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TERAHERTZ AND MICROWAVE RADIATION: GENERATION, DETECTION AND APPLICATIONS

CONFERENCE ABSTRACTS

National Research Tomsk State University

V.E. Zuev Institute of Atmospheric Optics,
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Institute on Laser and Information Technologies,
Russian Academy of Sciences

Lomonosov Moscow State University

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TERAHERTZ AND MICROWAVE RADIATION: GENERATION, DETECTION AND APPLICATIONS

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ABSTRACTS

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Сборник включает тезисы докладов 4-й Международной конференции «Терагерцовое и микроволновое излучение: генерация, обнаружение и применение – TERA 2020», посвященной фундаментальным вопросам генерации и обнаружения излучения терагерцового и микроволнового диапазонов.

Сборник представляет интерес для специалистов в области лазерной физики, спектроскопии, дистанционного зондирования, экологии, астрономии, астрофизики, материаловедения, а так же биологии, медицины, средств связи и безопасности.

The abstracts of reports of the 4th International Conference “Terahertz and Microwave Radiation: Generation, Detection and Applications—TERA 2020”, devoted to the discussion of fundamental and applied problems related to the generation and detection of terahertz and microwave radiation as well as its interaction with matter, are presented.

The collection of abstracts is of interest for specialists in laser physics, spectroscopy, remote atmosphere and environment sensing, biology, medicine, telecommunications, astronomy, astrophysics, and security.

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Аннотации докладов печатаются на основе электронных форм, представленных авторами, которые и несут ответственность за содержание и оформление текста.

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INTRODUCTION

The International Conference “Terahertz and Microwave Radiation: Generation, Detection and Applications–TERA 2020” is held the fourth time. It is the most representative international conference held in Russia, dedicated to the research of electromagnetic waves of the terahertz range, which occupies an intermediate position between the well-studied microwave and optical spectral ranges.

Until recently, the terahertz range was not available for both optical and radio-physical technologies. Progress in this field was made from both directions: from the millimeter-wave range and the infrared spectral range. Accordingly, the problem of generating, receiving, and applying terahertz waves is unique due to the synergetic combination of electronics and photonics, which differ significantly both in the theoretical basis and in the technique of generating, receiving and processing electromagnetic waves.

In recent years, the number of fundamental and applied research on this topic has increased dramatically, and new areas of practical applications are emerging. Such, for example, are the problems of medical diagnostics using terahertz waves, the study of the biological effects of terahertz radiation, the development of terahertz technologies is relevant for astrophysical research and atmospheric sensing, solving environmental problems, searching for minerals, creating telecommunications systems for a new generation of mobile communications.

The conference touches fundamental issues of terahertz spectroscopy of materials, including low-dimensional, and ultrafast phenomena in them; the physical basis of nano- and quantum devices for THz and sub-THz band; the development of fundamental approaches to detecting and generating THz waves, including quantum cascade lasers; metamaterials, plasmon materials, methods of super-resolution in the THz range; approaches to creating powerful MM and THz sources, as well as discussion of related nonlinear phenomena; physical bases of THz waves applications in industry, biology, medicine, telecommunications, astronomy, astrophysics, IR and THz atmosphere and environment sensing, security.

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PLENARY SESSION

P-1

PROGRESS IN HIGH FREQUENCY, HIGH POWER GYROTRON DEVELOPMENT IN RUSSIA

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The last decade has contributed to the rapid progress in the development of high-power microwave sources, especially of gyrotrons. This report aims to bring together information about the most striking experimental results, new trends in gyrotron development, modern remarkable applications, new demands in parameter enhancement and future goals. The paper separated into two parts: first, related to progress in MW class gyrotron development for nuclear fusion and second, focused on the development of terahertz band gyrotrons. The data about pulsed and CW tubes, working in both specified frequencies ranges, are given. In particular, the series of 1 MW / 170 GHz/CW tubes with efficiency more than 50% has been developed successfully for ITER project. Same time, despite the requirement for strong magnetic fields, the problem of high ohmic losses and electron beam formation, the gyrotrons go through magic 1 THz mark with kW power level and demonstrate (in some specific combinations) operation at extremely low voltage and beam current, narrow frequency spectrum, wide frequency tuning. Novel schemes of high-frequency gyrotrons are analyzed. The novel quasi-optical mode converters opened the possibility of phase-locking a number of tubes, which makes maximum power almost "unlimited".

The work was partially supported by the Russian Foundation for Basic Research, grant nos. 16-32-00166, 16-08-00736, 17-02-00183, 17-02-00785, 18-32-00132, 18-32-00772, and 19-32-90102.

P-2

SPATIAL AND ANGULAR PROPERTIES OF MEGAWATT FLUX OF THZ RADIATION GENERATED BY GOL-PET FACILITY

A.V. Arzhannikov[1, 2], I.A. Ivanov[1, 2], A.A. Kasatov[1, 2], S.A. Kuznetsov[1, 2], M.A. Makarov[1], K.N. Kuklin[1], S.S. Popov[1, 2], A.F. Rovenskikh[1], D.A. Samtsov[1, 2], E.S. Sandalov[1, 2], S.L. Sinitsky[1, 2], V.D. Stepanov[1, 2], V.V. Glinskiy[1, 2], I.V. Timofeev[1, 2]

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A relativistic electron beam can generate THz radiation in a plasma column due to development of the two-stream instability. At the GOL-PET facility, the beam with parameters 0.8 MeV / 15 kA/6 μs is injected into a magnetized (4.7 T) plasma column with diameter 6 cm, length 2.5 m and the density $8 \cdot 10^{14} \div 2 \cdot 10^{15}$ cm^{-3}. We have measured the characteristics of a flux in the frequency band $0.1 \div 0.8$ THz that goes out along the axis of the column with multi megawatt power. Theoretical interpretation of the obtained results is also given.

Work is supported by the Russian Sciece Foundation, project no. 19-12-00250.

P-3

TERAHERTZ WAVE GENERATION IN CRYOGENIC LIQUIDS

A. Shkurinov

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Institute of Laser and Information Technologies RAS, Moscow, Russia

In the presentation it is shown that an individual droplet of liquid metal as well as other liquids can be a source of coherent terahertz (THz) radiation, when it is excited by two femtosecond laser pulses of the same frequency. We describe the experimental results with the model of dynamic gain control, which considers the interaction of both laser pulses with the droplet and explains the THz generation process taking into account the dynamics of electrons and ions after photo-ionization of the metal droplet. The spatial distribution of THz radiation has a forward directed contribution, whose polarization properties are well described by a nonlinear susceptibility of the second order. The possibilities of terahertz wave generation in cryogenic liquids, including physical mechanisms and technical realizations will be discussed.

The work was supported by the Russian Science Foundation, grant no. 17-00-00275, and the Russian Foundation for Basic Research, grant no. 17-00-00275.

P-4

NONLOCAL TERAHERTZ PHOTOCONDUCTIVITY IN HETEROSTRUCTURES BASED ON THICK TOPOLOGICAL $Hg_{1-x}Cd_xTe$ FILMS

A.S. Kazakov[1], A.V. Galeeva[1], A.I. Artamkin[1], A.V. Ikonnikov[1], L.I. Ryabova[2], S.A. Dvoretsky[3], N.N. Mikhailov[3], M.I. Bannikov[4], S.N. Danilov[5], D.R. Khokhlov[1, 4]

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We have directly demonstrated existence of a nonlocal component of the terahertz photoresponse in thick epitaxial $Hg_{1-x}Cd_xTe$ films in a magnetic field. The film composition $x < 0.16$ corresponds to the topological phase. The sign of the nonlocal photoresponse depends on the position of the potential probe and the direction of the magnetic field, which indicates the chirality of the induced nonequilibrium transport. The observed nontrivial features of photo transport can be interpreted as a manifestation of the formation of a chiral edge conducting channel in the topological phase of $Hg_{1-x}Cd_xTe$ alloys. We discuss the results in terms of a qualitative model that takes into account the coexistence of bulk transport and boundary conducting channels.

SESSION A
BASIC PHYSICS

Invited reports

A-1

MODELING OF ULTRASHORT TERAHERTZ PULSES PROPAGATION AND AMPLIFICATION IN NONEQUILIBRIUM PLASMA CHANNELS FORMED IN GASES BY FEMTOSECOND UV LASER RADIATION

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The numerical model for the propagation of an ultrashort THz pulse in a highly nonequilibrium plasma channel created in air or xenon by intense UV laser radiation is proposed. It is shown that the spectrum of the initial THz pulse can be significantly red- shifted during the propagation, which leads to a significant distortion of the pulse shape and its duration. At gas pressures of several atmospheres, it is possible to achieve an increase in the energy of the THz signal by an order of magnitude or more over a length of ~ 30 cm.

This work was supported by the President of the Russian Federation, grant no. MK-1932.2020.2. Numerical modeling was performed at the Lomonosov supercomputer.

A-2

GENERATION OF QUANTUM CORRELATED PAIRS OF OPTICAL AND TERAHERTZ PHOTONS

G.Kh. Kitaeva, K.A. Kuznetsov, A.A. Leontyev, P.A. Prudkovskii

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So far, only the classical properties of terahertz radiation have been widely studied for various applications. Nevertheless, the extension of quantum optical technologies to the terahertz range can be very useful for its further development. We show that quantum-correlated pairs of photons of optical and terahertz ranges, generated under spontaneous parametric down-conversion (SPDC) in a strongly frequency non-degenerate regime, could be first examples of non-classical radiation matching the terahertz gap. The problems and prospects of application of optical-terahertz biphotons are analyzed considering quantum sensing, ghost imaging, and quantum calibration of efficiencies of the terahertz detectors.

The work was done under financial support the RSF, grant no. 17-12-01134, and RFBR, grant no. 19-02-00598.

A-3

OPTICALLY TUNABLE TERAHERTZ CHIRAL METASURFACE BASED ON MULTILAYERED GRAPHENE

M.S. Masyukov, A.V. Vozianova, A.N. Grebenchukov, K.V. Gubaidullina, A.D. Zaitsev, M.K. Khodzitsky

Terahertz Biomedicine Laboratory, ITMO University, Saint Petersburg, Russia

The polarization state is an important characteristic of light, accordingly, converting and manipulating the polarization of light are crucial for many potential photonics applications. The weakness of polarization manipulation provided by natural materials can be overcome by chiral metamaterials. Although chirality has been known for a long time, recently chiral structures are the subject of study both for applied and fundamental electrodynamics. Chirality is a property of asymmetry when an object is distinguishable from its mirror image by any rotations. Chiral metamaterials have a huge potential to achieve the necessary polarization effects, hence they provide the basis for ultracompact polarization components. The integration of materials with tunable properties, such as graphene, allows the creation of universal devices for polarization states control in terahertz frequency range based on metamaterials. Since graphene monolayer weakly interacts with pumping infrared radiation, we decided to use the multi-layered graphene in order to get rid of this drawback and to increase the efficiency of THz wave polarization control. In this work, we firstly propose MLG-based chiral planar metamaterial, or metasurface, with tunable transmission and polarization properties under the impact of optical pumping. It was shown that polarization state of the transmitted wave may be changed by optical pumping of multi-layered graphene. A change in ellipticity angle of 20 degrees is

shown at the frequency 0.76 THz. The present work paves the way for the realization of terahertz components capable of active polarization manipulation.

The reported study was funded by RFBR, project no. 19-31-90163.

A-4

SUPER-ENHANCEMENT FOCUSING OF TEFLON SPHERE IN TERAHERTZ BAND

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A Teflon sphere can focus the light near its shadow surface. In this paper, two circular hotspots having the extremely large field-intensity were discovered around the poles of a specifically sized Teflon sphere irradiated by a plane wave in terahertz band using an analytical algorithm. A huge contribution of scattering amplitude from a single order of mode in electric-field or magnetic-field is considered as the main factor to trigger this phenomenon of super-enhancement focusing. The work was partially supported by the Russian Foundation for Basic Research, grant no. 20-57-S52001.

Oral reports

A-5

LASER AND MATTER PROPERTIES EFFECT ON THE ENHANCEMENT OF TERAHERTZ WAVES ENERGY DURING LIQUID JETS DOUBLE PULSE EXCITATION

E.A. Ponomareva, A.O. Ismagilov, S.E. Putilin, A.N. Tsypkin, S.A. Kozlov

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One of the promising terahertz (THz) waves generation method is one based on the interaction of high-power laser pulses with matter and subsequent plasma formation. In this work, the THz waves energy enhancement in case of a double-pulse single-color excitation of various liquid jets is experimentally and theoretically investigated. In addition to the identified features of the THz waves energy enhancement during double pulse excitation of liquid jets with respect to the duration change for both pulses and their ratio variation, we state the possibility of achieving the optical-to-THz conversion efficiency value of 0.1% in case of double pulse excitation of alphapinene jet.

This study is funded by RSF, grant no. 19-12-00097.

A-6

GAS DISCHARGE SUSTAINED BY THE POWERFUL RADIATION OF 0.26 THz CW GYROTRON

A.V. Sidorov, S.V. Razin, A.P. Veselov, A.V. Vodopyanov, A.A. Orlovskiy, M.Yu. Glyavin

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This paper presents the results of the studies of the subthreshold discharge propagation under the action of the focused beam of sub-terahertz CW gyrotron (1 kW @ 0.26 THz). The discharge propagation velocity towards electromagnetic radiation was measured in various noble gases in the wide pressure range (0.1–2 atm) for various field intensities into the focal spot (5–15 kW/cm^2).

It was demonstrated that discharge velocity increase along with pressure decrease and drops with electric field decrease as it moves away from the focal spot. Typical velocity values and discharge spatial structure suggest the so-called equilibrium mechanism of discharge propagation.

A-7

OPTICAL PROPERTIES AND POTENTIAL OF KTA CRYSTAL FOR THz WAVE GENERATION

N.A. Nikolaev[1], A.A. Mamrashev[1], G.V. Lanskii[2], Yu.M. Andreev[2]

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Terahertz optical properties of $KTiOAsO_4$ (KTA) single crystal were studied by terahertz time-domain spectroscopy in the range of 0.3–2.1 THz. Dispersion of refractive index components was approximated in the form of Sellmeier equations. Phase-matching for difference frequency generation of $s-f \rightarrow f$ and $s-f \rightarrow s$ types was found

possible at room temperature. Conversion of intense near infrared laser radiation into millimeter waves in the range of < 0.4 THz was found efficient due to low absorption coefficients < 5 cm^{-1} for all three optical axes and high non-linear coefficient compared to other popular oxygen-containing nonlinear crystals such as LBO, BBO, and KTP. The research was carried out within state budget project no. AAAA-A17-117013050036-3.

A-8

HIGHLY EFFICIENT ELECTROMAGNETIC EMISSION DURING RELAXATION OF A THIN SUB-RELATIVISTIC ELECTRON BEAM IN MAGNETIZED PLASMA

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Recent experiments on the steady-state injection of a long-pulse sub-relativistic (100 keV) electron beam with an electric current below 100 A into a magnetized plasma at the multimirror trap GOL-3 have demonstrated high emission efficiency which seems unusual for a turbulent beam plasma system. Our theoretical and simulation studies have shown that the most likely candidate for explaining such efficient generation of this radiation is the mechanism of a beam-driven plasma antenna. In this work, we investigate how effectively this mechanism works at realistic parameters of the GOL-3 facility.

This work is supported by the Russian Foundation for Basic Research, grant no. 18-02-00232.

A-9

STUDY OF OH-RADICAL DYNAMICS BY ULTRAFAST TERAHERTZ TIME-DOMAIN MAGNETIC SPECTROSCOPY AT THE NovoFEL

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Fast dynamics of short-living OH-radicals was investigated by terahertz time-domain spectroscopy at the Novosibirsk terahertz free-electron laser. Continuous train of the NovoFEL pulses allowed obtaining of dynamics experimental points with period of 177 ns. The use of a magnetic field and cryogenic detectors gave a significant increase in sensitivity. Comparison experimental free induction decay signals with theoretical calculations showed excellent coincidence.

A-10

INVESTIGATION OF QUANTUM-CORRELATED OPTICAL-TERAHERTZ BIPHOTONS

A.A. Leontyev, K.A. Kuznetsov, P.A. Prudkovskii, A.M. Rudyak, G.Kh. Kitaeva

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We study the statistical properties of optical-terahertz biphotons generated by means of spontaneous parametric down-conversion. Numerical dependences of the second-order quantum correlation function were obtained depending on the frequency and temperature and polar angular aperture dependence.

