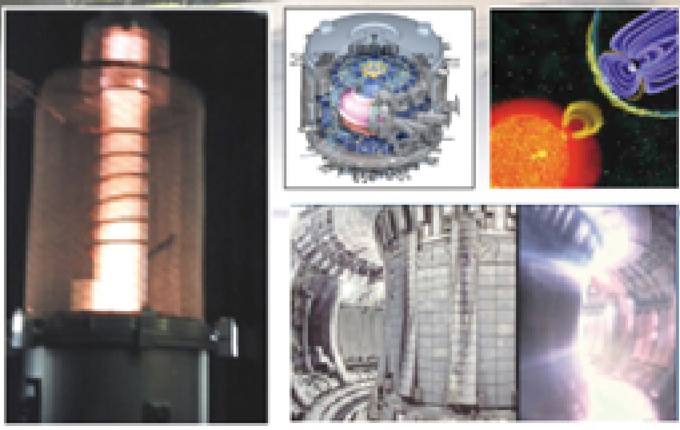
Israel Plasma Science and Technology Association
HIT - Holon Institute of Technology



Faculty of Sciences
HIT - Holon Institute of Technology
February 4, 2013

The 15th Israeli Conference on Plasma Science and Applications

Invited speakers:

- N. J. Fisch – Princeton U
- J. Jortner - TAU
- Y. Maron – Weizmann

Program committee:

- R. Boxman - TAU
- A. Fruchtman (Chair) - HIT
- Y. Krasik - Technion

מכון טכנולוגי חולון
Holon Institute of Technology
Quality & Excellence

http://plasma-gate.weizmann.ac.il/ipsta2013

ISRAELI PLASMA SCIENCE AND TECHNOLOGY ASSOCIATION

15th ISRAELI CONFERENCE ON PLASMA SCIENCE AND APPLICATIONS

H.I.T. – Holon Institute of Technology
February 4th, 2013

BOOK OF ABSTRACTS

http://plasma-gate.weizmann.ac.il/ipsta2013/

CONTENTS

PREFACE

We are delighted to host the 15^{th} annual conference of the Israeli Plasma Science and Technology Association (IPSTA). This is the second time that the Holon Institute of Technology (H.I.T.) is hosting the conference.

The aim of IPSTA is to encourage the interaction between scientists and engineers in all areas that involve plasmas: astrophysics, plasma processing, fusion research, sources of radiation and particle beams, pulsed power, or other basic and applied aspects of plasmas. Many processes in technologies that involve plasmas occur naturally in space. Nuclear fusion uses high temperature plasma such as found at the sun's center, lighting uses low temperature plasma such as found at the sun’s surface, and particle acceleration can occur in an environment such as found in other astronomical objects. Thus much of our activities in plasma science and technology are directed to understanding the processes occurring in nature on an astronomical scale, and realizing these processes on the laboratory scale and in practical technological devices. Diverse subjects are presented in this year’s conference and we hope to keep having presentations also about astrophysical plasmas in future years.

In addition to the importance of the interaction between scientists in our subfields, it is important also to encourage interaction between plasma scientists and scientists in neighboring fields. This year Professor Joshua Jortner from Tel Aviv University will give an invited talk on a novel scheme for conversion of laser energy to nuclear energy, bridging chemistry and plasma physics. The two other invited speakers are Professor Nathaniel J. Fisch from Princeton University who will suggest a new process of wave compression in plasmas and Professor Yitzhak Maron from the Weizmann Institute of Science who will unfold the dynamics of stagnating plasma in z pinch experiments.

We continue the tradition of awarding the Goldsmith Prize for best student presentations. Professor Samuel Goldsmith was a leading figure in the plasma science community in Israel and one of the founders of IPSTA. This year about 15 students participate in the competition through either oral or poster presentations.

The book of abstracts is organized as follows. Pages 5 – 7 contain the list of oral (in the chronological order) and poster (in the alphabetical order by the presenter's name) contributions, while their abstracts appear on pages 8 – 26 and pages 27 – 35, respectively. The author index is given in pages 36 – 37.

Please accept the best wishes of the Program Committee for a successful and enjoyable conference.

