NEWSLETTER

of the International Consortium "Development of High-Power Terahertz Science & Technology"

October 2016 № 4

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Dear Reader,

We are inviting contributions to the following rubrics:

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- Annotations of books, conference proceedings, software and internet resources. Additions to the list of the recent scientific publications and conference reports at the website of the Consortium (http://fir.u-fukui.ac.jp/Website_Consortium/publist.html).
- Information and announcements about awards and nominations.
- Short presentations of laboratories and research groups belonging to the participating institutions.

Please submit your contributions to the Newsletter as well as requests for information to:

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RESEARCH HIGHLIGHTS

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 Tokyo University (1 September – 21 October, 2016)

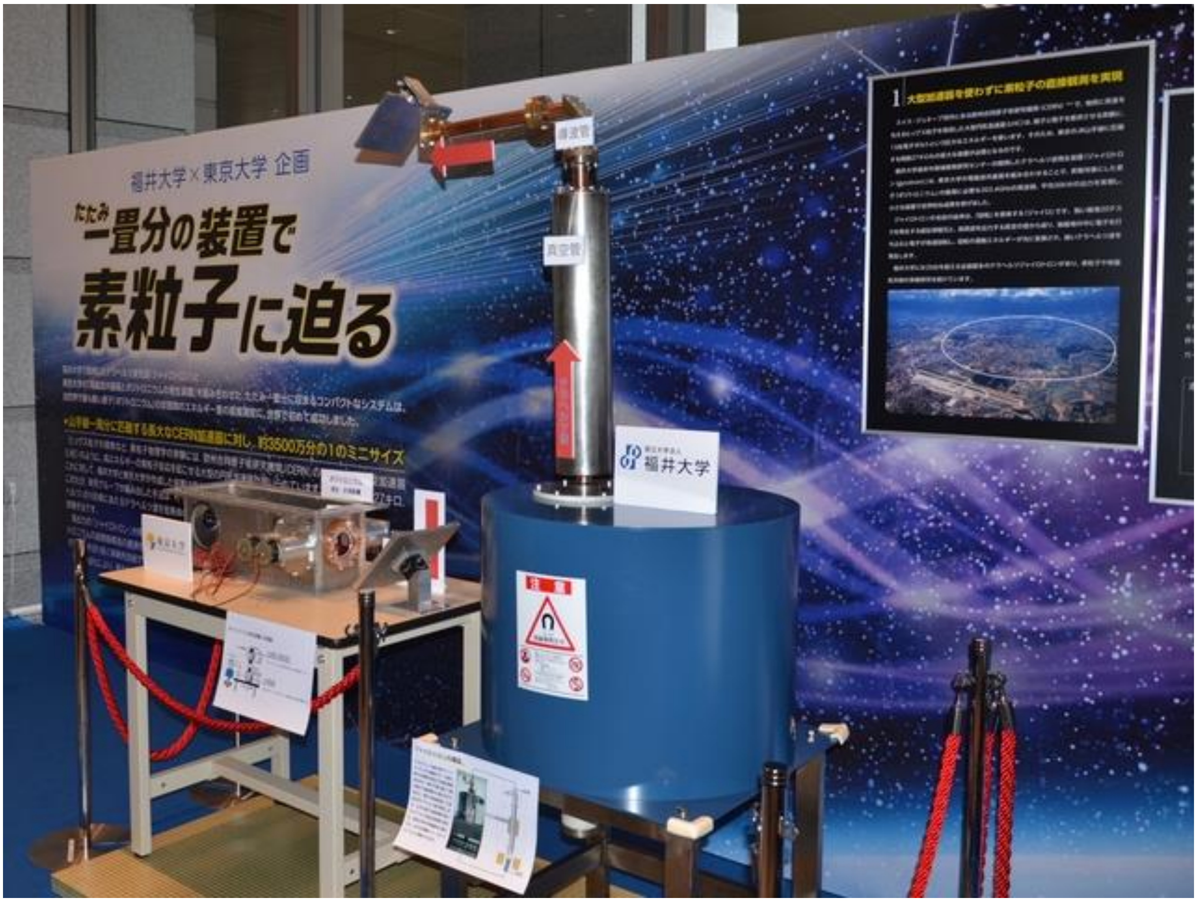
Presenters: **Coordinator:**

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
Associate Professor Hiromi Yokoyama
University of Tokyo Graduate School of Science; Deputy chief of the Strategy Planning Office

