NEWSLETTER

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

October 2018 № 10

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.
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- 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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Editor of the website and the Newsletter
Institute of Electronics of the Bulgarian Academy of Sciences
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Observation of extreme ultraviolet light emission from an expanding plasma jet with multiply charged argon or xenon ions initiated by a THz band gyrotron

A.G. Shalashov, A.V. Vodopyanov, I.S. Abramov, A.V. Sidorov, E.D. Gospodchikov, S.V. Razin, A.G. Luchinin, A.P. Fokin, S.V. Golubev and M.Yu. Glyavin*

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Abstract: We report on the first direct demonstration of the possibility to generate extreme ultraviolet (EUV) radiation with a freely expanding jet of dense plasma with multiply charged ions supported by high-power microwaves. The detected emission power is about 20 W at 18–50 nm for argon and xenon and 0.3 W at 13–17 nm for xenon. The discharge with a peak electron density of up to 3×1016 cm−3 and a characteristic size of 150 µm is supported by the focused radiation of a recently developed gyrotron with unique characteristics, having a 250 kW output power at 250 GHz and operated in a relatively long (50 µs) pulse mode. Up-scaling of these experimental results gives grounds for the development of a point-like kilowatt-level EUV source for high-resolution lithography, which is able to meet the requirements of the microelectronics industry.

Next-generation high-resolution projection lithography for chip production requires a powerful and reliable source of radiation at the short-wavelength boundary of the extreme ultraviolet (EUV) range. The only practical generation mechanism in this range is the line radiation of elements in a highly ionized state, such as Sn^{7+}–Sn^{12+}, which have a significant number of strong radiation lines at 13.5 nm ± 1%, and Xe^{10+}, which has a family of strong lines at 11.2 nm ± 1%. These two spectral bands are essentially eminent as they both correspond to the peak reflection coefficients of the available multilayer mirrors used for manipulation with EUV light.

While all the existing prototypes of an industrial EUV source operate with laser-produced Sn plasma, a microwave discharge provides an alternative potentially less constrained in terms of output EUV power and characterized by a simpler overall design and safe operation for EUV focusing optics, which is free from being spoiled by solid target particles and fast ions typical of explosive (a few nanoseconds) laser-produced plasmas. Microwave pulses last longer, from tens of microseconds to a continuous-wave operation, and there are no channels for significant ion heating due to direct resonant power load into electrons. In the pioneering experiments, a strongly non-equilibrium Sn plasma was confined in an open magnetic trap and heated by radiation of a high-power 75 GHz/50 kW gyrotron, resulting in up to 50 W emission in the 13.5 nm ± 1% band into 4π sr. Theoretical modeling shows a good potential of this scheme for the development of an industry-ready EUV source featured with a multi-kilowatt level in the 13.5 nm ± 1% band as most required hardware, namely, compact high-current sources of tin plasma and high-power gyrotrons.

A microwave discharge can certainly be used to produce EUV emission from heavy noble gases, an option that is also being studied for laser-produced plasmas. For the spectral band 11.2 nm ± 1%, featured with line radiation of xenon, there are Ru/Be and Mo/Be mirrors that have a nearly twofold higher peak reflection coefficient in comparison to Mo/Si mirrors in the 13.5 nm ± 1% band. Thus, a combination of xenon as an emitter and new mirrors potentially is more attractive for the EUV lithography development. The first experiment aimed at realizing point-like highly emissive discharge in a noble gas has been reported. Such an experiment becomes possible with the development of a gyrotron providing a 100 kW output power at a frequency of 670 GHz in a 20 μs pulse. Going to the higher frequencies allows supporting a microwave discharge at higher plasma densities ($\sim 10^{16}$ cm^{-3}) and narrower focusing of the radiation. In this case, no external confinement of the magnetic field is needed — the discharge is ignited in a target gas jet launched from a small nozzle at near atmospheric pressure and then freely expanding into a pumped-out chamber (7–200 mTorr at the wall). In these experiments, the possibility of the formation of a point-like hot plasma spot near the nozzle was proved, and a total emission of up to 10 kW in the 110–180 nm band from argon plasma was detected.

The new experiment session was arranged around another gyrotron, having 250 GHz/200 kW/CW output radiation with Gaussian wave beam content more than 98% [1, 2] Although this tube is designed for CW operation, at present, due to limitations of the available power supply and BN window, in contrast with diamond one, it works in pulsed mode, with a pulse length of up to 50 μs at a repetition rate of 10 Hz and increased power level of up to 300 kW. Using a higher microwave power level and longer pulses permit us to study in detail the dynamics of the plasma emission and perform an experiment in xenon. Our main result is the detection of plasma emission in the EUV spectral ranges 13–17 nm (for xenon) and 18–50 nm (for xenon and argon).

The schematic of the experiment is shown in Fig. 1. Neutral gas is injected into a vacuum chamber with a nozzle. The nozzle is 150 μm in diameter and pressure behind the nozzle is varied from 0.1 to 1 bar. High-power microwave radiation from a gyrotron is focused in front of the nozzle and is resonantly absorbed by electrons under conditions of the plasma resonance when the electron plasma frequency becomes equal to the wave frequency. This condition is locally met somewhere along the jet with decreasing plasma density. A high electron thermal conductivity provides efficient heat transport towards a more dense plasma near the nozzle. Direct power load into electrons leads to the formation of non-equilibrium high electron temperature plasmas with cold ions, characterized by high rates of the electron impact ionization/excitation and suppressed recombination. This is beneficial for generation of highly charged ions capable of emitting in the EUV band.

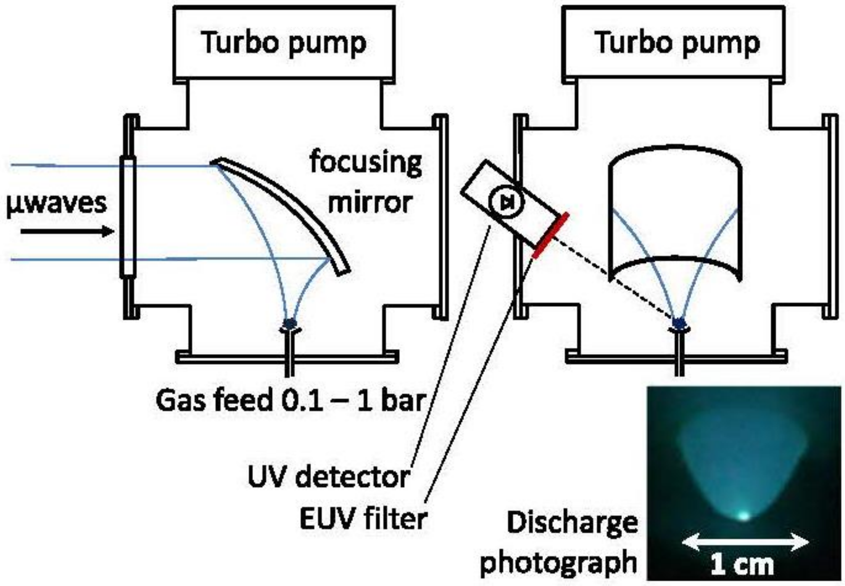

FIG. 1. The schematic of the experiment (front and side views) and a photograph of the point-like discharge.

Background pressure in the chamber is kept at the level below a few millitorr to make the media transparent for EUV light. A decrease in plasma density with the jet expansion provides good localization of the discharge,, resulting, in particular, in a point-like EUV emitting region near the nozzle, less than 1 mm in all dimensions. Noting that the optimal pressure for a microwave breakdown at 250 GHz is close to 200 Torr, the breakdown con- ditions are fulfilled only in a small area near the nozzle, where the plasma density rises above 10^{16} cm^{-3} at the developed stage of a discharge.