A-11

FEASIBILITY OF GENERATION OF ROTATING SURFACE PLASMON POLARITONS BY THE USE OF SPIRAL PHASE GRATINGS

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Bessel beams with orbital angular momentum (OAM) created using binary phase axicons can be used to generate surface plasmon polaritons (SPPs) on cylindrical conductors by diffraction at the end. The formed SPPs can carry OAM along the conductor, at the end of which it is possible to detect the topological charge of the initial beam, which

will open up the possibility of using "twisted" plasmons to create multiplexed transmission lines along which a superposition of plasmons carrying different topological charges propagates. The characteristics of axicons that can provide the creation of Bessel beams with the characteristics necessary for the formation of vortex SPPs in the spectral range from 8 to 141 μm are found. Experimental results obtained in them are found. Experimental results obtained in the experiments on Novosibirsk terahertz free electron laser will be presented.

This work was supported by the Russian Science Foundation, grant no. 19-12-00103. In the calculations, the results of experiments performed using the infrastructure of the Shared research facility "Siberian Synchrotron and Terahertz Radiation Center (SSTRC)" based on "NovoFEL" of BINP SB RAS were employed.

A-12

TERAHERTZ TIME-DOMAIN SPECTROSCOPIC POLARIMETRY OF CARBON NANOMATERIALS-BASED STRUCTURES

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Terahertz time-domain spectroscopic polarimetry (THz-TDSP) method was used to experimental study polarization properties of unaligned single-wall carbon nanotubes with different geometric parameters on glass substrates in a frequency range 0.2–0.8 THz at room temperature. Spectra of azimuth and ellipticity angles of a polarization ellipse of the electromagnetic waves transmitted through the samples were obtained for various values of an external 980 nm optical pumping of 0.2–1.0 $W \cdot cm^{-2}$ with an external static magnetic field of ~ 0.3 T acting the samples. The results show that using carbon nanomaterials-based structures it is possible to devise efficient magneto-optically tunable polarizers that can be used in the advanced fields of terahertz nanophotonics.

The reported study was funded by the Government of the Russian Federation, grant no. 08–08, the Russian Science Foundation, grant no. 19–72–10141, and the Russian Foundation of Basic Research, grant no. 19-31-90163.

A-13

PHOTOCONDUCTIVE ANTENNAS BASED ON TOPOLOGICAL INSULATORS

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Topological insulators can be used for manufacturing photoconductive antennas as well as semiconductor materials, for effective generation and detection of terahertz radiation. This work presents results of study of the radiating and detecting properties of antennas based on thin films of topological insulators Bi2-xSbxTe3-ySey with different chemical and physical characteristics. It was shown that BSTS topological insulators in the form of island films with a thickness of several tens of nanometers can generate effectively in terahertz antennas with a dynamic range of more than 65 dB. The relaxation mechanisms for hot carriers, which determine efficiency of the generation and detection of THz radiation in topological insulators, will be discussed.

A-14

NONLINEAR HEATING OF METALS AND TERAHERTZ GENERATION IN DAMAGING REGIMES

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We report on the latest theoretical and experimental results in terahertz (THz) signal generation during the interaction of femtosecond laser pulses with metals in strongly nonlinear and damaging regimes. Significant correlation between the behavior of ablation rate and THz energy was observed for different metals (copper, zinc, nickel and others). According to previous theoretical studies, the interconnection of these two effects is caused by their thermal nature.

The work was supported by RFBR, grant no. 18-42-520023 r_a. I.V.O. is grateful to the Foundation for the Advancement of Theoretical Physics and Mathematics "BASIS" for support.

A-15

TUNABLE MID- AND FAR-INFRARED PULSES FROM GAS IONIZED BY A CHIRPED TWO-COLOR LASER FIELD

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We propose and investigate a method for generating tunable and phase-controllable mid- and far-infrared pulses in gas ionized by an intense two-color laser field composed of the chirped fundamental and its second harmonic (SH) pulses with the group time delay. The generation frequency equals to the difference between the SH and the doubled fundamental frequencies and is continuously tunable by varying chirp or time delay. The duration of the generated pulses is determined by ionization duration, which is much smaller than the duration of the ionizing field and is controlled by stretching or changing the intensity of the driving pulse. Our quantum-mechanical calculations and analytical description show that this method can provide a wide tuning range spanning from several to more than a hundred THz using femtosecond lasers.

A-16

VISUALIZATION OF TERAHERTZ AND MID-IR PULSES DURING GAS IONIZATION BY INTENSE FEMTOSECOND LASER FIELD

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Coherent detection of terahertz and mid-infrared pulses is an urgent problem, essential for various applications, including time-domain spectroscopy. In this paper, we are developing a method for visualizing terahertz and mid-infrared radiation using the generation of harmonics of a probe femtosecond laser pulse and in the presence of a measured field. We find conditions when the temporal resolution of visualization is much higher than for the popular visualization method based on the second harmonic generation due to four-wave mixing in a neutral gas.

A-17

THZ-RADIATION IN A $ZnGeP_2$ SINGLE CRYSTAL PUMPED BY DUAL-WAVELENGTH OPTICAL PARAMETRIC OSCILLATOR BASED ON THE KTP SINGLE CRYSTAL

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The THz radiation on the type e–o–o difference frequency in $ZnGeP_2$ single crystal pumped by the double-frequency parametric generator based on KTP crystal at a wavelength of ~ 2.12 μm has been experimentally obtained. The maximal average THz power obtained in our experiment was ~ 3.3 nW (λ = 181 μm) with pump pulse repetition frequency 800 Hz, pulse duration of 10 ns, and energy per pulse of 1 mJ. Tuning of THz radiation was implemented at wavelengths ~ 120– 270 μm. Moreover, the tuning wavelength range was limited only by the $ZnGeP_2$ single crystal aperture.

This research was supported by the Ministry of Science and Higher Education of the Russian Federation, project no. 0721-2020-0038.

A-18

THE $ZnGeP_2$ SINGLE CRYSTALS RESEARCH OF DEFECTS BY A TERAHERTZ SPECTROSCOPY

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During the work complex research of $ZnGeP_2$ sample was done. Volumetric inclusions in test sample were visualized by the digital holography method in IR range. By obtained data an investigating zones was chosen for researching in terahertz band. As experimental results a dispersion spectra of the refractive index and the absorption coefficient were obtained in 300–1000 μm wavelength range. It was shown that local inclusions influence on the absorption coefficient value, which depends on inclusion concentration. This dependence could be used for express quality test of the material. Most informative wavelength band for such diagnostic (400–800 μm) was experimentally determined.

This research was supported by the Ministry of Science and Higher Education of the Russian Federation, project no. 0721-2020-0038.

A-19

NUMERICAL SIMULATION OF THE Z-SCAN TECHNIQUE IN THE TERAHERTZ SPECTRAL RANGE USING THE APPROXIMATE SOLUTION OF THE MODIFIED FIELD DYNAMICS EQUATIONS

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The conventional Z-scan technique was originally invented for quasimonochromatic radiation case. Though it is widely utilized for femtosecond pulses, which spectrum is quite wide, it is important that the parameters be chosen properly to use the method correctly. In this work, a numerical simulation of the high-intensity THz radiation propagation in accordance with Z-scan method principle based on the modified field dynamics equations was conducted, allowing one to take the features of THz radiation into account. The latter ones are namely, an extremely short duration, which imposes particularities on focusing, and a very wide spectrum, which does not follow the approximations of monochromaticity.

A-20

ELECTROMAGNETIC SUB-THZ EMISSION FROM BEAM-PLASMA SYSTEM WITH STRONG DENSITY INHOMOGENEITIES

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Recent experiments on the injection of kiloampere electron beams into a magnetized plasma at the GOL-PET facility have shown that the power of sub-terahertz radiation escaping along the plasma column increases by 30 times if strong transverse density gradients are preliminarily created in the plasma. In this work, the influence of transverse inhomogeneities of plasma density on the efficiency of electromagnetic radiation generation near the harmonics of the plasma frequency is studied using particle-in-cell simulations. For comparison with experiments, simulations are carried out for real beam densities and real scales of plasma inhomogeneities.

This work is supported by RSF, project no. 19-12-00250.

A-21

PUMP-PROBE STUDY OF TOPOLOGICAL INSULATORS Bi2-xSbxTe3-ySey

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Topological insulators (TI) constitute a new class of materials that are characterized by the presence of stable (topologically protected) edge surface states of electrons. TI, as well as semiconductor materials can be used for manufacturing photoconductive antennas for generation and detection of terahertz radiation. Therefore, study of the dynamics of hot electrons is very important for understanding the basic mechanisms of carrier relaxation. TI films were grown by MOCVD method: p-type Bi2Te3, n-type Bi2Se3, and Bi1.4Sb0.6Te1.5Se1.5 (BSTS) near the Ren's curve on the structure-composition diagram. The ultrafast dynamics of carriers in topological insulators upon excitation by short optical pulses with photon energies above and below the band gap is studied. It is shown for Bi2Te3 and Bi2Se3 that bulk states contribute to the slow relaxation dynamics, while for bulk insulator BSTS terahertz-induced dynamics is mostly driven through Dirac states on the surface with much higher relaxation rates.

Poster

A-22

FREE-CARRIER DYNAMICS IN P-DOPED SILICON INDUCED BY AN INTENSE TERAHERTZ FIELD

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We present experimental results on measurement of free-carrier dynamics in p-type silicon crystal in high electric fields of THz pulses in the MV/cm range. Carrier recombination dynamics in p-type silicon is analyzed through time-resolved pump-and-probe experiments in which THz pulse is used as a pump, and a femtosecond optical pulse is used as a probe.

The reported study was funded by the Russian Science Foundation, grant no. 17-19-01261.

A-23

TERAHERTZ INDUCED OPTICAL SECOND HARMONIC GENERATION IN THE CENTROSYMMETRIC ANTIFERROMAGNETIC NIO

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Few-cycle intense THz pulses and the process of the second harmonic generation are appealing techniques for excitation and investigation of ultrafast dynamic response of magnetically ordered systems, ferroelectrics and multiferroics at the picosecond timescale. In this study, we report on experimental findings on the optical second harmonic generation in the centrosymmetric antiferromagnetic NiO induced by intense THz pulses with electric fields up to 20 MV/cm.

The reported study was funded by RFBR, project no. 20-08-00627.

A-24

LASER INTERFEROMETRY OF TERAHERTZ DISCHARGE IN N_2

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The spatial-time dynamic of THz nitrogen discharge in the background pressure range from a few torrs to one atmosphere was obtained. The work discusses issues of discharge propagation mechanism and shock wave formation. The radiation source was the gyrotron with maximum pulse power of about 40 kW at frequency 0.67 THz and duration 20 us. The main diagnostic tool was laser interferometry, based on the analysis of changes in the fringe structures made by a probe beam (r = 12 mm at $1/e^2$ level) crossing the plasma cloud. The Michelson interferometer scheme with a diode laser at 532 nm was used.

A-25

TERAHERTZ PULSE SHAPING VIA SPIRAL PHASE PLATE IN THE TIME-DOMAIN SPECTROSCOPY SCHEME

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Previously, the possibility of changing the shape of a quasi-unipolar THz pulse using a diffractive optical element (DOE) namely a spiral-shaped phase plate (SSPP) was shown theoretically. DOE allows shaping the THz waveform by controlling the phases of the partial waves coming to the detector from different spatial positions.

In this work, we experimentally investigate how such SSPP (polymer, nTHz = 1.53) can be applied for bipolar 1.5 period THz pulses from $LiNbO_3$ shaping. The shape of pulse passing through DOE, located at different points, detected by electro-optical scheme is analyzed. Hence, pulse with different spatial phase is focused on the EO-detector and the result of temporary interference is observed. To avoid signal differentiation by focusing on the crystal during registration, a scheme without focusing is considered.

The reported study was funded by RFBR, project no. 20-32-70049.

A-26

TERAHERTZ PROPERTIES OF POTASSIUM TITANYL PHOSPHATE IN A WIDE TEMPERATURE RANGE

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Non-linear crystals of potassium titanyl phosphate (KTP) can be serving as promising converters of laser radiation in THz. The aim of this work is detailed study of the terahertz properties of KTP crystals in the region of $0.2 \div 2$ THz in a wide temperature range.

Using the home-made THz-TDS, the THz optical properties of two high-resistance KTP crystals, oriented along the optical axes were studied. The measurements were carried out at room temperature, when heated to temperatures: +50 °C, +100 °C, +150 °C, while cooling to temperatures: −50 °C, −100 °C, −150 °C, −195 °C. The refractive index and absorption coefficient were calculated for all temperatures for the three main axes. The dispersion of the components of the refractive indices is approximated in the form of the Sellmeier equations, the thermo optical coefficients and the temperature dependence of the angle Vz are determined for these crystals.

A-27

STUDY OF TERAHERTZ PROPERTIES OF LITHIUM NIOBATE AT CRYOGENIC TEMPERATURES BY SPDC-SPECTROSCOPY

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We examine the efficiency of the spontaneous parametric down-conversion (SPDC) in strongly frequency non-degenerate regime as a function of temperature ($297\ \mathrm{K} < T < 4\ \mathrm{K}$) of the nonlinear crystal. Frequency-angular SPDC spectra of signal photons allowed determining the dispersion of the refractive indices and absorption coefficients of the crystal at idler THz frequencies. We have measured these characteristics of $Mg : LiNbO_3$ crystal in a wide range of temperatures $297\ \mathrm{K} < T < 4\ \mathrm{K}$. Obtained data can be used in calculation of the spatial-frequency spectra of optical-terahertz biphoton fields.

SESSION B
ELECTRONICS

Invited reports

B-1

HIGH-HARMONIC LARGE-ORBIT GYROTRONS FOR PHYSICAL APPLICATIONS

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We describe high-harmonic gyrotrons with axis-encircling electron beams developing on the basis of two experimental setups. The 30 keV / 0.7 A CW gyrotron is developed for the spectroscopy applications. Recently, selective operation at the second (0.267 THz) and at the third (0.394 THz) cyclotron harmonics was achieved. Special quasi-regular cavities are designed to achieve the fourth-harmonic operation at frequencies of up to 0.65 THz. The pulsed 80–100 keV / 0.7–1.0 A gyrotron is aimed to provide high-power pulses of radiation at the third cyclotron harmonic at frequencies close to 1 THz. Now we study possibilities to increase the peak level of the output power up to the level of several kW in order to use this gyrotron in plasma applications.

B-2

INFLUENCE OF REFLECTED OR EXTERNAL SIGNAL ON GYROTRON OPERATION

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Gyrotrons are the most powerful microwave oscillators in sub-THz and THz bands, which are of great importance for many applications such as electron-cyclotron plasma heating, DNP/NMR spectroscopy, plasma diagnostics, biomedical applications, etc. All these applications require frequency-stable, single-mode operation. Apart from the traditional methods for frequency stabilization, several other approaches have attracted a considerable interest. In this paper, we present a review of recent studies aimed at deeper understanding of injection locking of a gyrotron by an external signal and self-injection locking by partial reflection of the output power from a remote load.

This work is partly supported by the Russian Science Foundation, grant no. 19-79-00307.

B-3

TETRAAMINODIPHENYL THIN FILMS OPTICAL AND MORPHOLOGICAL CHARACTERISTICS INVESTIGATIONS FOR HIGH SENSITIVE PYROELECTRIC SENSOR WITH WIDE SPECTRAL RANGE

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The possibilities of increasing the sensitivity of the pyroelectric detector in the THz range are considered. The spectral sensitivity and morphological characteristics of a pyroelectric photosensor based on tetraaminodiphenyl thin films were investigated. It was found that the pyroelectric sensor sensitivity weakly depends on the radiation frequency in a wide spectral range from visible to millimeter waves and is 2...8 times higher than the sensitivity of known pyrodetectors and the Goley cell. The tetraaminodiphenyl surface morphopology has a significant roughness of up to few μm with a 1 μm film thickness. The role of the abnormal skin effect is discussed.

The reported study was supported by RFBR, project no. 19-32-90150.