Usually, people associate the fundamental particle physics with large experimental infrastructures that include huge machines like linear accelerators, synchrotrons, colliders, storage rings, bulky detectors, etc. Take for example the Large Hadron Collider (LHC) at CERN (the European Organization for Nuclear Research). It uses a tunnel with a circumference of 27 km, which is comparable to the length of the Yamanote Line (railway loop line) in Tokyo. 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 of the order of *one tatami* (a mat used as a flooring material in traditional Japanese-style rooms) as can be seen on the next photos (Fig. 1).

In this experimental study for the first time in the world the energy levels of positronium (Ps) and the 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) as shown schematically in Fig. 2.

The positronium is a metastable bound state of one electron (e^-) and a positron (e^+) that form an exotic Hydrogel-like atom,. which can exists in two states, namely a triplet ($^3S_1$ ortho-positronium (o-Ps)) and a singlet ($^1S_0$ para-positronium (p-Ps)). The energy splitting between o-Ps and p-Ps, i.e. the HFS is about 203.4 GHz. A significant discrepancy of 3.9σ (15 ppm) between the measured HFS values and the theoretical prediction of the quantum electrodynamics (QED was a strong motivation to develop a novel method for direct and precise evaluation of the HFS [1]. In contrast to the previous indirect methods (by which the HFS is obtained from the measured Zeeman splitting in a static magnetic field) that are prone to systematic errors, the new approach relies on a stimulated transition from o-Ps to p-Ps induced by means of irradiation with strong electromagnetic wave with a frequency of about 203 GHz produced by a gyrotron. The experimental setup is shown schematically in Fig. 3. It includes a transmission line that delivers and couples the wave beam to a high-finesse Fabry-Pérot (FP) cavity, gas chamber and positron



