NEWSLETTER

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

June 2020 № 15

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 and invited 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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SHORT INVITED PAPER

Development of an electron-optical system with a field emitter for low-power, high-frequency gyrotrons

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At the moment, the gyrotrons have a leading position among the sources of high-power microwave radiation in the sub-THz and THz bands. In contrast to the MW level power tubes for plasma heating, the power about several tens of Watts looks reasonable for such applications as high-resolution spectroscopy, in particular Dynamic Nuclear Polarization (DNP) and Nuclear Magnetic Resonance (NMR). In recent years, some efforts are made to obtain high power generation in the millimeter-wave range using solid-state transistors and monolithic integrated circuits. The greatest success was achieved using solid state systems based on different nitrides, including GaN. So far, however, even with the best systems of GaN on the diamond substrate the power about several Watts can be obtained only at frequencies less than 50-100 GHz. The same power level at higher frequencies around 250 GHz or more, required for DNP / NMR, looks probably impossible for solid state devices, at least in the near future. Thus, it can be stated that currently the gyrotrons are the only acceptable sources of microwave radiation for the given type of spectrometers.

Traditionally gyrotrons use thermionic cathodes. Compact sub-THz and THz tubes have relatively small dimensions of their constructive elements, where heating of thermionic cathodes can cause a change of its geometrical dimensions and therefore an associated undesirable change of its output characteristics. Furthermore, a relatively long time is required to heat the thermionic cathodes to a stable operating temperature. So, it is not possible to provide a quick start of gyrotrons with thermionic cathodes. Meanwhile, maximally inertia-less on/off switching of the submillimeter gyrotrons may be necessary for some applications. Finally, miniature thermionic cathodes used in regimes when it is necessary to obtain large emission current densities from their surface, have short lifetime. As a result, in the miniature sub-THz and THz bands gyrotrons utilizing thermionic cathodes complicates their exploitation and narrows the field of application of these devices.

In view of what was said, it seems very attractive to replace the hot cathodes by field emitters. Field emitters do not require heating and are virtually inertia-free. Such a replacement is impeded by the fact that field emitters should have a high lifetime when operated in technical vacuum and, simultaneously, provide currents greater than 20-30 mA. Besides, an emission current density of the order of or more than 100 mA/cm^2 even in gyrotrons with small output power (tens of watts) for diagnostic and medical applications is needed. Until recently, there have been no field emitters which could satisfy simultaneously the high requirements mentioned above. However, recent studies have shown that multi-tip field emitters with innovative protection coatings can, after some modification, be employed in the high-frequency gyrotrons.

In what follows, we give the concept of the construction of electron-optical systems (EOSs) of submillimeter gyrotrons with field emitters and describe the main distinctive features of both the emission system and the resulting characteristic features of the helical electron beam (HEB) formation system of a gyrotron. The analysis is performed by an example of a gyrotron with an operating frequency of 263 GHz, an accelerating voltage of 15 kV, and an output power of about ten watts, which is sufficient for the purposes of the DNP/ NMR spectroscopy.

To obtain the required values of the field emission current, the electric field on the emitter surface should exceed 5 kV/mm. On the tip surface in a multi-tip structure with a typical tip diameter D = 30 - 50 nm and a height h = 30 μm, a field gain $\beta \geq 1000$ can be provided. For beam current higher than 5 μA from a single tip, usually, the tip will be destroyed and this fact give a physical limitation of the current from a single tip. Thus, the required current density can be achieved for $N \sim 10^4$ tips on the emitting cathode surface. Such structure has been developed and made by St.-Petersburg team (Fig.1).

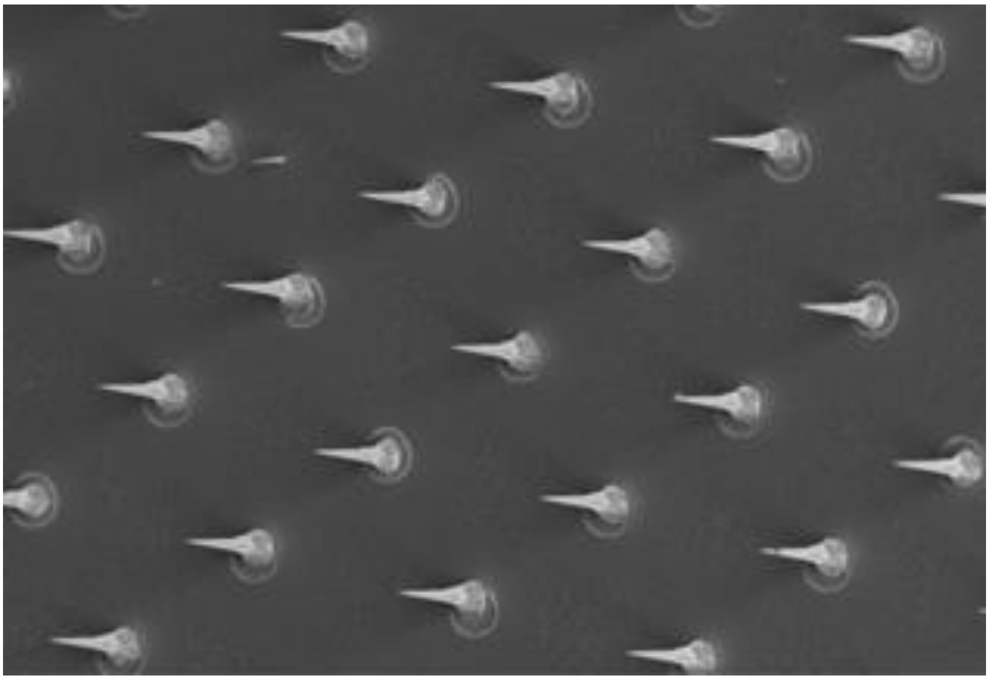

Fig.1. Photo of the multi-tip structure. The distance between the pins of a height h = 30 μ and a diameter D =36 nm is equal to 30 μm.

The number of tips that can be located on the emitter surface is limited by the so-called screening effect. To reduce the mutual screening effect it is needed to locate the tips at a sufficient distance from each other. The screening effect is negligibly small only if the ratio of the distance l between the tips to their height h is more than 2. Actually, it is not always possible to create the required number of tips on the emitter surface and, simultaneously, completely eliminate the screening. To provide the required emission currents in a device with specified geometry of the electron gun and the voltage between the cathode and anode, the morphology of the emitter surface should be optimized.

The experiments with a conventional gyrotron intended for use in the spectroscopic studies and operated at a frequency of 263 GHz showed that for an electron accelerating voltage of 15 kV the starting current does not exceed 20 mA. This gives a hope that in the gyrotrons for DNP/NMR spectroscopy it will be possible to use cold field emitters instead of hot cathodes and, at the same time, provide a sufficient output power level (more than 10 W) for spectroscopy applications.

To check the feasibility of this idea, it was decided to try it using the already existing gyrotron for spectroscopy, with only the beam generation system replaced and the other components (resonator, radiation-to-wave beam converter, collector, and magnetic system) left unchanged. The main parameters of the EOS are presented in the tables below and a general view is given in Fig.2

Table 1. Main parameters of the EOS.

Cathode-to-resonator distance, mm	440
Beam compression	53
Average current density, A/cm^2	0.25
Cathode coil power, W	630
Axial inclination angle of the magnetic field to the middle of the emitter, deg	7.9
Maximum beam current, mA	50
Velocity spread (0.1-0.9 level), %	34

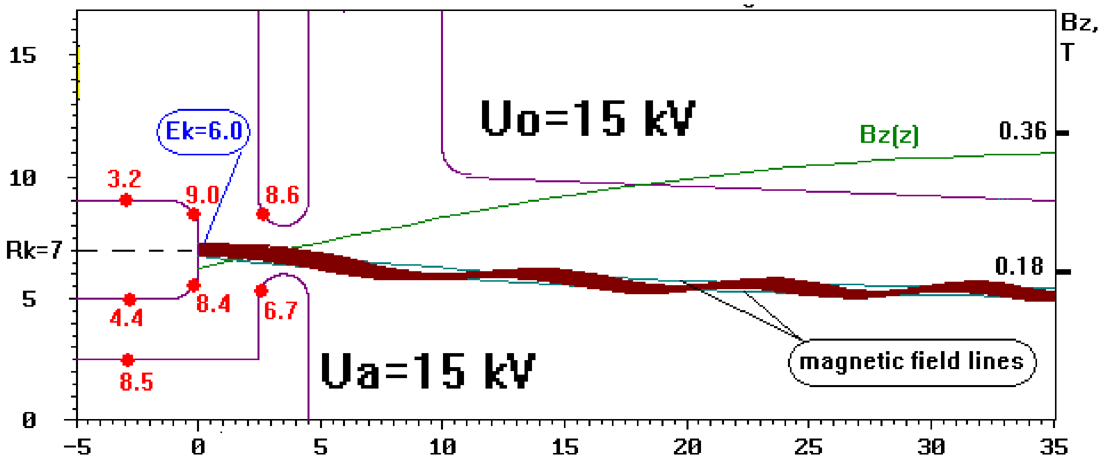

Fig.2. Scheme of the primary formation of the helical electron beam in a non-adiabatic EOS. Distributions of the axial magnetic field *B(z)* (right axis, data are in T) is presented. Red dots and corresponding numbers show the electric field value (kV/mm) at the most critical points. The electric field E_k at the emitter center is also shown. All dimensions are in mm.