Oral reports

B-4

REGIME OF MULTI-STAGE TRAPPING IN SUPER-RADIANT THz ELECTRON MASERS

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The use of electron-wave interaction systems consisting of several tapered sections is considered as a method of efficiency enhancement of electron masers operating in the super-radiant regime of emission of a short wave pulse from a short electron bunch. Such a regime is provided when of the electron-wave group synchronism takes place (the group velocity of the radiated wave coincides with the electron bunch velocity). In this case, the super-radiation process results in formation of a quasi-monochromatic wave packet propagating together with the electron bunch. We propose to use the multi-stage trapping regime in such a maser. In each act of the trapping (in each section), some fraction of the electron beam is trapped by the radiated wave and pass their energy to the wave. Repetition of this process from section to section involves in the electron-wave interaction almost all particles of the beam. As a result, the use of the multi-stage trapping provides a significant (at least an order of magnitude) increase in efficiency as compared to the saturated stage efficiency in the regular system. The work was financially supported by RFBR, project no. 18-02-00765.

B-5

ELECTRON MASERS BASED ON EXCITATION OF TALBOT-TYPE SUPERMODES

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A natural problem arising in the case of realization of a THz electron maser with a highcurrent relativistic electron beam is epy use of an oversized cavity, when it is difficult to provide selective excitation of a definite transverse mode. Our idea is to give up working on a fixed transverse mode, and to use excitation of a supermode formed by a fixed set of several transverse modes of an oversized waveguide. We propose to use the Talbot effect as a way to create an oversized microwave system that provides a high Q-factor for this supermode. We present a design of a Free-Electron Maser fed by a 10 MeV / 2 kA / 200 ns electron beam and based on excitation of a Talbot-type supermode at a frequency close to 2 THz. The presentation includes results of our detailed multi-frequency multi-mode simulations of the electron-wave interaction during the spatiotemporal process of formation and amplification of the supermode by electrons in an oversized microwave system. The calculated efficiency of this FEM at the level of 5–10% corresponds to the GW level of the output power.

B-6

MECHANISMS OF STABILIZATION AND TERAHERTZ RADIATION FROM SHORT DENSE ELECTRON BUNCHES

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Powerful coherent terahertz radiation from short photo-injector electron bunches formed is in demand for many applications including pump-probe experiments at X-ray FELs. If the electron bunch is shorter than the wavelength of the radiated wave, then a coherent radiation process does not need a special electron bunching and starts in radiation section immediately. However, at relatively low electron energy and high particle density, a strong mutual Coulomb repulsion of particles rapidly expands dense bunches and decreases radiation efficiency. Stabilization of the bunch length or even bunch compression may be provided by various suggested methods.

B-7

IMAGING OF HIGH-POWER MICROWAVE BEAM USING A MICROWAVE GAS BREAKDOWN INITIATED BY A SURFACE OF A METAL-DIELECTRIC SCREEN

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A technique for imaging of high-power millimeter wave (MMW) beams using an initiated microwave gas breakdown is discussed. We present the results of the first experiments on the imaging of the profile of a beam from high-power pulsed 250 GHz gyrotron by a microwave gas breakdown initiated by a surface of a metal-dielectric

screen. The screen was placed in metal chamber filled by helium or helium with admixture with other rare gases. Measured MMW intensity profiles are in good agreement with the data obtained using an infrared camera. Such a technique can be used for the development and commissioning of high-power MMW sources and for adjustment of transmission lines for millimeter waves.

B-8

THE PROJECT OF A 2nd HARMONIC 0.78 THz GYROTRON WITH A COAXIAL CAVITY

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The report proposes the project of a CW coaxial gyrotron with an output frequency of 0.78 THz and an output power of about 100–200 W, intended for spectroscopy applications and diagnostics of various media. As a magnetic system it is possible to use a cryomagnet with the maximum field intensity of 15 T available at FIR UF. To achieve the required output frequency such a value of the magnetic field implies the development of the tube operating at the 2nd harmonic. The project assumes $TE_{14.9}$ mode as an operating one.

B-9

RADIATION FROM MUTUAL SYNCHRONIZED ARRAYS OF JOSEPHSON JUNCTIONS

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Mutual synchronization of radiation sources leads to superradiant amplification of the emission power which is important for the development of efficient quantum THz devices. We observed the mutual amplification of the emitted power from the lines of niobium Josephson junction (JJ) arrays located either on a single or different substrates at frequencies up to 200 GHz and distances up to 0.9 mm between them. The study of mutual synchronization of large Josephson junction networks demonstrates the possible significant advantage of sub-mm wavelength radiation sources based on JJ's arrays.

The work was supported by the Russian Science Foundation, grant no. 20-42-04415.

B-10

GYROTRON SETUP FOR ECR-HEATING SYSTEM OF T-15MD TOKAMAK

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The report presents gyrotron-based system (developed by IAP RAS jointly with GYCOM Ltd.) for ECR plasma heating in the new T-15MD tokamak which is under construction in National Research Center "Kurchatov Institute". The first of a series (8 units) of microwave setups of a megawatt power level was developed and successfully tested. The setup includes a gyrotron, set of power supplies, a microwave radiation transmission line, and a fast protection system. 1 MW / 82.6 GHz generation regime during 30 second pulse with an efficiency of 57% was experimentally demonstrated.

B-11

DEVELOPMENT OF A MILLIMETER-BAND TRAVELING-WAVE TUBE WITH A MEANDER-LINE MICROSTRIP SLOW WAVE STRUCTURE

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Traveling-wave tubes (TWT) with microstrip planar slow wave structures (SWS) has attracted an increasing interest thanks to low operating voltage and size of the tube, as well as compatibility with modern microfabrication technologies. In this work, we report the results of design, fabrication, and experimental cold-test study of planar meander-line SWSs for millimeterband TWTs (V-, W-, and D-band). SWS samples have been fabricated using the technology based on magnetron sputtering and subsequent laser ablation. The results of 3-D PIC modeling of the TWT with sheet electron beam are presented.

This work is partly supported by the Russian Foundation for Basic Research, grant no. 20-57-12001, and DFG no. 430109039.

B-12

RADIATION OF FREESTANDING ACTIVE JOSEPHSON ANTENNAS

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Theoretical description and computer simulation of large-size Josephson systems containing a lot of junctions embedded in open waveguide system are carried out. We show that in some classes of such systems, traveling-wave regimes are possible, where all Josephson junctions are under identical electrodynamical conditions and make coherent contributions to the radiation field. Such systems, which we call active Josephson antennas, are scalable, i.e., in the case of optimal matching, the intensity of their radiation increases in proportion to the size of the system or the number of the Josephson junctions. Dynamics and directivity patterns of such Josephson antennas depending on bias current is investigated and it is shown that such oscillators with sufficiently large junction amount are prospective sources of terahertz radiation.

B-13

STRUCTURE OPTIMIZATION FOR RESONANT-TUNNELING DIODE CAVITY-TYPE TERAHERTZ OSCILLATOR

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We analyzed oscillation frequency limitations and structure dependences for resonant tunneling diode (RTD) THz oscillator with cylindrical cavity resonator. Based on the dependences of the oscillation frequency on resonant cavity dimensions, a method of the oscillator structure optimization was proposed. It is revealed that there is only one combination of the resonant cavity dimensions which gives the maximum possible oscillation frequency for this type of structure. Analysis of the calculation results has shown that fundamental oscillation up to 2.77 THz and output power up to −37 dBm at 2.5 THz could be expected for single RTD device considered in the present study.

B-14

PRINCIPAL ENHANCEMENT OF THz-RANGE GYROTRON PARAMETERS VIA FREQUENCY LOCKING

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We propose a way of advancement of the gyrotrons into the region of terahertz frequencies and megawatt-level power of radiation while keeping high efficiency and high stability of the frequency. These gyrotrons may be used for electron cyclotron resonance heating and current drive systems in future fusion setups, in large complexes of coherently radiating gyrotrons for THz data and energy transmission and for THz particle acceleration. We demonstrate implementability of this way on the example of the gyrotron with operating mode TE56.24 of very high order,

driven by a relatively weak external signal, and show that in the phase- and frequency-locking mode an essential enhancement of radiation frequency, power and efficiency can be achieved.

This work was supported by the Russian Science Foundation, grant no. 19-79-30071.

Poster

B-15

IRREGULAR AND NON-SYMMETRICAL CAVITIES FOR HIGH-HARMONIC THz GYROTRONS

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To ensure high selectivity of excitation of the operating high-cyclotron-harmonic waves in gyrotrons, as well as to provide an increase in the efficiency of high-harmonic gyrotrons due to decreased Ohmic losses, we propose using resonators of complex shapes. In this work, we describe axially-symmetrical cavities with one or more axial selective grooves, as well as quasi-axially symmetrical cavities with small azimuthal irregularities. The use of cavities of these types can be the way to achieve stable single-mode gyrotron operation at frequencies of about 1 THz with a sufficiently high (several kW) output radiation power level.

B-16

ON THE PROSPECTS OF THE EUV SOURCE BASED ON THE PLASMA IGNITED BY POWERFUL PULSED TERAHERTZ GYROTRON

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It is planned to use the radiation of a powerful terahertz gyrotron (1 THz, several kilowatts) to obtain a discharge in the gas flow. It is possible to form a beam with diameter of 0.3 mm in a waist. In this case, the power flux density will be about $5 \cdot 10^6$ W/cm^2, which should provide ignition of the discharge in a wide pressure range. Under these conditions, according to estimates, the plasma density will substantially exceed 10^{16} cm^{-3} with electron temperature of 50 eV. This should provide intensive discharge extreme ultraviolet glow. Supported by RSF, grant no. 19-19-00599.

B-17

CARBON DIOXIDE DECOMPOSITION IN ATMOSPHERIC PRESSURE PLASMA SUSTAINED BY GYROTRON RADIATION AT A FREQUENCY OF 24 GHz

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We report about conversion of carbon dioxide in the nonequilibrium plasma of microwave discharge heated by powerful radiation of gyrotron at frequency of 24 GHz under atmospheric pressure. The plasma sustained in such condition exhibits strongly non-thermal properties even at atmospheric pressure, which makes it attractive for the processes of CO_2 decomposition. The observed CO_2 conversion over 30% in CO_2 / Argon gas mixture can be significantly increased in the future due to various optimization of the reactor, the gas inlet system, the microwave coupling unit.

The work was financially supported by RFBR, project no. 18-48-520027.

B-18

BPSK FOR THZ DATA CHANNEL

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The heterodyne scheme for data channel receiver is most shared. In our work usage of cryogenically cooled receiver to increase data channel capacity is presented. This abstract described comparison of estimation low terahertz range data channel capacity in some configurations. Different source of THz carrier: BWO, Cascade of harmonics multiyear, gyrotron; type of demodulation, intermediate frequency, used I/Q demodulation etc. are analyzed. Estimations are based on Friis transmission equation and full noise temperature of cascade. The main issue for the future terrestrial data channel is atmospheric attenuation on considering frequencies: 230, 340 GHz. It was taken into account when evaluating a rate of a channel.

This work was supported have been supported by RSF, grant no. 19-19-00499.

B-19

THZ RANGE GYROTRON-BASED FACILITY FOR MATERIAL SCIENCE AND PLASMA PHYSICS RESEARCH

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The paper describes an experimental facility for material science and plasma physics research. The system provides effective transportation of radiation from gyrotron output to the area under investigation inside the vessel, which can be arranged for specific task and equipped with different control and measurement tools. This made it possible to realize a series of various experiments like initiating and studying of a terahertz discharge, obtaining nanopowders by evaporation condensation method, measuring of the dielectric properties of metal oxide powders. In our experiments we used 0.26 THz / 1 kW (CW or pulse) gyrotron. The main components of the facility are described and some results of recent experiments are given. The work was supported by RSF, grant no. 18-79-10194.

B-20

INTERACTION OF PLASMA FLOW HEATED BY GYROTRON RADIATION WITH MAGNETIC FIELDS OF AN ARCHED CONFIGURATION

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The paper investigates the interaction of plasma flows with magnetic fields, including under conditions of heating by gyrotron microwave radiation. Thus, it is possible in laboratory conditions to simulate the processes occurring in the magnetospheres of space bodies. Plasma flows was produced by MEVVA plasma generator. The effect of additional plasma heating under ECR conditions unambiguously leads to a broadening of the region occupied by the plasma. Moreover, this occurs in a wide range of magnetic fields and currents of the vacuum arc. Work was supported by RFBR, project no. 18-29-21014.

B-21

ESTIMATION OF COMMUNICATION CHANNEL CARRIER CAPACITY FOR TERAHERTZ PULSE SEQUENCE INFORMATION TRANSMISSION

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The quantity of transmitted information grows exponentially every year therefore the issue of existing data transmission systems modification becomes relevant. It is already known that the sixth generation of mobile communication will work in the terahertz frequency range. One of the promising methods of information encoding for use in existing WDM systems as well as in future terahertz communication systems is the formation of sequence of pulses and corresponding frequency comb. This work demonstrates the possibility of forming a terahertz pulse sequence with and the corresponding frequency comb by the interference of chirped terahertz pulses with a time delay much shorter than their duration. The possibility of encoding information in such structures by cutting out individual peaks in the frequency comb is shown, as well as the carrier capacity of the communication channel based on this method is investigated.

SESSION C
MATERIALS

Invited reports

C-1

HIGH-PERFORMANCE THIN-FILM SENSORS BASED ON TERAHERTZ METASURFACE

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Several approaches are considered that can increase the sensing performance of thin dielectric layers using a special design of metasurfaces operating in the terahertz regime.

Firstly, the plasmonic metasurface with the angle-sensitive resonance was proposed for THz thin-film sensing and its performance under oblique illumination was numerically investigated and experimentally tested. It is shown that the metasurface can be effectively used to substitute spectral measurements for the single-wavelength ones by tracking the transmission at different angles of incidence. The proposed approach is evaluated as promising for sensing submicron-thick analyte layers.

Secondly, we demonstrate the superior performance of a different from extraordinary optical transmission (EOT) resonant regime of hole array (HA) metasurfaces called anomalous EOT, by doing a thorough numerical and experimental study of its ability in thin-filmlabel-free sensing applications in the terahertz band.

Thirdly, a labyrinth metasurface sensor operating at the low-frequency edge of the THz band is presented. Its intricate shape leads to a high electric field confinement on the surface of the structure, resulting in ultrasensitive performance, able to detect samples of the order of tens of nanometers at a wavelength of the order of millimeters (i.e., five orders of magnitude larger).

The work is partially supported by Russian Foundation for Basic Research, project nos. 18-02-00615, 18-29-20066, and 19-52-12041.

C-2

ASYMMETRIC GRAPHENE METAMATERIAL FOR NARROWBAND TERAHERTZ MODULATION

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The properties of planar three-layer asymmetric split-ring metamaterial are studied analytically by coupled oscillator model and equivalent circuit model and verified using full-wave numerical simulations. The influence of geometrical parameters of the proposed metamaterial structure as well as graphene properties on the device terahertz spectral characteristics are investigated in details. Such a comprehensive approach in graphene metamaterial description allows to design efficient narrowband modulator for a wide range of specific tasks including applications in terahertz sensing and switching.

The reported study was funded by the Russian Foundation of Basic Research, grant no. 19-31-90163.

C-3

THIN-FILM STRUCTURES BASED ON BISMUTH AND ANTIMONY FOR TERAHERTZ PHOTONICS

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The terahertz frequency range is promising for solving various practically important problems and can be used in spectroscopy, visualization, detection and data transmission systems. However, for the terahertz technology development, there is still a problem with the lack of affordable and effective terahertz devices. And despite the fact

that over the past two decades, a significant amount of research has been devoted to the development of a highly sensitive, high-speed, compact terahertz radiation detector operating at room temperature, many unresolved problems remain in this direction. One of the main tasks is to search for new materials with high sensitivity to terahertz radiation at room temperature, for their use as a functional basis in detection systems. Most of the proposed terahertz sensors to date either have a high response speed, but have a low sensitivity, or have a high sensitivity with low speed. Thermoelectric materials based on solid solutions of bismuth and antimony have significant potential to solve this problem. Due to the small width of the bandgap, they belong to the class of semimetals with good thermoelectric characteristics. In this work, the terahertz radiation influence on to the properties of thermoelectric materials was investigated for the first time. Finding the material with the required characteristics will enable the creation of terahertz detectors with high sensitivity and high speed of operation. The obtained results should promote the usage of new thermoelectrics materials, as well as the developed devices based on them in various areas of modern THz photonics.

The reported study was funded by the Russian Science Foundation, grant no. 19-72-10141.