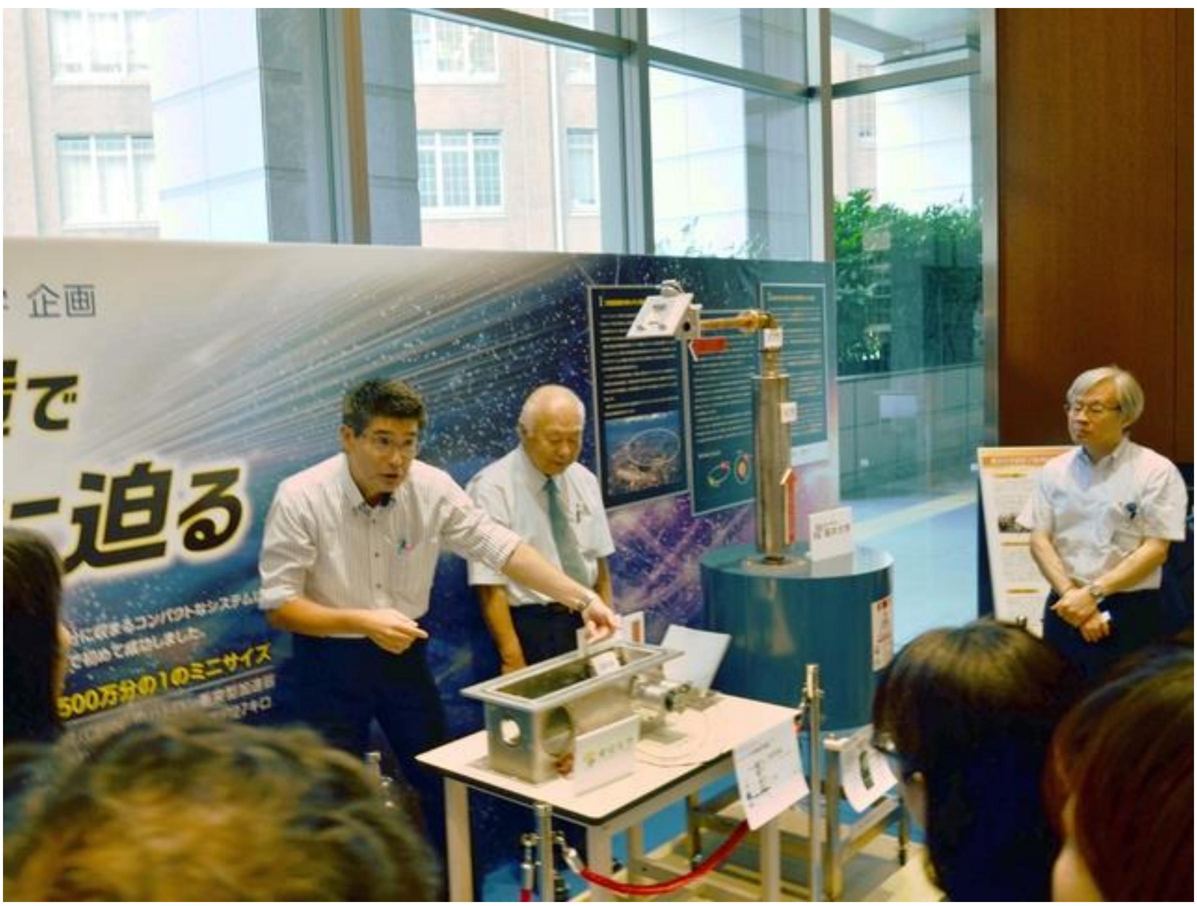


Fig. 1 Table-top (“one tatami”) experimental setup (upper photo) and the demonstration by Prof. S. Asai and Prof. T. Idehara (lower photo)

source as well as a system of detectors and electronic control modules. The positronium is formed in the cavity using a ^{22}Na source of positrons and nitrogen mixed by iso-Butane as a stopping target. Under the irradiation by a 203 GHz wave some of the o-Ps (decaying into 3-photons) transit into p-Ps (decaying into 2-photons) and consequently the ratio of 2-photon events increases. This process is monitored by the photon detectors ($LaBr_3$(Ce) scintilators) that are located around the cavity. In the measurements the frequency of the gyrotron is varied within ~2 GHz to observe a Bret-Wigner resonance of the transition. The hyperfine transition has been observed with a significance of 5.4 standard deviations. The transition probability that has been measured directly for the first time is found to be $A = 3.1^{+1.6}_{-1.2} \times 10^{-8}$ s^{-1} , which is in a good agreement with the theoretical value of $3.37\text{x}10^{-8}$ s^{-1} [2]. Recently, the whole Breit–Wigner resonance of the transition from o-Ps to p-Ps has been measured for the first time using a frequency-tunable millimeter-wave system and tuning the gyrotron in a very wide range from 201 GHz to 205 GHz by changing successively several gyrotron cavities of different radii [3].