As we mentioned above, the known experimental results show the possibility of stable single mode excitation in gyrotrons within the frequency range 0.2-0.5 THz at operation voltages about 10 - 15 kV and beam currents of several tens mA. As another example we proposed gyrotron with pulsed magnetic field coil (field intensity up to 30 T), which was developed for 0.67 THz operating frequency. For normal coil operation conditions, the design frequency of a gyrotron was chosen close to 0.5 THz and the TE$_{7,5}$ mode was selected as operating one. In such case the cavity radius is 2.3 mm, the optimal radius of the electron beam injection is equal to 0.74 mm and the cut-off frequency is 0.48 THz.

The mode excitation has been studied by the self-consistent code ANGEL for accelerating voltage U=11 kV, beam current I=40 mA, pitch-factor (ratio of electron oscillatory velocity to the longitudinal one) g=1.3. These beam parameters are close to the experimental ones, used for stable single mode excitation of the TE$_{5,3}$ mode with a frequency of 0.263 THz at similar excitation conditions. The model with non-fixed longitudinal RF-field structure takes into account the electron velocity spread ($\delta v_{\perp}=30$ % in calculations), the Ohmic losses in the cavity walls and the real resonator profile. A map of the starting currents and calculated dependencies of the output power and efficiency versus the magnetic field for an optimized cavity length of 13 mm are presented in Fig.3 and Fig.4, respectively.

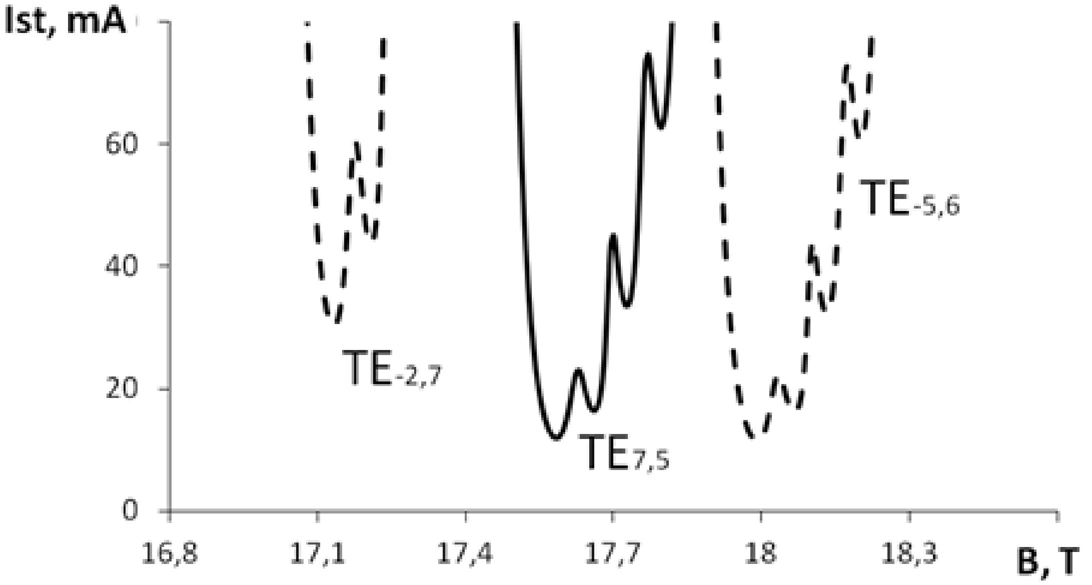

Fig.3 The dependence of the starting current for operating (solid line) mode $TE_{7,5}$ and the nearest competitive (dashed lines) modes versus magnetic field. For each mode several minimums corresponds to a different number (q=1, 2, 3, …) of longitudinal variation of the RF field profile.

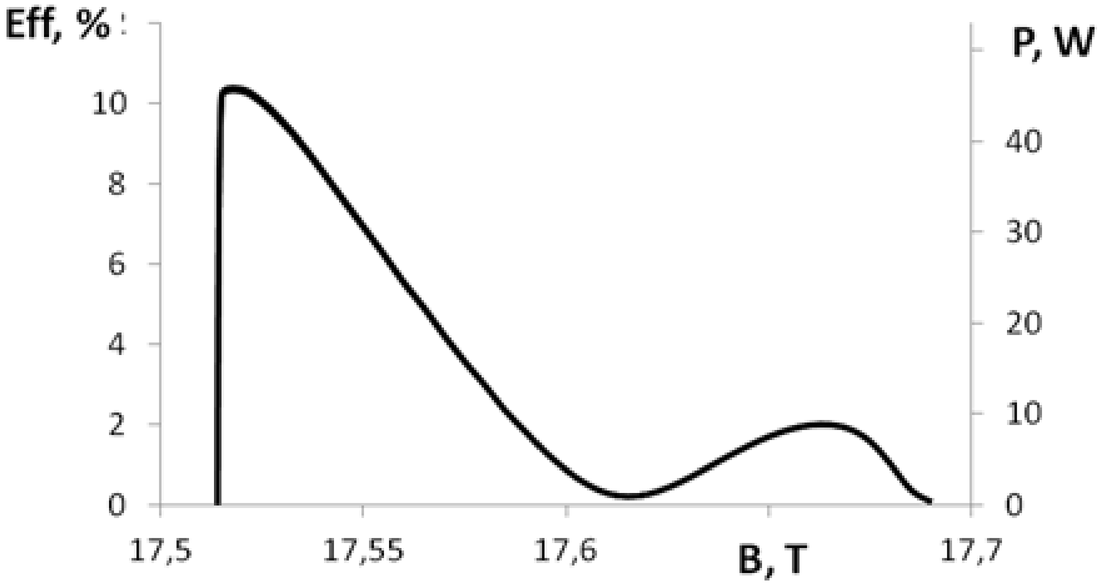

Fig.4 The output power and efficiency versus magnetic field for a cavity length of 13 mm.

The minimal starting current is about 10 mA that is suitable for field emission cathodes. Additionally, an 11 kV/40 mA electron beam with a pitch-factor g~1.3 looks reasonable for several tens Watts generation at 0.5 THz. Unfortunately, the optimal cavity length is much longer than the uniform magnetic field length in the existing magnetic system.

The tangent of the magnetic field angle is proportional to the gradient of the magnetic field. However, this gradient is significant only at distances from the magnetic system center of the order of the average radius of the solenoid, where the field value is 10-50% of the maximum. Estimations show that when the emitter is placed in an area where the field is 10-20% of the maximum (approximately 50-60 mm from the center of the solenoid), the required angle of inclination of the magnetic field to the axis is indeed provided. However, the magnitude of the magnetic field near the emitter region in this case is still very large and exceeds 0.2 T. As a result, the step of the electron trajectory here is only 1–1.5 mm, which is much smaller than all other characteristic scales of the formation system and the condition for non-adiabaticity (strong inhomogeneity of the magnetic field) is not fulfilled. Therefore, in such case it is impossible to ensure big enough rotational speed of the electrons and the pitch factor of the beam will remain close to zero.

On the contrary, if we shift the gun into the region of magnetic fields about 100 times smaller than the working one, then it is already possible to ensure the condition of non-adiabaticity of the magnetic field (the step of the trajectory becomes quite large). However, in this case, the magnetic field gradient is already small and the magnetic field line is almost parallel to the axis of the system. As a result, it is very difficult to ensure that the beam is shot at an angle to the magnetic field and the beam again turns out not to be twisted (the pitch factor is small). The large compressions of the magnetic field (more than 100) also leads to the fact that the initial rotational velocity is relatively small (at least 10-15 times less than in the cavity), therefore, small perturbations of the initial oscillatory velocity can lead to a large velocity spread.

Despite all described problems, a reasonable geometry of the electrodes was found. A diode type electron gun with a full accelerating voltage of 15 kV was investigated. Fig. 5 shows the cross section of this diode system. Two electrodes (1 and 2) under the same potential form a control electrode (anode) with an annular slot through which the electrons are emitted to the beam transport channel. The beam parameters are: current 50 mA, current density 0.14 A/cm^2, electric field on the emission surface 6.3-6.5 kV/mm (without tips taken into account). The calculated value of the pitch-factor is g=1.2 and velocity spread $\delta v_{\perp}\sim 0.35$.

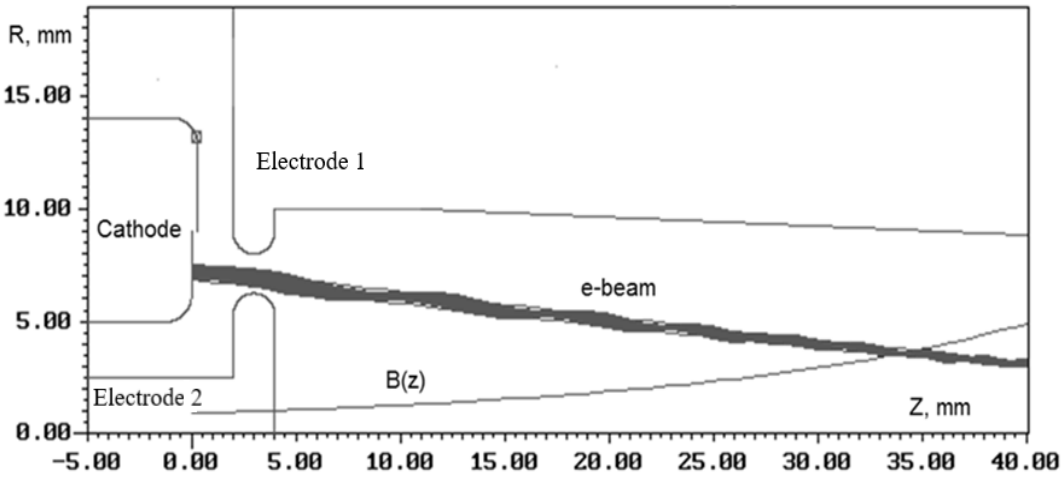

Fig.5 The electrodes geometry and the beam trajectories in the optimized electron gun

Based on the results of numerical modeling the design of the tube has been made (Fig.6) taking into account the available precision of manufacturing and existing technologies. The cathode and the electrodes 1 and 2 position can be slightly (2-3 mm) adjusted along longitudinal axis by spacer rings.