C-4

FUNCTIONAL DEVICES OF THz PHOTONICS BASED ON PLASMONIC METASURFACES

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Plasmonic metamaterials and their 2D counterpart – plasmonic metasurfaces (PMSs) – enable to noticeably extend functional properties of THz devices breaking the limits of classical optics. In this contribution, we review the results of extensive R&D activity focused on improving conventional and developing novel PMS-based instrumental solutions (including active devices) for the range of 0.1–5 THz to effectively manipulate THz beams in various applications. Practical examples of high-performance band-pass, low-pass, and high-pass frequency filters, broadband polarizers, quarter- and half-wave plates, planar focusing structures, absorbers and absorber-based detectors, thin-film and SEIRA sensors are discussed. The issues of design optimization, spectral characterization, and technological fabrication of the photonic structures using UV-, X-ray, and Ebeam lithography alongside with their integration with different THz metrological systems are considered. The work is partially supported by the Russian Foundation for Basic Research, grant no. 18-29-20066.

C-5

HIGH-EFFICIENT PLASMON-ASSISTED THz PHOTOCONDUCTIVE DEVICES

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Photoconductive terahertz antennas (THz PCAs) are the prevalent emitters and detectors of THz waves which are now commonly used in pulse and continuous-wave THz spectroscopy, as well as, imaging thanks to their reliability, cost effectiveness and a relative ease of fabrication. In present article we report on our recent approaches aimed at the enhancement of optical-to-THz conversion efficiency in the THz PCAs via implementation of either short photocarrier lifetime photoconductive substrates with new functional layers or geometry of the antenna electrodes including high-aspect ratio plasmonic gratings.

The work on materials was supported by the Russian Scientific Foundation (RSF), grant no. 18-79-10195, while the work on THz PCAs was carried out under the financial support of RSF, grant no. 19-79-10240. Modeling of plasmonic structures was conducted within financial support of the Russian Foundation for Basic Research, grant no. 20-32-70129 mol_a_ved.

Oral reports

C-6

CIRCULAR DICHROISM OF METASURFACES BASED ON RESONATORS WITH DIFFERENT N-FOLD ROTATIONAL SYMMETRY

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Metasurface with periodic subwavelength resonators, placed on dielectric substrate is one of the main research interests in the terahertz (THz) photonics. Based on metal/graphene hybrid materials such structures can achieve giant tunable asymmetric transmission and circular dichroism (CD). In this paper we discuss a circular dichroism (CD) of metasurfaces consists of resonators with n-fold rotational symmetry, i.e. C_2, C_3, C_4. The numerical simulation was performed in CST Microwave Studio. Theoretical analysis combines Jones Matrix approach and effective polarizability approximation for calculation of transmission and reflection coefficients. This research has both fundamental and applied relevance, and may be used in development of terahertz and microwave devices, such as waveplates, polarization sensitive absorbers, etc.

The reported study was funded by RFBR, project no. 19-31-90163.

C-7

Fe AND 5BDSR BASED COMPOSITE FLUOROPOLYMER FILMS FOR THz PHOTONICS APPLICATIONS

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Magnetic particles are able to form a periodic head-to-tail structures under the magnetic field. These structures possesses a high degree of magnetic and conductivity anisotropy allowing their use in THz photonics applications (attenuators or polarizers). In this study, the THz properties of composite films based on magnetic Fe nanoparticles (~ 100 nm) and 5BDSR (similar to FINEMET) microparticles (~ 5 mm) were studied. The composite films of ~ 200 μm were obtained on the base of F-42l fluoropolymer. They were formed both under and without a magnetic field of 100 mT. This work is supported by the Russian Science Foundation, grant no. 18-19-00268.

C-8

OPTICAL AND ELECTRONIC PROPERTIES OF THIN BISMUTH-ANTIMONY FILMS IN THE TERAHERTZ FREQUENCY RANGE

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The results of terahertz time-domain spectroscopy and galvanomagnetic measurements of thin Bi1-xSbx films are reported. The influence of a substrate material, semimetal film thickness and antimony concentration on DC resistivity, Hall coefficient, magnetoresistivity, mobility and concentration of electrons and holes is studied using galvanomagnetic methods, as well as on complex conductivity and permittivity spectra using terahertz time-domain spectroscopy in 0.2–1.0 THz frequency range. The plasma frequency, relaxation time, DC conductivity and effective carrier mass are extracted using Drude approximation. The results obtained are useful for development of various thermoelectric, electronic and optical devices, such as THz detectors or components which can control the parameters of THz radiation.

C-9

3D TERAJETS PRODUCED BY DIELECTRIC STRUCTURE

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Firstly a term “photonic nanojet” was used to describe a narrow high-intensity beam generated from the back of a micron-scale dielectric particle illuminated by a plane wave. Transverse full width at half-maximum (FWHM) of the “terajet’s” (the analogue of “nanojets” in THz frequency range) intensity has been studied numerically and the value

of 0.46λ was evaluated. The best FWHM value of the hot-spot in the focused imaging point of a continuous THz imaging system has been shown approximately 0.55λ. In this work the 3D "terajets" produced by dielectric structure was investigated theoretically and experimentally. "Terajets" were observed numerically in COMSOL Multiphysics at specific resonance frequencies, selected from S-parameters for the structure. The best resolution (theoretically FWHM was equal to 0.185λ) can achieve for PLA photopolymer-based structure at 0.109 THz. Using a continuous-wave high-precise THz spectrometer it was shown experimentally FWHM parameter about 0.321λ and 0.265λ was predicted numerically at 0.109 THz. These results offer significant advantages over the previous super-resolution methods. Compared to other methods and techniques a dielectric structure disposed on a dielectric substrate without any inclusions does not need a complex system or difficult realizations.

The reported study was funded by the Government of the Russian Federation, grant no. 08-08, and Russian Foundation of Basic Research, grant no. 19-31-90163.

C-10

SPECTRAL ANALYSIS OF A MIXTURE OF GASOLINE AND DIESEL FUEL USING TERAHERTZ TIME-DOMAIN SPECTROSCOPY

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Chemical methods for determining the quality of oil and oil products take a lot of time. To speed up the process of determining the quality of oil and oil products, it is possible to perform spectral analysis using terahertz time-domain spectroscopy. Spectral analysis of a mixture of gasoline with an octane rating of 98 and diesel fuel was performed depending on the concentration of gasoline. As a result, the concentration of gasoline in the mixture can be determined by spectral analysis and using effective medium.

C-11

IMPACT OF THE SHORT-PULSED MICROWAVE RADIATION ON THE METAL NANOPOWDERS PROPERTIES

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Metal nanopowders are the perspective materials for catalysts, solid propellants, additive technologies etc. Their modification is one of the main aims of the material science. Nowadays, using of the various chemical additions is the basic mode of metal nanopowders modification. We have founded experimentally the short-pulsed microwave irradiation leads to changing some properties of the metal nanopowders. The main reasons of such results are the metal reduction from the oxide in particle's shell and partial recrystallization of the oxide in the particle's shell. Such effects might be used for technical application in industry.

The reported study was funded by RFBR, project no. 19-03-00160.

C-12

DIELECTRIC PROPERTIES OF 3D-PRINTING ASA/MWCNTS COMPOSITES AT THE Sub-THZ FREQUENCY RANGE

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In recent years, there has been a trend in expanding additive technology, in particular in the production engineering elements millimeter and submillimeter range. We present the results of research of the dielectric properties of composite materials based on acrylonitrile styrene acrylate matrix and inclusions of multi-walled carbon nanotubes at the frequency range 100–300 GHz. A technique for producing a composite filament for 3D-printers based on the fused deposition method is described. The electromagnetic response and the calculation of the complex permittivity of 3D-printed samples of composites are given. The applicability of these composites in absorbers of Sub-THC radiation is assessed.

The work was partially supported by the Russian Foundation for Basic Research, grant no. 18-32-00810.

C-13

EXTRACTION THE DIAGONAL AND OFF-DIAGONAL COMPONENTS OF PERMITTIVITY TENSOR USING TERAHERTZ TIME-DOMAIN POLARIMETRY

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Terahertz time-domain spectroscopy is a unique spectroscopic technique that determines amplitude and phase shift resulting from beam interaction with material. The method terahertz time-domain polarimetry may be an alternative method. It is a characterization technique in which the change of polarization state of the light transmission from the object is measured. We propose analytical description of extraction the diagonal and off-diagonal components of permittivity tensor of materials in the terahertz frequency range using terahertz time-domain polarimetry. From the diagonal and off-diagonal components of the permittivity tensor of materials, the effective mass, Hall mobility, and scattering time can be calculated.

The reported study was funded by the Russian Science Foundation, grant no. 19-72-10141, and Russian Foundation of Basic Research, grant no. 19-31-90163.

C-14

Sub-THZ ABSORPTION PROPERTIES OF BLACK CARBON CONTAINING COMPOSITES FOR APPLICATION IN ADDITIVE TECHNOLOGY

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In this paper, the results of the research of electromagnetic characteristics of composite materials at the Sub-THz frequency range are presented. New filaments for 3D printing based on ABS and carbon black are created. Samples of composite materials obtained by the additive technology were made. The frequency dependencies of complex permittivity were measured at the frequency range from 120 to 260 GHz. The calculation of the frequency dependences of the reflection coefficient on a composite coating located on a reflective surface is carried out. The efficiency of absorption of electromagnetic radiation of 3D-printing carbon black contains materials at sub-THz range is shown.

The work was partially supported by the Russian Foundation for Basic Research, grant no. 18-32-00810.

C-15

FREQUENCY FEATURES OF ELECTROMAGNETIC RESPONSE OF THE FERRITE CONTAINING PETG COMPOSITES AT EHF RANGE

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The article presents the results of studies in the EHF range of electromagnetic responses of composite materials based on polyethylene terephthalate glycol (PETG) with the inclusion of micro-sized ferrites particles for use in additive technologies based on the fused deposition method. The complex permittivity spectra of the composite were calculated as a function of the concentration of ferrite. The frequency regions of the ferromagnetic resonance of the composite are determined. The possibility of the applicability of these materials in 3D printing of objects with frequency-selective properties in the EHF range is shown.

The work was partially supported by the Russian Foundation for Basic Research, grant no. 18-32-00810.

Poster
C-16

OPTICAL PROPERTIES OF 1% Nd-DOPED KGW CRYSTAL IN THE TERAHERTZ RANGE

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Potassium gadolinium tungstate crystal (KGW) is well-known for the generation of continuous and pulsed laser radiation as well as frequency conversion via stimulated Raman scattering. Here we present, terahertz optical properties of 1% Nd-doped KGW crystals studied by THz-TDS in the range of 0.2–2.4 THz. Typical values of refractive index are ng = 3.75, nm = 3.37, np = 3.40 at 1 THz. Absorption coefficient behaves similarly for all three optical axes and it is less than 5 cm^{-1} for the frequencies below 1 THz. Thus, we assume that relatively high cubic nonlinearity, small low-frequency terahertz absorption, and high birefringence put KGW crystal among candidates for efficient optical-to-terahertz conversion.

The work is partially supported by Russian Foundation for Basic Research, project no. 19-52-55004.

C-17

TRANSMISSION OF Fe- AND Nd-DOPED ZnSe CRYSTALS IN VIS, IR AND THz RANGES

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We present transmission of zinc selenide polycrystals modified by doping of iron and neodymium with different diffusion depth and concentration of impurities (Fe^{2+} ions with a concentration 0.05–0.45 wt.% and Nd^{2+} ions with 0.08–0.48 wt.%) measured by absorption spectroscopy in the visible, near-infrared (400–1100 nm) and time-domain spectroscopy in the terahertz range (0.1–1 THz). The introduction of dopants shows the significant and related change in the transmission in the wide range of frequencies. This can be effective for controlling the optical properties of samples, which then can be applied for creating effective optoelectronic components for wide spectral range and terahertz radiation control devices.

C-18

TERAHERTZ OPTICAL PROPERTIES OF POLYMER COMPOSITE BASED ON ELECTROSPUN PVC NANOFIBERS

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In the recent decade, electrospun nanofibers have attracted many attentions. Several researches about the optical properties of electrospun nanofibers were carried out in the visible and infrared frequency range. However, terahertz (THz) optical properties of materials based on electrospun nanofibers haven't been studied yet. The study of their terahertz optical properties makes it possible to develop THz optical components using electrospun nanofibers.

Terahertz (THz) time-domain spectroscopy (TDS) is an excellent tool for studying the THz optical properties of materials. The quantitative determination of the orientation and number of glass nanofibers in a polymer medium using THz time-domain spectroscopy (TDS) was studied.

In this work, we developed a composite material based on PP and PVC nanofibres. THz optical properties and the permittivity tensors of the composite material were measured using THz-TDS. The result shows that the special properties of the composite material bring good promises of using it as potential optical material. We also proposed a novel iterative theoretical approach to estimate the optical properties of the material and its polarization properties as a reliable basis for the design of other nanofiber-based optical material in the future.

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C-19

THE INVESTIGATION OF THE INFLUENCE OF OPTICAL PUMPING ON OPTICAL PROPERTIES OF THIN FILM BISMUTH IN TERAHERTZ FREQUENCY RANGE

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The research is aimed to investigate the influence of optical pumping on optical properties of thin film bismuth in terahertz frequency range. Experimental results were obtained using terahertz time-domain spectroscopy technique and showed the optical properties tunability at optical pumping for different values of power. Due to this property thin bismuth film becomes a promising alternative platform for realizing tunable hyperbolic medium.

C-20

TERAHERTZ PROPERTIES OF THIN FILM STRONTIUM BARIUM NIOBATE SINGLE CRYSTALS

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Terahertz optical and dielectric properties of strontium barium niobate $Sr_{0.5}Ba_{0.5}Nb_2O_6$ (SBN-50) were measured by terahertz time-domain spectroscopy in the range of 0.1–2 THz and in the temperature range of 293–473 K. Films of single crystal SBN-50 with the thickness of 1.8 μm were grown on MgO (001) 560-μmm-thick substrate. Properties were measured in transmission regime with the terahertz radiation polarized perpendicular to the polar c axis of the crystal. Vibrational modes around 1.6 THz and 2 THz were found which is consistent with the previously reported measurements by Raman and infrared reflection spectroscopy. General relationships of structure formation and characteristics of the films are discussed.

C-21

PHANTOM TISSUES FROM MEMBRANE BIOPOLYMER COMPOSITE MATERIALS FOR TERAHERTZ APPLICATIONS

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In recent years terahertz (THz) technologies has recently drawn increasing attention for biomedical application. This is due to the advantages of terahertz radiation. Such as THz radiation is strongly absorbed by water, it has low photon energy and many molecules exhibit strong absorption at these frequencies. The described above unique features allow using THz spectroscopy for many biomedical applications, for example cancer diagnosis. Fresh human tissue can be difficult to obtain for experimental investigation and for comparison with another tissue types. Phantom materials mimiking the optical properties of the tissues can be used instead. TX151, polyacrylamide, gelatin, agar, oil-in-gelatin are usually used for making phantoms in THz frequency range. In this work it was proposed to develop the THz phantom tissue from membrane biopolymer composite materials. The films based on biocomposite gelatin/starch with addition of an inert plasticizer glycerol and a bentonite as reinforcing filler were made. Several different phantoms were prepared with a 3, 5, 7, and 9 wt.% content of bentonite. For each sample the refractive indices, absorption coefficients and mechanical tensile properties of the films were measured. Optical properties were obtained in the frequency range of 0.2–1 THz. In addition, the change in optical properties depending on the thickness of the sample with bentonite particles content 9 wt.%, was considered. Also, it is proposed models that analytically determining the required content of components in membrane biopolymer composite material for simulating phantoms for the desired characteristics.

The reported study was funded by the Russian Foundation of Basic Research, grant no. 19-31-90163.

C-22

ELECTROMAGNETIC CHARACTERISTICS OF LIGHT TERAHERTZ MATERIALS

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Porous materials are promising for use in the terahertz range, when they have valuable properties: low weight, chemical inertia, thermal stability, and relatively low cost. These materials are required for effective shielding of electromagnetic radiation, attenuators, filters. Electromagnetic characteristics in the frequency range of 0.15–0.5 THz are considered. Samples are porous composite materials filled with carbonyl iron, waste from semiconductor production, and carbon nanostructures. Foamed polyurethane and foam glass material is used as a dielectric binder. The combination of high electromagnetic efficiency and the "green" origin of the constituent composites opens the way for successful practical use.

The reported study was funded by RFBR, project no. 19-32-90150.

