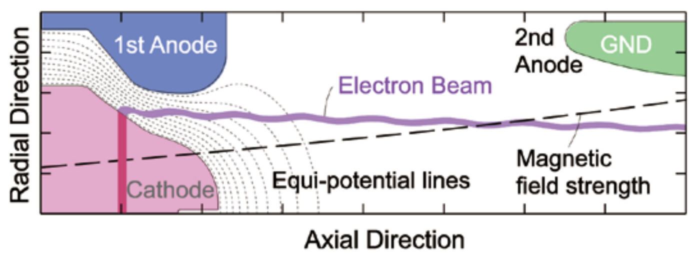
For the advancement of the gyrotrons, high-performance electron guns are needed to emit electrons as a generator of electromagnetic waves. We developed high-performance electron guns using an original design methodology.

Cathode



Cathode (Filament on)

Electrons emitted from the cathode wind around the magnetic field lines.



2 Materials science in the high-power far-infrared region

The applied research on the gyrotron is one of the most important research fields at the FIR UF. There, for the first time in the world, ESR measurements were successfully performed using a gyrotron. This new technology has been applied in solid-state physics as well as studies of advanced gyrotrons. Studies of gyrotron applications have led to applied research in the various aforementioned fields. We also developed an original materials processing system with the world's highest frequency (300 GHz) and advanced the study of materials processing with high-frequency electromagnetic waves. We continue to improve these new technologies of the high-power far-infrared region.

1. Material processing with gyrotrons

Heating by an electromagnetic wave at 2.45 GHz is the technique generally employed by microwave ovens. At the FIR UF, experiments on the heating of materials can be performed with electromagnetic waves at frequencies 100 times that of the microwave oven, owing to the high-frequency and high-power capabilities of gyrotrons. On heating by an electromagnetic wave, the energy is provided directly to the molecules, yielding a material unlike that produced by conventional heating. Thus, the characteristics of materials can be improved, with added functions, by tuning the frequency and output power of the electromagnetic waves.

Equipments for material processing with gyrotron 1

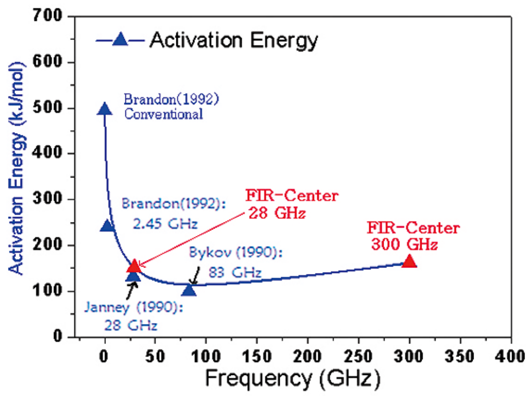
The world's first 300 GHz/2.3 kW high-power electromagnetic wave irradiation system

Equipments for material processing with gyrotron 2

28 GHz/15 kW high-power electromagnetic wave irradiation system

Features of material processing by electromagnetic waves

- Ceramics (materials for sintering) themselves are heated.
- We can realize a reaction process without a thermal equilibrium, using materials with different electromagnetic-wave absorption characteristics (differential heating).
- Innovative material development using special effects (“non-thermal effect,” electromagnetic wave effects).



The frequency dependence of the apparent activation energy of the high-purity alumina ceramics was revealed by 28- and 300-GHz electromagnetic-wave sintering experiments.

2. Development and application of the high-frequency magnetic resonance technique

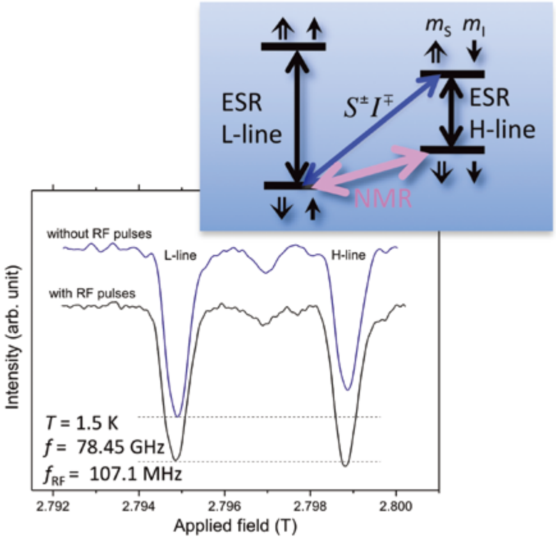
It is interesting to study the magnetic properties of a material under the extreme conditions of high magnetic fields and very low temperatures because the basic and fundamental physics in condensed matters are often revealed. We can investigate these properties on the microscopic scale, inside the material, using the magnetic resonance technique over a wide frequency range.

mm-wave vector network analyzer (MVNA)

FFT-NMR spectrometer

Magnetic field: 18-T static field, 40-T pulsed field
Temperature: 300~1.5 K (liquid He)
~0.1 K ($^3He/^4He$ dilution refrigerator)
Frequency:
Electron spin resonance (ESR): up to 800 GHz (MVNA)
Nuclear magnetic resonance (NMR): 5–400 MHz (300-W pulsed RF)

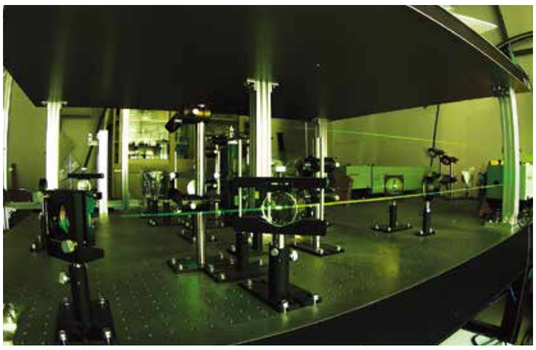
Example of ESR/NMR double resonance



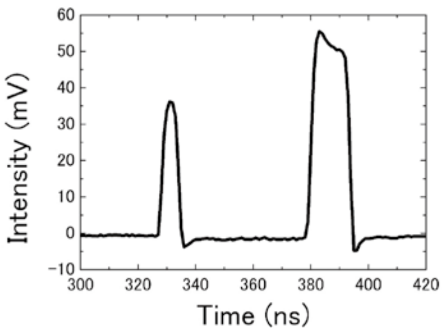
Evidence of dynamic nuclear polarization of ^{31}P lightly doped in silicon and control of nuclear polarization by applying RF pulses (Y. Fujii et al., Proc. of FIRT 2012)

3. Development of high-frequency electron spin echo measurement system

The electron exhibits both electric and magnetic properties. The magnetic properties have mainly been used in magnets. With the development of quantum mechanics, the realization of spin electronics and quantum computers using a quantum magnetic property (spin) of the electron is attracting considerable attention.
By measuring with irradiation pulses of a few nanoseconds (approximately a billionth of a second) with a high frequency and high-power electromagnetic waves from a gyrotron, we can examine the dynamic characteristics of the electron spin and control it to realize these new quantum applications.