For experimental verification of the possibility of gyrotron operation with field emitter, it was necessary to measure the currents of electrons flow passing through the cavity. To obtain such information, the cavity was removed from the experimental gyrotron and a grounded beam collector was installed at the position corresponding to the end of the cavity. This modification has small effect on the transport of the electron beam since the removed original elements and their replacements have similar dimensions and both are grounded. Therefore, the measurement of the collector current allows us to estimate the magnitude of the electron beam current passing through the cavity. The schematic representation of the EOS cross-section is demonstrated in Fig. 7 The cathode system with an annular emitter 1, control electrodes with an annular diaphragm, device body 3, the solenoid 4, and the collector 5 are also shown here.

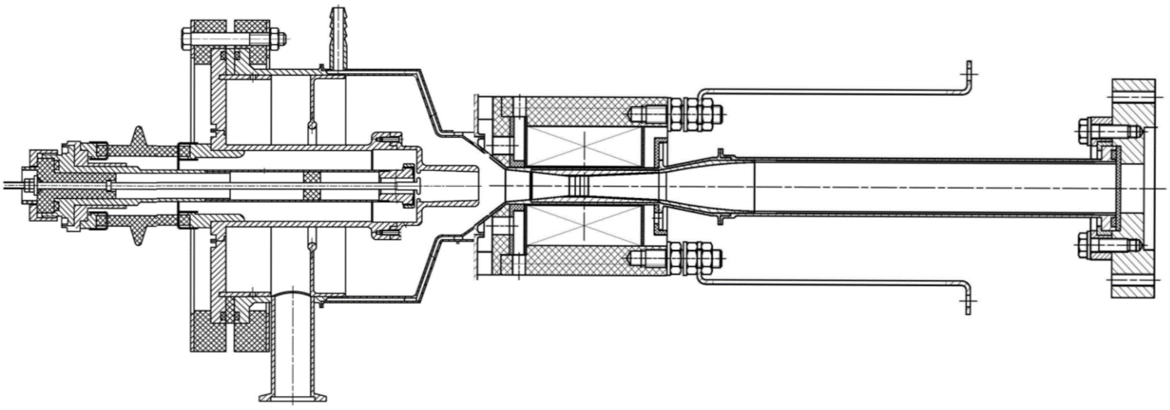

Fig.6 General view of the 0.5 THz gyrotron

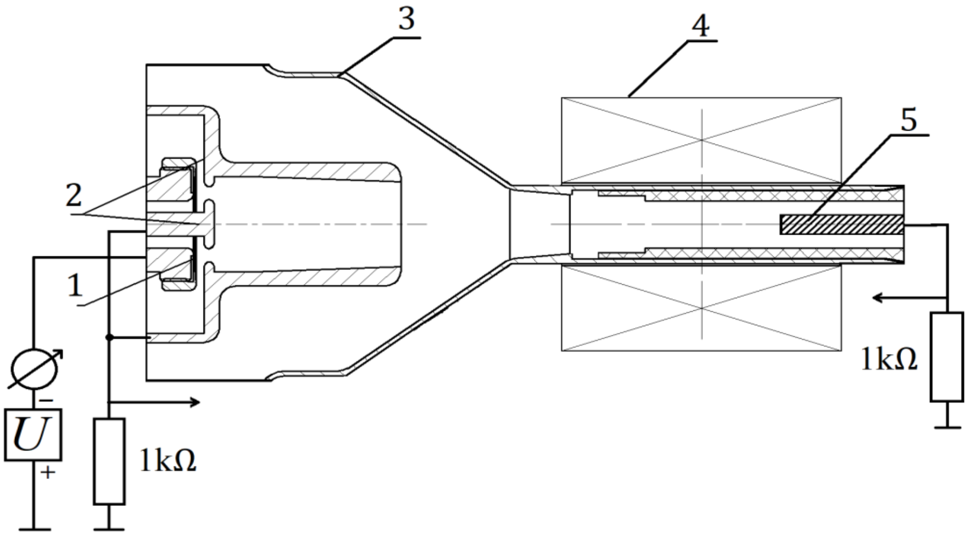

Fig. 7. Schematic representation of the EOS cross section with a non-adiabatic electron gun: 1 - cathode assembly with the annular field emitter, 2 - the anode, 3 - device body, 4 – solenoid, 5 - collector.

The tips of the multi-tip structure have height of about 30 μm and were located at a distance of 30 μm from each other. The tips had a two-layer metal-fullerene coating, protecting them from the destructive action of the ion bombardment which is intensive under technical vacuum conditions. The radius of the tips top with this coating was approximately equal to 20 nm.

The collector (I_{col}) and to the anode (I_a) currents were measured. The anode and collector were grounded through 1 kΩ resistors. To determine the currents to these electrodes, the voltage drops at the indicated resistances were recorded. Along with the collector and control electrode currents, the full cathode current was also controlled. The electric fields necessary for the formation of field emission from the multi-tip structure were created when a sufficient negative voltage U was applied to the cathode.

At the initial stage of the measurements, a long (several hours) training of the experimental setup was carried out in continuous mode at cathode currents from 10 μA to 1 mA. The measurements at higher currents were performed in the regime of single high voltage pulses with duration of 35 μs. They were carried out in the absence and in the presence of a magnetic field. The maximum magnetic field at the center of the cavity was 20 T. The pulses of the magnetic field had duration of approximately 8 ms. Pulse current was measured using the Agilent DSO-X 2024A oscilloscope.

According to the data obtained at the absence of a magnetic field, a big part (about 20 %) of the electrons emitted by the cathode is intercepted by the anode. When the magnetic field is on, this fraction of the electron flow decreases but remains yet significant (15%). Such a large current of the electrons to the anode may be due not only the interception of some electrons emitted by the cathode, but also by the reflection of electrons from the magnetic mirror or by the flow of secondary electrons from the collector.

The current-voltage characteristics of the collector and the anode, measured at the standard for the used experimental gyrotron distribution of the magnetic field, are shown in Fig.8. In the studied regimes with voltages *U* up to 11 kV, the collector current reached values of about 40 mA. Thus, despite the interception by the anode of a part of the electrons emitted by the cathode, the flow of electrons to the collector installed at the location of the cavity exit significantly exceeds the required starting currents of this gyrotron.

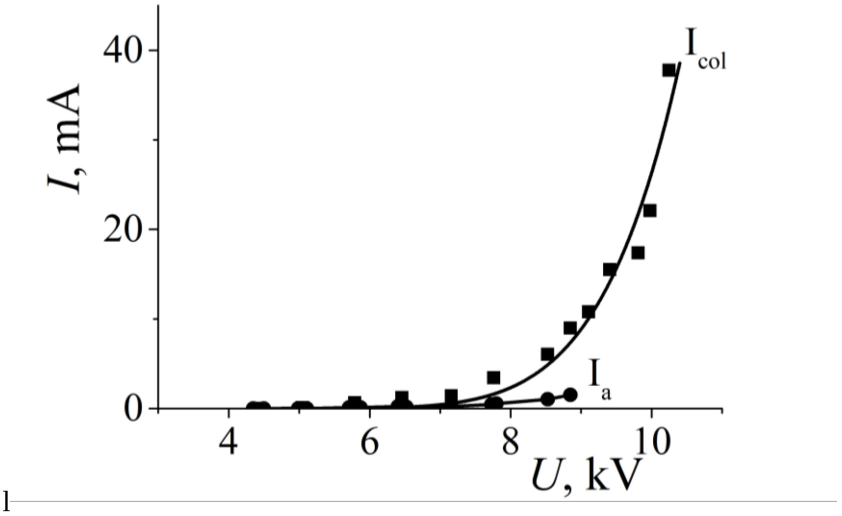

Fig. 8. Typical dependences of the electron currents *I* on the applied voltage *U*:
I_{col} - collector current, I_{a} - current of the anode.

In short, the results of the work can be summarized as follows:

(i) The main characteristics of the electron beam formed by the electron optical system (EOS) with a field emitter in a pulsed gyrotron with an operating frequency of about 0.5 THz were calculated.

(ii) On the basis of performed theoretical analysis, the cavity configuration and the conditions for the excitation of different modes are determined.

(iii) The multi-tip annular cathode with a metal-fullerene coating, which protects the emitter from the destructive effect of the ion bombardment, was manufactured.

(iv) An EOS of a gyrotron with a multi-tip field emitter was designed and manufactured.

(v) An experimental study of the operation of the EOS with a field emitter was carried out and the possibility of formation by this EOS of an electron flow passing through the gyrotron cavity with the current significantly exceeding the starting one was demonstrated.

As a whole, the results of this work, demonstrate the feasibility of the operation of a sub-THz gyrotron with a field emitter. The obtained data prove the stable functioning of the field emitter in a technical vacuum. The estimates show that for the obtained values of the emission current (of the order of several tens mA) the gyrotron could provide output powers of up to several tens Watts.

