Department of Mechanical Engineering

at Ben Gurion University of the Negev

and Israel Plasma Science and Technology Association

The 18th Israeli Conference on Plasma Science and its Applications

Book of Abstracts

Wednesday, March 2, 2016

Ben Gurion University of the Negev

Beer-Sheva, Israel

The 18th Israeli Conference on Plasma Science and its Applications

2/3/2016, Ben Gurion University of the Negev, Beer-Sheva

<u>The organizing committee:</u>

Prof. Michael Mond – Ben-Gurion University, chairman

Dr. Uri Keshet – Ben-Gurion University

Dr. Joseph Ashkenazy – Nuclear Research Center - Soreq

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The conference is sponsored by Ben-Gurion University of the Negev

Scientific Program

9:15 **Registration**

9:45 **Opening Remarks**

Morning Session 1, 10:00-11:40

10:00	***Invited:*** F. Skiff	Experiments on the kinetic degrees of freedom of electrons and ions
10:40	G. Shafir, M. Siman Tov, D. Zolotukhin, A. Shlapakovski, Yu. Bliokh, V. Godyak, V. Rostov, A. Fisher, R. Gad, J. Leopold, Y. Hadas and Ya. E. Krasik	Advancement in wakefield formation in plasma by a high power microwave pulse
11:00	H. R. Strauss	JET disruption simulations
11:20	A. Yahalom	Simplified Lagrangian and Hamiltonian of non-barotropic MHD

11:40 **Coffee Break**

Morning Session 2, 12:15-13:35

12:15	M. Gedalin	Collisionless relaxation in the shock front
12:35	L. Ofman	Turbulence, instabilities, and heating of the solar wind plasma
12:55	N. K. Dwivedi, P. Kovacs and M. Mond	Magnetic field turbulence spectra and associated power law of the Venusian magnetosheath
13:15	U. Keshet	Magnetization and particle acceleration in collisionless astronomical shocks

13:35 **Poster Session and lunch**

Afternoon Session 1, 14:45-16:25

14:45	***Invited:*** S. Eliezer	Novel physics with relativistic shock waves in the laboratory
15:25	D. Mikitchuk, M. Cvejic, E. Kroupp, R. Doron, C. Stollberg, Y. Maron, H. R. Strauss, A. L. Velikovich, J. L. Giuliani	Magnetic field evolution in Z-pinch implosion with preembedded axial magnetic field
15:45	A. Gover and R. Ianconescu	Fundamental processes of radiation emission from bunched electron Beam
16:05	A. Fruchtman and G. Makrinich	Helicon plasma thruster – an opportunity and a challenge
16:25	**Coffee Break**	

Afternoon Session 2, 16:50-18:30

16:50	E. Jerby and Y. Meir	Microwave ignition of thermite reactions and dusty plasmas
17:10	N. Balal, V.L. Bratman, Yu. Lurie, and A.V. Savilov	Negative mass instability in sources of coherent spontaneous undulator radiation
17:30	Impedans ltd.	Measuring plasma parameters in electrical discharges using rf current and voltage measurements
17:50	D. B. Zolotukhin, V. A. Burdovitsin and E. M. Oks	Plasma generated by continuous electron beam injected inside the dielectric flask
18:10	A. Shlapakovski, S. Gorev, and Ya. E. Krasik	Influence of laser beam parameters on output pulses of a high-power microwave compressor with a laser-triggered plasma switch
18:30	**Concluding Remarks**	

POSTERS

1.	A. Meirovich, N. Parkansky, R. L. Boxman, O. Berkh	Possibility of submerged pulse arc treatment of wastewater with organic contaminates in multi-electrode reactor
2.	D. Lev, G. Alon, A.Warshavsky and L. Appel	Low current heaterless hollow cathode R&D at Rafael
3.	G. Makrinich and A. Fruchtman	Electric force and ambient gas pressure
4.	G. Shafir, D. Zolotukhin, A. Shlapakovski, V. Godyak, A. Fisher, R. Gad, and Ya. E. Krasik	A large-scale uniform plasma system for microwave wakefield experiments
5.	G. Shafir, M. Siman Tov, D. Zolotukhin, A. Shlapakovski, Yu. Bliokh, V. Rostov, A. Fisher, R. Gad, J. Leopold, Y. Hadas and Ya. E. Krasik	A high power, short pulse, microwave source for wakefield experiment
6.	H. Marks, A. Gover, D. Borodin, Y. Lurie	Saturation Dynamics, Output Power Optimisation, and Chirp Control in a CW FEL Oscillator
7.	I.I. Beilis, Y. Koulik and R.L. Boxman	Anode temperature evolution in a vacuum arc with a black body electrode configuration
8.	J. G. Leopold, A. S. Shlapakovski, A. Sayapin and Y. E. Krasik	The A6 relativistic magnetron revisited
9.	L. Bareket, L. Inzelberg, M. David-Pur, D. Rand, D. Rabinovich , and Y. Hanein	Electronic tattoos with a plasma polymerized coating for human-machine interface and biopotential monitoring
10.	M. Siman Tov	Explosive emission cathodes as a source for hollow high-current electron beam, applied for microwaves generation in a backward wave oscillation

11.	R. Ben Moshe, V. Bratman and M. Einat	Design of a fourth-harmonic large-orbit gyrotron
12.	S. Biswas, R. Doron, V. Bernshtam, Y. Maron, M. D. Johnston, M. L. Kiefer, M. E. Cuneo	Determination of the plasma composition using blended Stark-Broadened emission lines in a self- magnetic pinch diode
13.	T. Queller, E. Kroupp, D. Naimark, A. Fisher and Y. Maron	Determination of the initial 2D gas density distribution used for plasma implosion experiments by both interferometry and Laser Induced Fluorescence (LIF) measurements

