NEWSLETTER

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

February 2018 № 8

CONTENT

EDITORIAL: HOW TO CONTRIBUTE TO THE NEWSLETTER

Dear Reader,
We are inviting contributions to the following rubrics:

- Research highlights (annotations) presenting the projects pursued by the members of the Consortium.
- Short regular papers.
- Proposals for collaborative research work.
- News from the participating institutions.
- Information about conferences, symposia, workshops, seminars.
- Programs and frameworks for an exchange of visits and mobility of researchers. Job opportunities (especially for young researchers, e.g. postdoctoral positions, specializations, internships).
- 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.ufukui.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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EXTENDING THE INTERNATIONAL COLLADORATION

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

Over the years, FIR UF Research Center has always been an active promoter of a broad international collaboration with many institutions around the world using various frameworks and schemes based on the signed agreements for academic exchange and memorandums of understanding. On this basis, many researchers from overseas were invited as visiting research fellows for various terms (typically 2-3 months) or for short visits (usually a couple of weeks) for collaborative research. As an organizer and a facilitator of the International Consortium for Development of High-Power Terahertz Science and Technology (established in 2015), FIR UF continues to seek new efficient forms for co-operation between the participating members (13 institutions from 9 countries altogether). From the beginning of the current academic year (which in Japan begins on 1st of April) FIR UF started successfully the implementation of a new scheme based on the cross-appointment of the overseas researchers. The first cross-appointed professors were Irina Zotova (accompanied by the PhD student Andrei Fokin, whose supervisor she is), Andrei Savilov, from the Institute of Applied Physics of the Russian Academy of Sciences (IAP-RAS) and Svilen Sabchevski from the Institute of Electronics of the Bulgarian Academy of Sciences (IE-BAS). Dr. Tsun-Hsu Chang from the National Tsing Hua University in Taiwan, Vladimir Manuilov from the Nizhny Novgorod State University, and Naum Ginzburg from IAP-RAS joined the academic staff of FIR UF as visiting professors. During his short visit in August 2018, Professor Mikhail Glyavin presented the scientific program of the cross-appointed researchers from IAP-RAS at the seminar of FIR UF.

Both the cross-appointed and the visiting researchers work at the International Research Division which was founded at FIR UF Center in the FY 2016. Together with their Japanese colleagues of the host institution they are conducting studies on the development of high-performance sub-terahertz and terahertz gyrotons for a wide range of applications in the high-power terahertz science and technology.

A nice example of a successful research carried out in the framework of this collaboration is the development and experimental investigation of a novel double-beam gyrotron, which operates at the second harmonic of the cyclotron frequency. Such tube with an output frequency of about 0.8 THz is an appropriate radiation source for the next generation of a high-field DNP-NMR spectroscopy at 1.2 GHz. Another variety of such tube with two generating beams is an oscillator with one generating beam and one absorbing beam which suppress the excitation of the competing parasitic mode. A realization of the latter scheme is under investigation now. Several other very attractive and promising concepts of advanced gyrotrons are under consideration as well. Among them is the planar gyrotron with a transverse (with respect to the propagation direction of the sheet electron beam) extraction of the radiation (see the short paper in the current issue of the Newsletter). Other direction towards a high-harmonic operation and thus towards higher frequencies is the concept of the large orbit gyrotron (LOG), which utilizes axis-encircling (uniaxial) helical electron beam. The experience at FIR UF in the development of the first LOG with a permanent magnet is considered as a basis for the realization of various other new and promising LOGs (e.g. with sectioned cavities).

We expect that such an active collaboration will enrich further the research conducted at FIR UF and will contribute significantly to the realization of the goals of the International Consortium.

In October 2017, the Research Center for Development of Far-Infrared Region, University of Fukui (FIR UF), announced a new International Collaborative Research Program. This program aims to support the development of the high-power Terahertz science and technology through international personnel exchange visits and studies, being performed at the FIR UF in a wide interdisciplinary field that includes the development of radiation sources (most notably gyrotrons and other gyro-devices) and their applications in physical experiments and advanced novel technologies.

More detailed information about the International Collaborative Research Program and the application form are available at the website of the International Consortium for Development of High-Power Terahertz Science and Technology (visit: http://fir.u-fukui.ac.jp/Website_Consortium/index.html). We are inviting proposals for collaborative research work advancing to this new International Collaborative Research Program.

SHORT PAPER

Terahertz-Range Planar Gyrotrons with Transverse Energy Extraction Operating at the Fundamental and High-Order Cyclotron Harmonics

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[2]A.S. Sergeev, and [1,2]M.Yu. Glyavin

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Introduction

In the last few years, a considerable progress has been achieved in the development of terahertz-range gyrotrons [1-4]. At the frequency of 1 THz, the radiation power amounts several kilowatts in conventional gyrotrons with tubular helical beams formed by magnetron injection guns [1-3] and up to hundreds of watts in large-orbit gyrotrons (LOG) with axis-encircling electron beams [4]. All these experiments were performed in the pulse regime. Recently, terahertz-range radiation at the second cyclotron harmonic was achieved. In the latter experiment, a superconductive magnet was used. A typical feature of such magnets is a fairly large diameter of the warm bore of 5-10 cm. At the same time, the transverse cross-sections of conventional terahertz gyrotrons with cylindrical resonator are quite limited and amounts of several millimeters (Fig.1a). These strong limitations are caused by problems with mode selection that restricted admissible waveguide radius. As a result, restrictions on the driving beam current arise. In order to provide adequate starting conditions, one should increase the interaction length above an optimal value that together with rather small cross-section results in substantial Ohmic losses. According to the simulations for experimental conditions corresponding to [5], the Ohmic losses amount to 80% of the radiation power. Obviously, the improvement of mode selection is the key issue in the further development of short-wavelength gyrotrons.