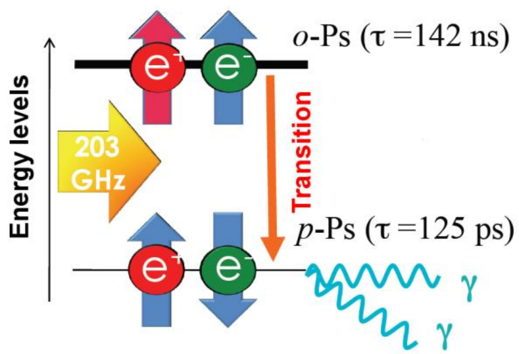


Fig. 2 Schematic representation of the energy levels and HFS of positronium

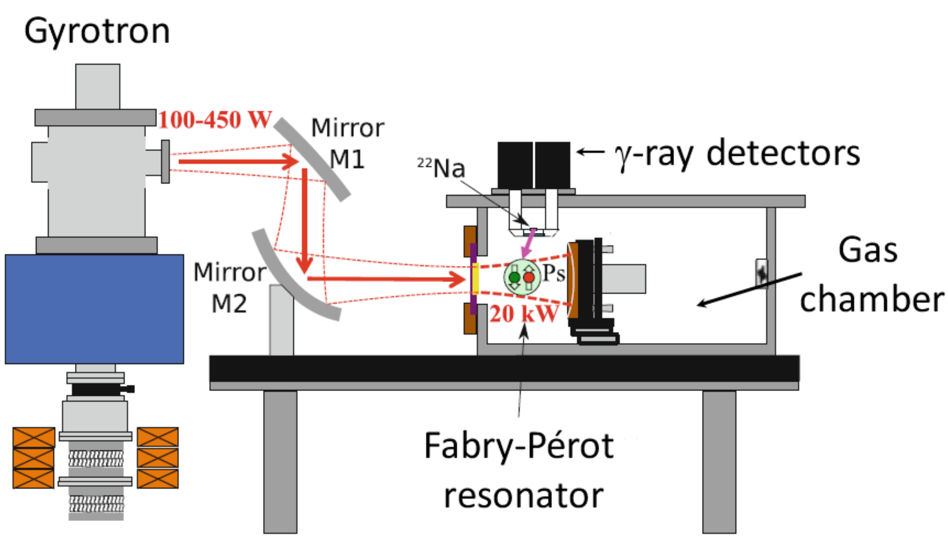


Fig. 3 Experimental setup

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AWARDS

Professor T. Idehara awarded the Kenneth J. Button Prize

During the 41th International Conference on Infrared, Millimeter, and Terahertz Waves (IRMMW-THz 2016) **Professor Toshitaka Idehara** from FIR UF has been 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”.

PERSONALIA

Andrei Viktorovich Gaponov-Grekhov (on his 90th birthday)

June 7, 2016 marks 90 years of the famous Russian scientist, Academician Gaponov-Grekhov.

Academician Gaponov-Grekhov is an author of fundamental works in the field of electrodynamics, plasma physics, physical electronics, the electrodynamics of a nonlinear medium, and the theory of distributed nonlinear systems. He has conducted theoretical and experimental research on induced cyclotron radiation, which allowed the development of masers on electron cyclotron resonance (State Prize of the USSR, 1967) and most notably the gyrotron. His remarkable achievements as a scientist and longstanding leader of the Institute of Applied Physics of the Russian Academy of Sciences (IAP-RAS) in Nizhni Novgorod have been reviewed in a recent memorial paper dedicated to his jubilee:

Bunkin F V, Denisov G G, Zheleznyakov V V, Zakharov V E, Zelenyi L M, Litvak A G, Mareev E A, Mesyats G A, Sergeev A M, Talanov V I, Fortov V E, Khazanov E A "Andrei Viktorovich Gaponov-Grekhov (on his 90th birthday)" Phys. Usp., vol. 59 613–615 (2016). DOI: 10.3367/UFNe.2016.05.037805.

For more details about the brilliant carrier and the most significant achievements of Academician Gaponov-Grekhov please visit:

http://ipfran.ru/english/staff/Gaponov-Grehov_1e.html

LIST OF SELECTED RECENT PUBLICATIONS

Bibliography and links to selected recent publications on topics related to the research field of the International Consortium

This is a cumulative list of selected publications in chronological order as collected from various bibliographical and alert services and published after June 2016, i.e. after issuing the previous Newsletter #3