C-23

CLUSTERING OF A MAGNETIC FLUID UNDER THE INFLUENCE OF A MAGNETIC FIELD FOR APPLICATION IN THz PHOTONICS

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As a result of the conducted researches, dependence of transmission of the measuring cell with magnetic fluid from the magnitude and direction of the external magnetic field, and also from concentration, the sizes and a configuration of particles have been derived. The results can be proposed that the parameters of the system in some cases can change more than much under the influence of a magnetic field. This result can find practical application in operations on synthesis of new functional materials, and also during creation of various THz devices, such as: THz filter, modulator, polarizer, isolator and sensor.

This work is supported by the Russian Science Foundation, grant no. 18-19-00268.

C-24

MULTILAYER GRAPHENE – ION GEL AMPLITUDE MODULATOR FOR TERAHERTZ FREQUENCY RANGE

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In this work, amplitude modulator of terahertz radiation was fabricated and experimentally studied. The sample consists of two plastic substrates, internally coated with multilayer graphene, the cavity between the plates was filled with ion gel. The fabricated sample was studied by terahertz time-domain spectroscopy method. In the experiment, waveforms of terahertz pulse transmitted through the sample at different applied DC voltage were obtained. It was shown that with increasing DC voltage, the amplitude of the transmitted terahertz radiation decreases. The results may be used to design attenuators and modulators for terahertz communication.

The reported study was funded by the Russian Foundation of Basic Research, grant no. 19-31-90163.

C-25

THz PROPERTIES OF SINGLE-LAYER Ni COATED COPPER FOILED POLYIMIDE GRATINGS

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Series of different gratings of 100 to 300 μm and spacing between them of 150–600 μm were examined in the range 0.2–1.4 THz via THz-TDS. Gratings were made from 100 μm thick copper foiled polyimide by photoetching of the 20 μm thick Cu layer with various patterns. To make patterned magnetic cores, these gratings were coated with nickel by chemical and galvanic methods. The possibility of using these gratings with systems of liquid THz filters based on magnetic nanoparticles in THz-transparent solvent was analyzed. This work is supported by the Russian Science Foundation, grant no. 18-19-00268.

C-26

DOWN-CONVERSION OF NEAR-IR LASERS INTO THE THz RANGE IN β-BiB_3O_6

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All three components of refractive index and absorption coefficient spectra of nonlinear β-BiB_3O_6 crystal were measured by THz-TDS in the range of 0.18–2.75 THz. Dispersion properties were approximated in the form of Sellmeier equations suitable for estimation of phase-matching conditions. Phase-matching in the principle plane XZ ($\phi = 0°$) and in a narrow range of ϕ angle was found. Namely, ffs and sfs (the first index is for the shortest wavelength; $\lambda_1 \geq \lambda_2 > \lambda_3$) type interactions can be realized. Maximal figure of merit was found to be 1.2 $(pm/V)^2$ for both types of interactions that was two times higher than for a widely used LBO crystal. This work is supported by the Russian Science Foundation, grant no. 19-19-00241.

SESSION D
SYSTEMS

Invited reports

D-1

STIMULATED EMISSION IN FAR AND MID INFRARED RANGES IN HgCdTe QUANTUM WELL HETEROSTRUCTURES

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Stimulated emission (SE) at wavelengths up to 31 μm (9.7 THz) and down to 2.8 μm is demonstrated from HgCdTe quantum well (QW) heterostructures under bandgap optical excitation. Non-radiative Auger recombination is shown to be mitigated due to the symmetry of electron and hole energy spectra. Pump-probe carrier lifetime measurements show that further increase in SE wavelength is feasible up to 60 μm (5 THz). In the short wavelength range SE down to 2.8 μm is demonstrated at temperatures available with Peltier coolers.

The work was financially supported by the RFBR, project no. 18-52-16013.

D-2

HIGH RESOLUTION THz SPECTROSCOPY BASED ON QUANTUM CASCADE LASERS FOR MEDICAL AND BIOLOGICAL APPLICATIONS

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High resolution THz spectroscopy based on quantum cascade lasers (QCL) is presented. The cornerstone of the QCL-based radiation source design is a phase-lock loop (PLL) and modulation system. The preliminary measurements have testified this method to open widespread trends of its using for various problems of medicine and biology. There are laboratory investigations of the processes in exhaled breath and vapors of biological liquids (urine, blood, serum), studying of metabolites dynamics. The method presented can be applied for diagnostics of social important diseases (diabetes, cancer etc.) and influence of therapy on the state of the human organism. The authors acknowledge for support of the Russian Foundation for Basic Research, grant no. 18-52-16017 NCNIL-a.

D-3

ENHANCEMENT OF DETECTOR RESPONSIVITY USING TERAJET EFFECT

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A mesoscopic dielectric particle-lens (Teflon cube with wavelength dimension) was used to couple the incoming terahertz radiation to the plasma wave based detector. We experimentally observed an enhancement of the detector responsivity of about 4.3 dB compared to that of a direct detection system where no particle-lens is used. A slight decreasing (~ 1.67 times) of noise equivalent power value was observed. The proposed method demonstrate the possibility to reduce the size and increase the sensitivity of various THz systems including imaging, sensing and ranging, which would significantly enable progress in different fields such as physics, medicine, biology, astronomy, security, etc.

Oral reports

D-4

SURFACE-EMITTING 7–8 μm RANGE RING CAVITY QUANTUM-CASCADE LASER

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A quantum-cascade laser with a surface emission of radiation through a grating formed in the layers of the top cladding of the waveguide by ion beam etching is fabricated. The active region of the QCL heterostructure was formed based on a heteropair of $In_{0.53}Ga_{0.47}As$ / $Al_{0.48}In_{0.52}As$ solid alloys with two-phonon resonance scheme. Lasing in the spectral range of 7–8 μm of quantum-cascade laser was demonstrated. Studies of the lasing spectra in the temperature range of 8–77 K showed that the mode spacing corresponds to whispering gallery modes.

The work was supported by the Russian Science Foundation, grant no. 20-79-10285.

D-5

PUMP SOURCE FOR DIFFERENCE FREQUENCY GENERATION BASED ON DOMESTIC PPKTP CRYSTAL

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We present the recent experimental results of optical parametric oscillator (OPO) at 1.9–2.2 μm spectral region based on periodical polled domestic potassium titanyl phosphate (KTP) pumped by 1 μm laser. One of the advantages of developed OPO source is high effective difference frequency generation in non-oxide crystals between signal and idler waves for MID-IR application.

The work was partially supported by the Russian Foundation for Basic Research, grant no. 19-32-60055.

D-6

OUTPUT POWER AND SPECTRAL CHARACTERISTICS OF TERAHERTZ QUANTUM CASCADE LASERS OPERATED IN A PULSED MODE

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Terahertz Quantum Cascade Lasers are widely adopted as prominent and easy-to-use solid state sources of terahertz radiation. Yet some applications require generation and detection of very sharp and narrow THz pulses with pulse length from tens to hundreds of picoseconds. In our work we used home-made THz QCL operated in a pulsed mode. With help of a novel laser biasing technique, we study generation and detection of THz pulses with use of a fast superconducting bolometer. Lasing pulse power and spectral composition were studied depending on the biasing parameters. In the presentation, experimental details and results will be discussed.

This work was supported partially by RFBR, grant no. 20-02-00362\20, and partially by RSF, grant no. 18-19-00493.

D-7

THz QUANTUM CASCADE LASERS: NOVEL APPROACHES FOR ORIGINAL DESIGNS, HIGH-QUALITY MBE GROWTH FOR THE HIGH-TEMPERATURE LASER PERFORMANCE

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Recently, active work on the development of THz quantum cascade lasers (QCL) has led to the emergence of the full-cycle QCL technology in Russia that successively covered issues from laser quantum design through the fabrication technology to the QCLs performance measurements. We have designed the original THz QCL scheme with active period based on three tunnel-coupled quantum wells with resonant phonon depopulation and predicted the maximum operation temperature of the proposed design to be more than 200 K. MBE growth technique and wafer processing have been developed using novel approaches. The fabricated QCLs have a lazing frequency of 3.4 THz and maximum operation temperature of more than 130 K.

The work was supported by the Russian Ministry of Higher Education and Science, project no. 0723-2020-0037 (MEPhI). IPM acknowledges the Russian Science Foundation, grant no. 18-19-00493.

D-8

PIN PHOTODIODE ON AN AlGaAs / GaAs / AlGaAs HETEROSTRUCTURE SIMULATION FOR WORK IN THE UPPER ATMOSPHERE

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Currently, information transmitting is carried out using electromagnetic waves the radio and the optical range. One of the main disadvantages of information transmitting using radio waves is frequency spectral limitation. In turn, the transmitting in the optical range occurs at higher frequencies, and also has a high throughput and characterized by low attenuation, which allows to transfer more information over long distances.

Therefore, the aim of this work is developing of model of optimal radiation-resistant *p–i*-nphotodiode operating in the range of the third transparency window 1550 nm, where the smallest signal loss is observed.

For photodiode simulation was used the COMSOL Multiphysics package, in which the simulation paid attention to the response of the heterostructure to irradiation with a ionizing radiation high flux, which observing in the upper layers of the earth's atmosphere. By comparing semiconductor material characteristics based on the need for stability under conditions of ionizing radiation, the AlGaAs / GaAs / AlGaAs heterostructure was chosen as the material for the simulated *p–i–n* photodiode. GaAs is capable of absorbing photons with a wavelength of up to $1.7 > m$, has a high breakdown electric field strength, and therefore can operate at a higher power than other materials. The heterostructure allows reducing the thickness of the inner layer in order to increase the speed of the pin photodiode.

Several designs were considered: PIN – photodiodes with two integration into microwave MIS methods: growing *i*- and *p*(+) – regions using the high-doped *n*(+) – region of the microwave MIS, and integration into the microwave MIS with growing all three regions (*n*(+), *i*, *p*(+)). Conductivity was set to $0.1 > m$. Changes in thickness in the region from 0.2 to $0.4 > m$ were calculated depending on the electric current on the concentration of charge carriers.

D-9

TERAHERTZ LASER WITH OPTICAL PUMPING FOR PHOTO-ACOUSTIC SPECTROSCOPY APPLICATION IN MEDICINE

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Molecular THz laser with waveguide CO_2 laser pumping have been made due to the necessity of their application in medical science. Molecular laser with optical pumping is inexpensive, mobile and one of the most effective sources of THz radiation. THz spectroscopy is promising technique for medicine, that allows noninvasive diagnose many pulmonary diseases. The radiation sources used for creation system for diagnosis of human diseases utilizing method of photo-acoustic spectroscopy and other methods.

The THz laser with optical pump consists of two parts. First one is tunable rf-exited waveguide CO_2 laser, second part is THz resonator with active medium. Preliminary experiments shows the THz laser can operate on 10 radiation lines molecular CH_3OH with pulse power up to 100 mW.

The work was partially supported by the Russian Foundation for Basic Research, grant no. 19-32-60055.

D-10

TERAHERTZ SURFACE PLASMON RESONANCE GHOST IMAGING AND MICROSCOPY

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Surface plasmon resonance microscopy is one of the most sensitive optical label-free method of microscopy. Nevertheless, it does not have a sufficiently high lateral resolution in comparison with other methods of optical microscopy. This is due to the fact that surface plasmon polaritons excited by terahertz (THz) radiation propagate from their excitation spot to macro distances (about ~ 100 >), thereby blurring the observed region, by analogy with a scattering medium. To eliminate this disadvantage, we propose to adapt method known as ghost imaging, which is notable for its tolerance to environmental aberrations between object and camera. This report will consider the advantages of implementation the ghost imaging method to surface plasmon-polariton resonance microscopy in the THz range and presents an analysis of factors affecting the resolution of proposed method. The work was supported by the Russian Foundation for Basic Research, project no. 20-52-54004.

D-11

BROADBAND 1D-GRID-BASED TERAHERTZ POLARIZERS AND THEIR APPLICATIONS IN THz-TDS

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Broadband terahertz polarizers based on one-dimensional metal grids on carrying thin-film polymeric substrates of different thicknesses were manufactured by photolithography and investigated with terahertz time-domain spectroscopy (THz-TDS). Polarizers patterned on 4 μm polypropylene (PP) and 3 μm polyethyleneterephthalate (PET) films showed the best overall characteristics: maximum power transmission > 0.95 and minimum power transmission $< 1 \cdot 10^{-3}$ in the studied spectral range of 0.1–2 THz that corresponded to 1000 : 1 extinction ratio. It is worth noting that the extinction ratio of a structure based on two stacked 4 μm PP polarizers exceeded the dynamic range of THz-TDS. The developed polarizers were used to study polarization of generated terahertz radiation and polarization sensitivity for an electrooptic detection system of THz-TDS.

Poster
D-12

ELONGATION OF THz PULSES IN PLANAR WAVEGUIDES WITH 2D PHOTONIC CRYSTALS

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Nowadays, terahertz (THz) technologies consider like a powerful tool to create physical foundations of 6G networks. The possibility of transmitting information in a quasi-discrete spectrum formed as a result of interference between two broadband THz pulses have already been demonstrated. The coding of information can be carried out based on cutting out spectral lines by removing the corresponding peaks in the temporal structure.

To provide the interference of the THz pulse with itself, shifted by a time delay shorter than the pulse duration, and the subsequent formation of a sequence with a quasi-discrete spectrum, the use of pulses with frequency modulation is necessary. The most promising method here is to directly propagate a THz pulse through a waveguide with high dispersion. In this work, we consider the coupling of radiation into a planar waveguide as well as the optimizing of its geometric parameters and filling.

D-13

TERAHERTZ VECTOR VORTEX BEAMS FOR SURFACE PLASMON GENERATION

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Surface plasmon polaritons propagating along a cylindrical «conductor-dielectric» interface are very promising for THz communication systems. For their an effective generation the polarization state of the THz beam must match the surface geometry. A vector beam with an orbital angular momentum (OAM) with "donut-like" intensity distribution can be applied. The radius of the beam has to be maintained. Thus, it can be achieved by perfect vortex beams with uniform intensity distribution with different OAMs.

In this paper THz vector beams were realized in a Mach–Zehnder interferometer using the Novosibirsk free electron laser. By diffractive optical elements the input Gaussian beams were transformed into Hermite–Gaussian modes (1,0) and (0,1) and later combined and further transformed into a Bessel beam with topological charges $l = 1$ or $l = 2$. A perfect vortex vector beam was created in the Fourier plane of a lens and characterized by a pyroelectric camera.

The experimental investigations were supported by Russian Science Foundation, grant no. 19-72-20202. The work was done using the infrastructure of the Shared research facility "Siberian Synchrotron and Terahertz Radiation Center (SSTRC)" based on complex "NovoFEL" of BINP SB RAS.

D-14

SUBWAVELENGTH PHOTONIC HOOK GENERATED BY SHAPED FIBER TIP WITH ASYMMETRIC TERAHERTZ RADIATION

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We demonstrate that subwavelength photonic hook is obtained in the vicinity of a shaped fiber tip with asymmetric terahertz radiation. A 0.25 THz continuous-wave source, commonly used for medical imaging, has been required. Photonic hook with a lateral feature size close to half wavelength is achieved using a shaped fiber tip with metallic mask. This breakthrough is carried out in ambient air by using a 300-μm-diameter sapphire fiber m-diameter sapphire fiber with a shaped tip. A good correlation is observed between the computed intensity distribution of photonic hook and the tip sizes. Photonic hook generated with a shaped fiber tip, easier to manipulate, shows far-reaching benefits for potential applications such as super-resolution microscopy, photolithography, and material processing.

The work was supported by the Russian Foundation for Basic Research, project no. 20-57-S52001.

D-15

STUDY OF WAVELENGTH AND SUBWAVELENGTH GRATINGS FOR TERAHERTZ PLASMONIC

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In the terahertz plasmonic, it is widely used wavelength and subwavelength 1D grooved metal gratings for excitation, detection, and sensing of surface plasmon polaritons. Spoof plasmons modes that supported by the subwavelength gratings are very sensitive to their dielectric environment due to their nature. It enables using this mode in sensor applications. Surface plasmon polaritons (SPPs) are traveling charge density waves at the surface of conducting materials. Since these modes have a non-radiative nature, it is possible to excite them only if the configuration providing the wavevector-matching condition between the incident light and SPP dispersion law. The wavelength gratings are the most suitable and cheaper solution to satisfy this requirement. We investigated surface plasmon resonance sensing based on attenuated total internal reflection method coupling to the spoof surface plasmon polariton mode and grating-coupled surface plasmon resonance. The careful optimization of the most suitable experimental parameters by numerical simulations leads to the enhancement of surface plasmon resonance response. In this paper, experimental and numerical results are discussed.

