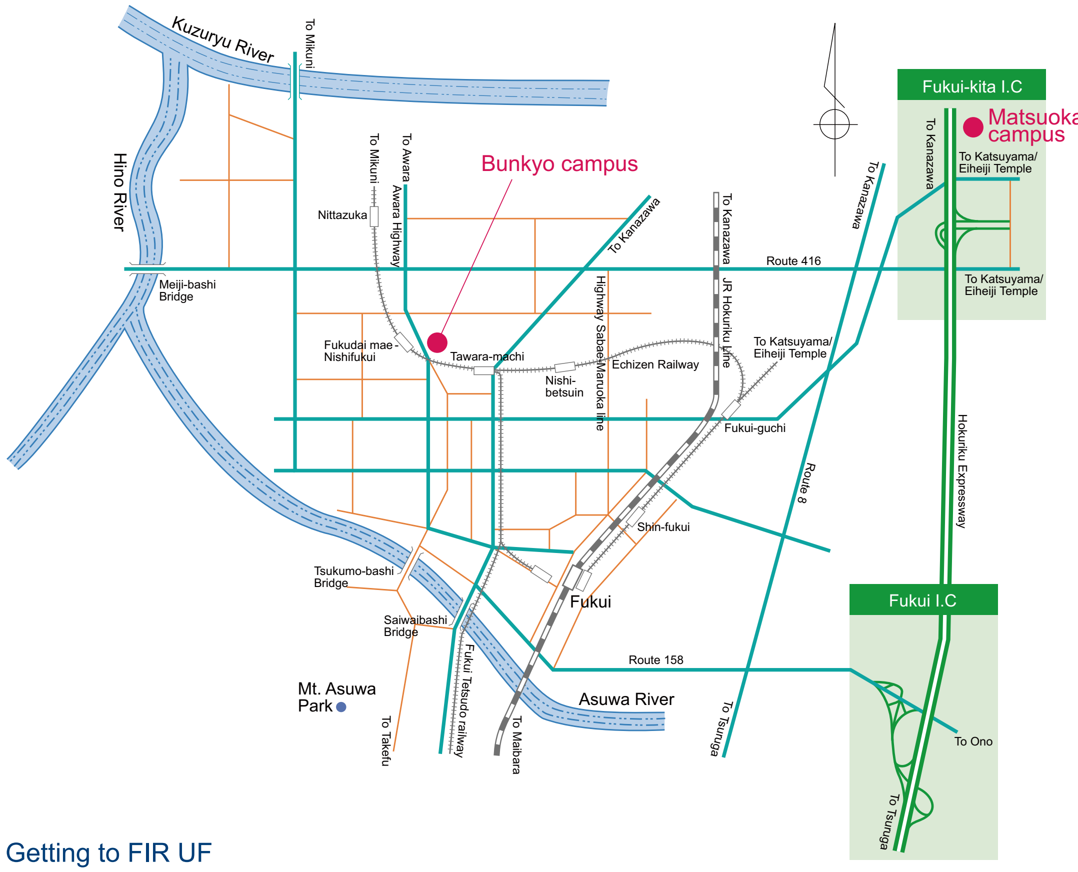
////// Campus Location, University of Fukui

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

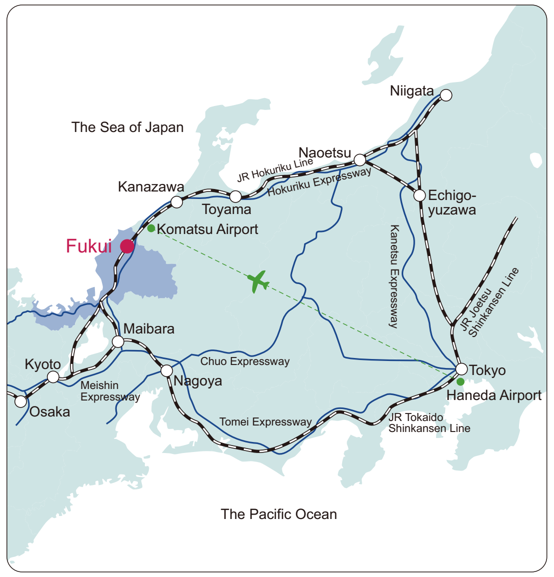
By train Take the JR limited express train, Thunderbird, at the Osaka Station, which takes you directly to the Fukui station in ~2 h.

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).



UNIVERSITY OF FUKUI
Research Center for Development of Far-Infrared Region

Bunkyo 3-9-1, Fukui 910-8507, Japan
TEL: +81-776-27-8680 FAX: +81-776-27-8770
URL http://fir.u-fukui.ac.jp/

福井大学 遠赤外領域開発研究センター

FIR UF

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

English

World class gyrotrons, which were originally developed at the FIR UF.

■ 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.

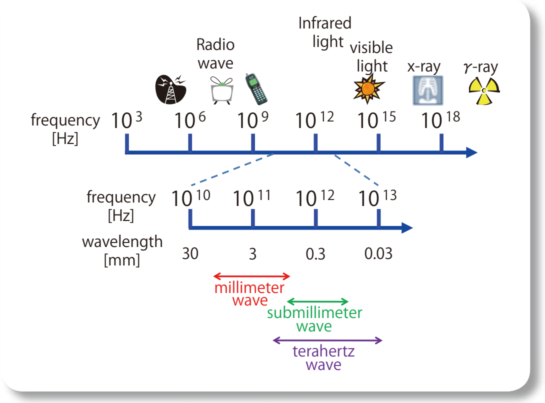
Director
Prof. Masahiko Tani

////// 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.

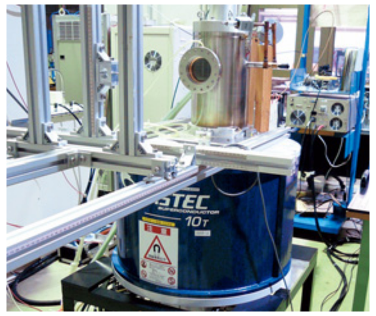
The FIR/THz wave region has long been regarded as an unexplored region because of the lack of powerful sources. Rapid and great progress is expected regarding the FIR region in the very near future. The FIR UF has developed a novel high power far-infrared source "Gyrotron" and is conducting the research 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



Gyrotron FU CW GV

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-effi-ciency 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

////// Chronology of FIR UF

Gyrotron FU I
Displayed in the entrance hall of FIR UF building

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, Culture, Sports, Science and Technology (MEXT)
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 MEXT as one of the research topics that must be performed intensively.
2016 ········· An assistant professor is added to enhance the organization.
International Research Division is established due to reorganization.
2017 ········· An assistant professor is added to enhance the organization.