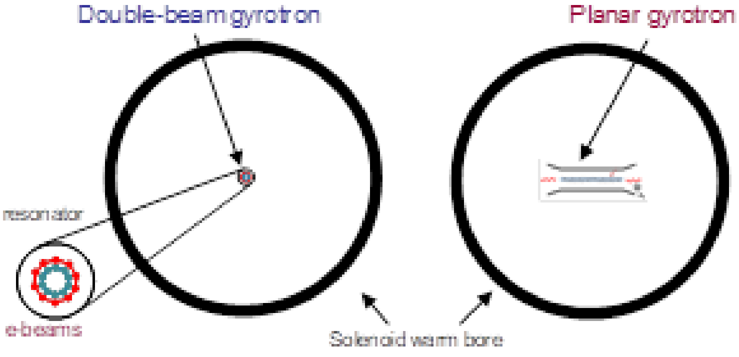

Fig.1. Transverse cross-section of (a) a double-beam and (b) a planar gyrotrons in the scale of the warm bore of the JMTD15T52 cryo-magnet.

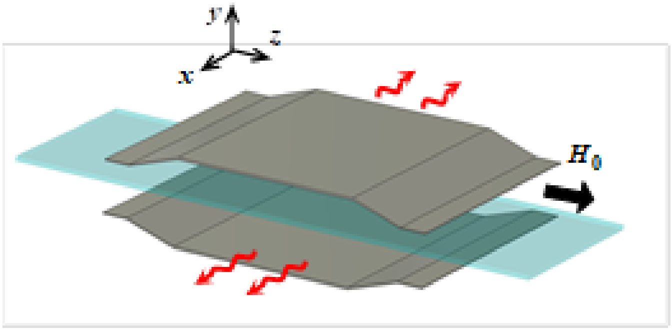

Fig.2. The model of a planar gyrotron. Arrows show the directions of energy extraction.

For a drastic increase in the output power of short-wavelength gyrotrons, we suggest using a planar scheme with a sheet electron beam and transverse (with respect to the electrons translation velocity) electromagnetic energy extraction (Fig.2). The main advantage of this scheme comparing it to the conventional cylindrical geometry is the possibility of effective mode selection over the open transverse coordinate in a combination with radiation out-coupling, which leads to a substantial reduction of the Ohmic losses [6,7]. It is important to note that in the existing cryomagnets, the warm bore diameter is sufficient for a significant increase of the cross-section of the terahertz-range gyrotrons and provides enough space for installation of additional reflectors required for arrangement of transmission of generated radiation in the direction of the collector.

It should be noted that in the considered planar scheme there are some peculiarities related to the excitation of odd ($s=1,3...$) and even ($s=2,4...$) cyclotron harmonics, respectively. Under the assumption that the sheet electron beam is injected along the resonator axis (in the middle of the cavity between the plates), the interaction of an electron beam at odd cyclotron harmonics occurs only for the resonator modes with odd transverse indexes $n=1,3...$, while the interaction at even harmonics occurs only for the modes with even transverse indexes $n=$ 2,4... (see Fig.3). Moreover, for example, for operation at the second harmonic, it is beneficial to use an even resonator mode with indexes n equal to a doubled even number. In this case interaction at second harmonic will be not accompanied by a simultaneous excitation of a lower order mode at the first cyclotron harmonic since the coupling factor of the 1st harmonic with an even mode is equal to zero. From the other hand, for excitation at the odd cyclotron harmonic the number of the resonator mode should not be dividable by s. For example, for $s=3$, the resonator mode number may be $n=5,7,11...$. In this case the parasitic mode at the 2nd cyclotron harmonic is not excited.

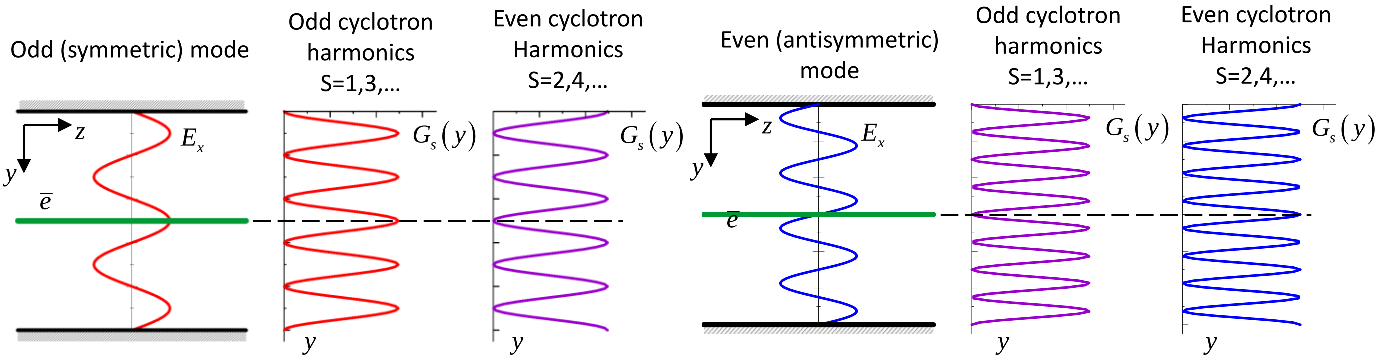

Fig.3. The coupling factor $G(y)$ for odd and even cyclotron harmonics.