At the same time, the results indicate the need for further studies aimed to reducing the electron flow intercepted by the control electrode, as well as increasing of the electron beam current passing into the cavity. The experimental tests of the gyrotron operation are planned after the modification of the magnetic system aiming at increasing the length of the homogeneous region.

For more detail:

1. M.Yu. Glyavin, V.N. Manuilov, G.G. Sominski, E.P. Taradaev, T.A.Tumareva, “The concept of an electron-optical system with field emitter for a spectroscopic gyrotron,” *Infrared Physics & Technology*, vol. 78, (2016) 185-189. DOI: 10.1016/j.infrared.2016.08.006.

2. E. Taradaev, G. Sominskii, V. Manuilov, A. Fokin, A. Sedov, and M. Glyavin, “Design and preliminary tests of pulsed magnetic field 0.5 THz gyrotron with field emitter,” *Infrared Physics and Technology* (2020, submitted)

FORTHCOMING EVENTS

November 8 - 13, 2020

45th International Conference on Infrared, Millimeter, and Terahertz Waves

According to the COVID-19 contingency plan as recently announced the dates of the IRMMW-THz 2020 meeting are changed to Nov. 8-13, 2020. All other conference deadlines will be shifted accordingly (see updated information at the following link).

11th International Workshop

MW 2020

Strong Microwaves and Terahertz Waves: Sources and Applications

July 5–10, 2020
Nizhny Novgorod, Russia

Announcement by the organizers: “We regret to inform you that because of the significant health risks and transportation disruptions associated with the COVID-19 pandemic we are forced to postpone the 11th International Workshop “Strong Microwaves and Terahertz Waves: Sources and Applications” until summer 2021.

We will inform you about the planned dates for the Workshop as soon as they are available.

Thank you for your interest in our Workshop and hope to see all of you in Nizhny Novgorod next summer.”

IW-FIRT2021

The 8th International Workshop on Far-Infrared Technologies
(IW-FIRT 2021)
(March 8-10, 2021, University of Fukui, Fukui, Japan)

The first International Workshop on Far-Infrared Technologies (IW-FIRT) was held in 1999 as a celebration event for establishing FIR FU, and the second IW-FIRT was held in 2002 as a part of the Fukui University International Congress to celebrate the 50th anniversary of our university. The third IW-FIRT was held in 2010, eight years after the second IW-FIRT, to commemorate the 10th anniversary of the foundation of FIR UF. The fourth, fifth, and sixth IW-FIRT were held in 2012, 2014, 2017, and 2019, successively, every few years. In these workshops it was aimed to discuss the recent developments and future directions of far-infrared and terahertz science and technologies with a special emphasis on high power radiation sources in this frequency region and their applications. We feel that it is the time to organize the next IW-FIRT to update our knowledge and understanding in this rapidly developing field. Therefore, we organize the 8th International Workshop on Far-Infrared Technologies (IW-FIRT 2021). For more detail please visit the website of the Workshop.

Professor Toshitaka Idehara at 80

Professor Toshitaka Idehara was born in Ibara Japan, on April 15, 1940. He received the B.S. degree in mathematics and the M.S. and D.S. degrees in physics from Kyoto University, Kyoto, Japan, in 1963, 1965, and 1968, respectively. After graduating from Kyoto University, he joined the University of Fukui, Fukui, Japan, and was a Lecturer from 1968 to 1970 and an Associate Professor from 1970 to 1990. During this term, he worked on fundamental plasma physics. After 1979, his interest was directed toward the development of high-frequency gyrotrons. From 1990 to 1999, he was a Professor in the Applied Physics Department, Fukui University, and from 1992 to 1999, he was the Head of the Laboratory for Application of Superconducting Magnet, Fukui University. Since 1999, he was a Professor and a founding Director of the Research Center for Development of Far-Infrared Region, University of Fukui (FIR UF). Since 2007 he was also a Supervisor of the research at FIR UF. From June 2004 to December 2010 he was an Editor in Chief of the International Journal of Infrared and Millimeter Waves and later Journal of Infrared, Millimeter, and Terahertz Waves. In 2009, he won the Prize for Science and Technology, The Commendation for Science and Technology by the Minister of Education, Culture, Sports, Science and Technology of Japan, for Study on High Power THz Radiation Sources High Harmonic Gyrotrons. In 2011, he was awarded the Prize for Science and Technology from Fukui Prefectural Governor for Development of high power THz radiation sources Gyrotrons, and application to THz technologies. In 2016 he was awarded the Kenneth J. Button Prize for outstanding contributions to the development of high power THz radiation sources (harmonic gyrotrons) and their applications to high power THz spectroscopy. His current research interests include development of frequency tunable, sub-THz and THz gyrotrons and their applications to high-power THz technologies, novel spectroscopic techniques (NMR-DNP, ESR), and advanced technologies.

Professor Idehara was an organizer and facilitator of the first International Consortium for Development of High-Power Terahertz Science and Technology established in 2015. He has an active international collaboration with a great number of institutions and researchers around the world. Professor Idehara is recognized worldwide as a brilliant scientist, devoted teacher, and leader in the field of development and applications of gyrotrons. His remarkable achievements in advancing the operation of gyrotrons towards the THz region is an epochal contribution, which is an inspiration for the new generation of younger researchers as well as for all his colleagues and collaborators.

We greet Professor Idehara on the occasion of his 80th anniversary and wish him strong health, happiness, and many remarkable achievements in his work!

Professor Seitaro Mitsudo at 55

Professor Seitaro Mitsudo was born in Okayama, Japan, on April 17, 1965. He received the B.S., M.S. and D.S. degrees in physics from Okayama University in 1989, 1991 and 1994, respectively. After graduating from Okayama University, he joined the Institute for Materials Research of Tohoku University, Sendai, Japan. From 1994 to 1998, he was Research Associate. During this term, he worked on the high-field magnetism. From 1998 to 1999, he was with the Applied Physics Department of Fukui University, Fukui, Japan, as an Associate Professor. Since 1999, he has been an Associate Professor of the Research Center for Development of Far-Infrared Region, Fukui University. Since 2006, he has been a Professor with the Research Center for Development of Far Far-Infrared Region (FIR Center), Fukui University and he currently is Vice Director of FIR UF.

In 2009 (together with Professor T. Idehara and Professor I. Ogawa) he won the Commendation for Science and Technology by the Minister of Education, Culture, Sports, Science, and Technology.

His current research interests include development and study of frequency tunable, sub-THz and THz gyrotrons and their applications in the wide field of the high-power THz science and technology.

We greet Professor Mitsudo on the occasion of his 55th anniversary and wish him strong health, happiness, and many remarkable achievements in his work!

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 February 2020, i.e. after issuing the previous Newsletter #14. 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

Stober, J., et al. "Exploring fusion-reactor physics with high-power electron cyclotron resonance heating on ASDEX Upgrade," Plasma Physics and Controlled Fusion, vol. 62, n. 2 (2020) 024012. DOI: 10.1088/1361-6587/ab512b.
https://iopscience.iop.org/article/10.1088/1361-6587/ab512b/pdf

Denisov G.G., Kuftin A.N., Manuilov V.N., et al., “Design of master oscillator for frequency locking of a complex of megawatt level microwave sources,” Microw. Opt.Technol. Lett., (2020) 1-7. DOI:10.1002/mop.32330.
https://onlinelibrary.wiley.com/doi/abs/10.1002/mop.32330

Leontyev A.N., Abubakirov E.B., Belousov V.I. et al., “Possibilities of Increasing the Output Radiation Power of High-Current Relativistic Gyrotrons Using Operating Modes of the TM Type,” Bull. Russ. Acad. Sci. Phys., vol. 84 (2020) 66–69. DOI:10.3103/S1062873820010165.
https://link.springer.com/article/10.3103/S1062873820010165

Kanda T., Kitawaki M., Arata T., Matsuki Y., Fujiwara T., "Structural analysis of cross-linked poly(vinyl alcohol) using high-field DNP-NMR," RSC Advances, vol. 10, n. 14 (2020) 8039. DOI:10.1039/D0RA00399A.
https://pubs.rsc.org/en/content/articlelanding/2020/RA/D0RA00399A#!divAbstract

Tatematsu Y., Yamaguchi Y., Fukunari M. et al. “Development of Gyrotron FU CW GVII: a Second Harmonic, Multifrequency Gyrotron that Radiates Gaussian Beams,” J Infrared, Millimeter, and Terahertz Waves (2020). DOI:10.1007/s10762-020-00681-7.
https://link.springer.com/article/10.1007%2Fs10762-020-00681-7

Denisov G.G., Glyavin M.Y., Fedotov A.E. et al. “Theoretical and Experimental Investigations of Terahertz-Range Gyrotrons with Frequency and Spectrum Control,” J Infrared, Millimeter, and Terahertz Waves (2020). DOI:10.1007/s10762-020-00672-8.
https://link.springer.com/article/10.1007%2Fs10762-020-00672-8

Bandurkin I.V., Bratman V.L., Kalynov Y.K., Manuilov V.N., Osharin I.V., Savilov A.V., "High-Harmonic Gyrotrons with Axis-Encircling Electron Beams at IAP RAS," Radiophysics and Quantum Electronics, (2020). DOI:10.1007/s11141-020-09997-9.
https://link.springer.com/article/10.1007%2Fs11141-020-09997-9

Proyavin M.D., Glyavin M.Y., Zavol’sky N.A. et al., “Development of a High-Power Continuous-Wave Gyrotron for High-Efficiency Technological K-Band Microwave Complexes,” Radiophys Quantum Electronics, (2020). DOI:10.1007/s11141-020-09996-w.
https://link.springer.com/article/10.1007%2Fs11141-020-09996-w