High-frequency electron-spin echo measurement system under development

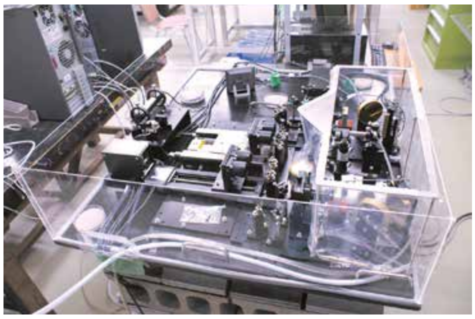


Ultra-short pulsed 154 GHz gyrotron output, 10- and 20-ns, while maintaining the coherency using a light-driven semiconductor switching device

3 Spectroscopic and application research using THz waves

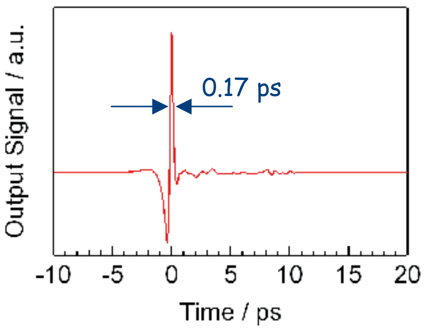
The Terahertz Science Research Group has conducted THz spectroscopic studies in materials science and has developed THz techniques for non-destructive inspection. Our major topics are as follows:

- Development and application of novel THz-wave emitters and detectors
- THz optical and spectroscopic research using broadband THz waves
- Time-domain coherent anti-Stokes Raman scattering (CARS) spectroscopy in the THz region

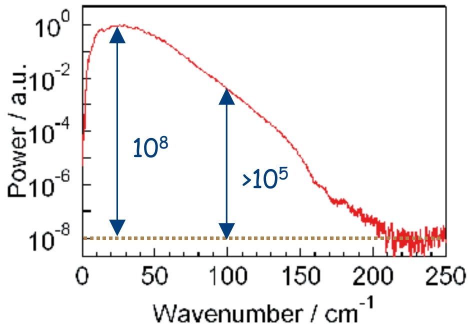


Terahertz time-domain spectrometer

In THz time-domain spectroscopy (THz-TDS), we measure the temporal shape of broadband THz waves with femtosecond time resolution. By transforming the time-domain data to the frequency domain, we obtain THz spectra in the range of 0.1–5 THz (frequency-domain data). We use femtosecond-pulse lasers and photoconductive switch devices to generate and detect the THz waves.



Temporal shape of terahertz wave

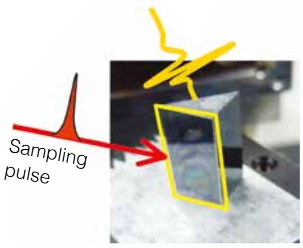


Power spectrum of THz wave

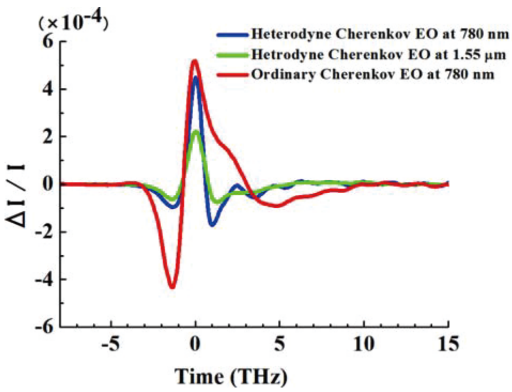
1. Development and application of novel THz-wave emitters and detectors: detection of THz waves by electro-optic sampling with Cherenkov phase-matching

As a novel THz wave detection method, an electro-optic (EO) sampling method based on a Cherenkov phase-matching scheme was developed. This method allows any optical sampling wavelength to be used, by adjusting the phase-matching angle between the THz wave and the sampling beams.

We also developed a heterodyne EO sampling method, whereby the intensity modulation of the sampling beam is detected without using any polarization optics.



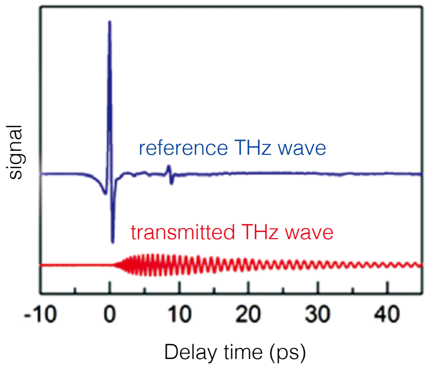
$LiNbO_3$ crystal



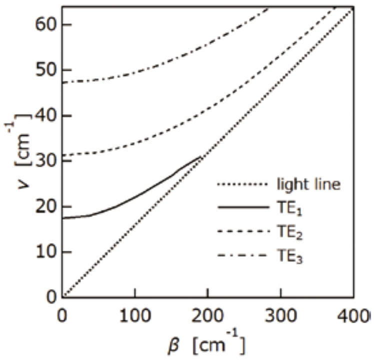
THz waveforms detected by EO sampling with Si-prism-coupled $LiNbO_3$ crystal in the Cherenkov-phase-matched heterodyne scheme.