Results of simulations

Simulations of the nonlinear dynamics of terahertz-range planar gyrotrons operating at the 1st and 2nd cyclotron harmonics were performed based on the self-consistent time-domain model developed in [6]. Similar to the well-known model of low-Q gyrotrons [8], the field evolution in [6] is described by a non-uniform parabolic equation. However, in order to describe the transverse energy extraction the diffraction of radiation over the transverse coordinate x is taken into account, while in z-direction the gyrotron resonator is closed by cut-off necks (see Fig.2). The main parameters are presented in Table 1.

Table 1

Harmonic number, s	1	2
Mode number	11	12
Wavelength, mm	0.768	0.384
I_b, A	2	2
U, kV	30	30
H_0, T	~15.03	~14.84
g	1.2	1.2
l_x, mm	15.3	7.7
L_y, mm	4.22	2.3
l_z, mm	10	20
Efficiency , %	31	7
Output power , kW	16	2.9
Losses, %	15	30

A) Operation at the first cyclotron harmonic

For the first harmonic operation, we choose the gap between plates of $l_y = 4.22$ mm (5.5λ), which corresponds to the eleventh (TE_{11}) mode of a planar waveguide. The sheet beam width was chosen equal to the transverse size of the interaction space of 15.3 mm (20λ). Simulations show the existence of zones of cyclotron resonance mismatch Δ, for which a steady-state regime takes place with excitation of modes having a different number of longitudinal variations m. The spatial distribution of radiated field amplitude for the mode with a single longitudinal variation $m=1$ is shown in Fig.4a. The dependence of electron efficiency $\eta_{\perp}$, output power P_{out} and Ohmic loss power P_{ohm} on the beam current I_b are presented in Fig.4b-d. For the fixed current we have optimized the system with respect to the interaction length l_z and the resonance mismatch Δ. One can see that with increasing the current, the optimal length decreases together with the Ohmic losses. Thus, the total radiation power increases. For a current of 20 A, the output power amounts to 115 kW at an electron efficiency of 21%. The Ohmic losses don't exceed 11%.

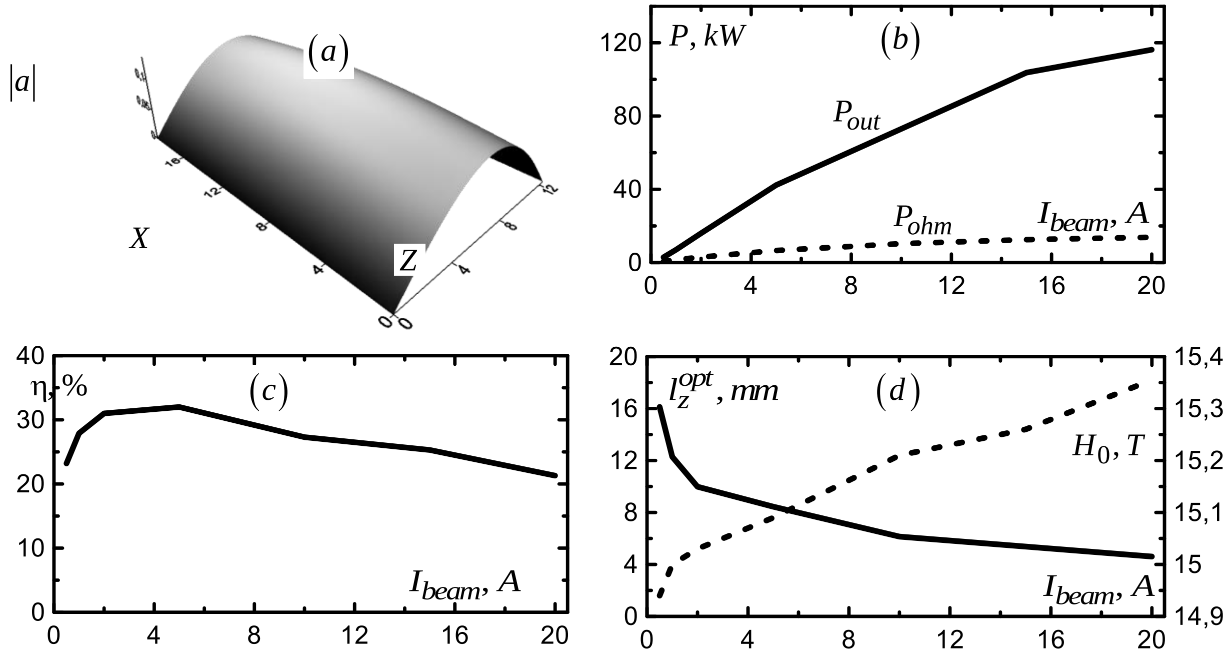

Fig.4. The field profile inside the interaction space of a planar gyrotron for the mode with a single longitudinal variation $m=1$ (a). Dependencies of electron efficiency (a), output power and Ohmic losses (b), optimal interaction length and magnetic field (c) on the injection current

B) Operation at the second cyclotron harmonic.