ABSTRACTS

Experiments on the Kinetic Degrees of Freedom of Electrons and Ions

Fred Skiff

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Plasmas differ from conducting fluids in that they potentially have a much greater number of electro-mechanical degrees of freedom. Even plasmas with a moderate level of particle collisions can have "tail" particles that exhibit dynamics very different from the "bulk". Two experimental systems will be presented as examples. Firstly, I will present measurements of the acceleration of suprathermal electrons by Alfven waves in an Auroral simulation experiment. Secondly the nonlinear interactions of ion kinetic degrees of freedom in a gas discharge are observed using laser-induced fluorescence. In both cases, observing the richness of plasma dynamics is shown to require particle-velocity resolving diagnostics.

Advancement in Wakefield Formation in Plasma by a High Power Microwave Pulse

G. Shafir[1], M. Siman Tov[1], D. Zolotukhin[1,2], A. Shlapakovski[1], Yu. Bliokh[1], V. Godyak[3], V. Rostov[4], A. Fisher[1], R. Gad[5], J. Leopold[1], Y. Hadas[6] and Ya. E. Krasik[1]

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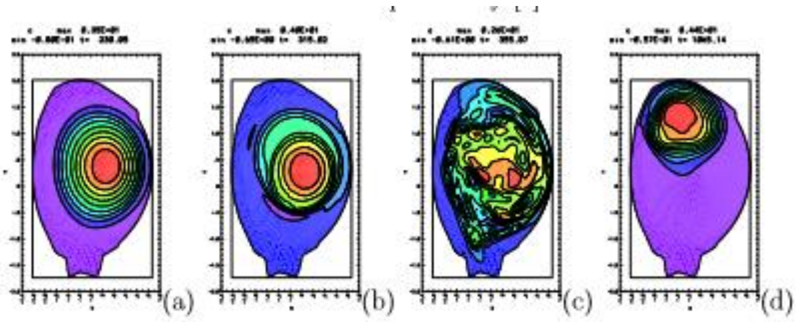
We present the present status of experimental research of plasma waves, driven by a short pulse (1 ns), high power (>100 MW) microwave beam. In the proposed experiment, the microwave beam will be focused inside an 80 cm long, 25 cm diameter, plasma chamber. The goal of this research is to investigate the effect of the ponderomotive force effects in the plasma, exerted by the electromagnetic wave non-linear interaction on the plasma electrons. In order to achieve this goal, we developed both the microwave source, based on high-current relativistic electron beam interaction with a backward wave oscillator operating in super-radiance mode. Also, a large-scale uniform plasma with controlling plasma electron density, based on a RF discharge generated by a quadruple antenna was developed. The results of the generation of focused high power microwave beam and the generation of uniform, under-densed plasma, investigated by different diagnostic techniques, will be presented.

JET Disruption Simulations

H. R. Strauss

HRS Fusion

The ITER tokamak is expected to experience disruptions, which are violent MHD instabilities, which can cause damage to the structures containing the plasma. The largest existing tokamak, JET, is the main source of information about the possible effects of disruptions [1, 2]. JET measurements indicate large forces will be generated on conducting structures surrounding the plasma. In ITER these forces will be scaled up by a factor of 20. It is important to be able to perform computer simulations of disruption events in JET and compare to ITER. Recently JET disruption simulations have been carried out initialized with JET data files. It was found that certain JET disruptions were caused by internal kink instability, unlike in previous ITER simulations [3, 4]. The kink instability grows on a rapid time scale and produces a thermal quench. It is followed by a vertical instability, which grows on the much longer timescale of the resistive penetration of magnetic field through the wall surrounding the plasma. During the vertical instability, large toroidally asymmetric forces occur. The plasma approaches a kinked toroidally rotating steady state. The rotation rate in the simulations is consistent with the experimental data. The toroidal flux is found to vary toroidally. The latter effect [2] was not understood, but is now shown to be related to the toroidal variation of the toroidal current discussed previously [4].



The figure shows contours of current density in a plane of constant toroidal angle at different times during the disruption: (a) initial state, (b) internal kink instability, (c) turbulence which causes a rapid loss of thermal energy, (d) vertical instability with stationary perturbations.

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Simplified Lagrangian and Hamiltonian of Non-Barotropic MHD

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Variational principles for magnetohydrodynamics (MHD) were introduced by previous authors both in Lagrangian and Eulerian form. Yahalom & Lynden-Bell [1] have introduced a simpler Eulerian variational principle for barotropic MHD from which all the relevant equations of magnetohydrodynamics can be derived. The variational principle was given in terms of six independent functions for non-stationary flows and three independent functions for stationary flows. This is less than the seven variables which appear in the standard equations of MHD which are the magnetic field $\vec{B}$ the velocity field $\vec{v}$ and the density ρ. Later Yahalom [2] has shown that four functions will suffice.

The case of non-barotropic MHD was not discussed in those earlier works and it is thus interesting to study whether a simplified variational principle can be given in this case as well. In particular it is important to understand the role of entropy and temperature for the variational analysis of MHD. We introduce a simplified Lagrangian and Hamiltonian for non-barotropic MHD and show that five functions will suffice to describe this physical system.in the case of a Lagrangian presentation [3].