2. THz optical and spectroscopic research using broadband THz wave: superfocusing of THz wave

It is difficult to focus a freely propagating THz wave into a beam with a submillimeter diameter, owing to the diffraction limit. Focusing a THz wave into a diameter less than 100 μm can be achieved using a metal waveguide comprising two tapered-metal plates. By this “THz superfocusing effect,” THz waves are available for a wide range of applications, e.g., the inspection of a small amount or a very thin sheet of samples. We have been performing fundamental research on THz superfocusing, as well as studies of its applications.



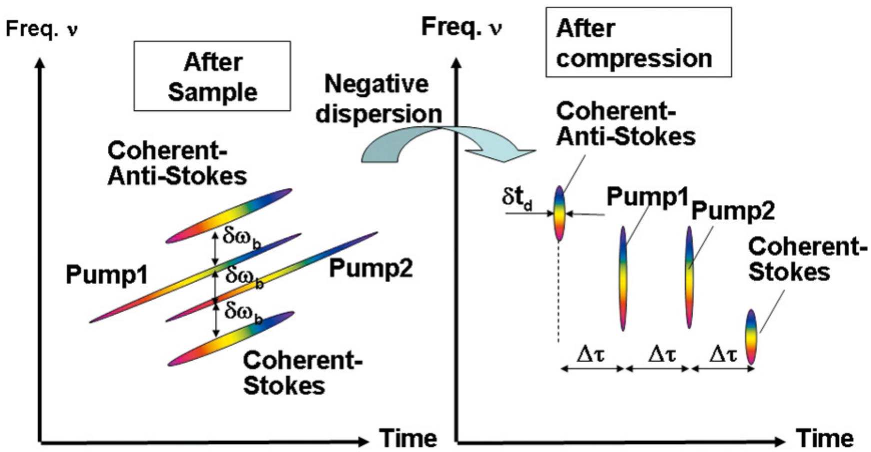
Blue and red lines represent transmitted THz waves through air and through a tapered-metal waveguide, respectively.



Dispersion curves of THz wave propagation through a metal-parallel-plate waveguide

3. Time-domain coherent anti-Stokes Raman scattering spectroscopy in the THz region

To study the molecular vibrations in the THz frequency region, we are developing coherent anti-Stokes Raman scattering spectroscopy (THz-CARS), in which the CARS signal is detected in the time domain. In this novel CARS spectroscopy, low-frequency Raman spectra, e.g., at several tens of GHz, can be measured using chirp-controlled optical pulses from a single femtosecond laser as the pump. This eliminates the need for two frequency-stabilized lasers with a THz difference frequency, as is required in conventional CARS spectroscopy.



Schematic illustration of the THz-CARS spectroscopy

International research collaborations

- The FIR UF has concluded agreements for academic exchange and MOUs with 11 and 11 overseas institutes, respectively, for the development of international joint research projects.
- FIR UF is the center of the international consortium “Promoting International Collaboration for Development and Application of Submillimeter Wave Gyrotrons,” with 6 overseas and 2 domestic institutes.
- Foreign visiting professors are invited under the bylaws of the FIR UF, and one or two of these professors are always present at the FIR UF to contribute to the promotion of the international joint research projects.

Institute for Plasma Research, Stuttgart University(IPR-SU), Germany
- Development of submillimeter-wave gyrotrons
- Applications in plasma diagnostics

Science-Technical Center of Microtechnologies, D. Y. Efremov Institute of Electrophysical Apparatus (NIIEFA), Russia
- Generation and applications of strong particle beams and electromagnetic waves

Institute of Applied Physics , Russian Academy of Science(IAP-RAS), Russia
- Development and applications of high-frequency gyro-devices

Center for THz-Bio Application Systems, Seoul National University, Republic of Korea
- Development of gyro-devices in the THz range and applications in bioscience

Institute for High Power Pulse and Microwave Technology, Karlsruhe Institute of Technology (IHM-KIT), Germany
- Development and applications of high-quality gyrotrons
- Development of high-efficiency transmission lines for submillimeter-wave gyrotrons

National Institute of Physics, University of the Philippines, Philippines
- Development of THz devices with semiconductors

Faculty of Science, De La Salle University, Philippines
- THz radiation from semiconductors with nanostructure

NMR Center, University of Warwick, UK
- DNP-NMR spectroscopy

Faculty of Mathematics and Natural Sciences, University of Haluoleo, Indonesia
- Applications in material processing

Institute of Electronics, Bulgarian Academy of Sciences(IE-BAS), Bulgaria
- Analysis and optimization of electron guns for compact shower devices and submillimeter-wave gyrotrons

Institute for Solid State Physics, University of Latvia, Latvia
- Physics of gyrotrons in THz range

Usikov Institute for Radio Physics and Electronics, National Academy of Science of Ukraine (IRE-NASU), Ukraine
- Development and applications of radiation sources in millimeter to THz-wave range

Guest Professor G. N. C. Santos from De La Salle University, Philippines

Members of collaboration with Usikov Institute for Radiophysics and Electronics, NASU, Ukraine

Topics of collaborative research works

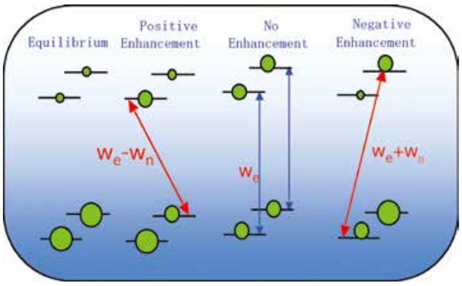
Collaborative research works

By collaborating with various institutions, the FIR UF achieved innovative research and development in a wide array of fields, including fundamental science, bio-science, and materials science.

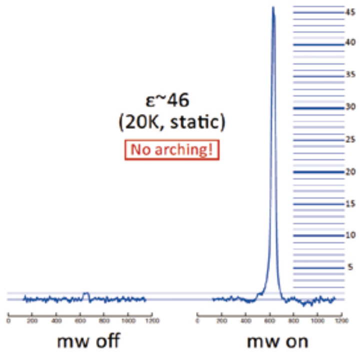
1. Analysis of the structure of protein molecules by DNP-NMR spectroscopy

(Collaborations with Institute for Protein Research, Osaka University, and NMR Center, University of Warwick (UK))

- The high magnetic polarization of the electrons is transferred to the nuclei by the irradiation of the sample with high-power THz radiation from the gyrotron (Dynamic Nuclear Polarization; DNP), and as a result, the sensitivity of the NMR spectroscopy is highly enhanced (DNP-NMR). This method will be applied for the analysis of protein molecules and the structure of the polymer surface.
- At Osaka University, an enhancement factor of 46 was achieved using a 395-GHz band gyrotron.
- At the University of Warwick, the NMR sensitivity was enhanced by 60 times using the DNP-NMR method with a gyrotron.