For the second harmonic operation, we decrease the gap between the plates up to $l_y = 2.3$ mm (6λ) that corresponds to the twelfth (TE_{12}) mode of the planar waveguide. The sheet beam width was chosen equal to the transverse size of the interaction space of 7.7 mm (20λ). As one can see from Table 1, the efficiency and output power at the second harmonic are lower comparing it with the first harmonic operation while the Ohmic losses increase. Nevertheless, these values exceed the calculated parameters of the double-beam gyrotron [9] for the same injection current.

3D PIC simulations of a planar gyrotron operation at the third cyclotron harmonic

Results in the frame of averaged approach were confirmed by direct simulations using the PIC (particle in-cell) code CST STUDIO SUITE. In particular, the possibility of an efficient generation at the 3^{d} harmonic has been demonstrated in the range of ~ 250-300 GHz (see Fig.5). The sheet electron beam used in the simulations possesses the following parameters: electron energy of 80 kV, electron current of 15 A, pitch factor of ~ 1. The distance between the plates was chosen to be 3 mm (~ 2.5 - 3 wavelengths), the width of the plates is 1 cm (about 8 - 10 wavelengths). Simulations show the establishment of a steady-state regime at the 3^{d} cyclotron harmonic for the guiding magnetic field of 3.35 T. In this regime the spatial structure of the radiation corresponds to the excitation of the TE_5 mode with high selectivity. For the chosen parameters the efficiency of the generation is about of 8% and the output power is 50 kW.

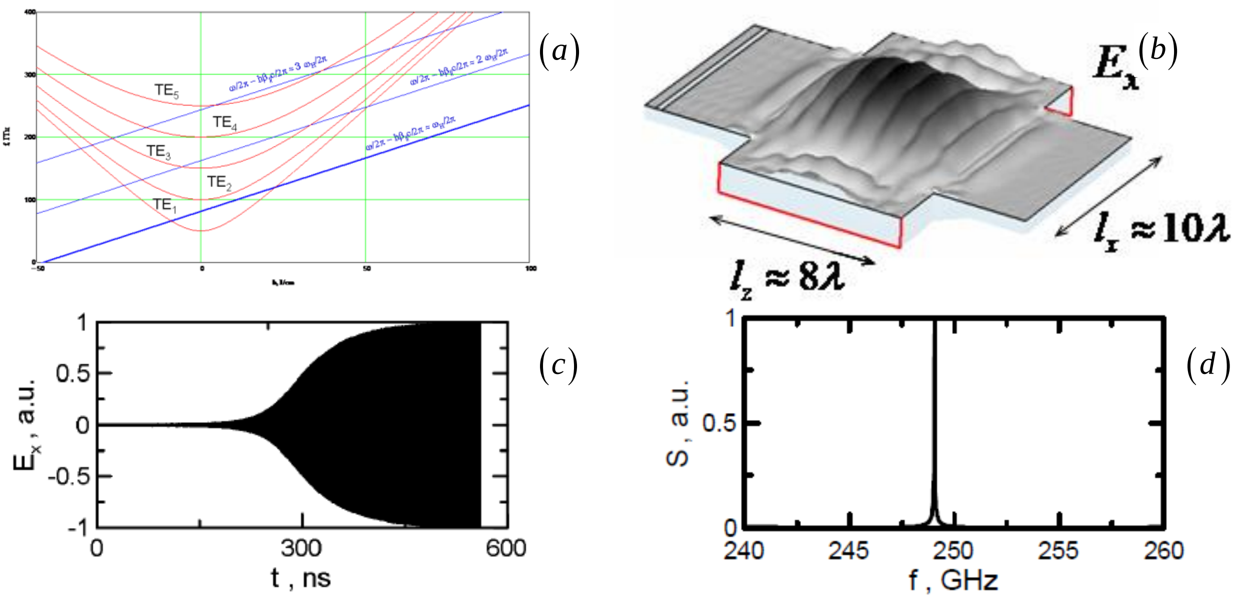

Fig.5. Results of PIC simulations for operation of a planar gyrotron at the 3^{d} cyclotron harmonic: dispersion diagram (a), spatial structure of the electromagnetic field (b), set-on of the steady-state regime (c) and the corresponding spectrum of the radiation (d).