An absolutely calibrated silicon detector with a set of filters is used to measure the ultraviolet light properties. We use a Mo/Zr filter for the 13–17 nm band and an Al/Si filter for the 18–50 nm band. To avoid errors due to accidental holes, both filters are used in single and double combinations. The detector has an effective radius R = 0.3 cm and is placed at L = 40 cm from the nozzle at different angles to the plasma. The received signals are independent of the observation angle.

Typical signals of the point-like plasma emission measured with and without EUV filters during a microwave pulse are presented in Fig. 2. Although the optimal conditions for the maximum luminosity are essentially the same in argon and xenon, the signals show a slightly different evolution in time.

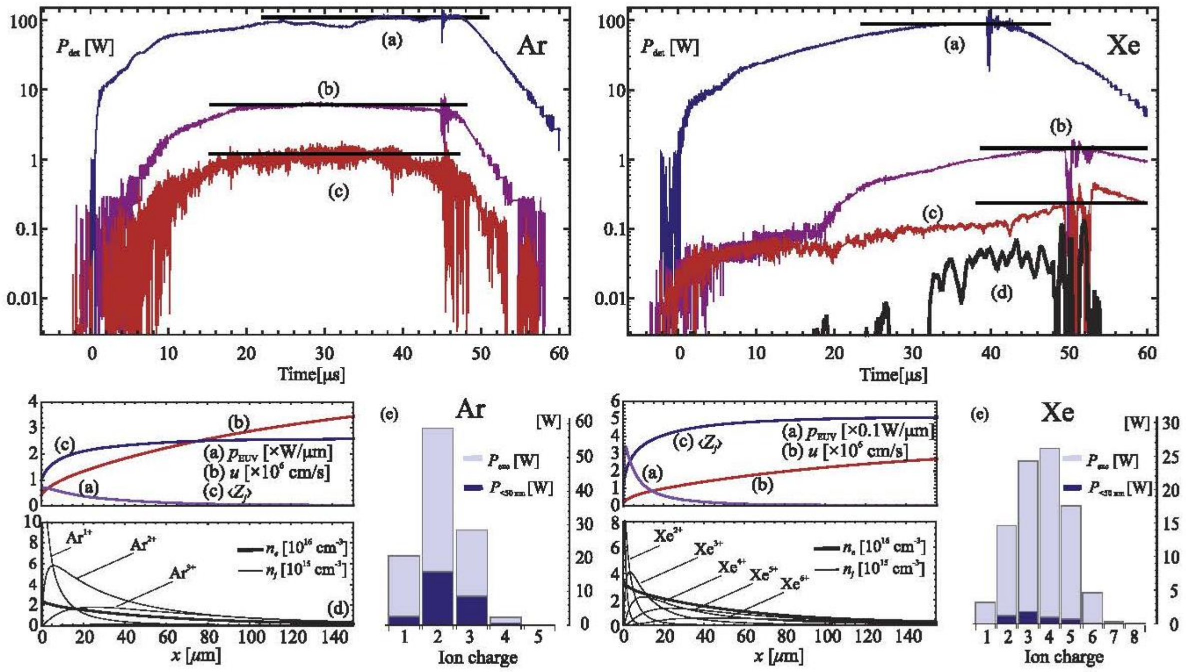

FIG. 2. Transmission coefficients of EUV filters $C_f(\lambda)$ (solid lines) and neutral gas $C_n(\lambda)$ (dashed lines) for different linear densities η_n: (a) Ar at 1.5×10^{15}cm^{-2}, (b) Xe at 1.5×10^{15}cm^{-2}, (c) Ar at 4.5×10^{16}cm^{-2}, (d) Xe at 6×10^{16}cm^{-2}.

For argon, the initial growth during the plasma set-up time (needed to establish a high-charge state) is followed by a stationary phase, and then a decay occurs after the gyrotron is switched off. The maximum EUV power of plasma emission at 18–50 nm, $P = 22$ W, is achieved with a heating power of 180 kW and a pressure of 0.55 bar behind the nozzle for argon. Emission of the argon plasma at 13–17 nm is almost zero. Most of the light belongs to the deep UV range. For xenon, there is no pronounced stationary phase: the luminosity increases with time reaching a maximum value at the end of the heating pulse. Such data correspond to times just before the gyrotron switch-off. EUV emission from the xenon plasma is observed in both of the available spectral bands. In the 13–17 nm band, the maximum light power of 0.3 W is achieved with a heating power of 250 kW and a nozzle pressure of 0.4 bar. With these parameters, the light power at 18–50 nm is 5.5 W. The experimental error in measuring the power is due primarily to the pulse-to-pulse repeatability. The appearance of a few microsecond jitter in the plasma leads to an about 10–15% deviation of the luminosity.

Figure 2 shows the results of simulations fitted to the set of strongest signals measured with an 18–50 nm filter. We reconstruct the main discharge parameters as varying functions along the flow and the distribution of radiation power losses over the ion charges. Fitted electron temperature is 45 eV. Calculated electron density $\sim 3 \times 10^{16}$ cm^{-3} is in good agreement with the results of measurements in similar conditions [3]. More heavy xenon is more easily ionized by an electron impact than argon and is therefore featured with higher electron densities and average ion charge. However, the xenon ions are still not ionized enough to emit effectively at 11.2 nm ± 1%. A fairly high effective density of neutrals in the halo, $\langle n_n \rangle \sim \eta_n/d \sim (3-4) \times 10^{18}$cm^{-3}, where $d \sim 150$ μm is a characteristic transverse size of the jet, which is comparable to the density of neutrals inside the nozzle, leaves some potential to significantly improve the EUV efficiency with a better chamber pump-out and conditioning.

Comparing to 670 GHz experiments [4], "low frequency" (250 GHz) experiments result in a dramatic, by two orders of magnitude, degradation of the conversion efficiency of the heating microwave radiation into ultraviolet light. For example, 180 kW absorbed at 250 GHz results in UV emission of 110 W corresponding to a 6×10^{-4} efficiency, while the same estimate for 670 GHz gives a 10 kW(UV)/100 kW(mw) = 10% efficiency. This can be explained by not optimal conditions for microwave absorption at the lower frequency. This is illustrated in Fig. 3 which shows a linear absorption efficiency of the Gaussian wave beam on a localized, radially inhomogeneous plasma object roughly imitating our discharge. The dependence on the plasma size and density is shown. Both parameters are normalized such that the plot is independent of the heating frequency.