About FIR UF

////// Research organization

- Director: Prof. Masahiko TANI
- Vice Director: Prof. Yoshinori TATEMATSU

////// Research groups of FIR UF

■ Core Research Division

Group for Development of fundamental far-infrared technologies

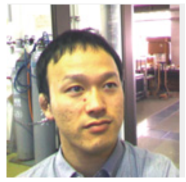
Prof. Yoshinori TATEMATSU, Assistant Prof. Masafumi FUKUNARI

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

▶▶▶ P5, 6

E-mail: tatema@fir.u-fukui.ac.jp
fukunari@fir.u-fukui.ac.jp


Yoshinori TATEMATSU


Masafumi FUKUNARI

■ Core Research Division

Group for Applications of THz technologies for research in materials science and sensing

Prof. Masahiko TANI, Associate Prof. Takayuki MAKINO, Assistant Prof. Takashi FURUYA

- Development and application of novel THz-wave emitters and detectors
- THz optical and spectroscopic research using broadband THz waves
- Investigation on photodynamics on renewable-energy-science-related materials by using ultra-fast lasers

▶▶▶ P9, 10

E-mail: tani@fir.u-fukui.ac.jp, tmakino@fir.u-fukui.ac.jp
furuya@fir.u-fukui.ac.jp


Masahiko TANI


Takayuki MAKINO


Takashi FURUYA

■ Core Research Division

Group for Development of new technologies in the far-infrared region

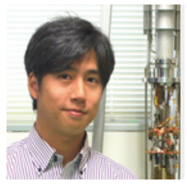
Prof. Seitaro MITSUDO, Assistant Prof. Yuya ISHIKAWA
Postdoctoral fellow Shigeo HARA

- 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

▶▶▶ P5, 6

E-mail: mitsudo@fir.u-fukui.ac.jp
ishikawa@fir.u-fukui.ac.jp


Seitaro MITSUDO


Yuya ISHIKAWA

■ Core Research Division

Group for Low-temperature and condensed-matter physics

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)

▶▶▶ P7, 8

E-mail: mitsudo@fir.u-fukui.ac.jp
yfujii@fir.u-fukui.ac.jp


Seitaro MITSUDO


Yutaka FUJII

■ International Research Division

Associate Prof. Mary Clare Sison ESCAÑO, Assistant Prof. Yuusuke YAMAGUCHI, Specially Appointed Assistant Prof. Dr. Hideaki KITAHARA,
Postdoctoral fellow Dr. Joselite E. MULDERA
In addition, several foreign researchers are employed as "Specially Appointed Professors" under the Cross-Appointment System or the Researcher Invitation System.

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

▶▶▶ P5, 11

E-mail: mcescano@u-fukui.ac.jp
y-yama@fir.u-fukui.ac.jp


Mary Clare Sison ESCAÑO


Yuusuke YAMAGUCHI

■ Visiting Professor's Division

Domestic visitor

Leading researchers in Japan are invited as Visiting Professors.

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

■ Visiting Professor's Division

Research adviser

Teruo SAITO, Akira FUKUDA

■ Cooperative Research Division

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 Division

THz spectroscopy and sensing / Millimeter wave communications / Optoelectronics

Prof. Kazuyoshi KURIHARA, Senior Assistant Prof. Takeshi MORIYASU /
Prof. Mitoshi FUJIMOTO /
Associate Prof. Sakae KAWATO /
Associate Prof. Kohji YAMAMOTO

- Application study of plasmonics to terahertz spectroscopy
- Study on propagation of terahertz pulse in photoexcited semiconductors
- Study on high performance millimeter wave antennas
- Study on material science by THz spectroscopy

■ Cooperative Research Division

Materials evaluation in the far-infrared region

Associate Prof. Tomomi HONDA

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

■ Cooperative Research Division

Medical and biological application of far-infrared technologies

Associate Prof. Hideki MATSUMOTO

- Evaluation of hyperthermia effect induced by irradiation of electromagnetic wave
- Effect of electromagnetic wave irradiation on biological objects and molecules

Research support organization

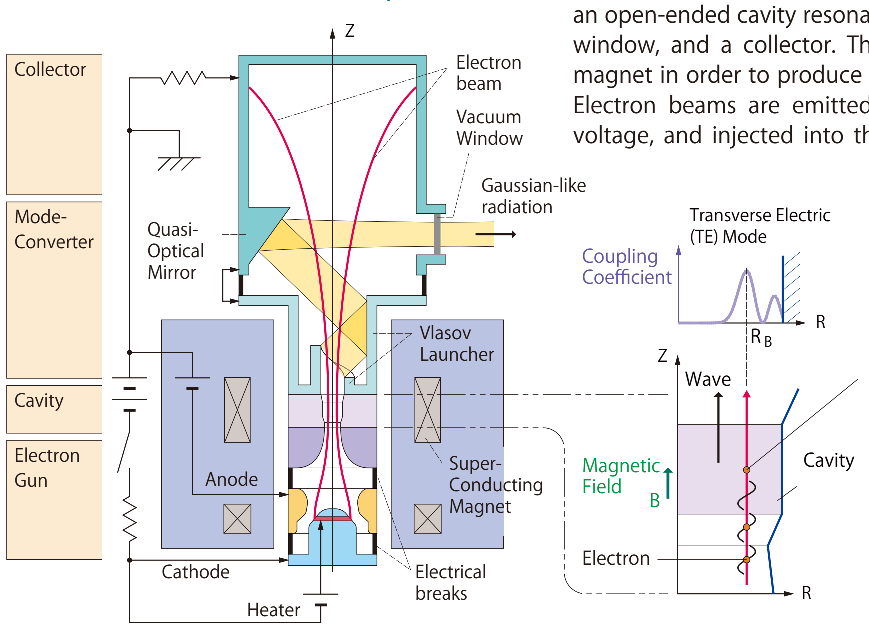
- Technical staff: Mr. Masashi TOZAWA
- Cryogen supply section: Prof. Seitaro MITSUDO (section head)
- Secretaries: Ms. Miyuki MORITO, Ms. Kaori YOSHIDA, Ms. Yoriko KUWASHIMA, Division of Research Promotion, Department for Strategic Planning & Promotion
- Temporary staff (dispatched from NAKATEC Co., LTD.): Mr. Shigenobu ARAKAWA

////// Research projects

1 Advanced Gyrotron Project

Gyrotrons are the most powerful source of electromagnetic radiation in the subterahertz frequency range. Recent advances in gyrotron development have unlocked a wide range of applications in scientific and technological studies.

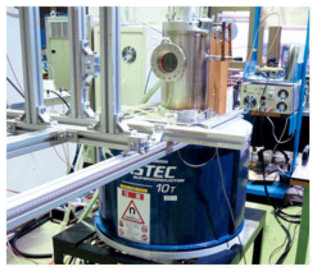
(1) Introduction to the Gyrotron



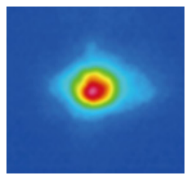
The gyrotron is an electron tube device that consists of an electron gun, an open-ended cavity resonator, an internal mode converter, a vacuum window, and a collector. The tube is installed in a superconducting magnet in order to produce high-speed cyclotron motion of electrons. Electron beams are emitted from a cathode, accelerated with high voltage, and injected into the cavity. In the cavity, the energy of the gyrating electrons is transformed into the energy of electromagnetic waves owing to the cyclotron resonance maser. The oscillation frequency depends on the cyclotron frequency of the electrons; therefore, it can be changed with the magnetic field strength in the cavity. The excited wave is formed into a Gaussian-like beam with the mode converter, and radiated through the vacuum window. 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.