The experiments were supported by the Russian Science Foundation, grant no. 18-72-00112. The modeling was supported by the Russian Science Foundation, grant no. 19-12-00103. The work was done using the infrastructure of the Shared research facility “Siberian Synchrotron and Terahertz Radiation center (SSTRC)” based on complex “NovoFEL”.

D-16

DEVELOPMENT OF A NEW GENERATION OF HIGHLY EFFICIENT TECHNOLOGICAL MEDIUM-POWER GYROTRONS BASED ON SHIELDED SOLENOIDS

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Due to the growing interest in a medium-level microwave radiation source with a radiation frequency of several tens of GHz, we developed a new generation of technological gyrotrons, the key features of which should be a high efficiency of the whole complex with an output radiation power of several tens of kW. To satisfy the future needs of consumers, a shielded magnetic system was created, which is not only several times more effective than the currently used warm solenoids, but also allows you to adapt the helical electron beam to interact with various cavity modes. An electron-optical system and a cavity have been developed for a technological gyrotron capable of operating in an extremely wide frequency range – up to W. The total system efficiency is about 35%, which is significantly superior to the existing analogs.

The work was financially supported by the RFBR, project no. 19-32-90102.

SESSION E
LARGE FACILITIES AND HIGH POWER EQUIPMENT

Invited reports

E-1

DEVELOPMENT OF HIGH FREQUENCY GYROTRONS AT FIR UF

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Research Center for Development of Far-Infrared Region, University of Fukui (FIR UF) had developed gyrotrons to aim at increasing their frequency till 2005. For this purpose, the Gyrotron FU series were developed. Fundamental, second and third harmonic oscillations were observed, and the breakthrough of 1 THz oscillation in gyrotron was achieved for the first time in the world. After that, gyrotrons have been developed for the purpose of applications. Among them, high frequency gyrotrons with various functions such as frequency tunability, multi-frequency Gaussian beam output and high-power output have been developed.

E-2

PERIODICAL PULSE GENERATION UNDER CYCLOTRON RESONANCE INTERACTION WITH AMPLIFYING AND ABSORBING ELECTRON BEAMS

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We present results of theoretical and experimental studies of periodical pulse generation under cyclotron resonance interaction of electromagnetic radiation with amplifying (rotating) and absorbing (rectilinear) electron beams. Under interaction with an initially rectilinear magnetized electron beam, the intense CW microwave radiation transforms into the periodical train of self-induced transparency solitons. In a gyrotron operating with high excess over the starting conditions, periodical formation of intense short electromagnetic pulses occurs due to self-synchronization of axial modes. The possibility of implementing considered mechanisms of pulsed generation in the sub-THz range is discussed.

The work is supported by the Russian Science Foundation, grant no. 19-72-10119.

E-3

OPTIMIZATION OF THz GENERATION IN TERAWATT LASER FILAMENT AT LOW PRESSURE GAS

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We study interaction of terawatt laser pulses with weak gas plasma during filamentation process. Such processes as THz and X-ray radiation generation, as well as boarding of fundamental and second harmonic visible spectra are experimentally studied. We optimize those processes by adjusting pulse chirp, energy and especially by decreasing gas pressure. High intensity (0.5 MV/cm peak electric field), short and broadband THz pulses are obtained in 20 mbar nitrogen atmosphere with 50 mJ, 40 fs, 800 + 400 nm negatively chirped laser pulses. Local intensity in the filament is additionally estimated by metal foil ablation time and accompanying X-ray generation efficiency.

E-4

GENERATION OF HIGH-POWER THz RADIATION IN PLASMA BY COLLIDING LASER WAKEFIELDS

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Results of theoretical and experimental studies on the original scheme of generating narrowband THz radiation by colliding plasma wakes excited in a supersonic gas jet by counterpropagating laser pulses are presented. Experiments are carried out in the Institute of Laser Physics SB RAS using the multiterawatt laser system capable of producing 180 + 20 mJ, 830 nm, 40 fs laser pulses. Full-scale particle-in-cell simulations show that focusing of these counterpropagating pulses into different-size spots inside the helium jet results in generation of 10 μm radiation with 30 MW maximal power and 40 μJ total energy.

The work is supported by RFBR, grant no. 20-32-70055.

Oral reports

E-5

NOVEL SCHEMES OF TRAPPING REGIME AIMED ON EFFICIENCY ENHANCEMENT IN FREE-ELECTRON DEVICES

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Novel schemes of a trapping regime in free-electron devices were studied. Proof-of-principle experiments on realization of “non-resonant” trapping were performed at Ka-band and high efficiency ultra-wideband free electron maser (FEM) amplifier has been realized. For short wavelength free-electron lasers (FELs) we describe two different ways of the use of regime of “multi-stage” trapping. First, this regime can be a way for efficiency enhancement of FELs operating in SASE regime. Second, multi-stage amplification of a single-frequency RF signal can lead to an effective cooling of the operating electron beam.

This work is partially supported by the Russian Foundation for Basic Research, grant nos. 18-02-40009 and 18-02-00765.

E-6

PROJECT OF POWERFUL LONG-PULSE BRAGG FEL OF SUB-THz TO THz-BAND: DESIGN, SIMULATIONS AND COMPONENTS TESTING

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Project of high-power long-pulse THz-band FEL is under development in collaboration between BINP and IAP RAS driven by the linac “LIU” 5–20 MeV / 2 kA / 200 ns of the new generation. The aim of this project is to achieve a record sub-GW power level and pulse energy content up to 10–100 J at THz frequencies. Advanced Bragg resonators based on coupling of propagating and quasi-cutoff waves were elaborated to provide stable narrow-band generation in the strongly oversized oscillator. The report presents design parameters, simulations and “cold” tests of the key components of the FEL.

This work is supported by the Russian Science Foundation, grant no. 19-12-00212.

E-7

SIMULATIONS OF TERAHERTZ WAVES GENERATION DUE TO THE FOCUSING OF ELECTRON BEAMS IN A PLASMA

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The interaction of electron beams with plasma is one of the most promising sources of powerful terahertz radiation emitted at harmonics of the plasma frequency. We consider counterpropagating kiloampere electron beams focusing into a spot of millimeter sizes in a plasma. To study such beam-plasma interaction, we use numerical simulation based on the PIC method in 2D3V axially symmetric geometry. In such a generating scheme, the power of THz radiation is shown to reach 1% of the total power injected with the beams.

This work was supported by the Russian Science Foundation, grant no. 19-71-00054.

E-8

PROPAGATION OF THE DISCHARGE IN NOBLE GASES SUSTAINED BY POWERFUL 0.67 THz GYROTRON

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This work presents the results of the studies of the self-ignited discharge propagation under the action of terahertz gyrotron radiation (40 kW @ 670 GHz). Measurements of propagation velocity were carried out in several ways: by snapshots from a camera with a high-speed shutter, by images from streak-camera. The dependence of the discharge propagation velocity in wide gas pressure ranges (0.1–2 atm) was investigated. It was shown that in all gases the discharge propagation velocity decreased with an increase in pressure value and was at the level of 10^5–10^7 cm/s depending on gas type.

E-9

POWERFUL CHERENKOV MASERS WITH 2D SLOW-WAVE STRUCTURES INTENDED FOR POWERING SYSTEMS OF COMPTON-TYPE FELS

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Conception of Compton FELs is under development in collaboration between IAP RAS and BINP RAS. For powering RF-undulators in Ka-band, sub-GW Cherenkov maser of cylindrical geometry is elaborated based on the Sinus-6 accelerator 0.5 MeV / 5 kA / 20 ns (IAP). Project of powerful W-band planar maser is initiated at the ELMI accelerator 1 MeV / 7 kA / 3 μs (BINP). To ensure high-coherence of the radiation in the strongly oversized oscillators, we exploit original idea of using 2D distributed feedback. Present paper is devoted to results of simulations and first experimental studies of these Cherenkov masers.

This work is partially supported by the Russian Foundation for Basic Research, grants nos. 18-02-40009 and 19-08-00550.

E-10

HYPERFINE MODE STRUCTURE OF THE TERAHERTZ NovoFEL IN THE HYBRID LONG-WAVELENGTH REGIME OF ITS OPTICAL RESONATOR

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The spectral range of the Novosibirsk free-electron laser (NovoFEL) was significantly expanded recently, especially in the long-wave side. In the report, experimental investigation of hyperfine mode structure of the NovoFEL in the hybrid long-wavelength regime of its optical resonator is presented. In the investigation, the ultra-high-resolution resonance Fabry–Perot interferometer was used in frequency and time-domain regimes.

E-11

CONTINUOUS ATMOSPHERIC PRESSURE DISCHARGES IN TERAHERTZ AND SUBTERAHERTZ FOCUSED BEAM

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The paper presents the results of recent experimental studies. The subject of research was the discharge of atmospheric pressure in a gas stream in focused beams of microwave radiation. The radiation sources were: a gyrotron with a radiation frequency of 263 GHz and a power of up to 1 kW, a free-electron laser with a radiation frequency of 2.3 GHz and with an average power of up to 400 W. The paper presents the results of measurements and calculations of breakdown fields, the results of measuring plasma parameters in these cases. Possible applications of these discharges are discussed.

E-12

USING REFLECTIONS FOR SUPPRESSING SPURIOUS MODES N A MULTIMODE GYROTRON

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For most of the modern gyrotrons operating on high-order transverse modes, mode competition phenomena play an important role. In recent years, possibility to control of gyrotron radiation by partial reflection of the output power from a remote load has attracted a considerable interest. In this paper, we discuss the possibility of suppressing the parasitic modes by using the delayed reflection. We consider a multi-mode gyrotron with nearly equidistant mode spectrum using the nonlinear theory with fixed profile of the RF field. We define the parameters of reflection providing stable single-mode operation with optimal efficiency.

This work is supported by Russian Science Foundation, grant no. 19-79-00307.

E-13

ELEMENTS OF SUBWAVELENGTH TERAHERTZ PHOTONICS

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Methods for fabrication silicon elements of terahertz photonics with subwavelength diffractive micro-relief are considered. The lithographical etching was used for fabrication subwavelength micro-relief at the surface of the silicon substrate. Fabricated elements were investigated by methods of computer simulation and natural experiments. Novosibirsk free electron laser (NOVOFEL) was used as a source of terahertz illuminating beam. It was shown experimentally that elements with subwavelength diffractive micro-relief allowing to form coherent terahertz beams with pre-given polarization state. Subwavelength structuring of silicon substrate surface opens a possibility of terahertz metamaterials fabrication. Perspectives of using such elements and metamaterials in terahertz information systems are considered.

This work was supported by the Russian Science Foundation, grant no. 19-72-20202.

E-14

AZIMUTHAL SCHMIDT MODES FOR STRONGLY NON-DEGENERATE PARAMETRIC DOWN-CONVERSION

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For a strongly non-degenerate parametric down-conversion, when the frequency of idler photons lies in the terahertz range, the angular width of phase matching is tens of degrees. In this case, the tensor character of the nonlinear crystal's susceptibility is important, and the parametric gain significantly depends on the scattering angles. In this work, we consider the decomposition of the biphoton field into the Schmidt azimuthal modes, taking this angular dependence into account. It is shown that the operator of nonlinear interaction of the angular modes of signal and idler radiation in the basis of the Fourier modes has a tri-diagonal matrix. The diagonalization of the scattering matrix obtained by solving the equations for field operators allows one to find Schmidt modes for any value of the parametric gain.

This work was supported by the RFBR, grant no. 20-02-00621A.

SESSION F
APPLICATIONS

Invited reports

F-1

THE POSSIBILITIES OF THz PULSE SPECTROSCOPY IN DIAGNOSIS OF GLIOMA MOLECULAR MARKERS

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We are focusing on gliomas molecular markers detection in brain tissue and the blood. Using the mice model of U87 human glioblastoma, we have shown the possibility of glioma development control by a combination of THz-TDS, Raman, and IR spectroscopy. 1H-Magnetic resonance spectroscopy is used as reference method for detection of glioma molecular markers at different stage of the tumor growth.

The work was supported by the RFBR and National Natural Science Foundation of China, research project no. 19-52-55004.

F-2

MEDICAL APPLICATIONS OF IR AND THZ LASER MOLECULAR IMAGING AND MACHINE LEARNING

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The focus of the report connected with content analysis of IR and THz laser molecular imaging data using Machine Learning methods. The analysis includes evaluation of hierarchy of informative features of initial data and classification. The examples of this approach to malignant tumor tissues classification and other applications will be presented.

The work was supported by the Russian Foundation for Basic Research, grant no. 17-00-00275 (17-00-00186).

F-3

OPTICAL CLEARING AND MACHINE LEARNING CONCEPTS FOR THz SPECTROSCOPY OF TISSUES

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The key problem of using machine learning for optical medical diagnostics is the presence of hidden relationships between a set of measured parameters and variations in a patient's status caused by pathologies. Compared to traditional approaches, these methods are more effective at analyzing multidimensional data. The main goal of this study is to discuss methods for extracting informative features from experimental data and creating prognostic models for medical diagnostics using machine learning methods and optical clearing of biological tissues (suppression

of scattering numerically and/or experimentally) to reduce the dimension of experimental data and, accordingly, increase the accuracy of the analysis.

The authors would like to acknowledge the support from RFBR, grant nos. 17-00-00272 and 17-00-00186 (17-00-00275).

F-4

MODELING OF BIOLOGICAL TISSUE INTERACTION WITH EM WAVE IN THz SPECTRAL RANGES: REAL OBJECTS AND PHANTOM EXPERIMENTS

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Terahertz study of tissues is difficult to carry out. Therefore we made phantoms of biological tissues from 1) agar and gelatin, 2) pellets, which was obtained after mixing a dried solution of polyethylene and drug-laden magnetic nanoparticles, and 3) thin pellets of dry human blood plasma from a diabetic and a control group and. Such samples are convenient to store, they are transportable, they practically do not absorb moisture, they have low absorption in the terahertz range and they can be conveniently fixed in a vertical holder in THz-TDS in transmission mode.

The reported study was funded by RFBR and CNRS, research project no. 18-51-16002, and by RFBR, project no. 17-00-00275 (17-00-00272).

F-5

THz SPECTROSCOPY AS A METHOD FOR DETECTING THYROID DISEASES

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For the first time, THz pulsed spectroscopy was used to study liquid and lyophilized blood plasma of healthy individuals and those with thyroid disease. It was shown that THz optical characteristics of the blood plasma of patients significantly differ from these characteristics in healthy people. The difference is due to a change in plasma composition during the development of the disease. The work was supported by the RFBR (project no. 17-00-00275 (17-00-00270) and 18-52-00040 (in data processing part)), by the Ministry of Science within the State assignment FSRC "Crystallography and Photonics" RAS in part of equipment.

F-6

OVERCOMING THE ABBE DIFFRACTION LIMIT IN TERAHERTZ MICROSCOPY OF SOFT BIOLOGICAL OBJECTS

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Dimensions of the structural elements of biological tissues (such as organelles, separate cells and their agglomerates, microfibrils) are usually small at the scale posed by the THz wavelengths [1, 2]. Such tissue elements could not be resolved using conventional modalities of THz imaging, which rely on the diffraction-limited lens- and mirror-based optical systems [3]. This pushes further developments into the realm of THz imaging of biological tissues with sub-wavelength spatial resolution.

In this talk, we review original developments in the area of high-resolution THz imaging of soft biological tissues, including:

– solid immersion microscopy with the resolution of 0.15λ [4–7];

– scanning-probe near-field microscopy based on a flexible sapphire fiber with the resolution of 0.25λ [8–10];
– imaging based on sapphire optical fiber bundles with the resolution of 0.3–0.55λ [11].

Finally, we compare these novel modalities of the THz imaging from the viewpoint of their spatial resolution and energy efficiency.

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F-7

REMOTE DIAGNOSTICS OF HUMAN PSYCHOEMOTIONAL STATES BY THE INFRARED–TERAHERTZ IMAGE

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One of the promising directions of development of contactless techniques for assessment of human psychoemotional states (PES) is the elucidation of the relationships between the psychophysiological indexes and electromagnetic radiation in IR and THz ranges. The purpose of this work is to develop a complex approach to diagnostics of PES by combining psychophysiological data with simultaneous registration of IR–THz images of a human face in stress situations.

The work was partially supported by the Russian Foundation for Basic Research, grant no. 17-29-02487, and partly by the Ministry of Science and Higher Education within the State assignment FSRC "Crystallography and Photonics" RAS.