A. Publications by authors from the institutions participating in the International Consortium

Glyavin M.Yu., Denisov G.G., Zapevalov V.E., Koshelev M.A., Tretyakov M.Yu., Tsvetkov A.I. "High power terahertz sources for spectroscopy and material diagnostics," Physics Uspekhi, vol. 59, no. 6 (2016). DOI: 10.3367/UFNe.2016.02.037801.
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Inventors: Sklyarevich, Vladislav (Bensalem, PA, US) and Shevelev, Mykhaylo (Bensalem, PA, US). Publication Date: 06/09/2016.
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Inventors: Koyama, Yasushi (Kamakura, JP), Tateishi, Yoshinori (Naka-gun, JP).
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Inventors: Lee, Sang-gug (Yuseong-gu, KR), Kim, Sun-a (Yuseong-gu, KR), Park, Dae-woong (Yuseong-gu, KR), Han, Seok-kyun (Yuseong-gu, KR). Publication Date: 07/21/2016.
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Publication date: 03/17/2016.
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Inventors: Vladislav Sklyarevich, Mykhaylo Shevelev. Publication Date: 09.06.2016.
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NEWS FROM THE NET (OUR BROADER HORIZONTS)

Terahertz waves rearrange polymer molecules

Using terahertz laser, scientists change the macromolecular conformation of a polymer

http://www.riken.jp/en/pr/press/2016/20160607_2/

See the original paper: Hiromichi Hoshina, Hal Suzuki, Chiko Otani, Masaya Nagai, Keigo Kawase, Akinori Irizawa, Goro Isoyama, "Polymer Morphological Change Induced by Terahertz Irradiation", Scientific Reports, DOI: 10.1038/srep27180. Open Access at:

http://www.nature.com/articles/srep27180

Convergence of Electronics and Photonics Technologies for Enabling Terahertz Applications

CELTA is the acronym for Convergence of Electronics and Photonics Technologies for Enabling Terahertz Applications. CELTA aims to produce the next generation of researchers who will enable Europe to take a leading role in the multidisciplinary area of utilising Terahertz technology for applications involving components and complete systems for sensing, instrumentation, imaging, spectroscopy, and communications. For more detail, visit the vebsite of the project:

http://www.celta-itn.eu/

A new imaging system can read closed books

In the latest issue of Nature Communications, the researchers describe a prototype of the system, which they tested on a stack of papers, each with one letter printed on it. The system was able to correctly identify the letters on the top nine sheets.

http://news.mit.edu/2016/computational-imaging-method-reads-closed-books-0909

The open access original paper “Terahertz time-gated spectral imaging for content extraction through layered structures” by A. Redo-Sanchez, et al., published in *Nature Communications* (DOI: 10.1038/ncomms12665 is available at:

http://www.nature.com/articles/ncomms12665

Rectifying light

An optical rectifying antenna, or ‘rectenna’, converts optical-frequency electromagnetic radiation into DC output. In these rectennas, light is treated as electromagnetic waves that are absorbed in micron-scale antennas and rectified by ultra-high-speed diodes. Even though the light is not absorbed in the same way that semiconductor solar cells absorb photons, the quantum nature of the electromagnetic fields is evident in the devices. This brings up fascinating questions about the nature of ultra-high-frequency rectification.

In their paper the authors Saumil Joshi and Garret Moddel have been investigating optical rectennas for power harvesting and detection [Joshi S., Moddel G., “Optical rectenna operation: where Maxwell meets Einstein,” J. Phys. D: Appl. Phys., vol. 49 (2016) 265602].

Visit: https://jphysplus.iop.org/2016/07/21/rectifying-light/

http://iopscience.iop.org/article/10.1088/0022-3727/49/26/265602/pdf

Manipulating superconducting plasma waves with terahertz light

An international team of researchers led by Andrea Cavalleri from the Max Planck Institute for the Structure and Dynamics of Matter at CFEL in Hamburg utilized the nonlinear interaction between a terahertz light field and a superconducting plasma wave in a high temperature cuprate superconductor to amplify the latter. This resulted in a more coherent superconductor, which is less susceptible to thermal fluctuations. Due to the non-dissipative superconducting nature of the plasma wave, the study opens up new avenues for "plasmonics", a field of science utilizing plasma waves for transmitting information.