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Collisionless Relaxation in the Shock Front

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The magnetic field profile of a collisionless shock is shaped mainly by ions. Upon crossing the shock ions begin to gyrate and form a non-gyrotropic distribution. The ion pressure tensor oscillates with the distance from the ramp. These oscillations damp due to collisionless gyrophase mixing. The latter is sensitive to the basic shock parameters. Chances to observe this relaxation are higher for shocks with lower upstream ion temperature.

Turbulence, Instabilities, and Heating of the Solar Wind Plasma

L. Ofman

CUA/NASA GSFC, Visiting TAU

The solar wind is a continuous and variable stream of magnetized plasma from the Sun flowing at 400-1000 km/s near Earths' orbit, shaping the heliospheric environment and affecting the Earth's magnetosphere. The existence of the solar wind was predicted theoretically and later discovered in spacecraft measurements. However, some key aspects of the physics of the solar wind sources, heating, and acceleration are still debated and intensively studied using spacecraft observations and numerical models. The task is complicated by the facts that the solar wind plasma is usually non-Maxwellian, and contains evidence of kinetic instabilities. The magnetic and velocity fluctuations show evidence of Alfven and ion-cyclotron waves, typically exhibiting turbulent power-law scalings with dissipation breaks. I will discuss the likely processes that lead to the solar wind plasma heating, and review recent progress in the modeling of the solar wind plasma turbulence. I will discuss the relation of the numerical modeling results to recent satellite observations.

Magnetic Field Turbulence Spectra and Associated Power Law of the Venusian Magnetosheath

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3. Department of Mechanical Engineering, Ben Gurion University of the Negev, Israel

Based on the Venus Express spacecraft observations in the magnetosheath under the solar minimum condition (778 Venus' magnetosheath crossings), we perform a statistical study on the magnetosheath turbulence properties to determine the power-law behaviour of the magnetosheath energy spectra. Venus' magnetosheath energy spectra manifest a power-law up to $k_{st\rho i} = 1$ with spectral index variation from −1.7 to −0.5 and display a smooth transition to steeper spectra with spectral slope values between −3 to −2 above $k_{st\rho i} = 1$. The magnetic field spectra exhibit a spectral break in the vicinity of ion inertial length at around $k_{st\rho i} = 1$. We observe that the Venusian magnetosheath magnetic field spectra show inertial range, however after the spectral break, the magnetic field spectra at high frequency show the steepening with spectral slope greater than Kolmogorov slope −5/3, which gives an indication of further cascade of energy from low frequency to high frequency. We use two parameters namely the propagation angle (θ_{kB}) and compressibility ($R_{||}$) to provide a fundamental test on the existence of different wave modes in the magnetosheath region. We observe that θ_{kB} is essentially perpendicular to the mean magnetic field (B_0), however $R_{||}$ shows a mixed distribution ($0.2 \leq R_{||} \leq 0.8$) at low frequencies ($f_{sc} \leq 0.2$Hz)). At high frequencies (fsc > 1Hz), θ_{kB} has a broad range ($10^\circ \leq \theta_{kB} \leq 90^\circ$), however $R_{||}$ has a small variation ($0.2 \leq R_{||} \leq 0.5$). We interpret the steepening in the energy spectra as realization of energy accumulation due to kinetic Alfv´en wave or ion cyclotron damping. However, the energy spectra at large scales give an indication of mirror mode onset to energy cascade as well as the realization of energy accumulation due to excitation of ion cyclotron waves by pickup process.

Magnetization and Particle Acceleration in Collisionless Astronomical Shocks

Uri Keshet

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Collisionless shocks magnetize the plasma and accelerate charged particles to ultrarelativistic energies in diverse astronomical systems. Recent progress in the theoretical modeling of these nonlinear processes has been driven largely by ab initio simulations. I will outline recent results, focusing mainly on relativistic shocks, often invoked as the sources of non-thermal particles in pulsar wind nebulae, gamma-ray bursts, and active galactic nuclei jets, and as possible sources of ultra-high energy cosmic-rays.

Novel Physics with Relativistic Shock Waves in the Laboratory

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Applied Physics Division, Soreq NRC Yavne, Israel and

Institute of Nuclear Fusion, Polytechnic University of Madrid, Spain

The recent and future developments of high power lasers are in the multi-Petawatt domain. At laser intensities greater than 10^{21} W/cm^2 one enters the regime of relativistic hydrodynamics.

In my lecture I consider the following novel proposals:

1-Relativistic Shock Waves in the laboratory (P ~ 10^{15} atmospheres)

2-New scheme for Fast ignition by a shock wave

3- Micro-accelerators of foils to relativistic velocities.

Based on collaboration with: J. M. Martinez-Val, Z. Henis, N. Nissim, S. V. Pinhasi, A. Ravid and E. Raicher.

Magnetic Field Evolution in Z-Pinch Implosion with Preembedded Axial Magnetic Field

Dimitry Mikitchuk[1], Marko Cvejic[1], Eyal Kroupp[1], Ramy Doron[1], Christine Stollberg[1], Yitzhak Maron[1], Henry R. Strauss[2], Alexander L. Velikovich[3], John L. Giuliani[3]

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We investigate the fundamental phenomena of magnetic-field flux and magnetized plasma compression by plasma implosion. This subject is relevant to many studies in laboratory and space plasmas. Recently, it has gained particular interest due to the high temperature and densities obtained in experiments, aimed at achieving fusion, that are based on the approach of magnetized plasma compression. In the experiment, we employ a cylindrical configuration, in which an initial axial quasi-static magnetic flux (up to 0.4 T) is preembedded in an argon gas column. A high-power electric discharge (300 kA, rise time 1.6 μs) ionizes the gas and generates the azimuthal magnetic field that compresses the plasma and the axial magnetic field embedded in it. Here, for the first time, we directly measure the evolution and distribution of the axial and azimuthal magnetic fields, simultaneously. This measurement was achieved by employing a novel spectroscopic technique based on the polarization properties of the Zeeman-split emission, combined with laser generated doping technique that provided mm-scale spatial resolution. The measurements revealed surprising results in which the azimuthal magnetic-field at the periphery of the imploding plasma is much smaller than calculated from the measured current and the observed plasma radius. Also, the axial field at stagnation is found to be ~ 4 × larger than the azimuthal field. These observations raise questions regarding the current distribution and the role of the plasma dynamics in the pressure balance.