Oral reports

F-8

THz AND IR MOLECULAR IMAGING OF DEPARAFFINIZED CANCEROUS TISSUES

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The gold standard in cancer validation is a histological analysis of a tissue biopsy. The promising method for diagnosing pathological tissue changes at oncological diseases is the combination of THz spectroscopy and multiphoton imaging and machine learning. THz spectroscopy provides distinguishing between dehydrated normal and cancerous tissues. Multiphoton microscopy has great potential for visualizing a morphological structure and chemical content of tissue samples. The aim of the report is a discussion of the ability of classification of deparaffinized cancerous tissue samples using THz and IR molecular imaging and machine learning.

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F-9

NON-CONTACT IR CONTROL OF THE PROCESS OF MICROWAVE HEATING OF DEEP FROSTBITE

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When warming a deep cold injury of a human limb in a microwave chamber, it is of interest to be able to control the temperature of a restored limb directly during an irradiation session. Despite the fact that only surface temperature is controlled, such measurements are very important because they eliminate the possibility of overheating. This opportunity can be realized by using an infrared receiver that receives thermal radiation from a heated limb. The ways to protect the IR receiver from direct heating by the microwave field of the camera are discussed.

F-10

THz SPECTROSCOPY OF SKIN PATHOLOGIES ASSOCIATED WITH WATER MIGRATION AND CONTENT

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Terahertz (THz) radiation is a non-ionizing and, therefore, non-invasive and attractive method, if repeated measurements are necessary to monitor the patient's condition and treatment. Since differences between healthy and pathological tissues exist at the morphological and molecular levels, they should manifest themselves in the spectra of THz radiation. The high water content in the tissues masks the spectra of chromophores important for the diagnosis. The aim of this study was to identify skin pathologies associated with water migration and content using THz spectroscopy using the method of immersion optical clearing.

The authors would like to acknowledge the support from RFBR grant no. 18-52-16025 (IYuY, VVN, VIK, and VVT), the National Research Tomsk State University Academic D.I. Mendeleev Fund Program (IYuY, VVN, VIK, VVT, and YuVK), Fundamental Research Program of the State Academies of Sciences for 2013-2020, line of research III.23.a (VVN, AIK).

F-11

MACHINE LEARNING METHODS FOR IN-VIVO ANALYSIS OF OOCYTES RAMAN MICRO-SPECTROSCOPY

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The paper presents an analysis of the Raman spectra of mouse preimplantation embryos using machine learning methods for visualization, assessing the separability of classes and highlighting informative areas of the spectrum.

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F-12

OPTICAL BIOPSY OF SKIN CANCER BASED ON RAMAN AND FLUORESCENCE SPECTROSCOPY

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Optical biopsy based on the Raman and fluorescence features of the skin tumors is proposed. The 1240 in vivo spectra were collected from 609 patients with skin tumors using the portable spectroscopic equipment with 785 nm excitation laser. The regression analysis of the spectral data allows one to classify the skin tumors based on the important spectral differences associated with contribute of the proteins, melanin, nucleic acid, lipids, phenylalanine etc. The result of the differentiating analysis was presented using sensitivity, specificity, accuracy. The proposed method leads to high (80–90%) accuracy that approves its high clinical potential to study skin tumors.

The work was partially supported by the Russian Foundation for Basic Research, grant no. 19-52-18001.

F-13

POSSIBILITIES FOR DECOMPOSING RAMAN SPECTRA OF AMINO ACIDS MIXTURE BY MULTIVARIATE CURVE RESOLUTION (MCR) ANALYSIS

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The paper is concerned with a decomposition of Raman spectra into spectra of pure components by multivariate curve resolution–alternating least squares (MCR-ALS) analysis. Raman spectra of prepared mixtures of amino acids are investigated. The possibility of using MCR-ALS analysis to determine the component composition of the mixtures is discussed. It is shown that one can evaluate the concentration of amino acids in the mixtures using the Raman spectra of the mixtures and the spectra of pure amino acids.

This study was supported by the RFBR, grant no. 19-52-18001 Bolg_a.a.

F-14

APPLICATIONS OF THz SPECTROSCOPY IN STUDY OF THE DRY PELLET OF BLOOD PLASMA

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This work is devoted to the study of a biological object using various diagnostic methods developed in THz laboratories. The biological object was presented in the form of pellets of human and laboratory rat blood plasma in the diabetic and control groups. These objects were analyzed in various laboratories using THz pulse spectroscopy and a THz high-resolution spectrometer based on a backward wave generator. The components of dry blood plasma were

identified by the detected spectral lines. Analysis of the THz spectra was carried out using the principal component analysis (PCA) to differentiate the spectral features between the diabetic and control groups.

The reported study was funded by RFBR, project no. 17-00-00275 (nos. 17-00-00270, 17-00-00272, 17-00-00184, and 17-00-00186) and by the Government of the Russian Federation, grant no. 08-08.

F-15

PULSE TERAHERTZ HOLOGRAPHIC RECONSTRUCTION OF OPTICAL PARAMETERS FOR BLOOD PLASMA PELLETS

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A blood plasma pellets of normal and pathological is proposed to perform predictive calculation and imaging measurements. The object is convenient for measurement, it is transportable, it transmits terahertz radiation well, its biochemical properties do not degrade over time, while it carries information about the glycated protein (diabetic case). We provided the numerical model of the blood plasma pellets using experimentally measured fields obtained by terahertz time-domain spectroscopy system in transmission mode. We also propose the approach of pulse hyper-spectral time-domain holography for diagnostics of such type of pellets in the terahertz frequency range. The essence of proposed method is a possibility to reconstruction the spatial distributed optical properties, as well as frequency-dependent characteristics.

The reported study was funded by RFBR-CNRS, research project no. 18-51-16002; RFBR, project no. 17-00-00275 (17-00-00272), and the Government of the Russian Federation, grant no. 08-08.

F-16

EFFECT OF TERAHERTZ RADIATION ON ALBUMIN RESPONSE TO OXIDATIVE STRESS

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Conformational transition in albumin under terahertz radiation was detected by us previously for bovine serum albumin. This transition affects albumin response to oxidative stress. The products and rate constants of the interaction of filmed albumin with ozone, a representative of biologically significant active oxygen species, were studied by means of EPR and high-performance liquid chromatography. Albumin irradiation within terahertz range was shown to cause changes in the mechanism of its interaction with ozone, which is evidenced by the formation of different products. Oxidative capacity of paramagnetic centers in albumin increases under irradiation. Biological consequences are assessed.

The work was supported by RFBR, project no. 17-00-00275 (17-00-00270).

F-17

MODELING OF ULTRA-SHARP LIGHT FOCUSING THROUGH TISSUE-LIKE SCATTERING MEDIUM UTILIZING SCALAR AND VECTOR MONTE CARLO METHODS

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Based on the unidirectional wave equation we introduce a new computational approach for simulation of ultra-sharp light focusing through a randomly inhomogeneous tissue-like scattering medium. The results obtained by this vector modeling approach are compared with the results of conventional scalar Monte Carlo method.

This work was partially supported by Russian Foundation for Basic Research and Administration of Tomsk region, grant nos. 19-42-703015 and 18-41-703004.

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F-18

MEASUREMENT AND ESTIMATION OF THE STRUCTURE OF LYMPHEDEMATOUS TISSUE ON ANIMALS MODEL

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Lymphedema is a chronic progressive disease of the lymphatic system that is associated with insufficient lymph circulation and subsequent accumulation of fluid, which leads to inflammation, hypertrophy of adipose tissue, and the spread of fibrosis. At the moment, there are no fully developed methods for early detection of this disease.

A model of lymphedema in laboratory animals was realized and analyzed with multiphoton microscopy (MPM). Computer vision methods were used to describe the textures of lymphedema tissue MPM images, then informative features of the fibrosis development were extracted. Besides, it were estimated the ratios of the autofluorescence lifetime to the second harmonic signal.

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F-19

TERAHERTZ DIELECTRIC SPECTROSCOPY OF INTERSTELLAR AND CIRCUMSTELLAR ICE ANALOGS

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Ices of various molecular composition (H_2O, CO, CO_2, CH_3OH, etc.) are one of the most common kinds of dense matter in the Universe [1]. A knowledge of the complex dielectric permittivity of these ices is the key to solve many relevant problems in astrophysics. It is required for study the radiative transfer in ice mantles of astrophysical dust particles and surface chemical processes, playing an important role in formation of new molecules in space [2, 3]. The collapsing of the dense molecular clouds to the young stellar objects (YSO) depends on its molecular composition and mass [4], and the dielectric properties can be used to estimate it (for example, for CO [3]). The presently available data on dielectric properties for laboratory analogs of the interstellar and circumstellar ices is still incomplete in the terahertz (THz) and far-infrared (FIR) ranges, meanwhile the observations are provided by the modern instruments like Hershel [5], SOFIA [6], ALMA. In this work, we have developed the experimental setup for the THz pulsed spectroscopy (TPS) and the algorithm for direct reconstruction of both real and imaginary parts of the dielectric permittivity for the interstellar and circumstellar ice analogs [7, 8]. TPS data were supplemented by equivalent measurements in the FIR by means of IR Fourier spectrometer. The pilot results of CO ice studies [7] agree well with Ref. [9]. The developed experimental setup and processing methods will be used for spectroscopy of ices with different molecular composition and porosity, obtained at different growth and annealing conditions. This work was partially supported by the Russian Foundation for Basic Research, grant nos. 18-32-00816 and 18-29-27010.

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F-20

STUDY OF WOUND HEALING BY TERAHERTZ SPECTROSCOPY

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Terahertz, is a non-invasive, and low energy imaging technique, has the potential to be another modality in wound healing and longitudinal scar assessment. There are several factors suggesting THz will be suitable for monitoring wound healing. Terahertz imaging is very sensitive to water and the bonds formed by water molecules. As a scar forms, the manner in which water is present in the wound changes. When a wound is fresh, the water is present in a mostly liquid form, the tissue saturated with plasma. As the wound heals, macromolecules of collagen form to seal the wound. This traps many of the water molecules that are present, and may alter the resulting THz signature of the scar tissue. The keen sensitivity of terahertz to the hydration level provides the possibility to detect the information relevant to the vasculature of the scar tissue based on the calculated absorption coefficient. The micrometer level wavelength of terahertz light which is comparable to the scale of collagen fibrils has the potential to provide the contrast of the different types of scars originated from their structural differences. This study evaluates the process of wound healing, based on in vivo terahertz reflection spectroscopy results.

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F-21

ALTERATION OF TRANSPORT FUNCTIONS OF ALBUMIN UNDER TERAHERTZ RADIATION: A MODELING STUDY OF THE INTERACTION WITH NITROGEN OXIDE

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Albumin interactions with biologically significant agents are key factors defining the transport functions of albumin in blood. Previous experimental studies revealed that irradiation within terahertz range causes changes in albumin binding with NO, important physiological regulator. To assess the mechanism of albumin binding with NO and its change under irradiation, modeling of this interaction was carried out within CS Chem 3D Pro software. Spatial hindrance for NO approach to reactive centers and chemical affinity were taken into account for a set of functional groups that are present in albumin. Groups responsible for terahertz-induced conformational transition in albumin were established. The work was supported by RFBR, project no. 17-00-00275 (17-00-00270).

F-22

INVESTIGATION OF NORMAL AND CANCER GASTRIC TISSUES BY TERAHERTZ AND INFRARED SPECTROSCOPIC METHODS

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Now, terahertz (THz) technologies have been actively studied and applied in various biomedical applications including cancer diagnosis. It is related with unique features of THz spectroscopy, such as high sensitivity to water and other polar molecules, the presence of resonant peaks of various biomolecules in the THz frequency range, harmless of THz radiation to biological tissues. In this work, we have investigated different types of gastric tissues using THz spectroscopy and infrared spectroscopy (IR) in order to compare the effectiveness of these methods. Analysis of the tissues using different optical methods allows one to obtain more complete information about them.

Poster

F-23

DOUBLE-STAND DNA FOCI FORMATION IN HUMAN SKIN FIBROBLASTS AFTER HIGH-POWER THZ PULSES EXPOSURE

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The use of intense THz sources may lead to major advances in understanding biological systems and help to resolve controversies over mechanisms of biological organization. In this study human skin fibroblasts were exposed by high-power THz pulses with a field strength of about 3 MV/cm for 30 and 90 minutes. The cells were fixed either immediately or the next day after exposure. The effect of high-power THz pulses resulted in the double-stand DNA foci formation in human skin fibroblasts, depending on the exposure time. The reported study was funded by RFBR, project no. 19-02-00762.

F-24

STUDY OF DIELECTRIC PROPERTIES OF BIOLOGICAL SAMPLES UNDER ITS MODIFICATION WITH REACTIVE OXYGEN SPECIES

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The aim of the work was a comprehensive assessment of the action of reactive oxygen species and nitric oxide on the scar tissue fragment ex-vivo in patients with Dupuytren's contracture. It was found that the treatment of scar tissue fragments by gas flow from singlet oxygen and nitric oxide generators leads to change dielectric properties of the tissue and the intensity of free radical processes. The peculiarity of the singlet oxygen action is a moderate increase permittivity. The NO effect at a concentration of 20 ppm is associated with a marked increase in permittivity and conductivity.

F-25

NEAR-FIELD MICROWAVE DIAGNOSTICS OF THE BURN WOUNDS

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The work is devoted to experimental research of the method of near-field microwave diagnostics of burn wounds. To measure the electrodynamic properties an impedance model of the measurement system is developed. This method has been tested and calibrated in controlled condition by measurements of two-layered medium (spirit-teflon). The complex dielectric permittivity of skin tissues with thermal injury was measured using the constructed sensors with sounding depth 3 and 5 mm. It is experimentally established the permittivity of the burn wound is less than intact skin. The dependence of the electrodynamics parameters on the burn's depth was established, which can be used for express analysis degree of thermal wound.

F-26

CLASSIFICATION OF THE IR SPECTRA OF EXHALED AIR USING THE VOTING METHOD

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Non-invasive diagnosis of diseases using analysis of exhaled air is actively developing in medical practice. The aim of work is to compare specifics groups of patients with pulmonary diseases. As features of the participants' state, absorption spectra of exhaled air samples were used. The analyzed spectrum is a bar chart which describes the dependence of the absorption coefficient on the wavelength. The problem to be solved is the choice of informative sub-

ranges of spectra to improve the classification of the studied groups and the subsequent classification of several spectra for one person by voting methods. An integrated approach was used to solve this problem using the principal component analysis, support vector machine with RBF core and the subsequent voting technique. The work was performed under the government statement of work for ISPMS Project no. III.23.2.10. The work was carried out under partial financial support of the Russian Foundation for Basic Research, grant no. 17-00-00186.

F-27

COMPARISON OF TYPES OF NEURAL NETWORKS IN THE SOLUTION OF THE PROBLEM OF SPECTRAL SUPER-RESOLUTION

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When solving the problem of component analysis, an important role that affects the quality of the result is played by spectral resolution. The most useful and perspective methods to improve spectral resolution is decreasing of impulse response function (IRF) and improving resolution using artificial intelligence and super-resolution (SR) methods. Popular methods of deconvolution are inverse Fourier convolution, digital filters and spline-approximation. Other methods use neural networks to improve spectral resolution called as SR. In this article described mechanisms of SR methods, common technologies and practices. For improving spectral resolution proposed using of different types of neural network (convolution neural network, generative advertisement neural network) trained on two collections of generated spectra. Idea is to generate from spectra with high resolution other spectra, to which IRF and some random noise will be added. Spectra with high resolution will be as output data for training. In this case, bad spectra and high-resolution spectra will be like image with low resolution and image with high resolution and best practices of superresolution methods can be used. Research part of work contains comparison of different types and architectures of neural networks to solve the problem of improving spectral resolution. The work was carried out under partial financial support of the Russian Foundation for Basic Research, grant no. 17-00-00186. The work was performed under the government statement of work for ISPMS Project no. III.23.2.10.

F-28

MODELING OF OPTICAL COHERENT TOMOGRAPHY IN THERAHZ RANGE FOR INHOMOGENEOUS MEDIA WITH SHARP BORDERS OF COMPLEX FORM ON AN EXAMPLE OF A TOOTH MODEL

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The paper proposes a methodology for modeling images obtained as a result of optical tomography technology in the terahertz range. This technique is based on a direct solution of the equations of stochastic Maxwell equations by the finite element method using parallel algorithms and statistical processing. Numerical results are obtained on the example of the formation of OCT imaging for a tooth model.