(2) Gyrotron with an internal mode 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 GV



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

FU CW GII:
- ○ Demountable tube
- ○ Second harmonic osc.
- ○ Frequency: 395 GHz
- ○ Application: DNP/NMR

FU CW GIII
(A second-harmonic oscillation efficiency of 4% was realized using a specially designed electron gun. Continuous operation for over ten hours was achieved):
- ○ Sealed-off tube
- ○ Second harmonic osc.
- ○ Frequency: 395 GHz
- ○ Power: 0.4 kW
- ○ Application: Pulsed ESR

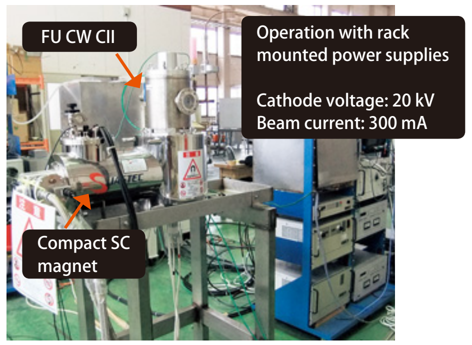
FU CW GI
(The first gyrotron of this series):
- ○ Demountable tube
- ○ Fundamental harmonic osc.
- ○ Frequency: 203 GHz
- ○ Power: 0.5 kW
- ○ Application: Direct measurement of positronium hyperfine splitting

FU CW GIV:
- ○ Sealed-off tube
- ○ Second harmonic osc.
- ○ Frequency: Continuously tunable around 395 GHz

FU CW GV:
- ○ Sealed-off tube
- ○ Fundamental harmonic osc.
- ○ Frequency: Stepwise tunable from 160 - 270 GHz
- ○ Power: ~ 1 kW
- ○ General purpose applications are possible.

(3) 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.



FU CW CI:
- ○ Demountable tube
- ○ Frequency tunable
- ○ Fundamental harmonic osc.: 107–205 GHz, 150–320 W
- ○ Second harmonic osc.: 290–396 GHz, 10–30 W
- ○ Applications: Studies on magnetic resonance and DNP-NMR

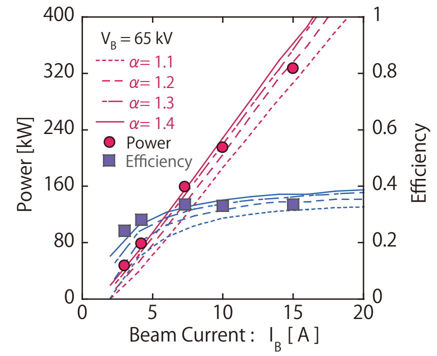
FU CW CII:
- ○ Sealed-off tube
- ○ Fundamental harmonic osc.: 203 GHz, 0.8 kW
- ○ Internal mode converter (Gaussian-like radiation)
- ○ Operation with rack-mounted power supplies

(4) Development of a high-power pulse gyrotron

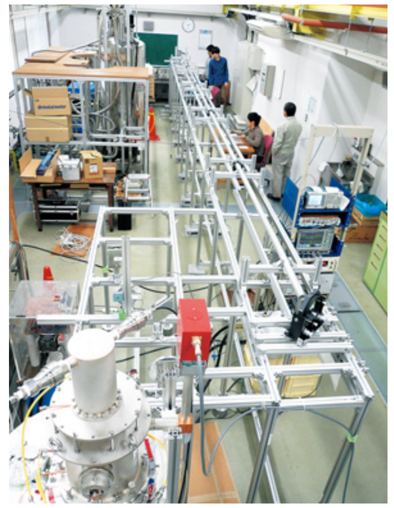
Using a gyrotron, the ion temperature of a fusion plasma can be measured up to 100 million degrees. For this application, more than 100 kW is required.

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.



We have achieved the target output power of 300 kW for the desired frequency of 303 GHz at the fundamental harmonic.



The long-range transmission test of the gyrotron output with a corrugated waveguide system has been performed.

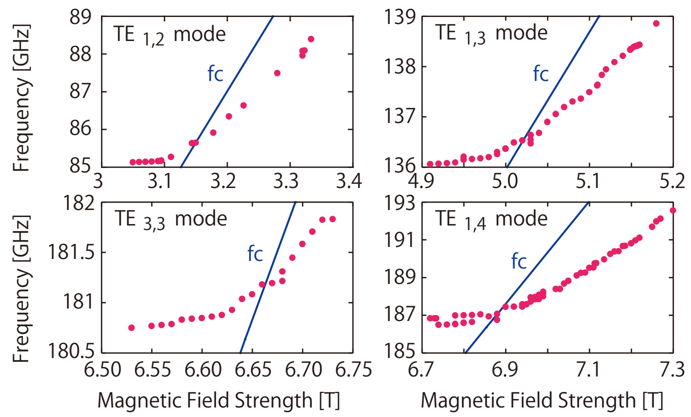
(5) Stabilization of power

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. We are also developing a computer-control system which can automatically operate the gyrotron.

A gyrotron operating system which is under development.

(6) 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. In FIR-UF, we have developed a multifunction gyrotron in which the oscillation frequency can be continuously changed in different frequency bands.



The observed oscillation frequency changes in the Gyrotron FU CW XA.

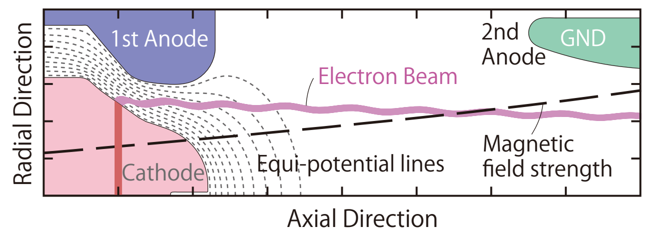
(7) Development of high-performance electron guns

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.