Fundamental Processes of Radiation Emission from Bunched Electron Beam

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In the context of radiation emission from an electron beam, Dicke's superradiance (SR) [1] is the enhanced spontaneous radiation emission from a pre-bunched beam, and Stimulated-Superradiance (ST-SR) is the further enhanced emission of the bunched beam in the presence of a phase-matched radiation wave. These processes were analyzed for Undulator radiation in the framework of radiation field mode-excitation theory [2]. In the nonlinear saturation regime the synchronism of the bunched beam and an injected radiation wave may be sustained by wiggler tapering [3]. Same processes are instrumental also in enhancing the radiative emission in the tapered wiggler section of seeded FELs [4]. Here we outline the fundamental physical concepts of Spontaneous Superradiadce (SR), Stimulated Superradiance (ST-SR), Taper-Enhanced Superradiance (TES) and Taper-Enhanced Stimulated Superradiance Amplification (TESSA), and compare their Fourier and Phasor formulations in a model of radiation mode expansion. Detailed further analysis can provide better design concepts and improved tapering strategy for enhancing the power of seeded short wavelength FELs. We further discuss the extensions of the model required for full description of these radiation processes, including diffraction [5] and spectral widening effects.

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Helicon Plasma Thruster – an Opportunity and a Challenge

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The use of a helicon plasma source as a plasma thruster, a Helicon Plasma Thruster (HPT) [1], is attractive. A thrust is generated as the several eV plasma, generated and heated by radio-frequency waves, is ejected away, being accelerated through a magnetic nozzle. The thrust is generated similarly to the way it is generated in a regular chemical jet engine in which the hot gas is accelerated when it passes through a regular nozzle. However, a higher energy per particle is deposited in the HPT than in the regular chemical thruster. This higher energy per particle and the resulting higher jet velocity (and specific impulse) are characteristic of electric thrusters. Moreover, the HPT does not use electrodes, which is an advantage relative to other electric thrusters. However, the efficiency of the HPT is found to be very low, about 10% (Hall thrusters reach efficiency of 50%).

The sources of the HPT inefficiency will be identified [2] and the limits on the efficiency of the HPT will be found. In order to estimate the maximal efficiency, a perfect radial confinement of the plasma, a full ionization of the propellant, and a perfect magnetic nozzle, are assumed. The only losses are then shown to be the energy flux into the HPT back wall and ionization and radiation losses, expressed as the ionization energy cost. The maximal efficiency is then predicted to be low. Planned research into new, more efficient configurations will be described.

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Microwave Ignition of Thermite Reactions and Dusty Plasmas

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The paper presents experimental observations of microwave-generated plasmoids in air atmosphere obtained from molten hotspots in various solid substrate materials. Their dusty-plasma features are estimated in view of the nano- and micro particles observed. A similar approach is applied to ignite thermite powders by localized microwaves in air atmosphere, as well as underwater [1]. The insertion of the hydrophobic thermite powder underwater is enabled by the recently discovered bubble-marble effect [2]. The heat and pressure generated by the thermite reaction underwater are measured and analyzed.

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Negative Mass Instability in Sources of Coherent Spontaneous Undulator Radiation

N. Balal [1], V.L. Bratman[1,2], Yu. Lurie [1], and A.V. Savilov[2]

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The effect of negative mass in THz sources of coherent spontaneous radiation with combined undulator and strong uniform magnetic fields can be used for stabilization of the axial size of very dense and short electron bunches produced in photo-injectors [1]. If the cyclotron electron frequency is larger than its undulator frequency there exists the regime [2,3], in which an increase in the electron energy leads to a decrease in its axial velocity. It has been shown that in such conditions Coulomb repulsion of electrons leads to their effective attraction and formation of a fairly stable and compact bunch "core". The required undulator field can be easily created by means of insertion of a periodic magnetic structure (for example, a helix) into the solenoid, which provides a strong uniform magnetic field. Simulations on the basis both simple 1-D model and 3-D code, which allows studying of interaction and radiation of electron bunches in a waveguide [4], demonstrate that the use of the negative-mass regime results in both a significant increase in the output power and narrowing of the spectrum of coherent spontaneous undulator radiation of electrons. An effective longitudinal size of bunches can be conserved at long distance even at extremely high electron density. Correspondingly, an energy extraction efficiency of more than 20% at the frequencies of about 1.5 THz is demonstrated at narrow radiation spectrum that makes possible realization of a compact and powerful THz source.

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Measuring Plasma Parameters in Electrical Discharges using rf Current and Voltage Measurements

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This paper describes a novel technique for determining plasma parameters using a radio-frequency (rf) biased electrode in electrical discharges. This technique relies on accurate measurement of the rf current and voltage waveforms applied to the electrode surface. A novel algorithm is used to calculate the real current-voltage (IV) characteristic from the measured waveforms. The resultant characteristic is analyzed in a similar way to a planar electrostatic probe. This method can be applied to rf biased substrate holders in plasma tools to obtain accurate ion flux measurements. It can also be applied to diagnostic probes introduced to a plasma system. Plasma parameters determined at the rf biased electrode in this experiment are shown to be in excellent agreement with independent Langmuir probe measurements. This method is also applicable in the case where an electrically insulating layer is deposited on the electrode surface.