Samsonov S.V., Bogdashov A.A., Gachev I.G. et al., “Studies of a Gyrotron Traveling-Wave Tube with Helically Corrugated Waveguides at IAP RAS: Results and Prospects,”Radiophys Quantum Electronics (2020). DOI:10.1007/s11141-020-09991-1.
https://link.springer.com/article/10.1007%2Fs11141-020-09991-1

Bakunin V.L., Guznov Y.M., Denisov G.G. et al., “An Experimental Study of the External-Signal Influence on the Oscillation Regime of a Megawatt Gyrotron,” Radiophys Quantum Electronics (2020). DOI:10.1007/s11141-020-09994-y.
https://link.springer.com/article/10.1007%2Fs11141-020-09994-y

Bakunin V.L., Denisov G.G., Novozhilova Y.V., “Locking of the Frequency of a Multimode Gyrotron by a Quasi-Monochromatic External Signal,” Radiophys Quantum Electronics (2020). DOI:10.1007/s11141-020-09995-x.
https://link.springer.com/article/10.1007%2Fs11141-020-09995-x

Ginzburg N.S., Yurovsky L.A., Vilkov M.N., et al., “Stretching, Amplification, and Compression of DOI:10.1007/s11141-020-09993-z
https://link.springer.com/article/10.1007%2Fs11141-020-09993-z

V. L. Bakunin, G. G. Denisov, Y. V. Novozhilova, "Principal Enhancement of THz-range Gyrotron Parameters Using Injection Locking," IEEE Electron Device Letters, (2020). DOI: 10.1109/LED.2020.2980218.
https://ieeexplore.ieee.org/document/9032119

Proyavin M.D., Manuilov V.N., Gachev I.G. et al., “A Magneto-Armored Warm-Solenoid Based System for K-Band Gyrodevices,” Instrum. Exp. Tech., vol 63 (2020) 97–100. DOI:10.1134/S0020441220010078.
https://link.springer.com/article/10.1134%2FS0020441220010078

Abubakirov E.B., Vikharev A.A., Ginzburg N.S. et al., “Pumping Systems for Compton Free-Electron Lasers: Microwave Undulators and Powering Sources.” Radiophysics Quantum Electronics, (2020). DOI:10.1007/s11141-020-09998-8.
https://link.springer.com/article/10.1007%2Fs11141-020-09998-8

Rozental R.M., Leontyev A.N., Sergeev A.S. et al., “Generation of Rogue Waves in Gyrotrons with High-Current Relativistic Beams,” Bull. Russ. Acad. Sci. Phys., vol. 84 (2020) 189–192. DOI:10.3103/S1062873820020306.
https://link.springer.com/article/10.3103/S1062873820020306

P. Wang et al., "Investigation of the Alignment method for High-Frequency Gyrotrons," IEEE Transactions on Terahertz Science and Technology, (2020). DOI: 10.1109/TTHZ.2020.2979116.
https://ieeexplore.ieee.org/abstract/document/9026800

S.V. Samsonov, G.G. Denisov, I.G. Gachev, A.A. Bogdashov, "CW Operation of a W-band High-Gain Helical-Waveguide Gyrotron Traveling-Wave Tube," IEEE Electron Device Letters, (2020). DOI: 10.1109/LED.2020.2980572.
https://ieeexplore.ieee.org/document/9035466

G. Golubiatnikov, M. Koshelev, A. Tsvetkov, A. Fokin, M. Glyavin, M. Tretyakov, "Sub-Terahertz High-Sensitivity High-Resolution Molecular Spectroscopy with a Gyrotron," IEEE Transactions on Terahertz Science and Technology, (2020). DOI: 10.1109/TTHZ.2020.2984459.
https://ieeexplore.ieee.org/document/9060985

N.S. Ginzburg, G.G. Denisov, M.N. Vilkov, A.S. Sergeev, S.V. Samsonov, A.M. Malkin, I.V. Zotova, “Nonlinear Cyclotron Resonance Absorber for a Microwave Subnanosecond Pulse Generator Powered by a Helical-Waveguide Gyrotron Traveling-Wave Tube,” Phys. Rev. Applied, vol. 13 (2020). DOI: 10.1103/PhysRevApplied.13.044033.
https://journals.aps.org/prapplied/abstract/10.1103/PhysRevApplied.13.044033

N. Balal, V.L. Bratman, E. Magory, “New varieties of helical undulators,” Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, (2020). DOI:10.1016/j.nima.2020.163895.

http://www.sciencedirect.com/science/article/pii/S0168900220303910

Torgashov R.A., Ryskin N.M., Rozhnev A.G. et al. “Theoretical and Experimental Study of a Compact Planar Slow-Wave Structure on a Dielectric Substrate for the W-Band Traveling-Wave Tube,” Tech. Phys., vol. 65, (2020) 660–665. DOI:10.1134/S1063784220040222.
https://link.springer.com/article/10.1134/S1063784220040222

Sintsov S.V., Vodopyanov A.V., Viktorov M.E., Morozkin M.V., Glyavin, M.Y., “Non-equilibrium atmospheric-pressure plasma torch sustained in a quasi-optical beam of subterahertz radiation,” J Infrared, Millimeter, and Terahertz Waves (2020). DOI:10.1007/s10762-020-00694-2.
https://link.springer.com/article/10.1007/s10762-020-00694-2

Saito T., Melnikova M.M., Ryskin N.M., Tanaka S., Shinbayashi R., Yamaguchi Y., Fukunari M., Tatematsu Y., “Effect of Reflection on Mode Competition and Multi-Frequency Oscillation in a High-Power Sub-THz Gyrotron: Experimental Observation and Theoretical Analysis,” J Infrared, Millimeter, and Terahertzz Waves (2020). DOI:10.1007/s10762-020-00695-1.
https://link.springer.com/article/10.1007%2Fs10762-020-00695-1

J. Järvinen, D. Zvezdov, J. Ahokas, S. Sheludiakov, L. Lehtonen, S. Vasiliev, L. Vlasenko, Y. Ishikawa, Y. Fujii, “Dynamic nuclear polarization and ESR hole burning in As doped silicon,” Phys. Chem. Chem. Phys., vol. 22 (2020) 10227-10237. DOI: 10.1039/C9CP06859G.
https://pubs.rsc.org/en/content/articlelanding/2020/CP/C9CP06859G

Manuilov V.N., Tsvetkov A.I., Glyavin M.Y., Mitsudo S., Idehara T., Zotova I.V., “Universal Electron Gun Design for a CW Third Harmonic Gyrotron with an Operating Frequency over 1 THz,” J Infrared Millimeter, and, Terahertz Waves, (2020). DOI:10.1007/s10762-020-00702-5.
https://link.springer.com/article/10.1007/s10762-020-00702-5

D. Mansfeld, S. Sintsov, N. Chekmarev, A. Vodopyanov, “Conversion of carbon dioxide in microwave plasma torch sustained by gyrotron radiation at frequency of 24 GHz at atmospheric pressure,” Journal of CO2 Utilization, vol. 40 (2020) 101197. DOI:10.1016/j.jcou.2020.101197.
http://www.sciencedirect.com/science/article/pii/S2212982020302742

Wagner D., Kasparek W., Leuterer F., Monaco F., Ruess T., Stober J., Thumm M., “A Compact Two-Frequency Notch Filter for Millimeter Wave Plasma Diagnostics,” J Infrared Milli Terahz Waves (2020). DOI:10.1007/s10762-020-00701-6.
https://link.springer.com/article/10.1007/s10762-020-00701-6

Fokin A.P., Glyavin M. Yu., Manuilov V.N., Osharin I.V., Savilov A.V., “On applicability of absorbing rectilinear electron beams in high-frequency gyrotrons operating at cyclotron harmonics,” Physics of Plasmas, vol. 27, n. 6 (2020) 064501. DOI: 10.1063/5.0006108.
https://aip.scitation.org/doi/10.1063/5.0006108

V.I. Shcherbinin, Y.K. Moskvitina, K.A. Avramidis, J. Jelonnek, "Improved Mode Selection in Coaxial Cavities for Subterahertz Second-Harmonic Gyrotrons," IEEE Transactions on Electron Devices, (2020). DOI:10.1109/TED.2020.2996179.
https://ieeexplore.ieee.org/document/9108542

B. Publications by other authors worldwide

Sattorov M., Hong D., Kim S., Kwon H.J., Kwon H.O., Min S.H., Park G.S. “Highly efficient compact gigawatts-level microwave source using relativistic electrons: radial relativistic magnetron,” Electronics Letters, (2020). DOI: 10.1049/el.2020.0062.
https://digital-library.theiet.org/content/journals/10.1049/el.2020.0062

Z. Wu, X. Liao, K. Wang, M. Wang, Y. Pu and Y. Luo, "A Circular TE$_{02}$ Mode Generator With High Purity for Gyro-TWT Study," IEEE Microwave and Wireless Components Letters, vol. 30, n. 2 (2020) 137-140. DOI: 10.1109/LMWC.2020.2966071.
https://ieeexplore.ieee.org/abstract/document/8982024

Zhang H., et al. “Generation of frequency-chirped density modulation electron beam for producing ultrashort THz radiation pulse,” Phys. Rev. Accel. Beams, vol. 23, n.2 (2020) 020704. DOI:10.1103/PhysRevAccelBeams.23.020704.
https://link.aps.org/doi/10.1103/PhysRevAccelBeams.23.020704