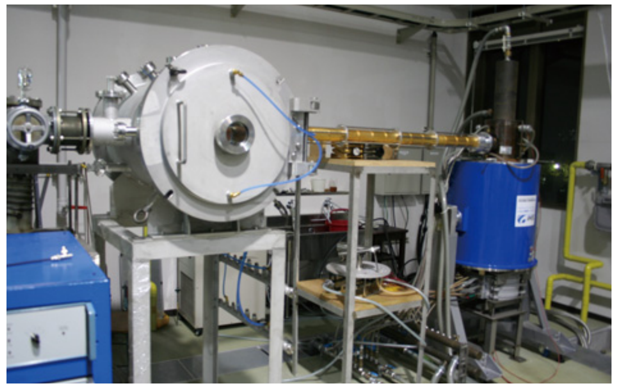
2 Materials science in the high-power far-infrared region

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



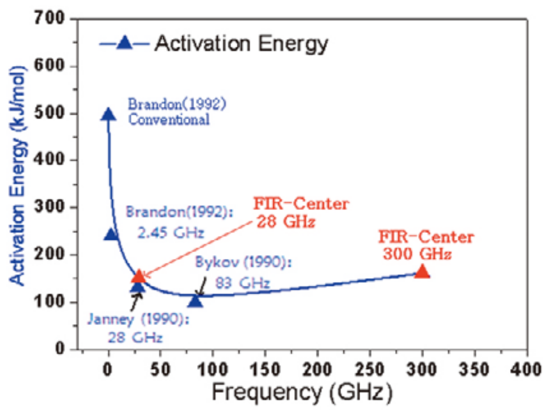
The world's first 300 GHz/2.3 kW high-power electromagnetic wave irradiation system

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).



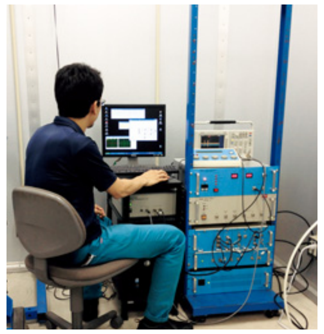
The frequency dependence of the apparent activation energy of the high-purity alumina ceramics was revealed by 28- and 300-GHz electromagnetic-wave sintering experiments.

(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.

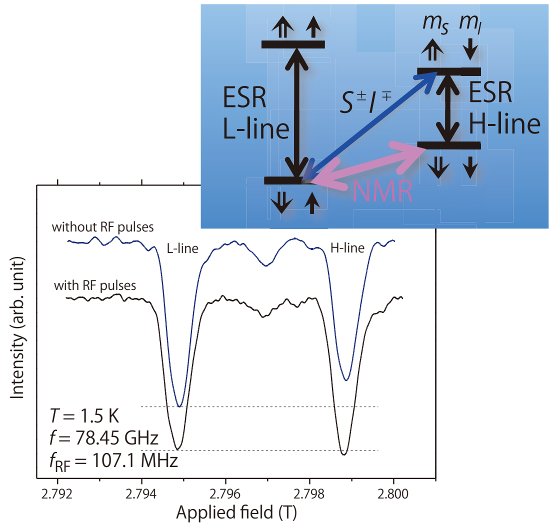
mm-wave vector network analyzer (MVNA)

FFT-NMR spectrometer



Magnetic field: 18-T static field, 40-T pulsed field
Temperature: 300˜1.5 K (liquid He)
˜0.1 K (^{3}He/^{4}He 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

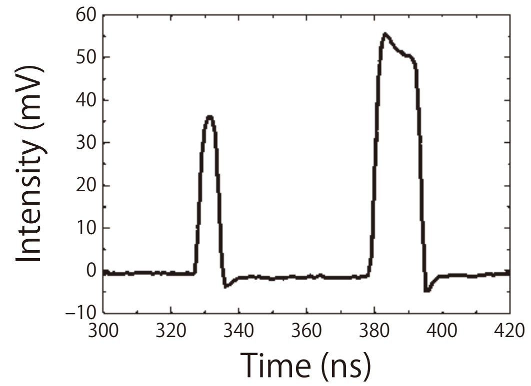


Evidence of dynamic nuclear polarization of ^{31}P lightly doped in silicon and control of nuclear polarization by applying RF pulses
(Y. Fujii *et al*., J. Phys.: Conf. Ser. **568** ('14) 042005)

(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

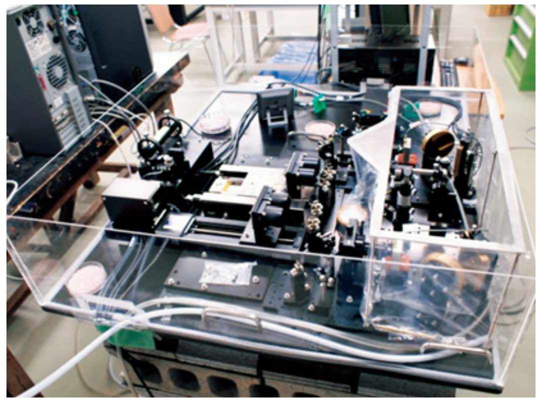


Ultra-short pulsed 154 GHz gyrotron output, 10- and 20-ns, while maintaining the coherency using a light-driven semiconductor switching device

3 Spectroscopic and application research using THz waves

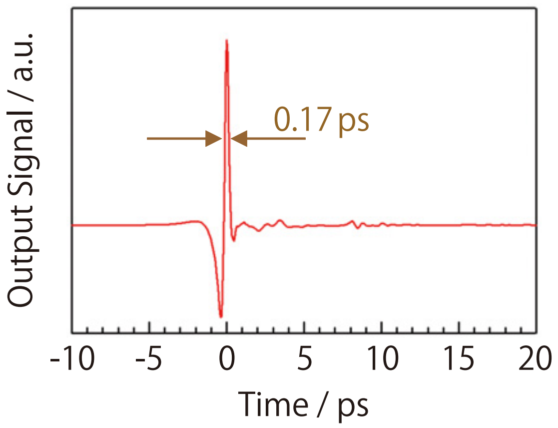
The Terahertz Science Research Group has conducted THz spectroscopic studies in materials science and has developed THz techniques for non-destructive inspection. Our major topics are as follows:

- 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

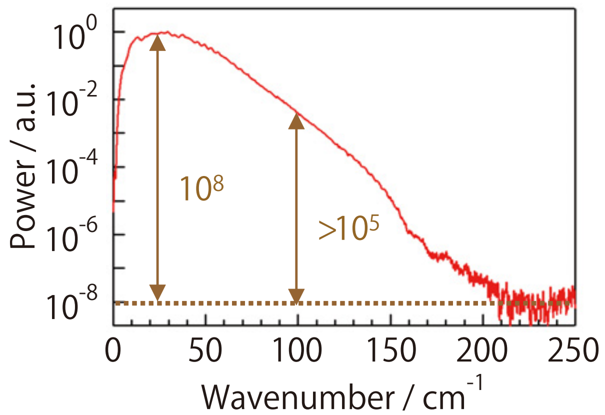


Terahertz time-domain spectrometer

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.