Plasma Generated by Continuous Electron Beam Injected inside the Dielectric Flask

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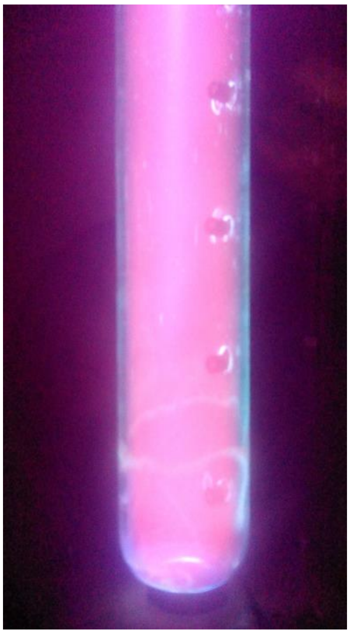

Electron-beam-produced plasmas[1] generated in fore-vacuum pressure range (1-15 Pa)[2] are very attractive tool for various applications because of their properties which could be easily regulated by electron beam parameters, gas composition and pressure. Despite the significant interest in beam-produced plasmas, there is a lack of works devoted to the generation of electron beam-produced plasmas inside the dielectric vessels such as tubes, bottles and containers, at the pressures of several Pascal, although, such type of plasma generation and processing looks attractive for improving of the container's inner surface parameters as biocompatibility[3], anti-fouling[4] and gas-barrier properties[5], and also for the sterilization[6].

The object of study in this work was the beam-produced plasma, which was generated inside a dielectric volume (cylindrical flask of 20 cm long and 4 cm of inner diameter with bottom) by injection of continuous electron beam with energy of 2-8 keV and current 10-100 mA at gas pressures of 2-13 Pa. Electron beam was formed by fore-vacuum plasma electron source with hollow cathode[2].

It is shown that at optimum beam energy and gas pressure, the non-uniformity in plasma density distribution along the length of the flask is less than 10%, and the plasma density and electron temperature in the flask are greater than for the plasma produced in the vacuum chamber with no flask. The measured parameters of the beam plasma in the flask are compared to the predictions of a model based on balance equations. We discuss the beam plasma properties, current continuity, and present preliminary results of application of such plasmas for sterilization of inner surface of the plastic container.

The work was supported by RFBR, grant №16-38-00230 mol_a.

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Influence of Laser Beam Parameters on Output Pulses of a High-Power Microwave Compressor with a Laser-Triggered Plasma Switch

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The operation of the resonant microwave pulse compressor with the plasma interference switch was investigated experimentally at different parameters of the laser beam used for ignition of the plasma discharge in the switch. The compressor represented a rectangular waveguide-based cavity connected to an H-plane waveguide tee with a shorted side arm filled with pressurized dry air ($\approx 2.6 \cdot 10^5$ Pa) and pumped by a conventional pulsed S-band magnetron (up to 450 kW power at 1.8 μs pulse duration). The operating frequency was 2765.8 MHz. The Q-switched Nd:YAG laser with the harmonics' unit was employed to initiate the formation of plasma filament in the tee side arm that leads to rapid release of the microwave energy stored in the cavity. The laser beam entered the switch through the wide wall of the tee waveguide, i.e., was directed along the RF electric field lines. Experiments were conducted with the 2^{nd} (532 nm) and 5^{th} (213 nm) harmonics of the laser radiation frequency, at different levels of light intensity, and with the unfocused and focused laser beams. In the latter case, the laser beam was focused at the center of the tee waveguide cross-section or at the back wall of the tee waveguide.

It was found that the laser beam focusing at the center of the waveguide provides most effective operation of the compressor. In this case, the efficiency of the output pulse extraction, i.e., the ratio of the peak output power to the stored cavity power (that of the traveling waves forming the standing wave in the cavity), reached ~47% at the output power of 13-14 MW. The said level of the output power and extraction efficiency was obtained both with the UV and with visible light beam; just the beam intensity was an order of magnitude lower in the UV case (~3.5 mJ in ~5-ns laser pulse). In the case of unfocused laser beam, the maximal extraction efficiency was only ~20% at 5-6 MW output power. For the beam focused at the back wall of the tee waveguide, the extraction efficiency was ~35%. In addition, the laser beam focusing lead to the significant decrease in the time delay of the microwave output pulse appearance with respect to the time of beam entrance into the switch (down to <1 ns compared to 8-12 ns for the unfocused beams). Accordingly, the time jitter of this delay decreased too. The influence of the laser beam intensity is also manifested in the decrease of the delay and its jitter with increasing intensity. The microwave output power was not affected by the laser beam intensity, except for the case of the focused 532-nm beam.

The physical mechanisms behind the influence of laser beam parameters on the compressor operation are discussed.