Read more at: http://phys.org/news/2016-07-superconducting-plasma-terahertz.html#jCp

Physicists Develop Novel Electron Microscope Capable of Mapping Electromagnetic Waveforms

Researchers at the Laboratory for Attosecond Physics, jointly operated by LMU and the Max Planck Institute for Quantum Optics (MPQ), who built an electron microscope capable of imaging high-frequency electromagnetic fields and tracing their ultrafast dynamics.

The new electron microscope exploits the ultrashort pulses of laser light. These pulses only last for a few femtoseconds. Bunches of electrons that consist of very few particles are generated using these laser pulses, and then temporally compressed by terahertz (10^{12} Hz) near-infrared radiation. The LMU and MPQ scientists, who are part of the research team in Ultrafast Electron Imaging, first demonstrated this method earlier this year in the Science journal, where they demonstrated the techniques capability to produce electron pulses, which are shorter than an optical half-cycle.
Visit: http://www.azoquantum.com/News.aspx?newsID=4773

Latest Research and Reviews in Terahertz Optics

Terahertz optics is a branch of optics and photonics that studies electromagnetic radiation with a wavelength between **0.1 and 1 millimetre**, so-called because this corresponds to a frequency of approximately one terahertz.

Several very interesting review papers on the recent progress of THz Optics published in September and October 2016 have been published in *Nature*. Please visit:
http://www.nature.com/subjects/terahertz-optics

Novel method of spin control discovered

An international team of scientists from Germany, the Netherlands and Russia has successfully demonstrated a novel, highly efficient and ultrafast magnetization control scheme by employing electromagnetic waves oscillating at terahertz frequencies. These findings are of great importance for the understanding of light-magnetism interactions on extremely short timescales and for information technology of the future.
For more information visit:
https://idw-online.de/de/news660013

The efforts to realize a Bloch oscillator continue

A theory developed by the Nobel laureate Felix Bloch suggested that a specially structured material such as super-lattices (SL) that allowed electrons to oscillate in a particular way might be able to conduct terahertz signals. So far however, the formation of high field domains in the semiconductor super-lattices has been hindering the realization of a Bloch oscillator proposed by Esaki and Tsu more than 40 years ago. The firs attempt to solve this problem using sub-THz radiation produced by a gyrotron has been made in a series of experiments for investigation of the current suppression in superconductor SL driven by intense sub-THz wave [Y. Sakasegawa, T. Idehara, Y. Yamaguchi, S. Mitsudo, K. Hirakawa, Current suppression in semiconductor superlattices driven by intense sub-Thz radiation from a gyrotron, Proc. 17th Int. Conf. on Electron Dynamics in Semiconductors, Optoelectronics and Nanostructures EDISON

17 (7–12 August, 2011, Santa Barbara, California) P1.18]. Recently (decades after Bloch's theory), Stanford physicists may have developed materials that enable these theorized oscillations, someday allowing for improvements in technologies from solar cells to airport scanners. In their study, the researchers created a two-dimensional SL by sandwiching a sheet of atomically thin graphene in between two sheets of electrically insulating boron nitride. The atoms in the graphene and boron nitride have slightly different spacing, so when they are stacked on top of each other they create a special wave interference pattern called a moiré pattern. So far this research did not actually produce a Bloch oscillator, but suggests promising novel material for its possible realization in near future.

For more details, please visit: http://m.phys.org/news/2016-10-theorized-mechanism-life.html
and the original paper:
Lee M., Wallbank J.R., Gallagher P., Watanabe K., Taniguchi T., Fal'ko V.I., Goldhaber-Gordon D.,"Ballistic miniband conduction in a graphene superlattice," vol. 353, no. 6307 (2016) 1526-1529. DOI: 10.1126/science.aaf1095.
at: http://science.sciencemag.org/content/353/6307/1526