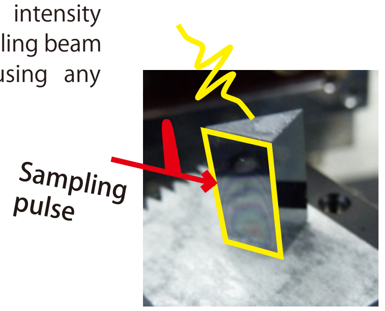
Temporal shape of terahertz wave



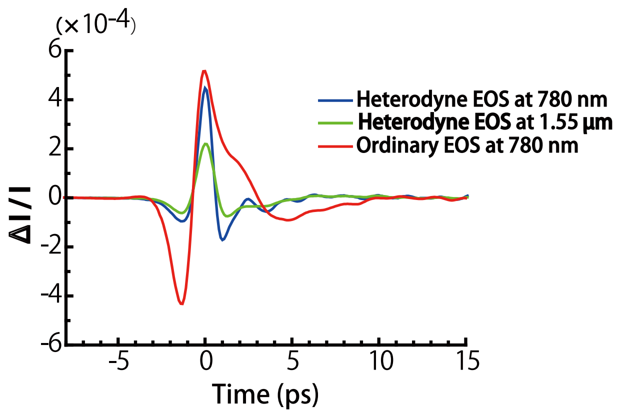
Power spectrum of THz wave

(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

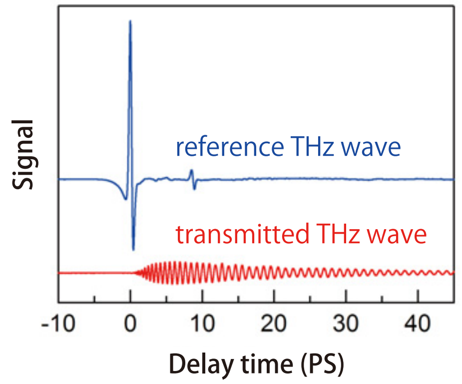


THz waveforms detected by EO sampling with Si-prism-coupled $LiNbO_3$ crystal in the Cherenkov-phase-matched heterodyne scheme.

(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.

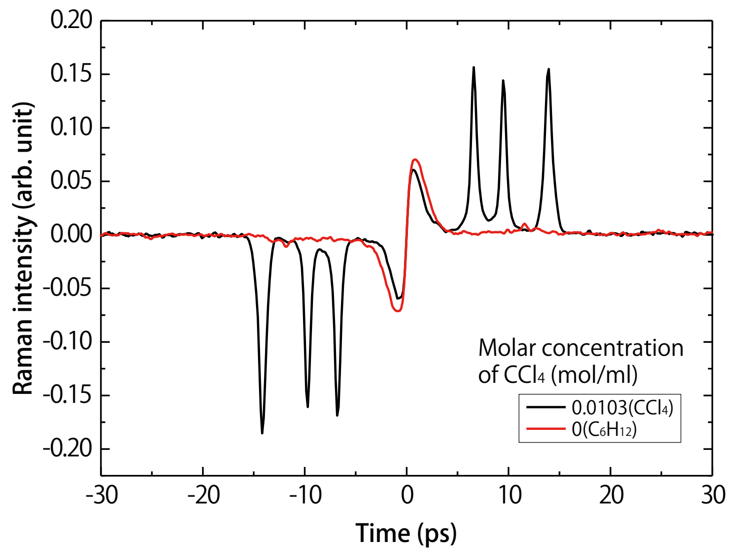
Metal waveguide



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

(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.



Measured Raman spectra of CCl_4 using time domain coherent Raman spectroscopy.

////// International research collaborations

- The FIR UF has concluded agreements for academic exchange and MOUs with tens of overseas institutes, respectively, for the development of international joint research projects.
- FIR UF has made a renewal of the international consortium which has continued during the past ten years. The new consortium titled "Advance of the Development of High Power THz Science and Technology" stadrted in 2015 with rearranged participating institutions (tens of overseas, several domestic institutions). FIR UF will continue the management as the facilitator of the renewed consortium.
- 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.

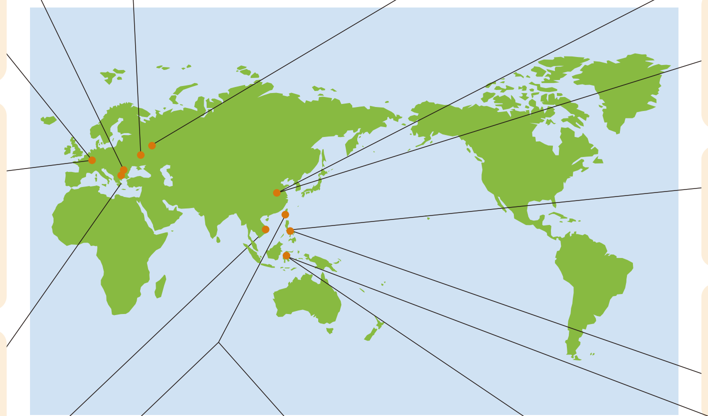
National Institute of Material Physics (NIMP), Romania (Romania)
- Development and applications of THz devices

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

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

The institute of Plasma Physics, The University of Electronic Science and Technology of China (China)
- Development and applications of high-frequency gyro-devices

Institute of Plasma Research (Germany)
- Development and applications of high-frequency gyro-devices



College of Mathematics and Science, Shanghai Normal University (China)
- Development and applications of THz devices

The Institute for Pulsed Power and Microwave Technology of Karlsruhe Research Center (IHM), and The Institute for Beam Physics and Technology (IBPT) (Germany)
- Development and applications of high-frequency gyro-devices

University of the Philippines (Philippines)
- Development and applications of THz devices

Institute of Electronics, Bulgarian Academy of Sciences (Bulgaria)
- Development and applications of high-frequency gyro-devices

College of Science, De La Salle University (Philippines)
- Development and applications of THz devices

Institute of Physics, Vietnam Academy of Science and Technology (Vietnam)
- Development and applications of THz devices

Industrial Technology Research Institute (Taiwan)
- Development and applications of THz devices

Terahertz Optics Photonics Center, National Tsing Hua University (Taiwan)
- Development and applications of high-frequency gyro-devices

Department of Physics, Faculty of Science and Mathematics, Diponegoro University (Indonesia)
- Applications of THz waves in material processing

University of Halu Oleo (Indonesia)
- Applications of THz waves in material processing

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

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

International Consortium
for Development of High-Power THz Science and Technology

http://fir.u-fukui.ac.jp/Website_Consortium/index.html

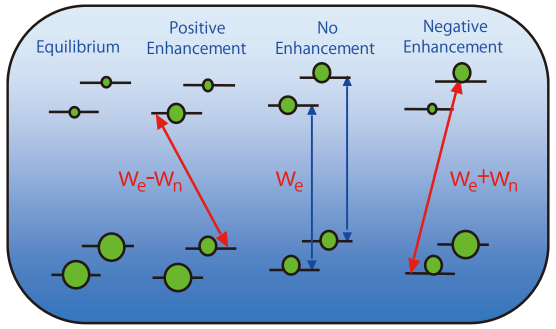
////// Collaborative research works

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.