Possibility of Submerged Pulse Arc Treatment of Wastewater with Organic Contaminates in Multi-electrode Reactor

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Pulsed submerged arc (SA) treatment generates plasma vapor bubbles submerged within liquid, creating free radicals and oxidative species which cause the decomposition of organic contaminates in liquid medium. The SA treatment was carried out in a new reactor which allows electrical discharges in a large volume of liquid. The discharges were carried out between multiple mobile electrodes, which are repetitively brought into collision contact within the fixed electrodes. The aqueous solutions containing 10 mg/L methylene blue (MB) were SA treated by using iron (Fe) based electrodes. The effects of alternating filtration, electrode quality, arcing energy, vibration, aging of the solutions after arcing and the added H_2O_2 concentration were studied. The 600 ml solutions were prepared using deionized water (DI) or tap water. The treated solutions were examined by absorption spectroscopy. It was found that alternating filtration greatly increases decomposition of MB. The ratio of the number of milliliters of the treated solution reached complete removal of MB to the time required for this is grater by factor of 7.5 than tis ratio for two electrode system obtained by same SA conditions. The treatment efficiency in multi electrode reactor is explained by the numerous collisions of multiple electrodes leading to the formation of eroded nano-particles with the surface catalytically active towards MB oxidation. In the presence of H_2O_2, intensification of Fenton like reactions in the treated solution and on the particle surface contributes to the further enhancement of the process efficiency. In addition, for treatments performed on actual industrial wastewaters, we obtained results which indicate the process's success in removing organic contaminates, pending process optimization and chemically specific adjustments.

Low Current Heaterless Hollow Cathode R&D at Rafael

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Heaterless Hollow Cathodes (HHCs) are a subclass of hollow cathodes that do not require external heating to heat up the electron emitter to its operation temperature. Instead of using external heating HHCs use a unique ignition technique. Firstly, high voltage pulse is applied between the emitter and keeper so to breakdown the injected gas. Immediately after the initial discharge creation a separate power supply controls the emitter-keeper current, a process during which the emitter is heated via ion bombardement. The heating process lasts until the emitter reaches its operation temperature and the voltage drops to a few tens of volts. Lastly, after steady discharge has been initiated the electric thruster is turned on by applying the required emitter-anode current. The entire thruster ignition duration is less than ten seconds. Since HHCs do not use external heating for ignition they posses advantages over their heaterutilizing cousins. First, In comparison to heater-utilizing cathodes that have typical readiness time in the order of minutes, due to the required heating duration, HHCs reach steady-state operation within seconds. Secondly, since no external heating is required the Power Processing Unit (PPU) does not contain the corresponding heater module, therefore lowering its mass. Lastly, since the discharge in HHCs is self sustaining these cathodes are energy efficient relative to heater-utilizing cathodes. In recent years Rafael has been investigating low current HHC physics for igniting and neutralizing low power Hall effect thrusters[1,2]. Particular attention and efforts were invested in (a) Thermally-efficient design (b) development of manufacturing processes and (c) ability to operate with various commercially available emitters[3]. This poster presents the recent activity conducted on a new version of Rafael's Heaterless hollow cathode, denoted the adjustable cathode.

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Electric Force and Ambient Gas Pressure

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The influence of the ambient gas pressure on the acceleration of a mixed ion-neutral flow by the electric force was studied experimentally in a Radial Plasma Source (RPS). The mixed ion-neutral flow was accelerated by an electric field across a magnetic field along a shaped (nozzle) acceleration channel. Argon gas was used. For a discharge current of 2.1 A, a magnetic field intensity of 270 G and a gas flow rate through the RPS anode of 20 SCCM, the accelerating voltage (potential drop across the acceleration channel), the ion current and the electric force were measured versus the ambient gas pressure. The diagnostic system included a planar Langmuir probe, a balance force meter and a capacitance manometer. The ambient gas pressure was varied from 3 mTorr to 11.5 mTorr by using an additional gas flow inlet in the vacuum chamber outside the RPS. The ion current and the accelerating voltage decreased 2 times with the ambient gas pressure changing in the measurement range. The electric force decreased 1.6 times as the ambient gas pressure varied from 3mTorr to 6mTorr and then the electric force was approximately constant when the ambient gas pressure was increased up to 11.5 mTorr. A possible explanation, for the variation of these discharge variables with the ambient gas pressure, is that the neutral gas density inside the acceleration channel is higher for a higher ambient gas pressure because the ambient gas pressure may penetrate the acceleration channel from the exit of the RPS. The increased neutral gas then affects the acceleration of the mixed ion-neural flow. The behavior of the electric force, the accelerating voltage and the electric force are discussed.

A large-Scale Uniform Plasma System for Microwave Wakefield Experiments

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For investigating the interaction between high power, short pulse microwave beam and underdensed plasma a large scale, uniform and density controlled plasma system was developed. The system is composed of a 2 MHz RF generator, matching system, and a quadruple antenna, 80cm long, 25cm diameter, gas control system and a Pyrex chamber. This setup allows us to achieve a quasi-continuous (hundreds of ms), highly uniform plasma with varying density (from 1·1010 to 5·1012 cm-3). The plasma parameters were studied using a single Langmuir probe, microwave cutoff and interferometry. The results of these measurements will be presented and discussed.

A High Power, Short Pulse, Microwave Source for Wakefield Experiment

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We designed a high power (160MW), 1ns microwave source, based on superradiance effect in a backward wave oscillator (BWO). The microwave source consists of the following elements: 1. a all solid stage generator generating at its output high-voltage pulse with amplitude of 300 kV at 200 Ω load with pulse duration of 10 ns and rise time of <1 ns. 2. magnetically insulated foilless diode with an edged graphite cathode for generation of a thin (<0.3mm) annular electron beam with current amplitude of 1.5 kA. 3. A slow wave structure, which creates a superradiance backward wave by the interaction with the electron beam transported in external guiding magnetic field of 2.5 T. 4. A mode converter and a cylindrical horn antenna, which creates a Gaussian microwave beam propagating to the free-space. 5. A dielectric lens, which focus the beam into the plasma chamber, with a waist less than 4cm. We achieved reliable operation of the microwave source with total power exceeds 160MW and pulse duration less than 1ns, making this source suitable for the investigation of wakefield generation in plasma.