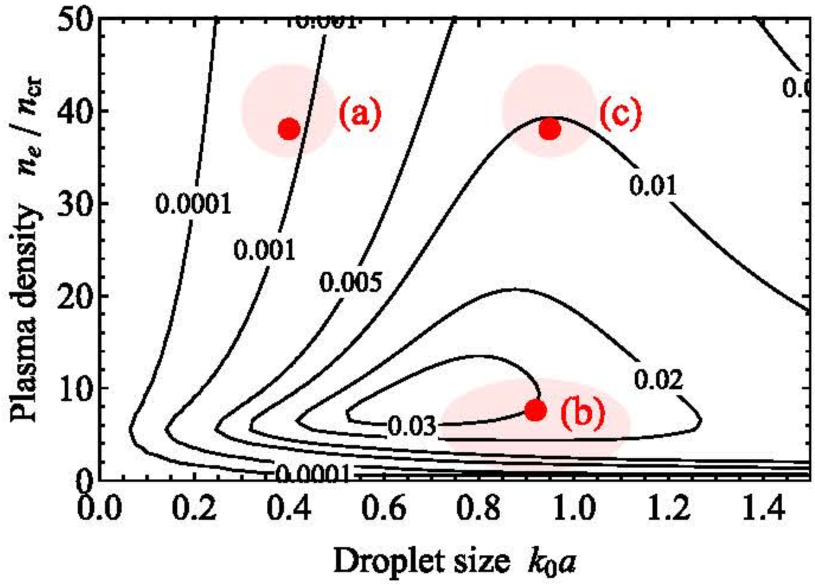

FIG. 3. Absorption efficiency of the Gaussian wave beam on a radially inhomogeneous spherical plasma droplet with the dielectric permittivity $\varepsilon(r) = 1 - (n/n_{cr})(1 - r^4/a^4)/(1 + i\nu/\omega)$ versus the plasma size, normalized by the wave number $k_0 = \omega/c$, and the central density measured in the critical cutoff plasma densities $n_{cr} = m_e\omega^2/(4\pi e^2)$. The incident radiation is polarized linearly and focused at the droplet center, where the intensity is distributed as $|E|^2 \propto \exp(-r^2/w^2)$. For a fixed beam divergence k_0w, the plot is the same for all frequencies; we consider the condition $k_0w = 2\pi$, (the beam is focused into one wavelength), which is close to the experiment. The efficiency is calculated in the "dipole" approximation, using a technique described in Ref. 6 (valid for $k_0a < 2\pi$).

Points *a* and *b* correspond, accordingly, to the experiments at 250 GHz and 670 GHz with the same nozzle diameter 150 μm and electron density 3×10^{16} cm^{-3}. By chance, the experiment at 670 GHz is close to the optimal conditions for microwave absorption ($n_e \sim 5\ n_{cr}$). In the experiments, we observed even higher efficiencies (~10%) because of the wider plasma profile than that we used for the modeling. Heating at 250 GHz is not effective for two reasons: the plasma is too dense compared to the cut-off density ($n_e \sim 40\ n_{cr}$) and the discharge is too small compared to the microwave beam waist. An increase in the nozzle diameter would eventually improve the absorption efficiency at 250 GHz (see point *c* in Fig. 4), but this spoils the discharge conditions. In the present experiments, we do not observe any improvement with larger nozzles.

To summarize, we have shown the possibility of direct conversion of high-power microwaves into EUV light in the ionized jet of noble gases. An advantage of such an approach for high-resolution projection lithography is a relatively simple design, compactness of the point-like emitting area, and the possibility of CW operation with available microwave sources. The main drawback of the existing experiment is a low conversion efficiency related to a poor coupling of the heating wave and point-like plasma dictated by the low frequency of the gyrotron available. The further increase in conversion efficiency can be achieved by using a more sophisticated electrodynamic system and by increasing the frequency of the heating wave in the existing circuit. For example, the existing 670 GHz gyrotron provides about 10 kW of microwave power deposited into a 150 μm discharge with an electron density of about 10^{17} cm^{-3}. This power can be increased severalfold with a low-Q quasi-optical cavity. The critical power needed to ionize the xenon ions strongly enough to obtain 12 nm emission is in the same range: the expected EUV power is 10 W at a 20 kW power load and 100 W at 40 kW (the ion charge varies, correspondingly, from $(Z_j) = 8.0$ to 8.6).

Acknowledgments

This work was supported by the Russian Science Foundation (project No. 14-12-00609). The simulation of the nonlinear interaction of high power THz beam with gases was supported in part by the RFBR grant under Project No. 17-02-00183.

References
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[6] A.Shalashov and E.Gospodchikov, IEEE Trans. Antennas Propag., 64(9), 3960 (2016).

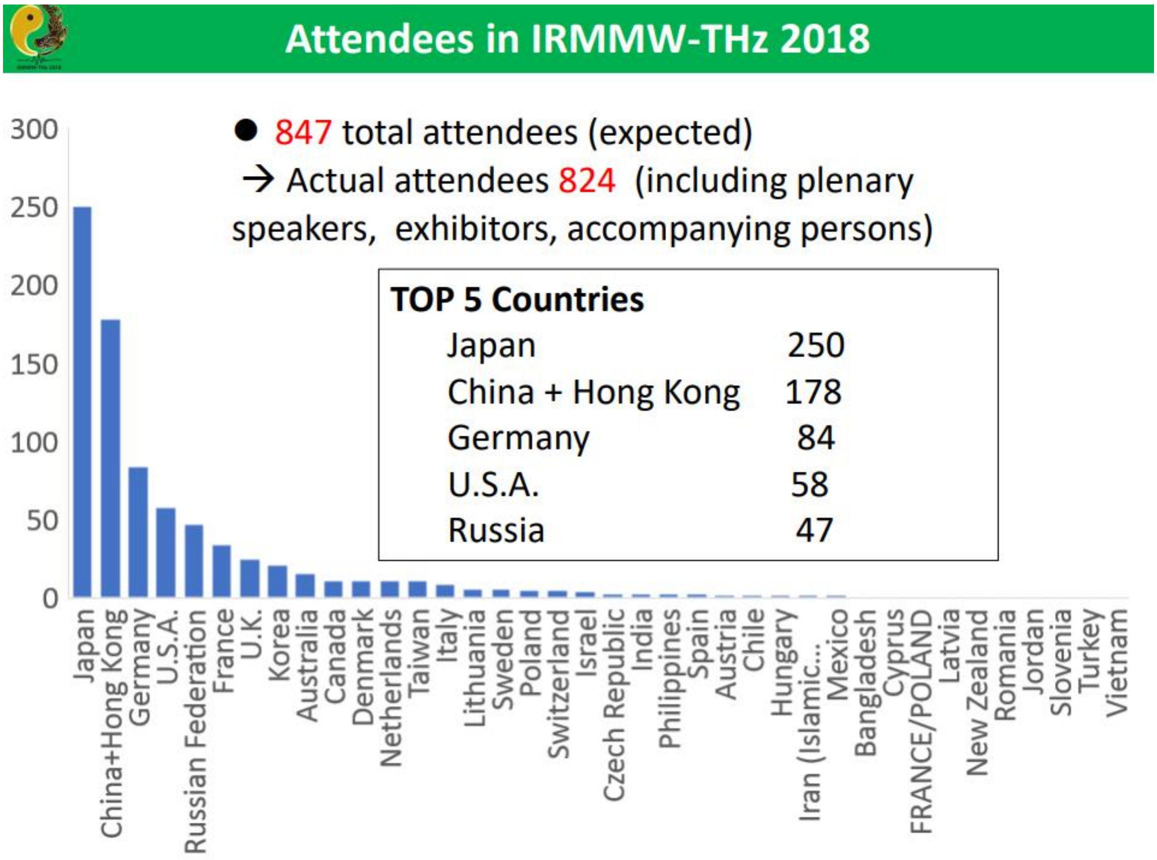
For additional information, please see the paper:

A.G.Shalashov, A.V.Vodopynov, I.S.Abramov, A.V.Sidorov, E.D.Gospodchikov, S.V.Razin, N.I.Chalo, N.N.Salashenko, M.Yu.Glyavin, S.V.Golubev. "Observation of extreme-ultraviolet light emission from expanding plasma jet with multiply-charged argon and xenon ions". Appl. Phys. Lett., 113, 153502 (2018) DOI: 10.1063/1.5049126.