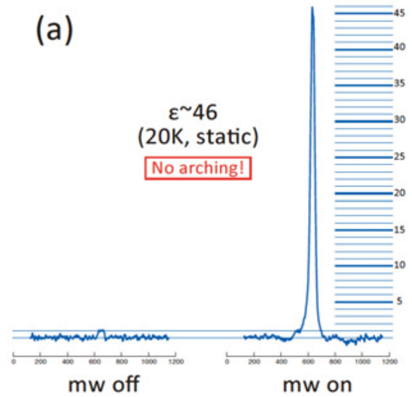
(1) Analysis of the structure of protein molecules by DNP-NMR spectroscopy

(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.

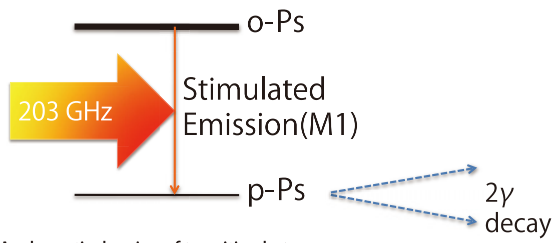


DNP-enhanced NMR spectrum measured at Osaka University
(left: conventional NMR, right: DNP-NMR)

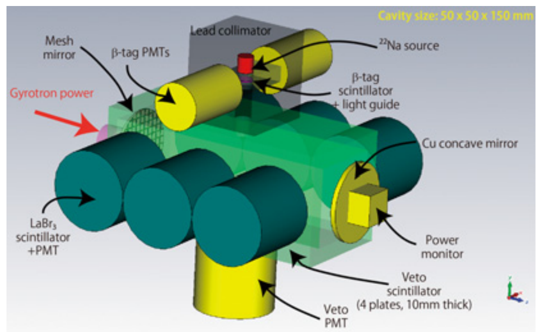
(2) Direct measurement of the hyperfine structure of positronium: a subject in elementary particle physics

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

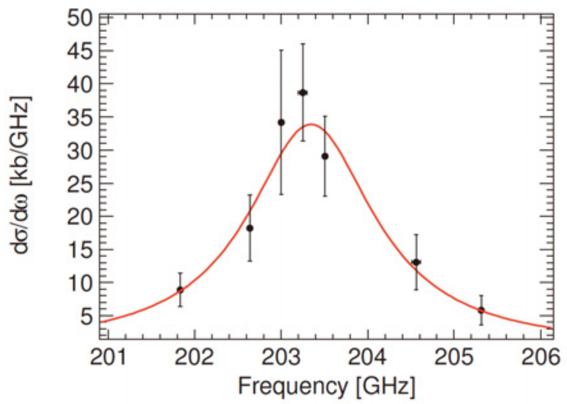
- The high-power THz radiation from gyrotrons is also applicable in elementary particle physics.
- By irradiating with the high-power THz light and measuring the γ ray emission simultaneously, the first direct measurement of the difference between the energy levels of the ortho- (o-Ps) and para-positronium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



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



Drawing of measurement devices

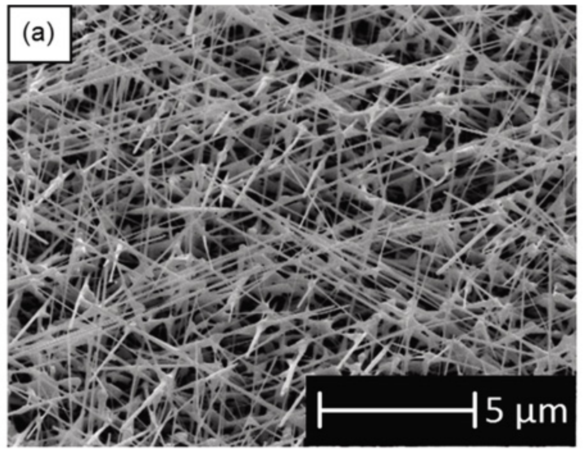


Frequency dependence of transition rate between the energy levels of o-Ps and p-Ps.
The transition rate is enhanced at a particular frequency corresponding to the difference between the energy levels.

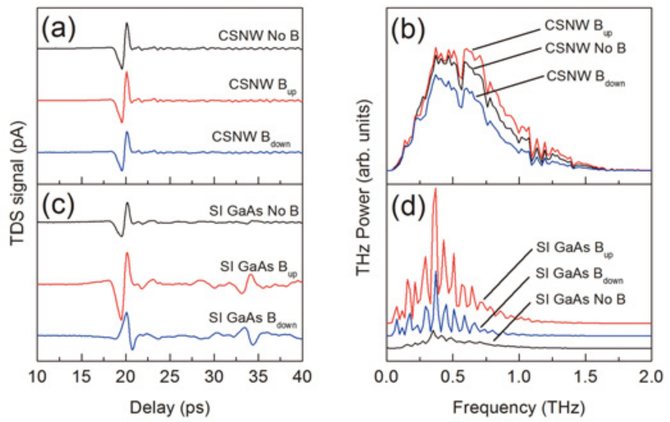
(3) Study of semiconductor nanostructures with THz waves - THz emission from semiconductor nanostructures -

(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

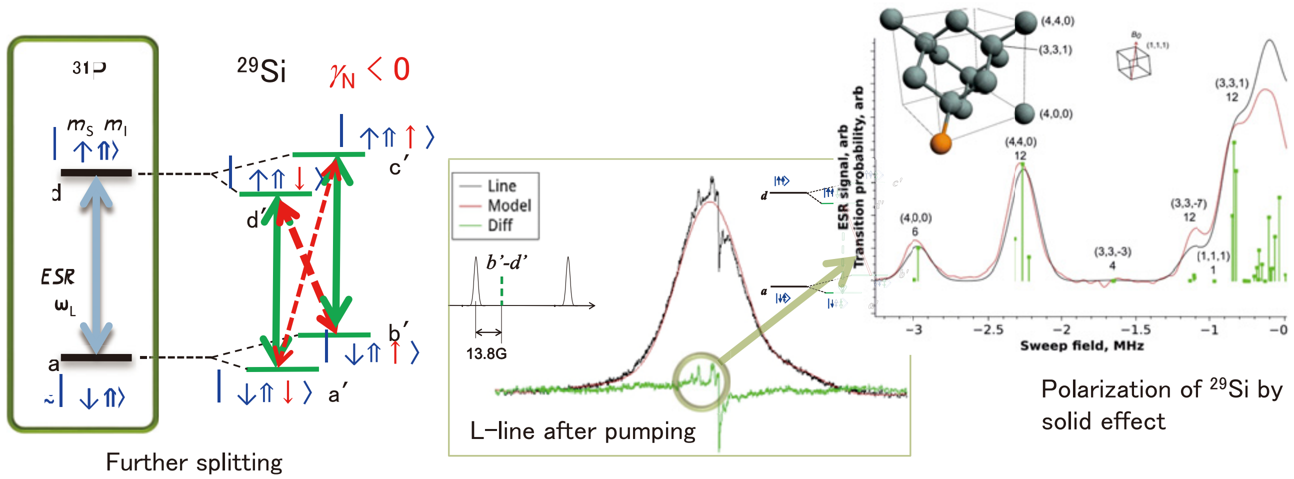


THz time-domain signals (left) and THz power spectra (right) from the GaAs-AlGaAs CSNWs ((a) and (b)) and the SI-GaAs substrate ((c) and (d)) without a magnetic field (no B), with a Bup polarity, and with a Bdown polarity.
※ The figures excerpted from Appl. Phys. Lett. **102** (2013) 063101