Principle of DNP-NMR spectroscopy
Irradiation of high-power THz radiation causes resonant transitions, indicated by the red and blue arrows.

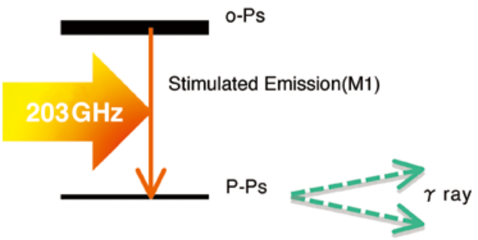


DNP-enhanced NMR spectrum measured at Osaka University
(left: conventional NMR, right: DNP-NMR)

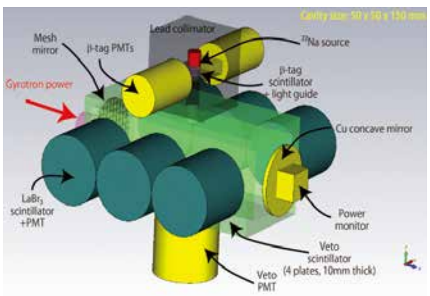
2. Direct measurement of the hyperfine structure of positronium: a subject in elementary particle physics

(Collaboration with the International Center for Elementary Particle Physics, The University of Tokyo)

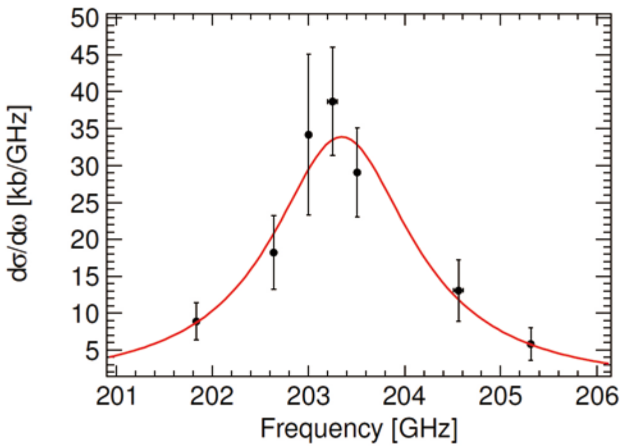
- The high-power THz radiation from gyrotrons is also applicable in elementary particle physics.
- By irradiating with the high-power THz light and measuring the γ ray emission simultaneously, the first direct measurement of the difference between the energy levels of the ortho- (o-Ps) and para-positronium (p-Ps) was achieved.



A schematic drawing of transition between energy levels and emission of γ ray



Drawing of measurement devices

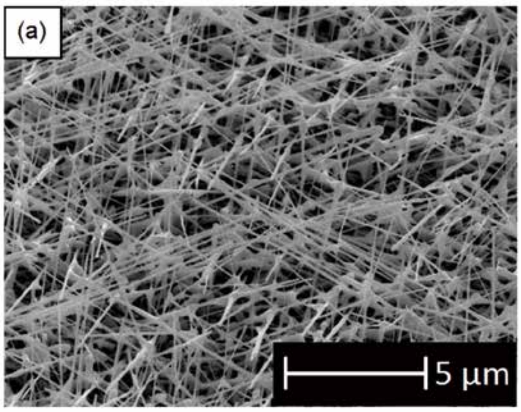


Frequency dependence of transition rate between the energy levels of o-Ps and p-Ps.
The transition rate is enhanced at a particular frequency corresponding to the difference between the energy levels.

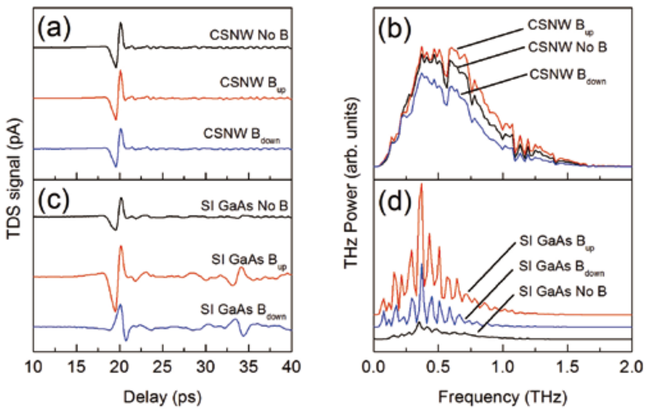
3. Study of Semiconductor Nanostructures with THz Waves – THz emission from Semiconductor Nanostructures –

(Joint Research with National Institute of Physics, University of Philippines)

- When semiconductor nano-structures, such as nanowires, are irradiated by femtosecond laser pulses, THz waves are emitted depending on the structure. The precise THz emission mechanism remains unknown; nonetheless, such THz emission can be utilized to examine nanostructures. In addition, it is possible to realize efficient THz emission devices based on the semiconductor nanostructures.



Microscopic image of GaAs-AlGaAs core-shell nanowires deposited on Si (100) substrates taken with a scanning electron microscope



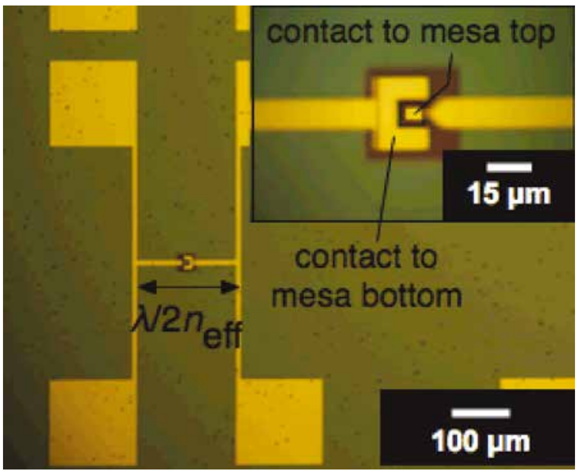
THz time-domain signals (left) and THz power spectra (right) from the GaAs-AlGaAs CSNWs ((a) and (b)) and the SI-GaAs substrate ((c) and (d)) without a magnetic field (no B), with a B_{up} polarity, and with a B_{down} polarity.