PAST AND FORTHCOMING EVENTS

IRMMW-THz 2018 in Nagoya handed the baton to IRMMW-THz 2019 in Paris

The 43rd International Conference on Infrared, Millimeter and Terahertz Waves (IRMMW-THz 2018) has been held from 9 to 14 September 2018 in Nagoya Congress Center, Japan. The impressive statistics (available here) shows that with more than 800 attendants this was probably the largest forum of this conference series. It was co-chaired by Professor Toshitaka Idehara and Professor Masahiko Tani, both from the Research Center for Development of Far-Infrared Region (FIR UF) at University of Fukui.



30th Joint Russian-German Meeting on ECRH and Gyrotrons

The 30th Joint Russian-German Meeting on ECRH and Gyrotrons has been held in Nizhny Novgorod, Russia, from 17 to 24 June 2018. The Workshop scope covers the following subjects: (i) Electron cyclotron plasma heating, current drive (ECRH/ECCD) and plasma diagnostics by microwaves in nuclear fusion devices; (ii) Gyrotrons and other high power microwave sources; (iv) Electrodynamic systems for conversion and transportation of high power microwaves; (v) Input/output barrier windows for high power microwaves; (vi) Non-fusion high power microwave applications. Impact of high power microwaves on materials.

The proceedings of the workshop are published in: EPJ Web of Conferences, Volume 187 (2018), 30th Joint Russian-German Meeting on ECRH and Gyrotrons, Nizhny Novgorod, Russia, June 17-24, 2018, V.E. Zapevalov (Ed.). An Open Access to this issue is available at the following link.

35 Annual Meeting of the Japanese Society for Thermal Medicine

The 35 Annual Meeting of the Japanese Society for Thermal Medicine has been held from 31 August to 1 September 2018 in Fukui, Japan. The book of abstracts in Japanese is available here. At this meeting, Professor Norio Miyoshi presented the following report:
Norio Miyoshi, Yukihiro Fukunaga, Shinji Ito, Eduard Khutorian, Svilen Sabchevski, Toshitaka Idehara, "Combination Therapy of Hyperthermia and Photodynamic Therapy of Tumor Model by the Radiation Source of Gyrotron in the Far-infrared Region," 35 Annual Meeting of the Japanese Society for Thermal Medicine (31 Aug – 1 Sep, 2018, Fukui, Japan) Book of abstracts, p. 52.

The third joint conference of the Asia-Pacific EPR/ESR Society and The International EPR (ESR) Society (IES)

The third joint conference of the Asia-Pacific EPR/ESR Society and The International EPR (ESR) Society (IES) has been held at the University of Queensland's St. Lucia campus from 23 to 27 September 2018. Mr. Yuta Koizumi from FIR UF received Best Student Poster Award for his report on "Development of Resonators for Millimeter-Wave Band ESR/NMR Double Magnetic Resonance Measurements of Thin Samples."

Mr. Yuta Koizumi in front of the awarded poster

The book of abstracts is available at the following link. The awarded paper is: Yuta Koizumi, Yuya Ishikawa, Kenta Ohya, Shunsuke Miura, Yutaka Fujii, Akira Fukuda, Akira Matsubara, Takao Mizusaki, Soonchil Lee, Eiichi Kobayashi, Hikomitsu Kikuchi, Seitaro Mitsudo, “Development of Resonators for Millimeter-wave Band ESR/NMR Double Magnetic Resonance Measurements of Thin Samples,” Book of Abstracts of The third joint conference of the Asia-Pacific EPR/ESR Society and The International EPR (ESR) Society (IES) (23-27 Sept 2018, University of Queensland’s St. Lucia, Australia), page 85.

XI All-Russian Seminar on Radiophysics of Millimeter and Submillimeter Waves

XI All-Russian Seminar on Radiophysics of Millimeter and Submillimeter Waves will be held from 25 to 28 February 2018. The scientific program includes a broad scope of topics related to the generation and various applications of radiation in the millimeter and submillimeter bands. The seminar will have the following sections:

- Sources and receivers of radiation in the terahertz frequency range
- Sources of high-power microwaves
- Receivers of microwaves, microwave spectroscopy and metrology
- Millimeter and submillimeter waves in applied studies

The venue of the conference is the country hotel “Dubki” in the village of Lukino near the city of Nizhniy Novgorod. The registration is open till 10 November 2018 at the following link. For more information please contact the Chairman of the event Professor M. Glyavin (glyavin@appl.sci-nnov.ru) or the Scientific Secretary Dr. O. Mocheneva (molga@appl.sci-nnov.ru).

IW-FIRT 2019

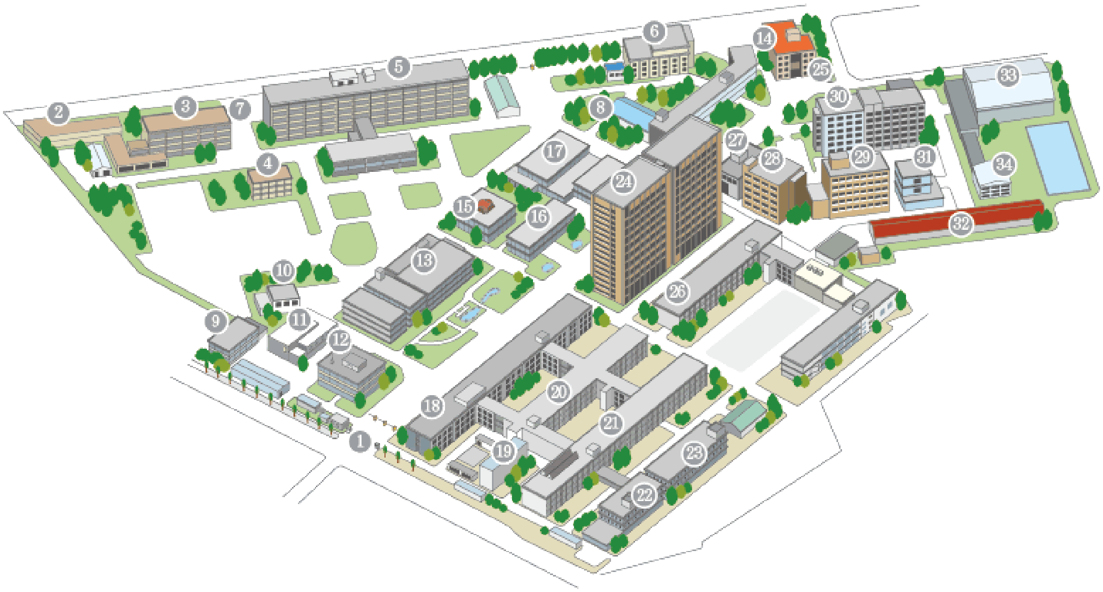
The 7th International Workshop on Far-Infrared Technologies (IW-FIRT 2019)
(5-7 March, 2019, University of Fukui, Fukui, Japan)

The International Workshops on Far-Infrared Technologies (IW-FIRT) has been held six times in the past from 1999 to 2017. In these workshops it was aimed to discuss the recent development 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 Seventh International Workshop on Far-Infrared Technologies (IW-FIRT 2019).
The workshop consists of invited talks, oral presentations and a poster session with the following scope of topics:

1) Development of high power radiation sources in the far-infrared region,
2) Application of high power terahertz technologies especially to the following topics
  2-1) Terahertz spectroscopy,
  2-2) Magnetic resonance phenomena in the far-infrared region,
  2-3) Material development with high-power FIR sources, and
3) Other subjects related to the far-infrared region.

Past Workshops of IW-FIRT and DHP-TST:
6th IW-FIRT 2017 and DHP-TST 2017, 5th IW-FIRT 2014, 4th IW-FIRT 2012, 3rd IW-FIRT 2010, and DHP-TST 2013.