Saturation Dynamics, Output Power Optimisation, and Chirp Control in a CW FEL Oscillator

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The Electrostatic Accelerator Free Electron Laser (EA-FEL) oscillator in Ariel is capable of generating high power radiation which is guided to a user room (100W-5kW). It is a tuneable source of radiation able to supply power at any frequency between 95 and 110GHz, with pulse times ranging from 1-50μs. The EA-FEL oscillator is a unique and versatile tool capable of delivering radiation with a linewidth as narrow as 0.1MHz. Frequency drift rates are typically below 80KHz/μs.

Using a variable out-coupling element on the end of the resonator of the EA-FEL oscillator, we can control the power leaving the resonator and maximisation of the power extraction from the electron beam. By changing the out-coupling we also exert control over the time before oscillation build-up and single mode lasing.

A voltage ramping device within the high voltage terminal of the accelerator allows us to positively or negatively vary the potential of our electrically-isolated resonator up to 20 kV whilst the electron beam is passing through it. Through positive voltage ramping we have experimentally demonstrated that on average we can extract 50% more power from the electron beam.

Anode Temperature Evolution in a Vacuum Arc with a Black Body Electrode Configuration

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Anode temperature in a Vacuum Arc with a Black Body Assembly (VABBA) was measured as a function of time. The electrodes were configured as a closed cathode-anode assembly which trapped and evaporated the macroparticles while the plasma was extracted through small anode apertures. The cathode was Cu with 30 mm diameter and the refractory anode was Ta of 50 mm diameter. The plasma was ejected through an array of 250 apertures of 0.6 mm diameter in the anode. Arc currents were *I*=175 and 225 A and the arc duration was 180 s. The anode temperature was measured in VABBA using high-temperature thermocouples at two positions (top and side) inside the anode body. The visual radiation emitted by the plasma plume was recorded with a digital camera.

The anode temperature increased rapidly for about 90 s and then slightly increased until the end of the arc, reaching at the top position 1650 K (*I*=175 A) and 1850 K (*I*=225 A). These temperatures were larger than at the side position by about 150-200 K.

The A6 Relativistic Magnetron Revisited

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When a relativistic magnetron was first described in 1976 by the MIT group led by Bekefi, it was suggested that such a device is expected to be amenable to long-pulse operation because of the axial insulating magnetic field parallel to the electron-emitting surface. Since then, radiation pulse-shortening was found to be inherent to relativistic magnetrons too and a vast amount of research has been invested in alleviating it. Explosive emission cathode plasma expansion became the accepted explanation for this phenomenon though in experiments performed by our group we have shown that for voltages up to a few hundred kV, cathode-anode distances of ~1-2 cm and microwave power of up to several hundred MW, the plasma remains close to the cathode during ~100 ns. The transfer of energy from the magnetically insulated electron beam, to the electro-magnetic radiated field developing in the magnetron resonant structure, is a very complicated electro-dynamic process, very difficult to understand without numerical simulations. The availability of present day computer power enabled us to perform extensive 3-D PIC simulations of a six-vane magnetron with a single radial output slot which brings new understanding of the dynamics of power pulse-shortening in the absence of plasma shorting. We find that the impedance mismatch between the generator supplying power to the magnetron and the various "loads" comprising the magnetron is important and that a delicate electrical power balance is responsible for the operation of this dissipative system.

Electronic Tattoos with a Plasma Polymerized Coating for Human-Machine Interface and Biopotential Monitoring

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Surface electrodes are a common, non-invasive tool used to record electrical activity from the surface of the body (e.g. electroencephalogram (EEG), electromyography (EMG) and electrocardiography (ECG)). For decades, it was commonly accepted that dry metallic electrodes establish poor electrode-skin contact, making them impractical for skin biopotential applications. Gelled electrodes are therefore the standard in surface recordings with their use confined, almost entirely, to laboratory settings.

Here we present novel dry electrodes based on a temporary tattoo platform exhibiting outstanding surface EMG (sEMG) recording along with excellent user comfort. The electrodes were realized using screen-printing of carbon ink on a soft support. The conformity of the electrodes helps establish direct contact with the skin, making the use of a gel superfluous. Plasma polymerized coating was used to enhance the specific capacitance of the electrode by a factor of 100 in wet conditions and by a factor of 10 on human skin. The suitability of the electrodes for long-term sEMG recordings from muscles in the hand, and thein face. The presented electrodes are ideally-suited for many applications such as human-machine interfacing, muscle diagnostics, post-injury rehabilitation, and gaming.

Explosive Emission Cathodes as a Source for Hollow High-Current Electron Beam, applied for Microwaves Generation in a Backward Wave Oscillation

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The results of experimental studies of different types of cathodes, carbon-epoxy rods, carbon epoxy capillary, edged graphite, stainless steel and metal-dielectric in a magnetically insulated foilless diode with guiding magnetic field of 2.5 T under the application of high-voltage pulses with amplitude of several hundreds of kV and pulse duration of several nanoseconds, are presented. The cathodes were used to generate a high current electron beam in order to produce a high-power microwaves (>100 MW, 1 ns) in a Backward Wave Oscillator (BWO) operating in super-radiance mode. The amplitude of the electron beam current, energy of electron, impedance of the diode and azimuthal uniformity of the beam are governed the efficiency of the BWO operation. The best diode performance and superior parameters of the electron beam was achieved with the edged graphite and carbon-epoxy-based cathodes characterized by uniform and fast (<1 ns) formation of explosive emission plasma spots, quasi-constant diode impedance and long life time of the cathode.