※The figures excerpted from Appl. Phys. Lett. **102** (2013) 063101

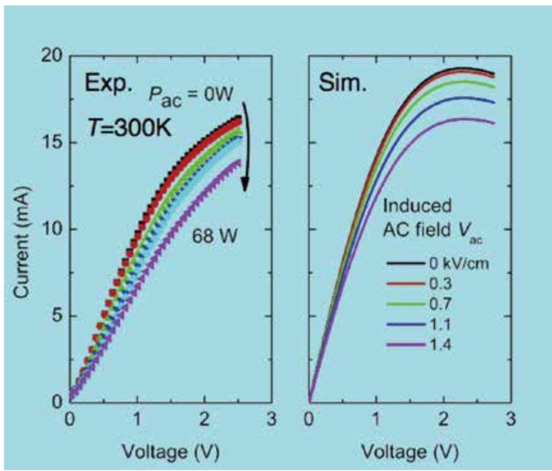
4. Study of the possibility of a Bloch oscillator by high-power THz irradiation with high power THz radiation

(Collaboration with Institute of Industrial Science, The University of Tokyo)

- A Bloch oscillator using a semiconductor superlattice is used to realize a frequency-tunable solid-state THz radiation source covering a wide frequency range.



Coupled system of an antenna and a superlattice fabricated at Institute of Industrial Science, The University of Tokyo



By high-power irradiation with a frequency of 0.395 THz, the V-I characteristics are changed. Thus, the high-field domain disappears, allowing a Bloch oscillator.

Topics

FIR UF organized the 5th International Workshop on Far-Infrared Technologies 2014

The 5th International Workshop on Far-Infrared Technologies 2014 (IW-FIRT 2014), March 5–7, 2014, was organized by FIR UF and co-sponsored by six academic societies. This workshop comprised 24 invited talks (eleven speakers from abroad, seven speakers from domestic institutions, and six FIR UF researchers) and 5 contributed talks, together with 19 poster presentations. A total of 84 researchers (14 from abroad) participated in the workshop. This workshop put emphasis on the development of advanced THz gyrotrons, new disciplines and possibilities of condensed matter physics with far-infrared light, and new THz spectroscopy with gyrotrons. Many interesting reports were presented and stimulated discussion was carried out. We hope many new works will appear in near future.

FIR UF hosted International Symposium on Development of Terahertz Gyrotrons and Applications

The International Symposium on Development of Terahertz Gyrotrons and Applications was held at the FIR UF from March 14–15, 2013. This symposium was combined with a congress of the international consortium (p.11). There were six participants from overseas institutions, thirteen from domestic institutions, and ten from the FIR UF. In the summary session, the evolution of the research due to the development of the THz gyrotrons and their applications in various fields, as well as the future prospects of the THz gyrotron, were discussed. It was adopted as a summary of the symposium that the importance of the framework for international collaboration, with the FIR UF as the core institution, was confirmed and that further development of the capabilities of FIR UF as the worldwide research base is required.

Collaboration for research on high magnetic field - KOFUC network

The “High Magnetic Field Collaboratory Plan” is a theme of the Ministry of Education, Culture, Sports, Science, and Technology (MEXT)’s large research projects. The plan is to build a domestic research base with high-magnetic-field facilities and enhance these facilities. In order to construct this base in western Japan, three research centers (FIR UF; Center for Advanced High Magnetic Field Science, Osaka University; and Molecular Photoscience Research Center, Kobe University) agreed to cooperate. This collaboration is called the “KOFUC network.”

New helium liquefier and helium gas recovery system

The cryogen supply section of the FIR UF has performed the management and operation of the Cryogenic Laboratory. The Cryogenic Laboratory supplies cryogen (liquid nitrogen, liquid helium) in University of Fukui. The first helium liquefier was installed in our university in 1968. Cryogen has been foundational to the study of high-frequency gyrotrons. A helium liquefier and gas recovery system were renovated in 2013. The liquefaction ability was improved (to 60 L/h in pure helium gas operation), and the storage capacity was increased.