(4) Basic research of lightly phosphorus doped silicon - a candidate device for a quantum computer - using the magnetic resonance technique at ultra-low temperatures and under high magnetic fields

(International collaboration between FIR UF, Finland (Univ. of Turku) and Korea (KAIST, KBSI))

- Lightly phosphorus doped silicon (Si:P), which is widely considered as one of the best candidate devices for quantum computers (QC), has been studied by electron spin resonance (ESR) in the ultra-low temperature region (T > 0.2 K) and under a high magnetic field (4.6 T).
- We have demonstrated that solid-effect (SE) dynamic nuclear polarization (DNP) can be used for polarizing ^{29}Si nuclei located in specific lattice sites near phosphorus donors.
- The SE DNP demonstrated in our work, unlocks the possibility of initialization of qubits based on ^{29}Si nuclear spins for quantum information storage and processing. The SE DNP technique can also be utilized for isolated nuclei as well as for ^{29}Si-^{31}P pairs, which is an other promising candidate for QC.



References J. Järvinen *et al.*: Phys. Rev. B **90** (2014) 214401
J. Järvinen *et al.*: Phys. Rev. B **92** (2015) 121202(R)

////// Visiting Professor Program and Cross-Appointment System

In order to promote research and education, University of Fukui has several schemes to invite researchers. Visiting Professor program is intended to enable eminent scholars with an international reputation. Cross-Appointment System is one of our personnel exchange systems for academic staff and researchers.

	Visiting Prof/Assoc Prof	Cross - Appointment
Position/ Title	Visiting Professors/ Assoc Professors	Specially Appointed Professors/ Assoc Professors
Memorandum of Agreement	Not necessary	Necessary (Annex is supplied for specification of working conditions of Cross - Appointed researchers)
Qualification	Having equivalent position in his/her mother institute, or having equivalent achievements suitable for the position as visiting or specially appointed Professor/Assoc Professor	
Term	3 months (Apr – Jun, Jul –Sep, Oct – Dec, Jan –Mar)	1 - 12 months (selectable)
Working condition or duty	1) Joint research	1) Joint research (multiple years) 2) Teaching duty (not heavy)
Advantages	1) Simple procedure	1) Flexible term 2) Multi - year project 3) Budget for research activities and for inviting post - doc researcher (graduate students)
Disadvantages	Fixed term	Complicated procedure

////// Research activities and publications

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. 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.

////// Topics

Professor T. Idehara awarded the Kenneth J. Button Prize (2016)

During the 41st International Conference on Infrared, Millimeter, and Terahertz Waves (IRMMW-THz2016), Professor Toshitaka Idehara from FIR-UF was awarded the prestigious Button Prize for: "outstanding contributions to the development of high power THz radiation sources (harmonic gyrotrons) and their applications to high power THz spectroscopy."

Professor T. Saito won the achievement award 2017 of the Japan Society of Infrared Science and Technology (JSIR)

Professor Teruo Saito was awarded for his outstanding contributions to the study of science and technology, industrial engineering, and social life relating to development and applications of high-power gyrotrons in the far-infrared region.

International Workshop on Far-Infrared Technologies (IW-FIRT) International Symposium on Development of High Power Terahertz Science and Technology (DHP-TST)

Every few years, we organize an international workshop on far-infrared technologies (IW-FIRT) and an international symposium on development of high-power terahertz science and technology (DHP-TST). The workshop will be attended by more than 100 participants from Japan and abroad, who will give oral and poster presentations on the latest research results in far-infrared technology, as well as engage in lively discussions. The international symposium will provide lively discussions on the development and application of wave sources in the sub-terahertz to terahertz range. It will be confirmed that the importance of the framework for international collaboration, with the FIR UF as the core institution, and that further development of the capabilities of FIR UF as the worldwide research base.

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, four research centers (FIR UF; Center for Advanced High Magnetic Field Science, Osaka University; Research Center for Utilization of High Magnetic Field, Osaka Prefecture University; and Molecular Photoscience Research Center, Kobe University) agreed to cooperate. This collaboration is called the "KOFUC network."

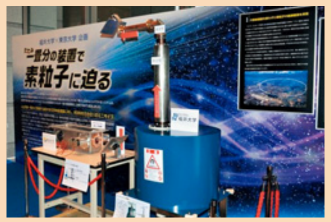
Fundamental particle physics using gyrotrons in table-top experiments. Exhibition (Entrance event) at MEXT (Ministry of Education, Culture, Sports, Science, and Technology of Japan) presented by University of Fukui and the University of Tokyo (1 September–21 October, 2016)

Professor Shoji Asai (University of Tokyo, Department of Physics, Graduate School of Science, Faculty of Science)
Professor Toshitaka Idehara (University of Fukui, Research Center for Development of Far-Infrared Region)

Usually, people associate fundamental particle physics with large experimental infrastructures, such as the Large Hadron Collider (LHC) at CERN (the European Organization for Nuclear Research). In contrast to such spacious facilities, the researchers from the University of Tokyo and the University of Fukui have demonstrated a table-top experimental setup, which occupies an area on the order of one tatami (a mat used as a flooring material in traditional Japanese-style rooms), as can be seen in the photos.

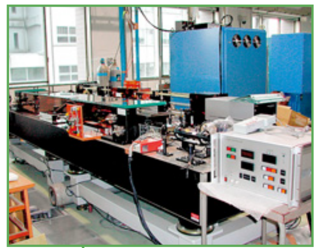
In this experimental study, for the first time in the world, the energy levels of positronium (Ps) and hyperfine splitting (HFS) have been measured by a direct method, which is based on the stimulated transition between two of the possible states, namely ortho-positronium (o-Ps) and para-positronium (p-Ps).