Yao H.-Yu, Chen C.-C., Chang T.-H., "Starting behaviors of the TM-mode gyrotrons," Physics of Plasmas, vol. 27, n. 2 (2020) 022113. DOI:10.1063/1.5134725.
https://aip.scitation.org/doi/10.1063/1.5134725

W. Fu, X. Guan and Y. Yan, "Generating High-Power Continuous-Frequency Tunable Sub-Terahertz Radiation from a Quasi-optical Gyrotron with Confocal Waveguide," IEEE Electron Device Letters, (2020). DOI: 10.1109/LED.2020.2972380.
https://ieeexplore.ieee.org/abstract/document/8986667

Corzilius B., "High-Field Dynamic Nuclear Polarization,"Annual Review of Physical Chemistry (2020). DOI:10.1146/annurev-physchem-071119-040222.
https://www.annualreviews.org/doi/10.1146/annurev-physchem-071119-040222

B. You, R. Takaki, C. Hsieh, R. Iwasa, J. Lu and T. Hattori, "Terahertz Bragg Resonator based on a Mechanical Assembly of Metal Grating and Metal Waveguide," Journal of Lightwave Technology, (2020). DOI: 10.1109/JLT.2020.2973247.
https://ieeexplore.ieee.org/document/8994054

He J., Dong T., Chi B. et al., “Metasurfaces for Terahertz Wavefront Modulation: a Review,” J Infrared Millimeter, and Terahertz Waves (2020).DOI: 10.1007/s10762-020-00677-3.
https://link.springer.com/article/10.1007/s10762-020-00677-3

M. Pilossof, M. Einat, "High-Average-Power Second Harmonic W-Band Gyrotron with Room-Temperature Solenoid," IEEE Transactions on Electron Devices, (2020). DOI:10.1109/TED.2020.2971653.
https://ieeexplore.ieee.org/document/9007515

G. Shu, Z. Qian and W. He, "Design and Measurement of an H-band Rectangular TE$_{10}$ to TE$_{20}$ Mode Converter," IEEE Access, (2020). DOI:10.1109/ACCESS.2020.2974819.
https://ieeexplore.ieee.org/document/9005381

P. Wang et al., "Optimization Design of Flat-Top Pulsed Magnet for an 800-GHz Second Harmonic Gyrotron," IEEE Transactions on Electron Devices, vol. 67, n. 3 (2020) 1234-1239. DOI:10.1109/TED.2020.2966584.
https://ieeexplore.ieee.org/document/8985282

R. K. Singh, M. Thottappan, "Design and PIC Simulation Studies of Millimeter-Wave-Tunable Gyrotron Using Metal PBG Cavity as its RF Interaction Circuit," IEEE Transactions on Plasma Science, (2020). DOI: 10.1109/TPS.2020.297479.

https://ieeexplore.ieee.org/document/9018181

Sattorov M., Hong D., Kim S., Kwon H.J., Kwon H.O., Min S.H., Park G. S.. “Highly efficient compact gigawatts-level microwave source using relativistic electrons: radial relativistic magnetron,” Electronics Letters, (2020). DOI:10.1049/el.2020.0062.
https://digital-library.theiet.org/content/journals/10.1049/el.2020.0062

X. Wang, Q. Xue, S. Zhang, G. Liu and D. Zhao, "Theory Analysis of Nonlinear Excitation of Second Harmonic THz Gyrotron for DNP-NMR," IEEE Transactions on Plasma Science, (2020). DOI:10.1109/TPS.2020.2973307.
https://ieeexplore.ieee.org/abstract/document/9016370

Wang P., Wang Z., Deng Z., Han X., Xia D., Qi X., Li X., Chen X., Liu L., Xiao H., Li L., "Investigation of the Alignment method for High-Frequency Gyrotrons," IEEE Transactions on Terahertz Science and Technology, (2020). DOI:10.1109/TTHZ.2020.2979116.
https://ieeexplore.ieee.org/document/9026800

Allio A., Difonzo R., Leggieri A., Legrand F., Marchesin R., Savoldi L., “Test and Modeling of the Hydraulic Performance of High-Efficiency Cooling Configurations for Gyrotron Resonance Cavities,” Energies, vol. 3, n. 5 (2020) 1163. DOI: 10.3390/en13051163.
https://www.mdpi.com/1996-1073/13/5/1163

Sominskii G.G., Sezonov V.E., Taradaev E.P., et al., “Field Emitters for Miniature High-Voltage Electronic Devices Operating in Technical Vacuum,” Radiophys Quantum Electronics (2020). DOI:10.1007/s11141-020-10000-8.
https://link.springer.com/article/10.1007%2Fs11141-020-10000-8

D.N. Nguyen, D.T. Vo, "Comprehensive Finite Element Modeling for Pulsed Magnet Design Using COMSOL and Java," IEEE Transactions on Applied Superconductivity, vol. 30, no. 4 (2020). DOI: 10.1109/TASC.2020.2971935.
https://ieeexplore.ieee.org/document/8986595

K. Fahad et al., "Triband Ultrathin Polarization Converter for X/Ku/Ka-Band Microwave Transmission,“ IEEE Microwave and Wireless Components Letters, (2020). DOI:10.1109/LMWC.2020.2973040.
https://ieeexplore.ieee.org/document/9011748

S.P. Savaidis, S A. Mitilineos, Z C. Ioannidis, N.A. Stathopoulos, "Experiments on the Pulse Repetition Frequency Optimization of 1.3-GHz, 100-kW Microwave Pulse Compressor," IEEE Transactions on Microwave Theory and Techniques, (2020). DOI: 10.1109/TMTT.2020.2978046.
https://ieeexplore.ieee.org/document/9040426

L. Luo, S. Pan, C. Du, M. Huang and P. Liu, "Terahertz Ultralow-Voltage Gyrotron with Upstream Output," IEEE Transactions on Plasma Science, (2020). DOI:10.1109/TPS.2020.2979224.
https://ieeexplore.ieee.org/document/9043608

T. Song et al., "Investigations on the Effect of the Electron Beam Misalignments on a Continuously Frequency-Tunable Gyrotron," IEEE Transactions on Electron Devices, vol. 67, no. 4 (2020) 1819-1825. DOI: 10.1109/TED.2020.2975548.
https://ieeexplore.ieee.org/abstract/document/9031747

Judge P.T., Sesti E.L., Alaniva N., Salib, E.P., Price L.E., Gao C., Halbritter T., Sigurdsson S.T., Kyei G.B., Barnes, A.B., “Characterization of Frequency-chirped Dynamic Nuclear Polarization in Rotating Solids,” Journal of Magnetic Resonance, (2020) 106702. DOI: 10.1016/j.jmr.2020.106702.
https://www.sciencedirect.com/science/article/abs/pii/S1090780720300203

Shimamura K., Matsukura M., Ozaki N., Miyawaki K.,"Wireless Power Transmission Efficiency for Microwave Rocket Using 28 GHz Gyrotron,"Journal of Spacecraft and Rockets, (2020). DOI:10.2514/1.A34726.
https://arc.aiaa.org/doi/pdf/10.2514/1.A34726

G. Shu, C. Ruan, W. He, "Study of H-Band High-Order Overmoded Power Couplers for Sheet Electron Beam Devices," IEEE Transactions on Microwave Theory and Techniques, (2020). DOI: 10.1109/TMTT.2020.2976998.
https://ieeexplore.ieee.org/abstract/document/9028073

Y. Xu et al., "Proof-of-principle Experiment of a 20-kW-Average-Power Ka-band Gyro-Traveling Wave Tube with a Cut-off Waveguide section," IEEE Electron Device Letters, (2020). DOI: 10.1109/LED.2020.2979629.
https://ieeexplore.ieee.org/abstract/document/9028143

Akash and M. Thottappan, "Design, Beam-Wave Interaction, and Efficiency Enhancement Studies of Millimeter Wave Gyro-TWT With a Three-Stage Depressed Collector," IEEE Transactions on Plasma Science, (2020). DOI: 10.1109/TPS.2020.2978792.
https://ieeexplore.ieee.org/abstract/document/9036994

S. Hou, "Numerical Research on Mode Competition of a Coaxial Corrugated Gyrotron With Two Electron Beams," IEEE Transactions on Plasma Science, (2020). DOI: 10.1109/TPS.2020.2978827.
https://ieeexplore.ieee.org/abstract/document/9044639

Li B., Hu K., Shen Y., “A Scientometric Analysis of Global Terahertz Research by Web of Science Data,” IEEE Access, vol. 8 (2020) 56092-56112. DOI: 10.1109/ACCESS.2020.2981999.
https://ieeexplore.ieee.org/abstract/document/9042326

Xu W., Xu H., Liu F., Yan X., "Control of the gyrotron filament power supplies for the experimental advanced superconducting tokamak,"Review of Scientific Instruments, vol. 91, n. 4 (2020)043503.DOI: 10.1063/1.5142787.
https://aip.scitation.org/doi/full/10.1063/1.5142787

S. Li, C. Ruan, A. K. Fahad, P. Wang, Z. Zhang, W. He, "Novel Coupling Cavities for Improving the Performance of G-Band Ladder-Type Multigap Extended Interaction Klystrons," IEEE Transactions on Plasma Science, (2020). DOI: 10.1109/TPS.2020.2982957.
https://ieeexplore.ieee.org/document/9062296

X. Chen, H. Xiao, X. Li, J. Liao , T. Peng, "A Modified Mechanical Model for the Optimization of High Field Solenoid Magnets," IEEE Access, (2020). DOI: 10.1109/ACCESS.2020.2985574.
https://ieeexplore.ieee.org/document/9056523