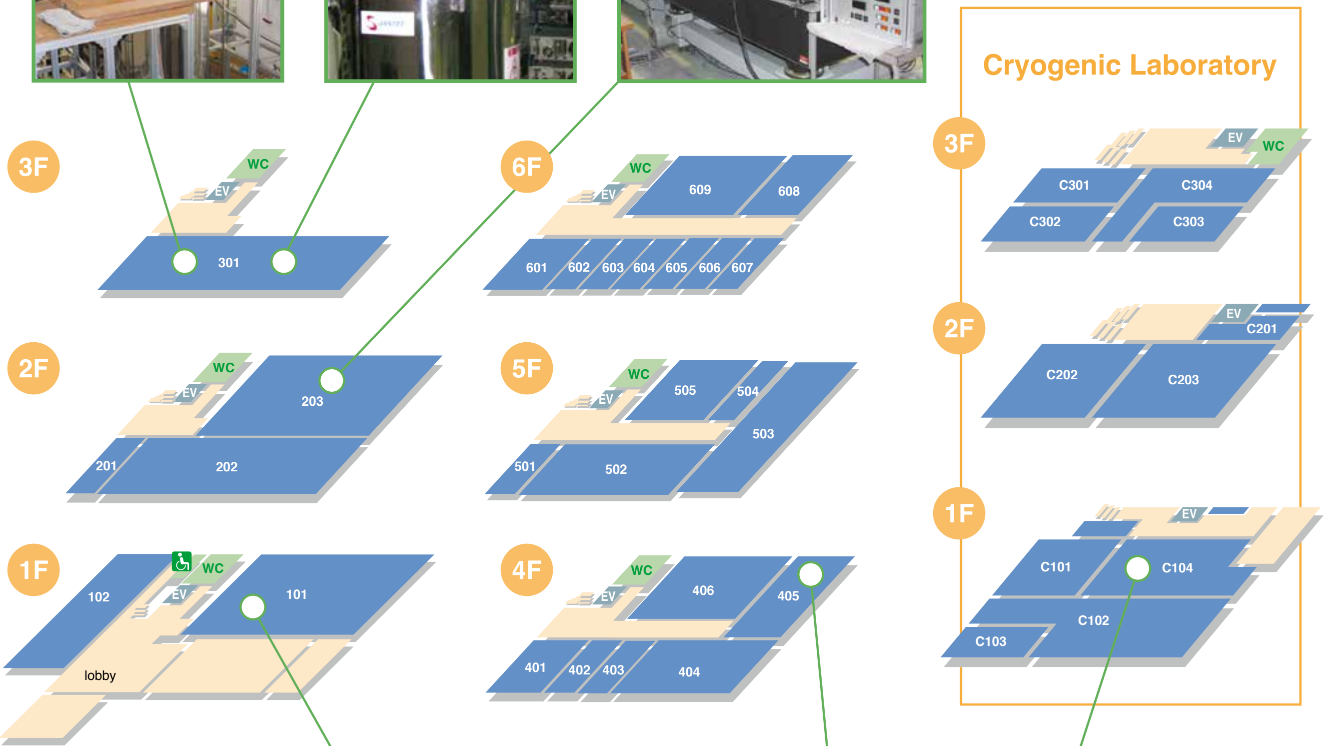
FIR Center map

Major equipment of FIR UF

1 THz gyrotron FU CW III
with a 20-T superconducting magnet

Gyrotron with an internal converter
Gyrotron FU CW G I

Far-infrared molecular laser



28-GHz microwave sintering system（Room 101）

THz time-domain spectrometer（Room 405）

THz ESR spectrometer（Room C104）

- Gyrotron FU CW IIA
- Gyrotron FU CW IIB
- ●Gyrotron FU CW III (Room 301)
- Gyrotron FU CW IV
- ●Gyrotron FU CW G I (Room 301)
- Gyrotron FU CW G III
- Gyrotron FU CW G V
- Gyrotron FU CW C I
- Gyrotron FU CW C II
- Pulse gyrotron
- Pulsed THz gyrotron
- 15-T helium-free superconducting magnet
- ●Far-infrared molecular laser (Room 203)
- Backward-wave oscillator system
- Millimeter-wave orotron
- ●28-GHz microwave sintering system (Room 101)
- 24-GHz microwave sintering system
- ●THz time-domain spectrometer (THz-TDS) (Room 405)
- Regenerative amplifier system of femtosecond pulse laser
- Atomic force microscope (AFM)
- Cavity dumping system (10-fs pulse)
- Optical parametric amplifier system of femtosecond pulse laser
- Self-mode locking system (100-fs pulse)
- ●THz ESR spectrometer (consisting of 18T-SCM and MVNA) (Room C104)
- 18-T superconducting magnet with variable temperature insert or $^3He/^4He$ dilution refrigerator (18T-SCM)
- Millimeter-wave vector network analyzer (MVNA)
- Electromagnetic-wave anechoic room
- Submillimeter-wave plasma-scattering system

● indicates an apparatus shown in the pictures

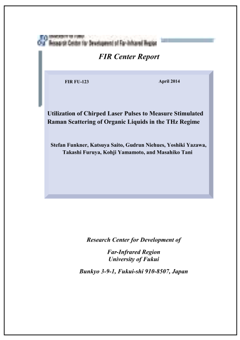
Research activities and publications

Research activities

	2009	2010	2011	2012	2013	Total
Original papers	12	21	10	25	17	85
Reviews and reports	6	18	9	0	2	35
Presentations at international conferences (invited presentations)	78 (24)	43 (8)	106 (31)	53 (8)	61 (17)	341 (88)
Presentations at domestic conferences (invited presentations)	68 (1)	96 (9)	86 (9)	91 (3)	84 (2)	425 (24)
Books (including textbooks, translations)	0	1	4	2	1	8
FIR Center Report	8	4	9	5	2	28
Agreements for academic exchanges	8	9	10	11	11	49
MOUs for international collaborations	9	9	9	10	11	48
Cooperative scientific research projects under bilateral agreements	3	3	3	3	2	14
International collaborations	25	23	19	22	21	110
Domestic collaborations	18	17	25	27	40	127
Visits to overseas institutes and/or conferences	26	22	32	20	20	120
Visitors from overseas	26	5	15	8	17	71
Domestic visiting professors	4	5	5	4	4	22
International visiting professors	3	4	4	4	6	21
Postdoctoral fellows	4	5	5	4	5	23
FIR Center seminars	19	16	9	11	15	70

Research publications

In addition to our publications in academic journals and at conferences, our recent research results and achievements are published in our "Annual Report" and in "Research and Development in the Far Infrared Region" (in Japanese), which are released annually by the FIR UF. We also organize the International Workshop on Far-Infrared Technologies (IW-FIRT) every few years and publish its proceedings to summarize the recent achievements of the FIR UF and those of the international joint projects. For the fast publication of our latest research results, preprints of our papers are issued as the "FIR Center Report" and are posted on the FIR UF webpage.



FIR Center seminar

The FIR UF holds open seminars on the FIR and THz region by active researchers invited from across the world. We have 10–20 seminars per year. The schedule and other information can be found at the FIR UF webpage.

How to participate in FIR UF research

There are programs for international students to study at the University of Fukui:

A. Global Engineering Program for International Student (GEPIS)

B. Global Network Engineering Program for International Students (GNEPIS)

C. The University of Fukui Student Exchange Program (UFSEP),

D. The University of Fukui Exchange Student Program (UFESP).

GEPIS and GNEPIS are programs for regular students, and UFSEP and UFESP are for exchange students.

http://ryugaku.isc.u-fukui.ac.jp/english/manabi/fukudai_program.html

Undergraduate or graduate students at the University of Fukui can participate in studies at the FIR UF. Admission information can be obtained at the following website:

http://www.u-fukui.ac.jp/eng/index.html

At the FIR UF, a number of PhD fellows are engaged in our research. If you are interested in the PhD positions at the FIR UF, please contact the Center members listed on pp. 3–4.