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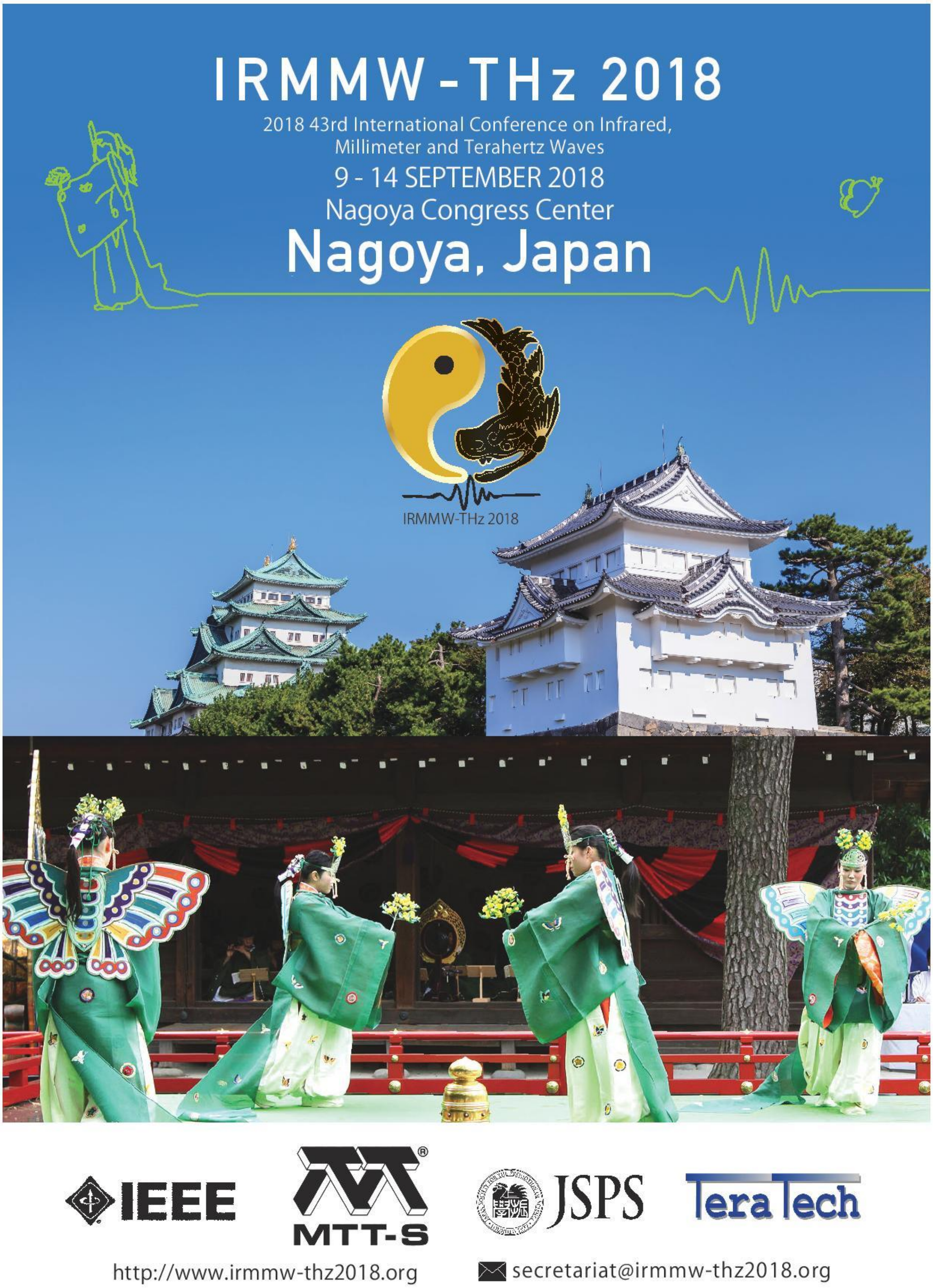
[9] N.S. Ginzburg, M.Yu. Glyavin, A.M. Malkin, V.N. Manuilov, R.M. Rozental, A.S. Sedov, A.S. Sergeev, V.Yu. Zaslavsky, I.V. Zotova and T. Idehara, *Improvement of stability of high cyclotron harmonic operation in the double-beam THz range gyrotrons,* IEEE Trans. on Plasma Sci., **44** **(**8) 1303-1309 (2016).

The first author of this short paper, Professor Naum Ginzburg was a Visiting Professor at the University of Fukui from November to December 2017. On 15 December 2017 he delivered a talk “Development of Terahertz-Range Planar Gyrotrons with Transverse Energy Extraction Operating at the Fundamental and High-Order cyclotron harmonics” at the FIR UF seminar. The paper summarizes the main results presented and discussed there.

NEXT IRMMW-THz CONFERENCE



IRMMW-THz 2018

2018 43rd International Conference on Infrared,
Millimeter and Terahertz Waves

9 - 14 SEPTEMBER 2018
Nagoya Congress Center
Nagoya, Japan

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For up-to-date information, registration, etc. follow the link to the website of IRMMW-THz 2018

IRMMW-THz 2018

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OTHER CONFERENCES

19th International Vacuum Electronics Conference
Monterey, US, 24 - 26 April 2018
http://ivec2018.org/

6th ITG International Vacuum Electronics Workshop 2018
Physikzentrum Bad Honnef (PBH), Bad Honnef (Germany), 6.09.2018 - 07.09.2018
https://www.ihe.kit.edu/download/VDE(ITG)_%20WORKSHOP_IVEW%202018_Call_V2.pdf

7th Euro-Asian Pulsed Power Conference (EAPPC) and 22nd International Conference on High-Power Particle Beams (BEAMS)
Changsha, China, 16-20 September 2018
http://www.eappc-beams2018.org/

The 40th PIERS (Progress In Electromagnetics Research Symposium)
Toyama, Japan, 1 - 4 August 2018
http://piers.org/piers2018Toyama/

13th International Conference on Electron Beam Technologies
Varna, Bulgaria, 13-18 June 2018
http://www.ebtconference.com/index.html