Tadenuma Y, Murakami T, Brameld M, Washio M, Sakaue K, Kuroda R, Taira Y., “Quasi-monochromatic THz pulse generation using Cherenkov radiation from a spatially modulated electron beam,” Journal of Instrumentation, (2020) C04016. DOI: 10.1088/1748-0221/15/04/c04016.
https://iopscience.iop.org/article/10.1088/1748-0221/15/04/C04016/meta

Jiang S., Wang S., Li L., "Development of repetitive pulsed high magnetic field with high repetition rate," Review of Scientific Instruments, vol. 91, n. 4 (2020) 044704. DOI:10.1063/1.5144494.
https://aip.scitation.org/doi/10.1063/1.5144494

M. Pilossof, M. Einat, "High-Average-Power Second Harmonic W-Band Gyrotron With Room-Temperature Solenoid," in IEEE Transactions on Electron Devices, vol. 67, no. 4 (2020). DOI:10.1109/TED.2020.2971653.
https://ieeexplore.ieee.org/document/9007515

Sintsov S., Tabata K., Mansfeld D., Vodopyanov A., Komurasaki, K., " Optical emission spectroscopy of non-equilibrium microwave plasma torch sustained by focused radiation of gyrotron at 24 GHz," Journal of Physics D: Applied Physics, (2020). DOI: 10.1088/1361-6463/ab8999.
https://iopscience.iop.org/article/10.1088/1361-6463/ab8999/meta

Liu Y., Liu J., Tang Ch., Wang H., "Thermal analysis of magnetron injection gun for 170 GHz gyrotron," Microwave and Optical Technology Letters, (2020). DOI:10.1002/mop.32397.
https://onlinelibrary.wiley.com/doi/abs/10.1002/mop.32397

Yeh Y.S., Luo C.C., Huang B.H., Wang C.C., Hung S.X., "Comparative analysis of terahertz fourth-harmonic gyro-TWAs and multiplying gyro-TWAs with axis-encircling electron beams," AIP Advances, vol. 10, n. 4 (2020) 045325. DOI:10.1063/1.5129728.
https://aip.scitation.org/doi/full/10.1063/1.5129728

Syrovoy V.A., "Formation of Intense Quasicylindrical Charged-Particle Beams," Phys. Part. Nuclei Lett., vol. 17 (2020) 211–238. DOI:10.1134/S1547477120020211.
https://link.springer.com/article/10.1134/S1547477120020211

Y. Li et al., "Analysis of Phase Characteristics of Gyrotron Traveling-Wave Tubes," IEEE Transactions on Electron Devices, vol. 67, n. 5 (2020) 2170-2175. DOI: 10.1109/TED.2020.2981165.
https://ieeexplore.ieee.org/abstract/document/9057497

Singh R.K., Akash, Thottappan M., "Design and simulation investigations of high-power millimeter-wave gyrotron," Journal of Electromagnetic Waves and Applications, (2020). DOI:10.1080/09205071.2020.1750974.
https://www.tandfonline.com/doi/abs/10.1080/09205071.2020.1750974

Nagata Y., Michishio K., Iizuka T., Kikutani H., Chiari L., Tanaka F., Nagashima Y., "Motion-Induced Transition of Positronium through a Static Periodic Magnetic Field in the Sub-THz Region," Phys. Rev. Lett., vol. 124, n. 17 (2020) 173202. DOI: 10.1103/PhysRevLett.124.173202.
https://journals.aps.org/prl/abstract/10.1103/PhysRevLett.124.173202

Vishant, O. Ranjan, A. Bera, R.K. Sharma, "Numerical Investigations into Higher Order Axial Modes of Terahertz Gyrotron Resonator with Significantly Up-Tapered Midsection," IEEE Transactions on Plasma Science, vol. 48, n. 5 (2020) 1357 – 1362. DOI:10.1109/TPS.2020.2985135.
https://ieeexplore.ieee.org/abstract/document/9072276

F. Zhang, M. Huang, H. Wang and G. Chen, "Study of Dual-Frequency Polarizer for Electron Cyclotron Resonance Heating Systems of 105 and 140 GHz," IEEE Transactions on Plasma Science, (2020). DOI: 10.1109/TPS.2020.2984084.
https://ieeexplore.ieee.org/abstract/document/9066997

Sei N., Takahashi T., "First demonstration of coherent resonant backward diffraction radiation for a quasi-monochromatic terahertz-light source," Sci Rep., vol. 10 (2020) 7526. DOI:10.1038/s41598-020-64426-1.
https://www.nature.com/articles/s41598-020-64426-1

D.A. Packard et al., "HFSS and CST Simulations of a GW-Class MILO," IEEE Transactions on Plasma Science, (202o). DOI:10.1109/TPS.2020.2990163.
https://ieeexplore.ieee.org/abstract/document/9089299

R.V. Shah et al., "Design and Development of Fast Protection and Fast Monitoring Module Compatible with NI Compact RIO System for ITER-India Gyrotron Test Facility," IEEE Transactions on Plasma Science, (2020). DOI: 10.1109/TPS.2020.2987384.
https://ieeexplore.ieee.org/abstract/document/9088981

Guan Xiao-Tong, Fu Wen-Jie, Lu Dun Yang, Tong-Bin, Yan Yang, Yuan Xue-Song, “Design of second harmonic terahertz gyrotron cavity based on double confocal waveguide,” Acta Physica Sinica, vol. 69 (2020) 068401.DOI: 10.7498/aps.69.20191222.
http://wulixb.iphy.ac.cn/fileWLXB/journal/article/wlxb/2020/6/PDF/6-20191222.pdf

Geng Z., Zhang R., Yang X., Liao Y., Xu S., “Design and simulation of a W‐band gyrotron oscillator based on self‐consistent nonlinear theory,” Microw Opt Technol Lett., (2020) 1‐5. DOI:10.1002/mop.32458.
https://onlinelibrary.wiley.com/doi/abs/10.1002/mop.32458

Wong P., Zhang P., Luginsland J., “Recent theory of traveling-wave tubes: a tutorial-review,” Plasma Research Express, vol. 2, n. 2 (2020) 023001. DOI: 0.1088/2516-1067/ab9730.
https://iopscience.iop.org/article/10.1088/2516-1067/ab9730/meta

Akash and M. Thottappan, "Design and Efficiency Enhancement Studies of Periodically Dielectric Loaded W-Band Gyro-TWT Amplifier," IEEE Transactions on Electron Devices, (2020). DOI: 10.1109/TED.2020.2996191.
https://ieeexplore.ieee.org/document/9107343

K. Wang, Q. Xue, S. Zhang, D. Zhao and L. Zhang, "Design and Simulation of Coaxial Magnetron Injection Gun for a 170-GHz MW-Class Gyrotron," IEEE Transactions on Plasma Science, (2020). DOI:10.1109/TPS.2020.2991256.
https://ieeexplore.ieee.org/abstract/document/9093066

Y. Annaka et al., "Design and Fabrication of 200-GHz Oversized Surface-Wave Oscillator," IEEE Transactions on Plasma Science, (2020). DOI:10.1109/TPS.2020.2998119.
https://ieeexplore.ieee.org/document/9109707

C Patents

Multi-input multi-output guided wave system and methods for use therewith
Inventors: Giovanni VannucciPaul Shala HenryThomas M. Willis, III
US Patent: US10554235B2
Date of publication: 2020-02-04
https://patents.google.com/patent/US10554235B2/en

Method and apparatus for launching a wave mode that mitigates interference
Inventors: Paul Shala HenryRobert BennettFarhad BarzegarIrwin GerszbergDonald J. BarnickelThomas M. Willis, III
US Patent: US10560145B2
Date of publication: 2020-02-11
https://patents.google.com/patent/US10560145B2/en

Systems and methods for use and measurement of non-thermal effects of microwave radiation
Inventors: Khashayar GhandiPooya Afaghi
US Patent: US20200068672A1
Date of publication: 2020-02-27
https://patents.google.com/patent/US20200068672A1/en

Microwave Heating Glass Bending Process
Inventors: Jiao, Yu (Blawnox, PA, US); Schrier, Russell W. (Oakmont, PA, US); Yu, Chao (Gibsonia, PA, US)
US Patent: 20200087191
Date of publication: 2020-03-19
http://www.freepatentsonline.com/y2020/0087191.html

Apparatus and methods for launching guided waves via plural waveguide systems
Inventors: Paul Shala, Henry Robert Bennett, Farhad Barzegar, Irwin Gerszberg, Donald J. Barnickel, Thomas M. Willis, III US
Patent: US20190393612A1
Date of publication: 2020-03-17
https://patents.google.com/patent/US20190393612A1/en

Methods and apparatus for selectively controlling energy consumption of a waveguide system
Inventors: Bennett, Robert (Southold, NY, US); Barzegar, Farhad (Branchburg, NJ, US); Vannucci, Giovanni (Middletown, NJ, US); Henry, Paul Shala (Holmdel, NJ, US); Willis III, Thomas M. (Tinton Falls, NJ, US); Gerszberg, Irwin (Kendall Park, NJ, US); Barnickel, Donald J. (Flemington, NJ, US)
Patent: 10587310
Date of publication: 2020-03-10
http://www.freepatentsonline.com/10587310.html

NEW BOOKS

Weiye Xu, "Review of the high-power vacuum tube microwave sources," (Center for Open Science, 2020). (Preprint). DOI:10.31219/osf.io/vdk43.
https://osf.io/vdk43/