Ref: http://www.mext.go.jp/joho-hiroba/

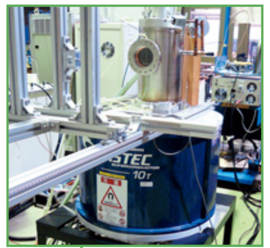


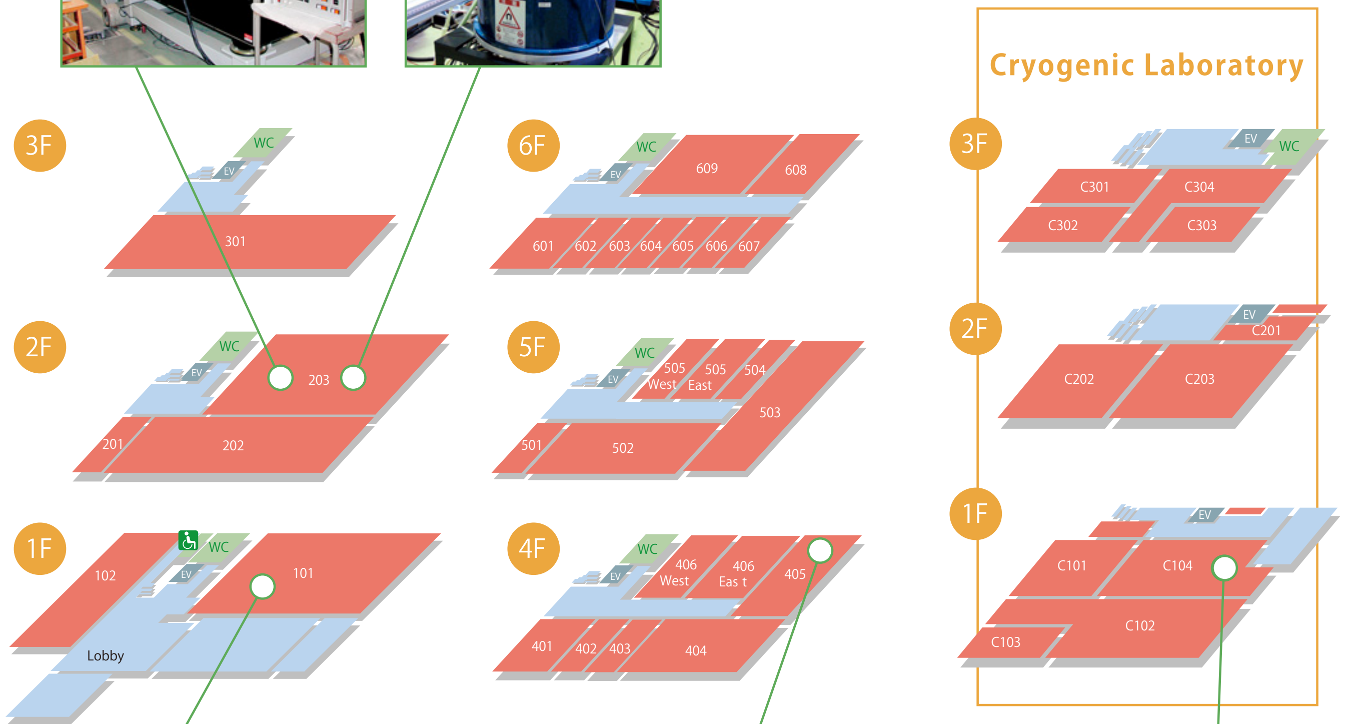
////// Major equipment of FIR UF

Far-infrared molecular laser

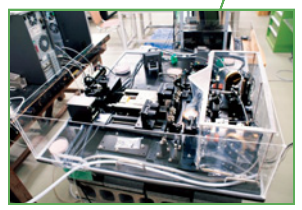


Multi-frequency gyrotron with internal mode converter (Gyrotron FU CW GV)

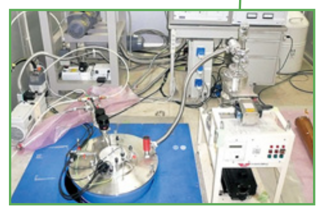




28-GHz microwave sintering system (Room 101)



THz time-domain spectrometer (Room 405)



THz ESR spectrometer (Room C104)

- Gyrotron FU CW GI
- Gyrotron FU CW GIII
- ● Gyrotron FU CW GV (Room 203)
- Gyrotron FU CW GVIB
- Gyrotron FU CW GVII
- Gyrotron FU CW VIIB (Pulsed ESR System)
- Gyrotron FU CW X
- Gyrotron FU CW CI
- Gyrotron FU CW CII
- Pulse 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 ^{3}He/^{4}He 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

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/admissions/

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, postdoctoral fellow 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.

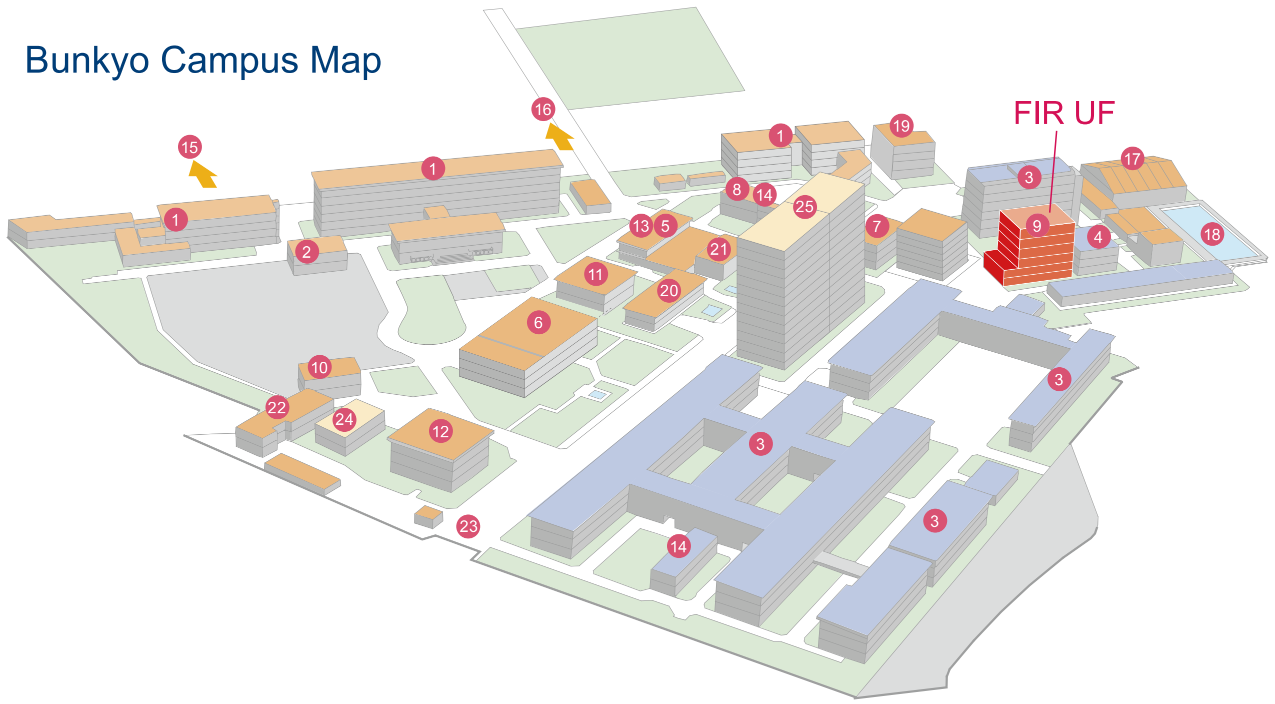
(Dr. Gudrun Niehues and Dr. Stefan Funkner)

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.



1. Faculty of Education and Regional Studies
2. Integrated Research Center 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 Students 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