GeMiC 2018 – German Microwave Conference
Konzerthaus Freiburg, Germany, 12-14 March 2018
https://www.gemic2018.de/

The 3rd Conference on Microwave and Terahertz Technology (ICMT 2018)
Arnoma Hotel, Bangkok, Thailand, 5-7 January 2018
https://waset.org/conference/2018/08/bangkok/ICMT

8th International Workshop on Terahertz Technology and Applications
Kaiserslautern, Germany, 20-21 March 2018
https://www.vdi.de/index.php?id=47465

Asia Pacific Microwave Conference
Kyoto, Japan, 6 - 9 November 2018
http://www.apmc2018.org/

International Applied Computational Electromagnetics Society Symposium ACES-2018
Denver, CO, United States, 24-29 March 2018
http://aces-society.org/conference/Denver_2018/

The IEEE International Conference on Computational Electromagnetics ICCEM-2018
Chengdu, China, 27-29 March 2018
http://www.aconf.org/conf_108661.html

International Conference on Terahertz Emission, Metamaterials and Nanophotonics
Hacienda Uxmal Plantation & Museum, Mexico, 25-29 March 2018
https://www.mifp.eu/SCHOOLS/TERAMETANANO-3/

International Conference on Microwave and Millimeter Wave Technology (ICMMT2018)
Chengdu, China, 7-11 May 2018

https://www.aconf.org/conf_111318.html

3rd International Conference on Microwave and Photonics (ICMAP 2018)
Dhanbad, India
http://www.icmap2018.org/

IEEE MTT-S International Conference on Numerical Electromagnetic and Multiphysics Modeling and Optimization
Reykjavik, Iceland, 8-10 August 2018
http://nemo-ieee.org/

IEEE MTT-S The International Microwave Biomedical Conference (IMBioC)
Philadelphia, PA , USA, 14-15 June 2018
https://www.imbioc-ieee.org/

2nd Asia-Pacific Conference on Plasma Physics AAPPS-DPP2018
Kanazawa, Japan, 12-17 November 2018
http://aappsdpp.org/DPP2018/index.html

International Conference Advanced Laser Technologies (ALT 2018)
Tarragona, Spain, 10-15 September 2018
http://altconference.org/alt18

LIST OF SELECTED RECENT PUBLICATIONS

Bibliography and links to selected recent publications on topics related to the research field of the International Consortium and published after October 2017, i.e. after issuing the previous Newsletter #7. This cumulative list is in chronological order as collected from various bibliographical and alert services

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

Proyavin M.D., Glyavin M.Yu., Manuilov V.N., “Magnetically shielded electron-optical system of a continuous gyrotron with an operating frequency of 24 GHz,” Journal of Communications Technology and Electronics, vol. 62, n. 10 (2017) 1165-1171. DOI:10.1134/S1064226917100126.
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Rozental R.M., Ginzburg N.S., Sergeev A.S., Zotova I.V., Fedotov A.E., Tarakanov V.P., “Gyrotron generation of broadband chaotic radiation under overlapping of high- and low-frequency resonances,” Technical Physics, vol. 62, n. 10 (2017) 1562-1568. DOI:10.1134/S106378421710019X.
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C. *Patents*

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United States Patent Application 20170310111
Inventors: Badapanda, Manmath Kumar (Indore, IN)
Publication Date:10/26/2017

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Strong-Magnetic-Focused Magnet System with Terahertz Source
United States Patent Application 20170372824
Inventors: Wang, Qiuliang (Beijing, CN), Hu, Xinning (Beijing, CN), Dai, Yinming (Beijing, CN)
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Waveguide system for slot radiating first electromagnetic waves that are combined into a non-fundamental wave mode second electromagnetic wave on a transmission medium
Inventors: Henry, Paul Shala (Holmdel, NJ, US), Bennett, Robert (Southold, NY, US), Barzegar, Farhad (Branchburg, NJ, US), Gerszberg, Irwin (Kendall Park, NJ, US), Barnickel, Donald J. (Flemington, NJ, US), Willis III, Thomas M. (Tinton Falls, NJ, US), Guntin, Ed (Barrington, IL, US)
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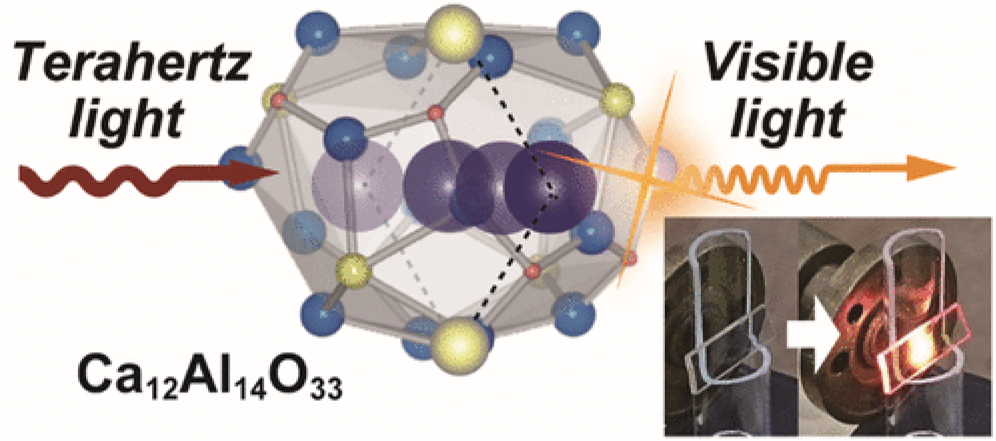
NEWS FROM THE NET (OUR BROADER HORIZONS)