Messages from foreign students

Having spent time studying in Japan, especially in FIR-Center of University of Fukui, I got lots of memories not only in academic matters but also in all aspects of my life. During my first days in Japan, I did experience confusion on both language and research. Fortunately, students in the Center were always there to provide kind help. Studying and doing research at the FIR UF blessed me with the opportunity to join the world-class research and development center with a high-power far-infrared source like the gyrotron and its applications, as well as THz science. Moreover, I also had the opportunity to meet and discuss various fields with experts from various countries visiting the Center. The emotional bond will sustain forever, and memories of Fukui will always be here with me. I do hope to still have updated news from the University of Fukui and I am looking for every chance to visit the place again.

(I Nyoman Sudiana, former doctoral student of University of Fukui, Indonesia)

Dr. Sudiana (left)

I am happy with my decision to come to Japan to pursue a PhD in Applied Physics while doing research on THz science at the FIR UF. I can really say that I came to the right place and I joined the right institution. the FIR UF is a great research environment not only for the Japanese, but also for foreign nationals. I arrived in Japan not knowing how to speak, read, or write Japanese, but this did not set me back. I was able to embrace my new life here with relative ease because the people at the FIR UF are very supportive and easy to get along with. In addition to having opportunities to participate in world-class research activities, being part of the FIR UF allows me to make the most out of my stay in Japan. I am never bored as there is always something to do. Outside the FIR UF, there are also opportunities to make more friends, visit other places, and experience the sights, culture, and local life, especially through the various programs of the University of Fukui's International Center and Fukui's International Association.

(Valynn Katrine P. Mag-usara, doctoral student of University of Fukui, from Philippines)

Ms. Mag-usara

About living in Fukui - Message from postdoctoral fellows from overseas

We joined the FIR UF in the end of 2012 as postdoctoral fellows working in the THz science group of Prof. Tani. The FIR UF offers comprehensive resources and well-equipped laboratories enabling cutting-edge research. Quarterly change of guest professors and many visitors from Japan and overseas expand the inspiring and motivating environment of the FIR UF. Right from the beginning, all FIR members supported us in every aspect, scientifically as well as in everyday life. Here, Fukui provides various options, ranging from traditional Japanese experiences (e.g., in the Eiheiji Temple) to the beautiful countryside. Fukui is only a stone’s throw from the ocean as well as mountain areas, and after short train rides, one reaches Japanese metropolises like Nagoya or Osaka. In Fukui, every visitor can taste great food, for example, fresh sushi, Echizen crab, and local soba noodles.

(Dr. Gudrun Niehues and Dr. Stefan Funkner)

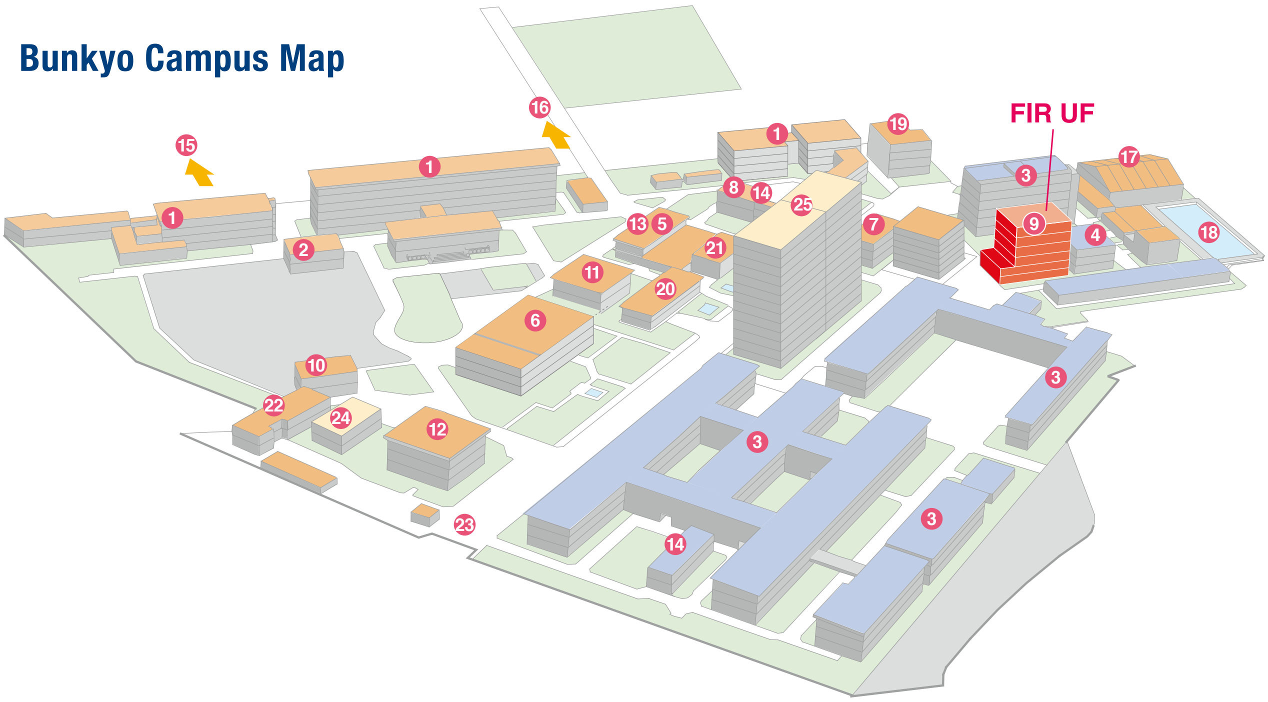
About University of Fukui

URL: www.u-fukui.ac.jp

Population statistics of University of Fukui

The University of Fukui comprises three faculties: the Faculty of Engineering, Faculty of Education and Regional Studies, and Faculty of Medical Sciences. More than 5,000 students, including over 150 foreign students, study at these faculties. The Faculty of Engineering is supported by around 180 professors and associate professors, including those of the FIR UF.