Design of a Fourth-Harmonic Large-Orbit Gyrotron

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Gyrotron operation at a s^{th} cyclotron harmonic allows *s*-times decrease in the value of magnetic field that is especially important at short-millimeter and terahertz waves. Conventional gyrotrons operate only at the fundamental and second cyclotron harmonics (s=1,2) because of severe mode competition. The so-called Large-Orbit Gyrotron (LOG), where electrons move along helical trajectories with guiding centers close to the axis of an axisymmetric cavity, has better mode selectivity and can operate at higher harmonics. The fact is that due to symmetry only cavity modes TE_{mp} with azimuthal indices *m* equal to the numbers of resonant cyclotron harmonics *s* can be resonantly excited in a LOG with an ideal electron beam.

Pulsed operation in LOGs at harmonics s=2-5 with a relatively low efficiency was already demonstrated at the frequencies up to 1 THz. According to estimations, LOGs can be also very attractive for CW generation at short waves. In this presentation, the possibility of an efficient CW operation in a fourth-harmonic LOG with the frequency of about 100 GHz is studied.

It should be noticed that the electron-wave interaction at high cyclotron harmonics is fairly weak and, correspondingly, a long cavity should be used. In such situation, the radial mode index *p* should be as large as possible from the point of view of parasitic modes excitation in order to decrease Ohmic losses and to increase the operating current. The cavity length and diffraction *Q* for the chosen operating mode have been optimized with taking into account these effects. The calculated power is higher than 10 kW at the efficiency of about 10% and 30% without and with an energy recovery (using depressed collector), respectively. Requirements to beam shift from the cavity axis are obtained. Such inevitable shift weakens the interaction of the electrons with the operating mode and makes possible resonance excitation of parasitic modes. Estimations of a LOG electron-optical system with a cusp of magnetic field near the cathode and its detailed simulations on the basis CST Particle Studio with EM Solver and General Particle Tracer have demonstrated a possibility to form the beam with voltage of 60-70 keV, current of 2A, and pitch-factor of 1.7-2.0 at an admissible velocity and position spread in the operating field smaller than 1 T.

Determination of the Plasma Composition using Blended Stark-Broadened Emission Lines in a Self-Magnetic Pinch Diode

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We analyzed visible spectra obtained in self-focusing, relativistic-electron diode experiments performed on the RITS-6 [1] accelerator facility at Sandia National Laboratories (SNL). An electron beam emitted from the cathode strikes a planar anode surface with high current densities (~1 MA/cm^2), forming a plasma in the anode-cathode (A-K) gap. Radiation emitted from the plasma is imaged onto a spectrometer input slit via an optical fiber bundle. The spectrometer output is coupled to a gated, intensified charge-coupled device (ICCD) camera, yielding spatially resolved (2mm) spectra. The spectra from the high-density plasma region mainly exhibit emission that appears to be from a continuum source. However, the radiation intensity distribution cannot be explained by free-free or free-bound emissions. Rather, we suggest that the spectrum originates from the blending of many Stark-dominated spectral lines. Accordingly, the spectral intensity distribution provides information on the plasma composition and thermodynamic parameters.

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Determination of the Initial 2D Gas Density Distribution used for Plasma Implosion Experiments by Both Interferometry and Laser Induced Fluorescence (LIF) Measurements

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The properties of imploding plasmas such as in z-pinch experiments, the development of instabilities during the implosion and stagnation stages, and properties of the emitted radiation are all affected by the 2D (or 3D) distribution of the plasma. MHD or numerical simulations, generally used for implosion modeling, thus require a detailed knowledge of the gas spatial density and velocity distributions prior to the application of the current pulse. Indeed, simulations of our implosion data, performed by our colleagues at NRL demonstrated that the z-pinch implosion is highly sensitive to the initial density distribution of the gas [J. L. Giuliani, J. W. Thornhill, E. Kroupp, D. Osin, Y. Maron, A. Dasgupta, J. P. Apruzese, A. L. Velikovich, Y. K. Chong, A. Starobinets, V. Fisher, Yu. Zarnitsky, V. Bernshtam, A. Fisher, T. A. Mehlhorn, and C. Deeney, Phys. Plasmas **21**, 031209 (2014)]. The present experimental work aims at providing a high spatial resolution and accurate description of the initial conditions set for the discharge of the Weizmann Institute gas-puff Z-pinch machine. Two independent experimental methods were implemented; Interferometry and LIF. Using a Mach-Zehnder interferometer we were able to record the time dependent interference pattern along chords traversing the jet. Assuming the jet has cylindrical symmetry, an inverse Abel transform of the phase difference enabled us to obtain the 2D gas distribution at that moment. Using a short (~5ns) laser pulse (266nm, beam diameter of ~1mm) for LIF measurements, this enabled us to achieve a spatial resolution of ~50μm in the radial direction, and thus fine density changes could be observed. This can be highly important for the prediction of instability growth in MHD modeling. Using LIF we were also able to record the gas velocity profile, by utilizing the fact that following the short duration fluorescence, the longer duration phosphorescence could be observed by our sensitive apparatus. This allowed us to monitor the motion of the laser-excited gas molecules. A two dimensional interference pattern of the AK gap right before discharge was also obtained and all results are compared and discussed. Moreover, we are currently analyzing data for two different azimuthal directions in order to study deviations from cylindrical geometry, which are also important for obtaining correct modeling of the implosion.