Rattling motion of oxygen ions converts the terahertz rays generated by a gyrotron to visible light

In a recently published paper, which presents the results from the experiments carried out at the Research Center for Development of Far-Infrared Region at the University of Fukui (FIR UF Center), it has been demonstrated that the irradiation of nanoscale cages of $Ca_{12}Al_{14}O_{33}$ crystal (called mayenite) converts the CW Terahertz radiation produced by a gyrotron to a visible light. The authors explain this by the fact that these crystallographic cages are partially occupied with weakly bonded oxygen ions and have a narrow conduction band that can be populated with localized, albeit mobile electrons. Under the influence of the electromagnetic field of the terahertz wave, the encaged oxygen ions exercise a rattling motion (vibration), which promotes an electron transfer of the electrons to the neighboring vacant cages. At sufficiently high irradiating power (of the order of several tens of Watts) the combined effect of several phenomena (coupling between the forced rattling motion in a confined space, excitation and ionization of the oxygen species, and most notably the corresponding recombination processes) is an intense emission of bright visible light. Schematically, the observed effect is illustrated in the following figure (courtesy of ACS Publications):



Schematics of the observed phenomenon and a detail of the experimental setup

As pointed out by Science Daily (November 28, 2017) , “The finding is a breakthrough for functional materials research and could lead to the development of a new kind of terahertz detector.” Further, the article in Science Daily emphasizes that “The study is an example of strategic research on functional materials under the Element Strategy initiative supported by Japan's Ministry of Education, Culture, Sports, Science and Technology (MEXT) and the Japan Science and Technology Agency (JST).” In an interview for the same on-line edition, Hideo Hosono of Materials Research Center for Element Strategy, Tokyo Tech says: “"Our group has been concentrating on the cultivation of new functionalities using abundant elements, but it's the first time for me to focus on ionic motion - this is completely new. Right now, our material is good at detecting strong terahertz radiation. The challenge will be how to adjust the sensitivity."

This breakthrough result has become possible due to the remarkable progress in the development of high-power, terahertz range gyrotrons at the FIR UF Research Center demonstrated recently. These gyrotrons have opened the road to many novel and pioneering applications in the fundamental physical studies and high-power terahertz science and technologies.

Please access the original article at ACS NANO:

Yoshitake Toda, Shintaro Ishiyama, Eduard Khutoryan, Toshitaka Idehara, Satoru Matsuishi, Peter V. Sushko, Hideo Hosono, “Rattling of Oxygen Ions in a Sub-Nanometer-Sized Cage Converts Terahertz Radiation to Visible Light,” ACS Nano, 2017. DOI: 10.1021/acsnano.7b06277.

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News from the Internet Portal Scientific Russia

Multi-megawatt millimeter-wave gyrotron

(Visit: https://scientificrussia.ru/articles/multimegavattnyj-millimetrovyj-girotron (in Russian)

The range of millimeter waves has always been of particular interest for the physical research. The length of these waves is already so small that their propagation occurs in much the same way as light waves, which makes it possible to build on millimeter waves, for example, effective high-resolution radar systems. On the other hand, in this range there are characteristic frequencies of radiation absorption by various substances, therefore these waves are extremely interesting for spectroscopy. Prospective schemes of charged particle accelerators also relay on millimeter-wave radiation in order to realize high rates of acceleration. Effective sources of intense radiation in the short-wave part of the millimeter range are the gyro-resonance devices, in particular, the gyrotrons. Their operation is based on the creation of conditions for coherent radiation of electrons rotating in an external magnetic field. Modern gyrotrons for plasma heating in the reactors for controlled thermonuclear fusion provide an output power of up to 2 MW in continuous mode (CW) at a frequency of 170 GHz. A further increase in the gyrotron power is possible increasing the energy of the electron beam up to the levels of hundreds of thousands of electron Volts, which means a transition to the region of relativistic energies. For a long time, it was believed that in this region the efficiency of gyrotrons is significantly reduced. However, detailed numerical simulation of electron-wave interaction processes in the gyrotron resonators has shown, that irrespective of the electron energy, conditions can be realized in which even in highly relativistic gyrotrons the efficiency reaches 35-45%. This was confirmed experimentally in the Institute of Applied Physics of the Russian Academy of Sciences, where gyrotrons operating at a wavelength of 3 and 1 cm with a record-high output power values of about 10 MW have been developed. The experience, gained during the research on such such devices has made it possible to a gyrotron with similar characteristics in the 3-mm wavelength range.

The 3-mm relativistic gyrotron (see the photo) was realized on the basis of the pulse-periodic electronic accelerator "Saturn-F". An electron beam with a particle energy of 250 keV and a current of 90-100 A with a pulse duration of 1 μs was formed in the accelerator. The beam propagated in a magnetic field with a maximum field intensity up to 5T, which was created by a superconducting magnet.