[Venue](#): Bunkyo Campus, University of Fukui (Fukui, Japan). Main conference room and poster session: On the 13th floor of the Science Tower I (No.24 in the campus map). Workshop banquet: At the academy hall (No.11 in the campus map)



List of invited speakers (In alphabetical order of family names):

Marco Battiato (*Nanyang Technological Univ., Singapore*)
Elmer S. Estacio (*The Univ. of the Philippines Diliman, Philippines*)
Gerd Gantenbein (*IHM, Karlsruhe Institute of Technology, Germany*)
Mikhail Yu. Glyavin (*Institute of Applied Physics, RAS, Russia*)
Jarno Järvinen (*Univ. of Turku, Finland*)
Tae-In Jeon (*Korea Maritime and Ocean Univ., Korea*)
Yusuke Kajihara (*The Univ. of Tokyo, Japan*)
Shojiro Kimura (*Tohoku Univ., Japan*)
Stefan Knirck (*Max-Planck-Institut für Physik, Germany*)
Masami Kojima (*Kanazawa Medical Univ., Japan*)
Seitaro Mitsudo (*FIR UF, Japan*)
Yuichi Ogawa (*Kyoto Univ., Japan*)
Hitoshi Ohta (*Kobe Univ., Japan*)
Michael Shapiro (*Massachusetts Institute of Technology, USA*)
Kohei Shimamura (*Univ. of Tsukuba, Japan*)
Yukihisa Suzuki (*Tokyo Metropolitan Univ., Japan*)
Susumu Takahashi (*Univ. of Southern California, USA*)
Masahiko Tani (*FIR UF, Japan*)
Yoshinori Tatematsu (*FIR UF, Japan*)
Keisuke Tominaga (*Kobe Univ., Japan*)
Johan van Tol (National High Magnetic Field Laboratory, Florida State Univ., USA)

For up-to-date information of the Workshop please visit the [link](#) and contact by an E-mail the Secretariat: iwfirt2019_secretariat@fir.u-fukui.ac.jp.

ANNIVERSARIES OF OUR MEMBER INSTITUTIONS

60th Anniversary

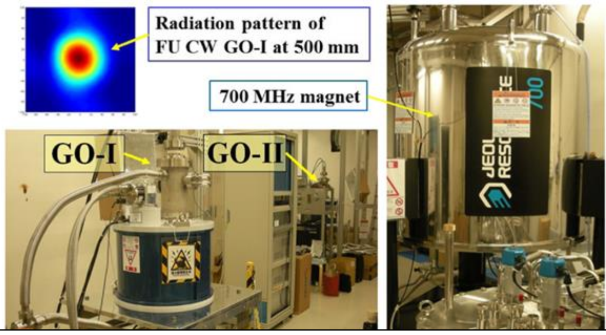
INSTITUTE for PROTEIN RESEARCH

IPR celebrates its sixtieth anniversary

Established in 1958 with the aim of exploring basic research on proteins, the Institute for Protein Research (IPR), Osaka University celebrates its 60th anniversary in 2018. To date, while conducting a wide range of cutting-edge protein research, IPR has engaged in support of structural analysis using crystallography and NMR techniques, management of structural databases, joint research projects and seminars. In doing so, IPR has contributed greatly to the protein research community both in Japan and overseas. In addition, with the aim of serving society with the unique technologies and facilities developed in the institute, IPR has extended a welcome to its research facilities and equipment not only to academic but also to private sectors.

IPR will hold an international symposium on 16th November 2018, inviting prominent researchers from Japan and overseas including two Nobel Laureates, in celebration of sixty years of endeavor and advancement, as well as to launch challenges to leap forward.

The Institute of Protein Research is an active participant in the International Consortium for Development of High-Power Terahertz Science and Technologies. Among our members, this institute is well known as a place where advanced equipment and methods for NMR-DNP spectroscopy are being implemented using as radiation sources the gyrotrons developed at FIR UF Research Center.



Gyrotrons FU CW GO-I and GO-II (left) installed in the 700-MHz DNP-NMR spectrometer at IPR

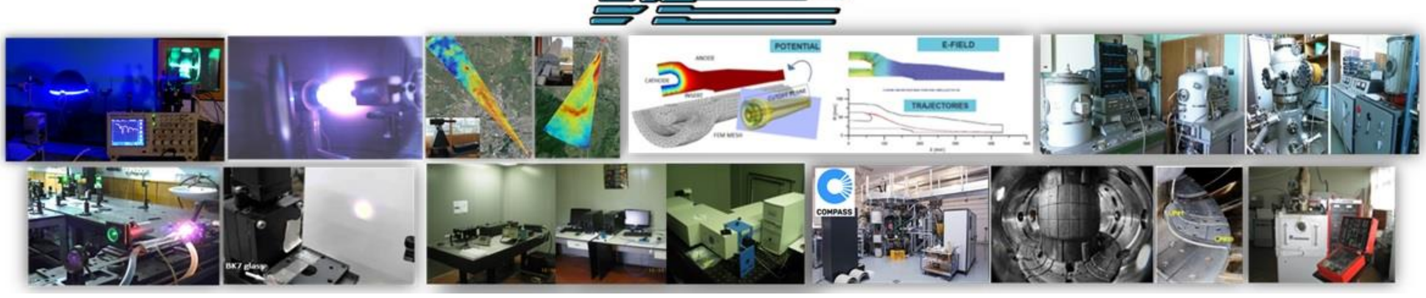
IE-BAS celebrates its fifty-fifth anniversary

The Institute of Electronics at the Bulgarian Academy of Sciences was established in 1963 as a non-profit state organization conducting research, education and dissemination of scientific knowledge in the fields of Physical Electronics, Photonics and Quantum Electronics and Radio Sciences. Soon, the Institute of Electronics evolved as a leading scientific institution in these areas of applied physics and engineering within the Bulgarian Academy of Sciences and in Bulgaria.

Through the years, the Institute's research field and structure have developed dynamically in response to the changes taking place in the main trends in applied physics and technologies: materials science and technologies, physics of nano-sized objects and nanotechnologies, nanoelectronics, photonics, opto-electronics, quantum optics, environmental physics and monitoring, biomedical photonics and biomedical applications.

At the Institute of Electronics many devices and methods have been developed in Bulgaria for the first time. Among them are: first Bulgarian laser, lidar, plasma torch, ultrahigh vacuum pump, micro-channel electron-optical converter, parametric microwave amplifier, Josephson junctions and SQUID, portable microwave moisture meter, magnetometer, installations for electron lithography, electron beam melting, refining, and welding were built, followed by the development of several advanced e-beam technologies, novel types of optical gas sensors, pioneering achievements in nanostructuring and nanoparticle formation, laser and plasma high technologies.

IE-BAS is an active member of the International Consortium for Development of the High-Power Terahertz Science and Technologies and has a longstanding and fruitful collaboration with the FIR UF Research Center.