This work was partially supported by the Russian Foundation of Basic Research, grant no. 17-00-00186, the Russian Foundation of Basic Research and the Administration of the Tomsk Region, grant nos. 19-42-703015 and 18-41-703004. This work was performed under the government statement of work for ISPMS Project no. III.23.2.10.

F-29

RESEARCH OF A LYMPHEDEMATOUS TISSUE MODEL BY OPTICAL COHERENT ELASTOGRAPHY

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Early diagnosis of lymphedema using optical coherence elastography (OCE) demonstrates great potential for use. In this work, we studied the changes in the stiffness modulus on the models of lymphedematous tissue by the method of OCE. In the course of the research, data on the dependence of the mass modulus on a sample of biological tissue

were obtained and analyzed. The work was performed under the government statement of work for ISPMS Project no. III.23.2.10. The work was carried out under partial financial support of the Russian Foundation of Basic Research, grant nos. 17-00-00186 and 18-42-703012.

F-30

THE DIFFERENCE IN TERAHERTZ DIELECTRIC PROPERTIES OF DNA SOLUTIONS IN WATER AND ETHANOL

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The dielectric properties of calf thymus DNA solutions in water and ethanol were investigated by means of terahertz time-domain spectroscopy in the range of 0.1–1 THz. Complex dielectric permittivity of solutions was fitted by two-component relaxation Debye model with an overdamped oscillator and their parameters were estimated. The difference between the properties of the distilled water and all aqueous solutions is the most pronounced, while the ethanol-water mixture with and without DNA shows minimal changes of about 2%, which is comparable with the experimental accuracy.

The work was partially supported by the Russian Foundation for Basic Research, grant no. 17-00-00275.

F-31

BRIEF HISTORY OF TERAHERTZ PHOTONICS AND PLASMONICS AT TOMSK POLYTECHNIC UNIVERSITY

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To develop new ideas, scientists are reaching out to their colleagues around the world – academic research is becoming ever more international in science, technology and innovation. Ideas transcend borders, no country controls the marketplace of scientific ideas. New ideas come when you interact with scientists from diverse Universities and Institutes. Constructive interference increases power above sum of individual powers. In a brief review, we share the experience of scientific international cooperation with various research groups in the field of terahertz mesoscale photonics, plasmonics and acoustics, carried out under the guidance of professors of Tomsk Polytechnic University I.V. Minin and O.V. Minin.

This study was partially supported by Russian Foundation for Basic Research, project no. 20-57-S52001.

SESSION G
ASTRONOMY, ASTROPHYSICS AND ATMOSPHERIC SCIENCE

Invited reports

G-1

DEVELOPMENT OF SIS RECEIVERS FOR RADIO ASTRONOMY FOR SPACE PROJECT MILLIMETRON AND FOR GROUND-BASED OBSERVATIONS

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Here we present our recent results in development of heterodyne THz receivers based on Superconductor-insulator-superconductor (SIS) mixers. Currently we are focused on receivers for frequency ranges 211–275 GHz (1.3 mm) and 800–950 GHz (0.3 mm), which are demonstrating dual-sideband mixer noise temperature of about 25 K and 220 K correspondingly. These receivers are planned to be used for radio astronomy as spaceborne instruments and in ground-based telescopes.

The work was supported by the Russian Foundation for Basic Research, grant no. 19-52-80023.

G-2

JET SPECTROSCOPY AND MOLECULAR DYNAMICS OF WEAKLY BOUND COMPLEXES OF ASTROPHYSICAL INTEREST

L.A. Surin

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High resolution infrared (IR) and terahertz (THz) spectroscopy of weakly bound molecular complexes allow detailed study of the intermolecular forces, which are responsible for many phenomena in science, especially in astrophysics and atmospheric physics. Within the large number of weakly bound complexes, which have been studied spectroscopically, those containing the ammonia (NH_3) molecule are particularly important. The inversion-tunneling splitting in NH_3 is extremely sensitive to intermolecular interactions and is thus a valuable probe of asymmetry in the potential energy surface (PES) along the inversion coordinate. The investigation of the effects of the van der Waals interaction on the NH_3 inversion tunneling gives opportunity to study the coupling of inter- and intramolecular dynamics.

In the present work the new microwave, millimeter- and submillimeter-wave observations of the NH_3–H_2, NH_3–N_2, NH_3–He, NH_3–Ne van der Waals complexes in a supersonic jet will be discussed. These systems are of particular interest, because ammonia is the most commonly used tracer of the temperature in a variety of interstellar environments and the most important alkaline gas of many atmospheres of our solar system and extrasolar planetary systems. The rotational excitation and de-excitation of the NH_3 molecules in collisions with the dominant colliding partners in the molecular regions of interstellar media and planetary atmospheres are of crucial importance for the observed ammonia population distributions and the interpretation of its spectra.

This work was supported by the Russian Science Foundation, grant no. 17-12-01395, and the Russian Foundation for Basic Research, grant no. 19-03-00998.

Oral reports

G-3

APPLICATION OF IR-THz ROVIBRATIONAL SPECTROSCOPY AND ARTIFICIAL INTELLIGENCE FOR TRACE GAS ANALYSIS OF ATMOSPHERIC COMPOUNDS

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The most of gas phase small and medium-sized, stable and unstable, atmospheric compounds may be monitored by probing their rotational or rovibrational transitions in the THz and IR spectral domains, respectively. Using optical/laser, optoelectronic/electronic sources, high-resolution absorption spectroscopies may be performed in this domain as a powerful tool to analyze complex mixtures of trace gas compounds. That requires the capacity to assign very congested spectra and to extract a huge quantity of information. Often, practical tasks of atmosphere monitoring are associated with control of essential number of molecular components. It complicates solving of inverse spectroscopic problem (ISP) by traditional methods such as line by line assignment. In this presentation, we first present the complexity of gas phase spectra of atmospheric compounds measured in the IR and the THz by TSU and ULCO groups. Next, we suppose using combination of Deep learning networks and Spectral taxonomy to tackle ISP for multicomponent analysis of molecular atmosphere.

The work was partially supported by the Russian Foundation for Basic Research, grant no. 17-00-00275 (17-00-00186).

G-4

MILLIMETER-WAVE ASTROCLIMATE STUDIES IN THE NORTH CAUCASUS: EXPEDITION AND FIRST RESULTS

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[3]Special Astrophysical Observatory RAS, N. Arkhyz, Russia

We are presenting the first results of astroclimatic studies on North Caucasus started in February 2020 in the expedition. The main goal of the studies is comparison of millimeter-wave optical depth characteristics of four sites of the North Caucasus: BTA-6, RATAN-600, CMO of GAISh, and the Terskol Observatory. The optical depth was collected by atmospheric dip method in 3 mm and 2 mm atmospheric windows. The comparison of astroclimate conditions is presented in terms of the statistical data on these four sites. The astroclimatic analysis is a prerequisite for selecting a site for radio astronomical observations in the millimeter bandwidth.

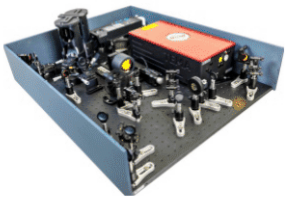
The expedition on astroclimate research was provided with financial support of RSF, project no. 19-19-00499, the data processing was made under the scientific program of the Scholarship issued by RF President under Project СП-5103.2018.3, and the data processing methodic was developed under the IAP RAS state program (Project no. 0035-2019-0005).

Author's index

TYDEX

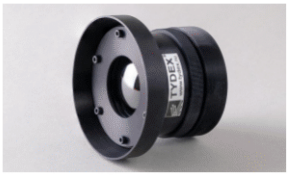
THz DEVICES AND ASSEMBLIES

PULSED TERAHERTZ SPECTROMETR PTS-1 is an instrument for THz time-domain spectroscopy. PTS-1 utilizes optical rectification of femtosecond pulses to generate THz radiation. PTS-1 uses MgO:$LiNbO_3$ crystal as a source of THz radiation. The generated pulses propagate through free space and are registered by an Electro-Optical Detector (EOD).
Key features: spectral range: 0.1÷2.5 THz; dynamic range: ≥60 dB; average output power (THz radiation): ≥ 200μW; spectral resolution: 5 GHz

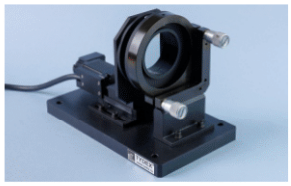


ELECTRO-OPTICAL DETECTOR (EOD) is intended for the pulsed THz radiation registration. It is characterized by availability of integrated optics or built-in lock-in amplifier.
Key features: signal wavelength: EOD-NIR - 600÷1100 nm / EOD-MIR - 1100÷1700 nm; EO optical crystal: EOD-NIR - ZnTe / EOD-MIR - CdTe; modulation frequency: 0.015÷250 kHz

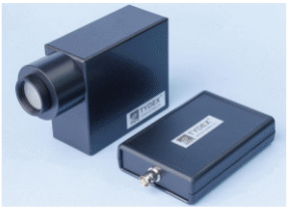
THz OBJECTIVE LENSES are necessary to acquire high-quality images. Two types of objective lenses are produced for use with a matrix of uncooled micro bolometers with a diagonal 10.4 mm and 4:3 aspect ratio.
Key features: operating range: 50÷8000 μm (0.04-6 THz); focal distance: 44 mm; distance to object / f-number: 0.95 / ≥90 cm, 0.7 / ≥60 cm



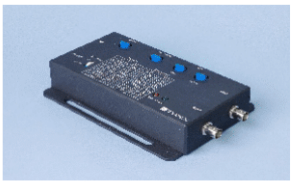
THz SCANNING FABRY-PEROT INTERFEROMETER (TSFPI) is intended for measuring wavelength and intensity of narrowband THz radiation. TSFPI may be used with pulsed or continuous sources.
Key features: operating range: 0.1÷15 THz; free spectral range: 0.1÷1.8 THz; free aperture: 52 mm; spacing setting accuracy: ±1.25 μm



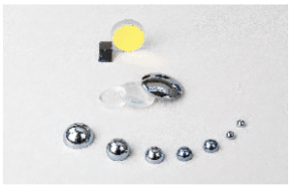
GOLAY DETECTOR is one of the most efficient detecting devices. It has excellent sensitivity at room temperature and flat optical response. The application is monitoring and control of THz radiation. Detectors are individually calibrated for THz radiation power measuring.
Key features: wide operating wavelength range: 0.4÷8000 μm; noise-equivalent power @ 20 Hz: $(0.8\div1.4)\times10^{-10}$ W/$Hz^{1/2}$; optical responsively @ 20 Hz: $(1\div1.5)\times10^{5}$ V/W; modulation frequency: 15±5 Hz



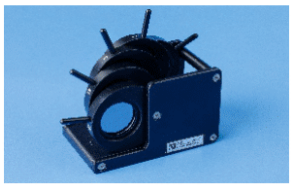
LOCK-IN AMPLIFIER SU-1 is designed to amplify weak signal in high-noise environment. All operating parameters (amplification, time constant and phase) are manually adjustable. Also SU-1 is used to measure phase shift of the signal.
Key features: frequency range: 0.01÷250 kHz; maximum input voltage: ±15 V; maximum dynamic reserve: 50 dB; time constants range: 0.003÷10 s



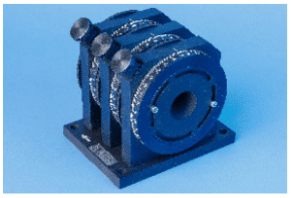
THz OPTICS: Fabry-Perot etalon, polarizers, windows, lenses, prisms, mirrors, waveplates, spectral splitters, beam splitters



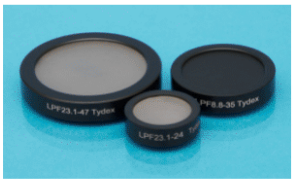
THz ATTENUATOR - a set of THz attenuators is used to reduce the output power of high-intensity THz radiation sources to levels safe for other sensitive equipment.
Key features: operating wavelength range: 40÷8000μm; attenuator plates transmission grades: 30%, 10%, 3%, 1%; transmission tolerance of attenuator plates: +/- 10% of nominal value; apertures: 25.4 mm, 50.8 mm



THz POLARIZATION CONVERTER is an alternative to the set of monochromatic waveplates for a certain wavelength range. The converter changes polarization direction of linear polarized radiation of fixed wavelength within a specified range. The same part converts linear polarization of fixed wavelength radiation within another range to circular one and vice versa.
Key features: operating modes: λ/2 plate within 80÷160 μm, λ/4 plate within 150÷300 μm, 120 μm birefringent filter; aperture: 24 mm; custom design: possible



THz LOW PASS FILTERS (LPF) are meant to transmit THz radiation and block short wavelengths.
Key features: cutoff frequency: 23.4 THz, 23.3 THz, 23.1 THz, 14.3 THz, 10.9 THz, 8.8 THz, 5.5 THz, 4.3 THz, 4.0 THz, 3.2 THz; max transmittance in pass band: 73÷95% depending on cutoff frequency; transmittance in stop band: <0.1%; apertures: 25 mm, 35 mm, 47 mm



THz BAND PASS FILTERS (BPF) are meant to transmit the radiation in a specified pass band.
Key features: any pass band in the range 0.1÷15 THz (20÷3000 μm); transmittance in pass band: 60÷90% depending on the band; transmittance in stop bands: <4% (≈0.1% for double BPF); damage threshold: 65÷100 W/cm^2; apertures: 25 mm, 35 mm, 47 mm

THz BROAD BAND PHASE TRANSFORMERS are used when it is necessary to have nearly constant retardation at the specified wavelength range.
Key features: types: λ/4 and λ/2 achromatic waveplates, λ/4 achromatic polarization converter; frequently used option: λ/4 polarization converter for 60÷300 μm; aperture: 25 mm; custom design: possible

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Ranked 212th

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51 laureates of the State Prize of the Russian Federation

3 research institutes

33 leading scientific schools

V.E. Zuev Institute of Atmospheric Optics of Siberian Branch of the Russian Academy of Sciences

1969–2019

V.E. Zuev Institute of Atmospheric Optics SB RAS, the first academic institute in Tomsk, was founded in 1969 from the Laboratory of Infrared Radiation of the Siberian Physical-Technical Institute of the Tomsk State University. Under the leadership of its founder, Hero of Socialist Labor, Laureate of the USSR State Prize and the USSR Council of Ministers Prize, Academician Vladimir Zuev (1925–2003), the Institute was formed into the world's largest institution leading research in atmospheric optics. The Institute was a parent for research fields, which formed a basis for the Institute of Monitoring of Climatic and Ecological Systems SB RAS in 1971, Institute of High-Current Electronics SB RAS in 1977 and the Institute of Strength Physics and Materials Science SB RAS in 1984.

The Institute carries out fundamental and applied investigations, creates instruments and develops technologies in the main scientific areas:

- Fundamental problems of optics and laser physics, including atmospheric optics and spectroscopy, propagation of optical radiation in the atmosphere, study of processes determining the optical state of the atmosphere, optoelectronic systems and technologies for environmental studies.
- Physical and chemical processes in the atmosphere and on the Earth's surface, mechanisms of formation and climate change, including optically significant components of the atmosphere and processes determining the radiative regime and climate of the Earth.

Several unique world-level research stations have been created and are functioning at the Institute. The Siberian lidar station and the Tu-134 "Optic" aircraft laboratory are registered by the Ministry of Science and Higher Education of the Russian Federation as unique scientific installations. The staff of the Institute carry out research on the basis of three observatories, annually participate in complex expeditions to various regions of the world, collaborate with colleagues from research organizations and universities in Russia and the world. The Institute combines the work of optimally placed monitoring stations with the organization of large-scale complex experiments to measure the main climatically significant parameters of the atmosphere. Mobile laboratories based on land, ship, water and air vehicles are actively operating. The unique multi-level system for monitoring greenhouse gases created by the Institute meets the requirements of the World Meteorological Organization for measurement accuracy.

The Institute publishes the scientific journal of the Russian Academy of Sciences "Atmospheric and Oceanic Optics" in Russian and coordinates publishing the English version of the journal by Springer. The Institute trains highly qualified specialists in the field of atmospheric physics and optics in postgraduate studies, the Doctoral Dissertation Council is actively functioning.

The Institute is assigned to the First category of organizations performing research, development and technological work in the profile "Generation of knowledge" in the reference group "Physics of the ocean and atmosphere, geophysics" from 2018. The Institute is awarded the status of the leading organization of the academic sector in the field of atmospheric optical research from 2019.