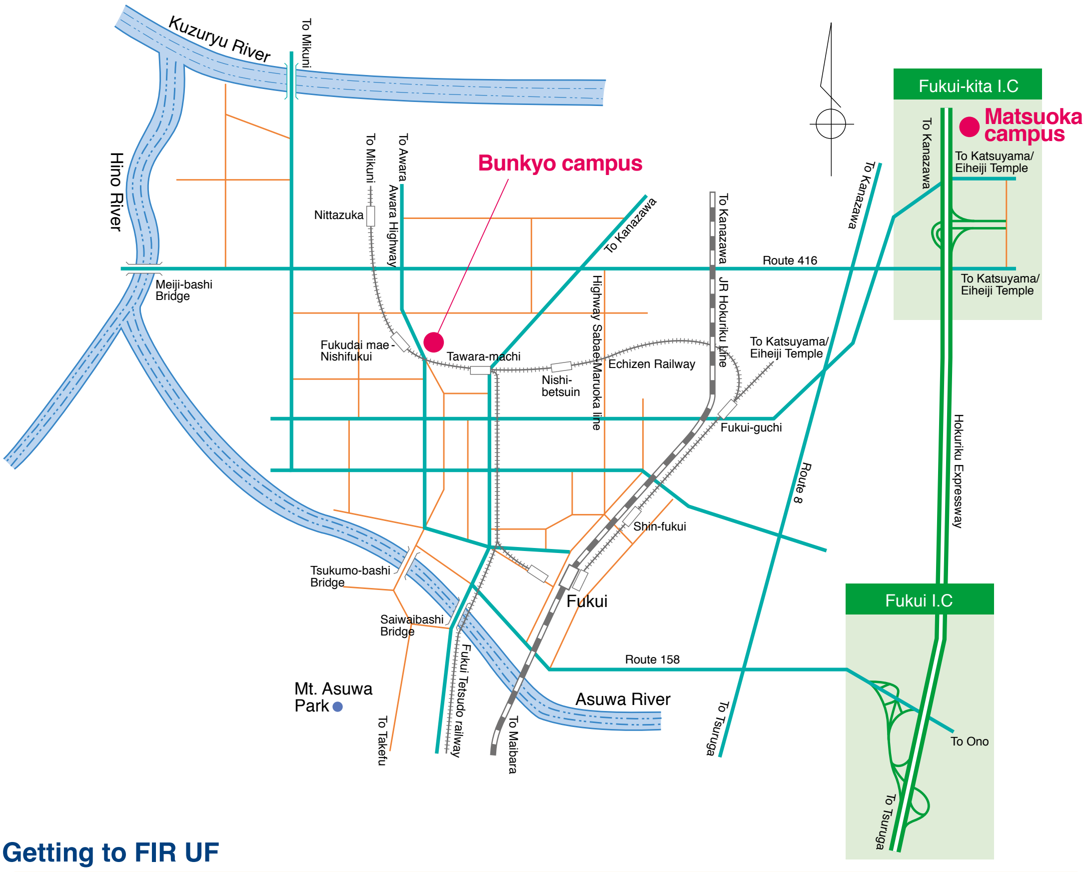
Bunkyo Campus Map



1 Faculty of Education and Regional Studies
2 Integrated Research Center for Educational Practice
3 Faculty of Engineering
4 Cryogenics Laboratory
5 Center for Interdisciplinary Studies
6 University Library
7 Headquarters for Innovative Society-Academia Cooperation
8 Admission Center
9 **FIR UF**
10 Health Service Center
11 Center for Computing and Network Services
12 Central Administration Building
13 Student Services Center
14 International Student Center
15 Tennis courts and volleyball courts
16 Athletics ground
17 Gymnasium
18 Swimming pool
19 Extracurricular Activities Center
20 University Hall
21 Shop and cafeteria
22 Guest house
23 Main gate
24 Academy Hall
25 Integrated Research Building

Campus Location, University of Fukui

FIR UF is located on Bunkyo Campus



Getting to FIR UF

By taxi: A taxi service is available at the JR Fukui station, taking you to the Bunkyo Campus in ~10 min.
By train: Take the Mikuni-Awara line, on the Echizen Railway, adjacent to the JR Fukui station at the Fukui station. Alight at Fukudaimae-Nishi station. The journey takes ~10 min.

From Tokyo

By air Fly from Haneda Airport to Komatsu Airport (journey of ~1 h). At Komatsu Airport, take a shuttle bus to Fukui.

By train Take the JR Tokaido Shinkansen Line from Tokyo to Maibara (approximately 2 h and 40 min). There, change trains and take a limited express train on the JR Hokuriku Line to Fukui (~1 h).

By car Take the Tomei Expressway from Tokyo and continue through Nagoya on the Meishin Expressway until you reach the Maibara Junction. Enter the Hokuriku Expressway and continue to Fukui I.C. (~ 7 h).

From Osaka

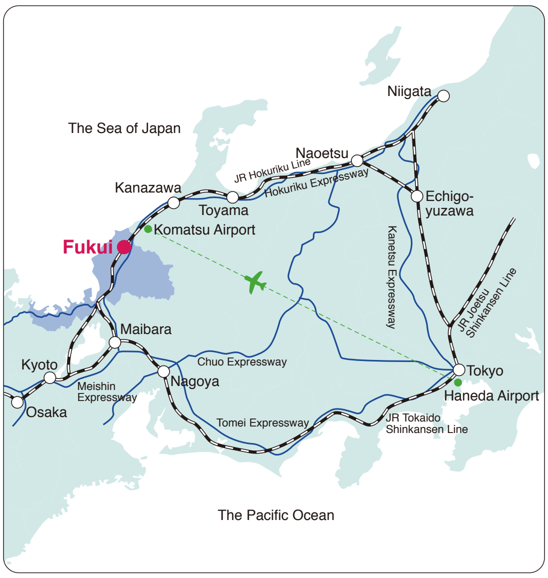
By train Take the JR limited express train, Thunderbird, at the Osaka Station, which takes you directly to the Fukui station in ~2 h.

By car Take the Meishin Expressway from Osaka to the Maibara Junction. Enter the Hokuriku Expressway and continue to Fukui I. C. (~ 3 h total).

From Nagoya

By train Take the JR limited express train, Sirasagi, at Nagoya Station, which takes you directly to the Fukui station via Maibara in ~2 h.

By car Take the Meishin Expressway from Nagoya to the Maibara Junction. At the Maibara Junction, enter the Hokuriku Expressway and continue to Fukui I. C. (~2 h and 30 min).



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