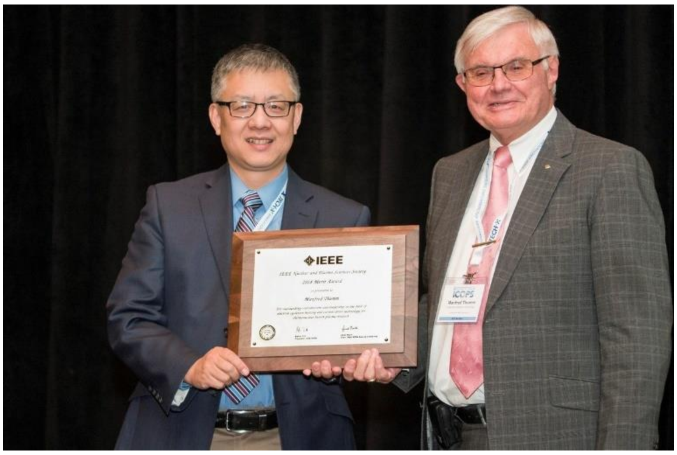
AWARDS AND PERSONALIA

IEEE NPSS 2018 Merit Award for Prof. Dr. Dr. h.c. Manfred Thumm

At the 45th IEEE International Conference on Plasma Science" in Denver, CO, USA, June 24-28, 2018, Prof. Dr. Ing. Dr. h.c. Manfred Thumm from IHM and IHE of KIT was awarded the "IEEE Nuclear and Plasma Sciences Society (NPSS) 2018 Merit Award"

"For outstanding contributions and leadership in the field of electron cyclotron heating and current drive technology for thermonuclear fusion plasma research".

The Merit Award is the highest award for outstanding scientific and technical contributions in the field of NPSS.



Presentation of the IEEE NPSS 2018 Merit Award to Prof. Thumm by the Chairman of the Plasma Science and Application Committee (PSAC), Prof. Michael Kong, from Old Dominion University of Norfolk, VA, USA.

Dr. Manfred Thumm (SM'94-F'02) was born in Magdeburg, Germany. He received the Dipl.-Phys. and Dr. rer. nat. Degrees in Physics from University of Tübingen, Germany in 1972 and 1976, respectively. At the University of Tübingen, he was involved in the investigation of spin-dependent nuclear forces in inelastic neutron scattering. From 1972-1975 he was Doctoral Fellow of Studienstiftung des deutschen Volkes. In 1976 he joined the Institute for Plasma Research of University of Stuttgart, Germany where he worked on RF production and heating of toroidal pinch plasmas for thermonuclear fusion research. From 1982-1990 his research was devoted to electromagnetic theory and experiments in the areas of component development for transmission of high-power millimeter waves through oversized waveguides and of antenna structures for RF plasma heating with microwaves. In June 1990 he became a Full Professor at the Institute of Radio-Frequency Engineering and Electronics of University of Karlsruhe, Germany and Head of the Gyrotron Development and Microwave Technology Division, Institute for Technical Physics, Research Center Karlsruhe (FZK). From 1999-2011 he was the Director of the Institute for Pulsed Power and Microwave Technology, FZK. In October 2009, the University of Karlsruhe and FZK merged with the Karlsruhe Institute of Technology (KIT).

Dr. Thumm has authored/coauthored six books, 21 book chapters, and 373 papers in peer-refereed scientific journals, more than 1,470 conference proceedings articles, and holds 14 patents. His current research projects are the development and application of high power gyrotrons, dielectric vacuum windows, transmission lines and antennas for nuclear fusion plasma heating, and industrial material processing. From 2007-2008 Dr. Thumm was Vice Chair of the FZK Scientific Technical Council and KIT Founding Senate. From 2008-2010 he was the Deputy Head of the Topic Fusion Technology of KIT. He was General Chair of the IRMMW-THz 2004 and IEEE ICOPS 2008 Conferences in Karlsruhe. He has been a member of international organization and advisory committees of many international conferences and a member of the editorial boards of several ISI refereed journals. From 2003-2010 he was Ombudsman for upholding good scientific practice at FZK/KIT. Since 2012 he has been the Editor for Vacuum Electron Devices of IEEE Trans. on Electron Devices, an IEEE NPSS Distinguished Lecturer, and a KIT Distinguished Senior Fellow. Since 2016 he has served as a member of the Scientific Advisory Council of Leibniz Institute for Plasma Science and Technology Greifswald, Germany. He wasa former member of the IEEE EDS Vacuum Devices Technical Committee and the NPSS PSAC Executive Committee. Dr. Thumm was awarded the Kenneth-John-Button-Prize 2000. In 2002 he received the title of Honorary Doctor from the St. Petersburg Technical University. He received the IEEE-EDS 2008 IVEC Award for Excellence in Vacuum Electronics. In 2010 he was awarded the IEEE-NPSS Plasma Science and Applications Award. He was a winner of the 2010 open grant competition of the Government of the Russian Federation (Leading Scientist at Novosibirsk State University). Together with A. Litvak and K. Sakamoto, he was the recipient of the EPS Plasma Physics Innovation Prize 2011. In 2012 he was awarded with the Heinrich Hertz Prize of the EnBW Foundation and the KIT HECTOR School Teaching Award. In 2017 he received the Exceptional Service Award of the IRMMW-THz Society.

Sources: KIT News and NPSS News Issue 2, June 2018, pp. 4-5.

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Tunable band-locked waveguide filter
Inventors: Yu.V. Rodin, A.V. Palitsin
Russian patent: RU 2649089
Publication date: 28 Mar 2018
http://www.findpatent.ru/patent/264/2649089.html

Method and apparatus for transmitting electromagnetic waves
Inventors: Paul Shala Henry, Robert Bennett, Irwin Gerszberg, Farhad Barzegar, Donald J. Barnickel, Thomas M. Willis, III
US Patent: US10020843B2

Publication date: 10 Jul 2018
https://patents.google.com/patent/US20170373717A1/en

Advanced drilling systems and methods
Inventor**:** John Hanback
US Patent: US20180209218A1
Publication date: 26 Jul 2018
https://patents.google.com/patent/US20180209218A1/en

Chambers for Microwave Plasma Generation
Inventor: Mike Hammer
US Patent: US 2018 / 0228012 A1
Publication date: 9.08.2018
https://patentscope.wipo.int/search/en/detail.jsf?docId=WO2017021808&recNum=52&docAn=IB2016054300&queryString=(PA/agilent)%20&maxRec=13187

High Power Magnetron
Inventors**:** Geun Ju Kim, Jung Il Kim, In Soo Kim, Jeong Hun Lee
US Patent: US 2018 / 0261419 A1
Publication date: 18 Sep 2018
https://tinyurl.com/ybj6dea2

Guided-wave transmission device with non-fundamental mode propagation and methods to use therewith
Inventors: Paul Shala Henry, Robert Bennett, Irwin Gerszberg, Farhad Barzegar, Donald J. Barnickel, Thomas M. Willis III
US Patent: US 10 , 079 , 434 B2
Publication date: 18 Sep 2018
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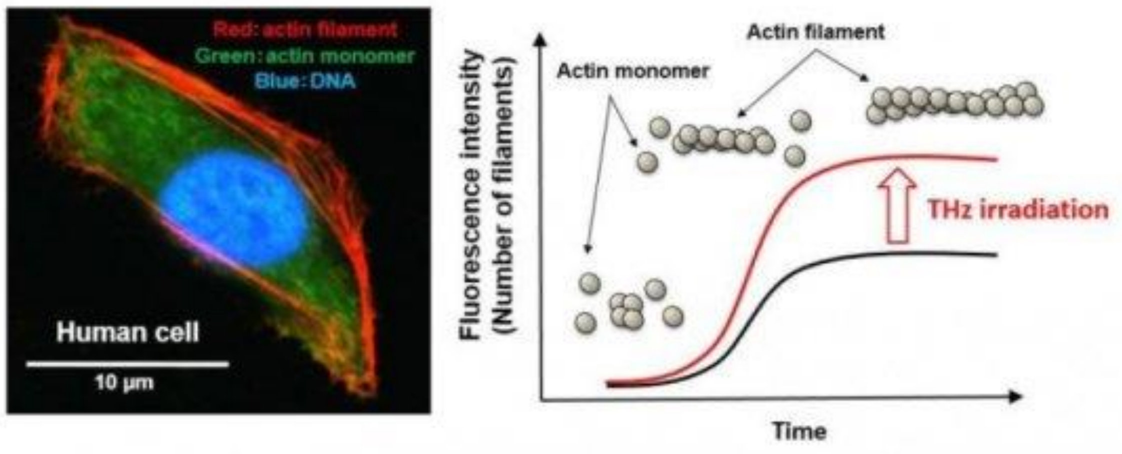
NEWS FROM THE NET (Editor's Pick)