Mladen Božanić, Saurabh Sinha, "Millimeter-Wave Integrated Circuits Methodologies for Research, Design and Innovation," Part of the Lecture Notes in Electrical Engineering book series (LNEE, volume 658). DOI:10.1007/978-3-030-44398-6. Print ISBN 978-3-030-44397-9, Online ISBN 978-3-030-44398-6.
https://link.springer.com/book/10.1007/978-3-030-44398-6

Arindam Biswas, Amit Banerjee, Aritra Acharyya, Hiroshi Inokawa, Jintendra Nath Roy, "Emerging Trends in Terahertz Solid-State Physics and Devices," Springer Nature Singapore Pte Ltd., 2020. DOI:10.1007/978-981-15-3235-1. Print ISBN 978-981-15-3234-4, Online ISBN 978-981-15-3235-1.
https://link.springer.com/book/10.1007/978-981-15-3235-1

Tapio O. Niinikoski, "The Physics of Polarized Targets," Cambridge University Press, 2020. Online ISBN: 9781108567435. DOI: 10.1017/9781108567435.
https://tinyurl.com/wpy7sc5

NEWS FROM THE NET (OUR BROADER HORIZONS)

Fourth gyrotron complex for ITER has been tested successfully in N. Novgorod

On 8 June 2020, the web portal "Scientific Russia" announces that from May 25 to June 2, 2020, the Institute of Applied Physics of the Russian Academy of Sciences (IAP RAS) and GYCOM Ltd. tested the fourth gyrotron complex for the ITER (International Thermonuclear Experimental Reactor). As in the case of the three complexes manufactured earlier, the tests demonstrated that the device is fully compliant with the specifications

of the ITER Organization, which means an official recognition that the gyrotron can be put on the construction site of the future installation. The Director of IAP-RAS G.G. Denisov and E.M. Tai, director of the Nizhny Novgorod Branch ("GYCOM-NN") noted in particular: “The complex, which has passed acceptance tests these days, was manufactured and pre-tested in November 2019. It should be noted that the acceptance of our complexes always proceeds with great confidence in us from the foreign colleagues. These tests were planned in August-September 2020, but since preliminary tests showed high reliability, we asked the ITER International Organization to conduct final tests in June. The positive results obtained give us a temporary reserve for the tests of the fifth delivery complex. Acceptance tests were first performed remotely due to difficult epidemiological conditions. Representatives of the ITER International Organization and representatives of the Russian ITER Agency watched the tests via video broadcasting, then held a joint video conference.”

Jointly, the Institute of Applied Physics of the Russian Academy of Sciences and GYCOM are recognized world leaders in the production of gyrotron complexes. Of the 24 complexes for the ITER reactor, eight will be produced in Russia in accordance with the Supply Agreement between the ITER Organization and the Russian ITER Agency, signed by the parties in 2012. These devices are unique in their characteristics: a frequency of 170 GHz with a power of 1 MW and a pulse duration of up to 1000 sec. In accordance with the schedule, the first pair of Russian gyrotron complexes should be delivered to the ITER Organization in mid-2021.

The original announcement (in Russian) is available at the following link. The same news has been announced also at the website of ITER.

Melting and drilling of rocks – a new “profession” of the gyrotrons

Among the numerous applications of gyrotrons in various fields of science and technology its usage as a high-power source of electromagnetic radiation for melting and drilling of rocks is relatively less known despite the successful demonstration of this technique by Paul Woskow at MIT many years ago. In its March issue the IEEE Spectrum announces that AltaRock Energy is leading an effort to melt and vaporize rocks with millimeter waves. Instead of grinding away with mechanical drills, scientists use a gyrotron to open holes in slabs of hard rock. The goal is to penetrate rock at faster speeds, to greater depths, and at a lower cost than conventional drills do in order to utilize efficiently the abundant geothermal energy of the Earth.

The Seattle-based company AltaRock Energy recently received a US $3.9 million grant from the U.S. Department of Energy’s Advanced Research Projects Agency–Energy (ARPA-E). The three-year initiative will enable scientists to demonstrate the technology at increasingly larger scales, from burning through hand-size samples to room-size slabs. Project partners say they hope to start drilling in real-world test sites before the grant period ends in September 2022. The ARPA-E grant will allow the MIT team to develop their process using megawatt-size gyrotrons at Oak Ridge National Laboratory, in Tennessee.

For more detail please visit the source of this information following the link. Another article on this method is available in the March issue of the Quarry Magazine.

Another related news appeared on 9 June 2020 an the website of Renewable Now. Their article says: “Quaise Inc, a US company developing a new drilling technology for the geothermal energy sector, on Monday said it has secured USD 6 million (EUR 5.3m) in seed funding. The investment in the company, which is a Massachusetts Institute of Technology spinout, was led by venture capital firm The Engine. Venture capitalist Vinod Khosla played an important role in the company's inception and provided funding, while venture capital firm Collaborative Fund also contributed to the funding round. Quaise explains that geothermal energy development has so far been limited because of the difficult access in deeper earth layers through existing drilling technology. The hybrid deep drilling method invented at the MIT Plasma Science and Fusion Center and developed by Quaise **uses a gyrotron for millimetric electromagnetic wave generation**. The new technology makes drilling possible at depths that could not be reached with conventional drilling. With the seed funding, Quaise will be able to mature the technology and form a team in three locations -- Boston and Houston in the US and Cambridge in the UK. The company will also extend its links with field development partners and extend partnerships with research institutions.” Additional information is available at the following link as well as here.

Can high-power microwaves reduce the launch cost of space-bound rockets?

On 20 April 2020 *ScienceDaily* reports on the work of scientists from the University of Tsukuba. In their research, they calculated the efficiencies of four important features of microwave-beam-powered propulsion systems for rockets. These findings are critical to minimizing or possibly reducing the cost of rocket propulsion systems. In a paper published in the Journal of Spacecraft and Rockets, the research team from the University of Tsukuba have helped solve important wireless power transmission and other efficiency issues that must be overcome to use high-powered microwaves to supplement -- or nearly replace -- chemical fuel for rocket launches. Their study will help researchers in this line of work properly focus their efforts. Researchers commonly believe that a rocket requires a megawatt of beam-powered propulsion -- that's approximately the power output of 10 automobiles -- per kilogram of payload to reach a minimal orbit. Whether microwave transmission is sufficiently efficient for real-world applications is an open question.

Microwave beams have been transmitted by using a ground antenna that is the same size as a rocket antenna. "However, practical applications will require a large ground-based transmitter and a small receiver on the rocket, and thus variable-focus transmission," explains Assistant Professor Kohei Shimamura, lead author of the study. "We wanted to not only demonstrate this approach, but also quantify its efficiency." In their comprehensive study, the researchers calculated the efficiencies, at short distances, of a ground-based microwave generator (51%), wireless power supply that sends the microwaves to the rocket propulsion system (14%), receiving antenna on the rocket (34%), and propulsion device that uses the microwave energy to heat the rocket propellant (6%). "Researchers can now put numbers on how efficient variable-focus transmission is at present," says Associate Professor Tsuyoshi Kariya, the other main author of the study. Future research will need to study and improve efficiencies at long distances. In the words of Associate Professor Shimamura: "This is a difficult challenge, but an important next step in advancing microwave technology to practical use in rocket launches." Rockets are essential technology, but their launching cost is a major disadvantage for scientific missions. With future research, high-power microwaves may one day be a low-cost method of rocket propulsion, concludes the publication in *ScienceDaily*.

Journal Reference:

Kohei Shimamura, Maho Matsukura, Naoto Ozaki, Kaisei Miyawaki, Shigeru Yokota, Ryutaro Minami, Tsuyoshi Kariya, Tsuyoshi Imai, “Wireless Power Transmission Efficiency for Microwave Rocket Using 28 GHz Gyrotron,” *Journal of Spacecraft and Rockets*, 2020; 1 DOI: 10.2514/1.A34726.

Please visit the source of this information at the following link.

Collective Thomson scattering diagnostic for the GDT open magnetic trap

Specialists of the Institute of Nuclear Physics. G.I. Budker (INP SB RAS) and the Institute of Applied Physics RAS (Nizhny Novgorod) are implementing a project on the physics of the retention of energetic ions in an open magnetic trap GDL (gas-dynamic trap) of the INP SB RAS. In a recent publication, they have proposed a collective Thomson scattering (CTS) diagnostic for fast ion measurements for the GDT facility at the Budker Institute. The diagnostic utilizes the **54.5 GHz gyrotron** usually used for electron cyclotron resonance heating as a source of probe radiation and is aimed at reconstruction of distributions over transverse and longitudinal velocities of NBI-driven ions in the plasma core. In their paper the researchers present a feasibility study of this concept showing a possibility to receive a strong CTS signal of several hundred eVs for a wide range of GDT parameters. The main limitations come from the refraction of the probe and scattered radiation propagating in inhomogeneous plasma: to provide well-resolved CTS measurements the on-axis plasma density should be kept less than $1.5\text{x}10^{13}\ \text{cm}^{-3}$ while usual GDT discharges correspond to the density of $(0.9 - 1.3)\ 10^{13}\ \text{cm}^{-3}$.

Journal Reference:

Shalashov A.G., Gospodchikov E.D., Khusainov T.A., Lubyako L.V., Smolyakova O.B., Solomakhin A.L., "Collective Thomson scattering diagnostic for the GDT open magnetic trap," *Plasma Physics and Controlled Fusion*, vol. 62, n. 6 (2020) 065010. DOI:10.1088/1361-6587/ab83cc.