As the working mode of the gyrotron, a rotating $TE_{12,5}$ mode of a circular waveguide was selected. Such high-order mode has been used for the first time in a relativistic gyrotron. The numerical simulations have shown the possibility of obtaining output power at a level of several megawatts with an electron efficiency of about 35%. In the developed gyrotron (in contrast to the long-wavelength devices realized earlier) an internal quasi-optical mode converter is used, which forms a Gaussian wave beam with a conversion efficiency of more than 95%.

During the experiments with a magnetic field values set close to the cyclotron resonance for the working mode, the gyrotron demonstrated stable generation at a frequency close to that expected. The operational performance of the gyrotron was optimized for a set of control parameters, the main ones being the intensity of the magnetic field in the resonator, the rotational velocity of the electrons, and the radius of the beam in the working space. The maximum output pulse power observed in the experiment was 5.6 MW at 94.4 GHz with an efficiency of about 20%.

Photo of the relativistic gyrotron, installed on the experimental stand "Saturn-F"

E.B. Abubakirov,
Leading Researcher of IAP RAS

For more detail about the progress in the development of relativistic gyrotrons, please access the recently published paper:

Abubakirov E.B., Denisenko A.N., Konyushkov A.P.,Osharin I.V., Rozental R.M., Tarakanov V.P., Fedotov A.E., "Developing a high-current relativistic millimeter-wave gyrotron," Bulletin of the Russian Academy of Sciences: Physics, vol. 82, n.1 (2018) 48-52. DOI:10.3103/S1062873818010033.
https://link.springer.com/article/10.3103%2FS1062873818010033

The world's first serial production gyrotron for ITER was developed by Nizhny Novgorod scientists

(Visit: https://scientificrussia.ru/partners/institut-prikladnoj-fiziki-ran/pervyj-v-mire-serijnyj-girotron-dlya-iter (in Russian)

In October 2017, members of the international commission, which included managers and specialists of the Russian Agency "ITER" and the International Organization "ITER" tested the device, after which a protocol was signed with the resolution "adopted." Gyrotrons for ITER are developed by several international collaborations: the EU countries, India, the Russian Federation and Japan. In total, the ITER facility will use 24 megawatt gyrotron complexes with a frequency of 170 GHz and 1 MW output power of each unit. At least 8 of them will be Russian.

The gyrotron complex is a sophisticated facility that includes about 30 different systems (a cryogen-free superconducting magnet, other auxiliary magnets, power supplies, cooling system, control system, etc.) that are being developed by an interdisciplinary research team. But the heart of the complex is a gyrotron - a source of powerful coherent electromagnetic radiation operating in the millimeter wavelength range. It should be mentioned that the priority in the invention of the gyrotron belongs to the scientists from the IAP RAS. Today, more than half of the existing experimental plasma heating plants in the world are equipped with Nizhny Novgorod's gyrotrons, for the production of which the Scientific and Production Enterprise GIKOM was established twenty-five years ago. The gyrotron complex for the International Project "ITER" demanded from the developers a serious and long cycle of research in order to satisfy the requirements imposed by the ITER project. The prototype complex with the necessary parameters (output power of 1 MW, frequency of 170 GHz, efficiency 50%, and a pulse duration 1000 s) Nizhny Novgorod created in 2015, the first of all countries participating in the project.

The photo shows the world's first serial gyrotron complex for the International Thermonuclear Reactor "ITER" created in Nizhny Novgorod (Russia) by scientists of the Institute of Applied Physics of the Russian Academy of Sciences in cooperation with the Scientific and Production Enterprise "GIKOM" and the company "RTSoft".

Novel Broadband Gyrotron Travelling Wave Amplifier (gyro-TWA) with an Axis-Encircling Electron Beam and a Helically Corrugated Interaction Region

Recently, researchers from the Department of Physics, University of Strathclyde, UK and SUPA (Scottish Universities Alliance in Physics) have published a paper[1] in Physical Review Letters, which presents experimental results of a broadband, high power, gyro-TWA operating in the 75-110 GHz frequency band and based on a helically corrugated interaction region. It utilizes an axis-encircling (aka uniaxial) electron beam with an energy of 55 keV and current of 1.5 A, which interacts resonantly with a traveling $TE_{2,1}$ at the second harmonic of the cyclotron frequency achieving broadband amplification. The gyro-TWA demonstrates a 3-dB gain bandwidth with at least 5.5 GHz in the experimental measurement with 9 GHz predicted for a wideband drive source with a measured unsaturated output power of 3.4 kW and a gain of 36-38 dB.

This remarkable results demonstrate the potential of combining two advanced concepts, namely dispersion engineering (which allows to obtain an appropriate, close to the “ideal”, dispersion diagram in a threefold helically corrugated waveguide) and the interaction with an axis-encircling beam produced by a cusp electron gun. The authors claim that such approach may allow a gyro-TWA to operate at 1 THz.

For an access to the original paper (published by the American Physical Society under the terms of the Creative Commons Attribution 4.0 International license.) at publisher’s website please follow the link.

[1] He W., Donaldson C.R., Zhang L., Ronald K., Phelps A. D. R., Cross A.W. “Broadband amplification of low-terahertz signals using axis-encircling electrons in a helically corrugated interaction region,” Physical Review Letters, 119(18) (2017) 184801. DOI: 10.1103/PhysRevLett.119.184801.