Terahertz wave produced by a gyrotron activates filamentation of actin

Japanese researchers have discovered that terahertz (THz) wave irradiation activates the filamentation of actin protein. The discovery offers a new possibility for the manipulation of cellular functions. The research team includes Drs. Shota Yamazaki and Masahiko Harata (Graduate School of Agricultural Science, Tohoku University), Dr. Yuichi Ogawa (Graduate School of Agriculture, Kyoto University); Dr. Hiromichi Hoshina (THz imaging and the sensing team at RIKEN), and Professor Toshitaka Idehara (FIR UF Center at University of Fukui). Such important discovery has been made possible using a gyrotron developed at FIR UF as a radiation source. This device, which belongs to the Gyrotron FU CW (continuous wave) series of gyrotrons is called FU CW VIB. It is also known as FU CW GOIII, according to the nomenclature adopted at the Institute of Protein Research of the Osaka University, where it is used for DNP-NMR spectroscopy. In the experiments, it has been operated at a frequency of 0.46 THz in a regime of macro-pulses with a 1-Hz repetition rate, each pulse being 10 ms long.



Actin forms filaments in cells and plays essential roles in multiple cellular functions including cell motility, cell division, and gene expression (left). By monitoring the polymerization reaction of purified actin protein under THz irradiation, it was found that THz wave activates the filamentation of actin.
Credit: Shota Yamazaki

Actin forms filaments through its polymerization in cells, and functions as a major component of the cellular architecture. Actin plays a central role in various cellular functions, including wound healing and the metastasis of cancer cells. In addition, a portion of actin exists in the cell nucleus and regulates gene regulation. For example, actin is required for gene reprogramming, which is required for establishing iPS (induced pluripotent) cells. In this research, the polymerization reaction of purified actin protein was monitored under irradiation of THz wave, and it was found that the THz wave activates the filamentation of actin.

Actin governs various functions of cells. Therefore, a variety of drugs have been developed for controlling actin filamentation, and applications of these drugs for medical purposes have been explored. However, these drugs are inefficient in their delivery into, and clearance from, cells. THz irradiation is a non-invasive method and could overcome these identified problems in drugs. THz wave is expected to become a novel tool for the manipulation of cellular functions by modifying actin filamentation. This research team is now trying to understand the basic mechanism of the THz assisting filamentation to extend this technology to various proteins so that THz irradiation can be widely applied to various biological technologies.

Source: Tohoku University
Date: August 30, 2018
https://www.sciencedaily.com/releases/2018/08/180830095339.htm
https://phys.org/news/2018-08-terahertz-filamentation-actin-possibility-cellular.html
The press release of Tohoku University in Japanese is available here.

For more details please see the original paper *(Open Access)*:

Shota Yamazaki, Masahiko Harata, Toshitaka Idehara, Keiji Konagaya, Ginji Yokoyama, Hiromichi Hoshina, Yuichi Ogawa. Actin polymerization is activated by terahertz irradiation. Scientific Reports, 2018; 8 (1) DOI: 10.1038/s41598-018-28245-9.

A New Profession for Gyrotrons

As a powerful source of CW sub-THz radiation, the gyrotrons have numerous applications in various technologies for a thermal treatment of materials, most notably for ceramic sintering. One of the latest new applications is the gyrotron based melting. This novel method has been reviewed recently by P. Woskov from MIT in a chapter of the conference proceedings "78th Conference on Glass Problems: Ceramic Engineering and Science Proceedings, Volume 39, Issue 1".

This chapter demonstrates how cold crucible melting, basalt glass melt pour directly from a solid into a container, and sealing of crystalline rock boreholes. Phase transitions and flow from the heating beam can be seen in the thermal emission detected by the radiometer. The new capabilities for non-contact rates of heating, high temperatures, localization, and real-time diagnostic access open up new possibilities for researching and processing glass materials. The energy deposited by a directed energy millimeter-wave (MMW) beam will be spatially localized to a size cross-section depending on the frequency used, the size of the waveguide launch aperture, the propagating mode, and the distance to the target surface. The effective maximum power to the samples was limited to about 5 kW by the transmission line system, which included a reflected power isolator to prevent sample surface reflections from interfering with gyrotron operation. The depth of the melt was limited by the high viscosity of granite melt, which limits the flow into the gaps between the fragments and by the limited penetration depth of the MMW beam into the melted granite.

Paul P. Woskov, "Gyrotron Based Melting," Chapter 20, In: *78th Conference on Glass Problems: Ceramic Engineering and Science Proceedings*, Volume 39, Issue 1, Ed. S.K. Sundaram (First published: 06 August 2018). DOI:10.1002/9781119519713.ch20.
https://onlinelibrary.wiley.com/doi/pdf/10.1002/9781119519713.ch20

For more information about this technology please see the posting "Engineer explores a new path through the Earth's crust" at PhysOrg *published two years ago and the original source at* MIT News.

Magnetic field milestone. Researchers from University of Tokyo generate the strongest-ever controllable magnetic field

Physicists from the Institute for Solid State Physics at the University of Tokyo (UT) have generated the strongest controllable magnetic field ever produced with a maximum field intensity of 1200 T. The field was sustained for longer than any previous field of a similar strength. This research could lead to powerful investigative tools for material scientists and may have applications in fusion power generation.

The ability to create stronger fields advances many areas of science and engineering. ProfessorShojiro Takeyama from UT and his team created a large sophisticated device in a purpose-built lab, capable of producing the strongest controllable magnetic field ever using a method known as electromagnetic flux compression. By comparison, this is a field strength about 400 times higher than those generated by the huge, powerful magnets used in modern hospital MRI machines, and it is about 50 million times stronger than Earth's own magnetic field.

"Decades of work, dozens of iterations and a long line of researchers who came before me all contributed towards our achievement," said Professor Takeyama. "I felt humbled when I was personally congratulated by directors of magnetic field research institutions around the world."

At 1200 T the generated field dwarfs almost any artificial magnetic field ever recorded, however, it's not the strongest overall. In 2001, physicists in Russia produced a field of 2800 T teslas, but their explosive method literally blew up their equipment and the uncontrollable field could not be tamed. Lasers can also create powerful magnetic fields, but in experiments they only last a matter of nanoseconds.

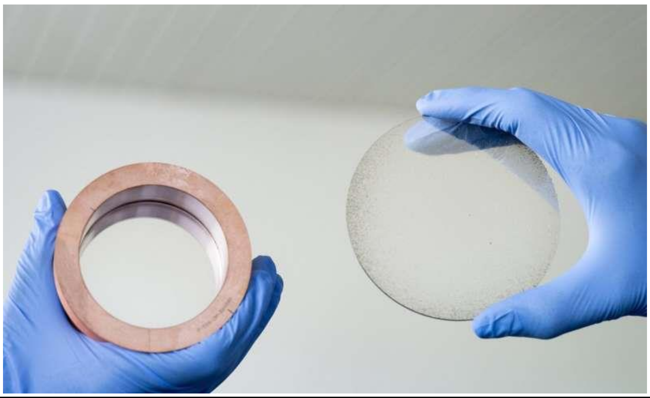
The magnetic field created by Takeyama's team lasts thousands of times longer, around 100 microseconds, about one-thousandth of the time it takes to blink. It's possible to create longer-lasting fields, but these are only in the region of hundreds of teslas. The goal to surpass 1000 T was not just a race for the sake of it, that figure represents a significant milestone. "With magnetic fields above 1000 T, you open up some interesting possibilities," says Takeyama. "You can observe the motion of electrons outside the material environments they are normally within. So we can study them in a whole new light and explore new kinds of electronic devices. This research could also be useful to those working on fusion power generation." This is an important point, as many believe fusion power is the most promising way to provide clean energy for future generations. "One way to produce fusion power is to confine plasma - a sea of charged particles - in a large ring called a tokamak in order to extract energy from it," explains Takeyama. "This requires a strong magnetic field in the order of thousands of teslas for a duration of several microseconds. This is tantalizingly similar to what our device can produce."

The above material (slightly abridged) courtesy of:
https://www.eurekalert.org/pub_releases/2018-09/uot-mfm091818.php
https://www.sciencedaily.com/releases/2018/09/180917135933.htm

The original journal paper:
D. Nakamura, A. Ikeda, H. Sawabe, Y. H. Matsuda, and S. Takeyama, "Record indoor magnetic field of 1200 T generated by electromagnetic flux-compression," Review of Scientific Instruments, vol. 89 (2018) 095106. DOI:10.1063/1.5044557.
https://aip.scitation.org/doi/full/10.1063/1.5044557

Progress in the fabrication of diamond output windows of gyrotrons for fusion

Researchers of Karlsruhe Institute of Technology (KIT) develop diamond disks for the output windows of powerful (megawatt class) gyrotrons used to heat the plasma in fusion reactors. In cooperation with a company called Diamond Materials, they have now produced a diamond disk of 180 mm in diameter**.**



Polycrystalline CVD diamond disks for window units in fusion reactors and gyrotrons. Credit: Tanja Meißner, KIT

At KIT, gyrotrons are being developed for the ITER research reactor and smaller reactors, such as Wendelstein 7X and ASDEX Upgrade. To guide microwave radiation from the gyrotrons into the plasma and in order to maintain a vacuum and keep the radioactive tritium inside the reactor, a team around Dr. Dirk Strauss and Professor Theo Scherer of KIT's Institute for Applied Materials (IAM) designs appropriate window units. For the disks, only one material is suited: "diamond is indispensable," says Dirk Strauss. "No other known material survives the extreme microwave radiation and, at the same time, has the required permeability with low losses."

To guide radiation of more than one megawatt power into the ITER research reactor, numerous diamond windows have been designed by IAM and produced in cooperation with industry partners. Meanwhile, scientists are also working on window units for ITER's successor called DEMO, in which power will be produced from 2050 onwards. As a consequence of the planned multi-frequency operation of the microwave heating system in DEMO, however, new types of gyrotrons will be required. They are presently being developed by the research team of Professor John Jelonnek at KIT's Institute for Pulsed Power and Microwave Technology. These new gyrotrons will need new window units with larger diamond disks. The corresponding prototype is now available. "Our disk has a diameter of 180 mm and is up to 2 mm thick," says Theo Scherer. "This makes it the biggest synthetic diamond structure ever produced ready for use." Now, IAM is examining the surface structure and high-frequency characteristics with respect to microwave losses of the window.

The disks are made of synthetic diamond by chemical vapor deposition (CVD), a special coating technique. The CVD diamonds grow on a silicon surface in a small vacuum reactor filled with a gas mixture. By means of microwave irradiation, this mixture is turned into a plasma, similar to what happens in a fusion reactor, but with much smaller energy consumption. The plasma consists of atomic hydrogen that prevents undesired graphite formation and a small amount of methane that supplies carbon for the diamond. "It is a time-consuming and very complex process," Dirk Strauss says. "The diamond window grows a few micrometers per hour." The end product is accordingly expensive. Production of a diamond disk for the DEMO reactor costs a six-digit amount, Strauss says.

However, the options of using a diamond material in the fusion technology are not yet exhausted. So far, diamond disks with a polycrystalline structure have been designed at IAM. These disks consist of a number of small diamonds. "At the moment, we are working on the development of monocrystalline diamond disks," Theo Scherer says. "This might further reduce microwave losses during transmission."

The original press release published on 17 July 2018 by Martin Heidelberger is available here.
The above text abridged from the posting of PhysOrg.

Latest progress in the field of DNP-NMR spectroscopy using gyrotrons

Bruker's line of Dynamic Nuclear Polarization (DNP) NMR systems has now expanded to include a 263 GHz klystron microwave source for DNP NMR for materials research at 400 MHz, and a 593 GHz gyrotron microwave source for high-field 900 MHz DNP NMR for biological research. The 263 GHz klystron offers DNP at lower cost and with reduced footprint and facility requirements. Bruker delivered the first 593 GHz DNP system in October 2017 to EPFL in Lausanne, Switzerland. Development included a new gyrotron tube design for 593 GHz, using an 11.7 T gyrotron magnet, custom microwave transmission line, and new 900 MHz low-temperature MAS DNP probes.

Source: Bruker
https://www.bruker.com/news/bruker-introduces-new-probe-technology-enabling-full-automation-in-high-resolution-mas-nmr-for-biomolecular-materials-and-clinical-research.html

See also the book of abstracts of EURMAR 2018 (Nantes 1-5 July 2018) available here.

Intense microwave pulse ionizes its own channel through plasma

More than 30 years ago, researchers theoretically predicted the ionization-induced channeling of an intense microwave beam propagating through a neutral gas (>103 Pa) and now it has finally been observed experimentally.

Breakthrough new research shows that ionization-induced self-channeling of a microwave beam can be achieved at a significantly lower power of the microwave beam and gas pressure for radially nonuniform plasma with minimal on-axis density than in the case of plasma formed as the result of gas ionization.

In the journal Physics of Plasmas, from AIP Publishing, Israel Institute of Technology researchers report observing this effect for the first time and studying it in detail in a plasma preliminarily formed by a radiofrequency discharge, in a low-pressure gas (<150 Pa). They were able to do this by using analytical modeling and numerical particle-in-cell simulations, and their work centers on the concept of the nonlinear effect on plasma and magnetic wave interaction.

"Ionization-induced plasma self-channeling is the foundation for microwave plasma wakefield research," said lead author Yang Cao. "A plasma wakefield is a wave generated by particles traveling through a plasma. And a microwave plasma wakefield experiment could give us information about laser wakefield research that's extremely difficult to obtain due to the short time (femtosecond) and geometry scale involved."

This work is significant because microwaves will always diverge, unlike lasers that can be trapped within optical fibers. "In this [way], a self-induced 'microwave fiber' is created that may help the microwave propagate a much longer distance," Cao said.

In the future, the microwave ionization-induced self-channeling effect could be used for further exploring the microwave plasma wakefield or, since it's a form of directed energy, it may also find military applications as a directed-energy weapon.

Original journal paper:

Y. Cao, J. G. Leopold, Y. P. Bliokh, Ya. E. Krasik. Self-channeling of a powerful microwave beam in a preliminarily formed plasma. Physics of Plasmas, 2018; 25 (10): 103101 DOI: 10.1063/1.5051226.

Source: American Institute of Physics. "Intense microwave pulse ionizes its own channel through plasma," ScienceDaily, 9 October 2018. Available at the following link.