Amnon Fruchtman – Chair
Reuven Boxman
Yakov Krasik
(Program Committee)

CONFERENCE ORGANIZATION

IPSTA Committee	Conference Program Committee
Ya. E. Krasik, Technion - Chair	R. L. Boxman, TAU
Y. Pinhasi, Ariel	A. Fruchtman, HIT – Chair
E. Gruenbaum, TAU	Ya. E. Krasik, Technion
R. Doron, WIS	**Goldsmith Prize Committee**
E. Jerby, TAU	E. Jerby, TAU - Chair
A. Raveh, NRC Negev	A. Yahalom, Ariel
J. Ashkenazy, Soreq	Y. Hadas, Rafael
R. L. Boxman, TAU	
M. Mond, BGU	
A. Fruchtman, HIT	

Program

08:15 - 08:45	**Registration and Coffee**	
08:45 - 09:00	**Welcoming Remarks**	
09:00 - 10:30	**First Session (Chair: A. Fisher)**	
09:00 – 09:30	Y. Maron, *WIS* (Invited)	Dynamics of the K-radiating stagnating plasmas in z-pinch experiments: Implications for pressure and energy balance
09:30 - 09:45	R. Doron, B. Rubinstein, A. Fruchtman, R. Arad. J. Citrin, and Y. Maron, *WIS* and *HIT*	The structure of a magnetic-field front propagating through low-resistivity, multi-ion species plasma
09:45 - 10:00	O. Antonov, S. Efimov, D. Yanuka, V. Tz. Gurovich and Ya. E. Krasik, *Technion*	Generation of converging strong shock wave by underwater electrical explosion of spherical wire array
10:00 - 10:15	D. Shafer, G. Toker, V. Tz. Gurovich, S. Gleizer and Ya. E. Krasik, *Technion*	Convergence of shock wave generated by underwater electrical explosion of ring-shaped wires
10:15-10:30	I. Be'ery, O. Seemann, A. Fruchtman, A. Fisher and J. Nemirovsky, *Technion* and *HIT*	Measuring drift velocity and electric field in mirror machine by fast photography
10:30 - 10:50	**Coffee break**	
10:50 - 12:20	**Second Session (Chair: N. J. Fisch)**	
10:50 - 11:20	J. Jortner, *TAU* (Invited)	Conversion of laser energy to nuclear energy
11:20 - 11:35	E. Schleifer , S. Eisenmann, M. Botton, E.Nahum, Y. Pomerantz, F. Abricht, J. Branzel, G. Priebe, S. Steinke, A. Andreev, M. Schnuerer, W. Sander, D. Gordon, P. Sprangle and K. W. D. Ledingham, and A. Zigler, *HUJI, MBI, NRL, USG*	Enhanced proton acceleration by an ultrashort laser interaction with structured dynamic plasma targets
11:35 - 11:50	I. Gissis, A. Rikanati, I. Be'ery, A. Fisher, E. Behar, *Technion*	Spectroscopy of a nitrogen capillary discharge plasma aimed at a recombination pumped x-ray laser

11:50 - 12:05	E. Jerby, Y. Meir, Z. Barkay, D. Ashkenazi, J. B. Mitchell, T. Narayanan, N. Eliaz, J. L. LeGarrec, M. Sztucki, *TAU, Rennes, ESRF*	Experimental Characteristics of dusty plasmoids excited by localized microwaves in air atmosphere
12:05 - 12:20	E. Faktorovich-Simon, N. Parkansky, V. Yacubov, B. Alterkop, O. Berkh, R. L. Boxman, Z. Barkay, Yu. Rosenberg, L. Burstein, A. Khatchtouriants, *TAU*	Electrode erosion effect on decomposition of methylene blue in aqueous solutions
12:20 - 14:00	**Lunch and Posters**	
14:00 - 15:15	**Third Session (Chair: L. Friedland)**	
14:00 – 14:30	N. J. Fisch, *Princeton* (Invited)	Wave compression in plasma
14:30 - 14:45	P. Khain and L. Friedland, *HUJI*	Resonant excitation of plasma waves via formation of holes in phase space
14:45 - 15:00	A. Yahalom, *Ariel*	Aharonov Bohm constraints for fusion
15:00 - 15:15	J. H. P. Mizrahi and Ya. E. Krasik, *Technion*	Radial ion dynamics in a cylindrical hollow cathode
15:15 - 15:35	**Coffee break**	
15:35 – 16:50	**Fourth Session (Chair: H. R. Strauss)**	
15:35 - 15:50	G. Makrinich and A. Fruchtman, *HIT*	Enhanced momentum delivery by electric force due to ion-neutral collisions
15:50 - 16:05	D. Lev, *Rafael*	Review of Magneto-Plasma-Dynamic (MPD) thrusters
16:05 - 16:20	M. Einat, M. Pilossof, R. Ben-Moshe, H. Hirshbein and D. Borodin, *Ariel*	95GHz gyrotron with ferroelectric cathode
16:20 - 16:35	I. I. Beilis, Y. Koulik, R. L. Boxman, *TAU*	Effective Cathode Voltage Increase in a Vacuum Arc with a Black Body Electrode Configuration
16:35 - 16:50	E. Gidalevich and R. L. Boxman, *TAU*	Steady-state plasma bubbles excited by microwave radiation
16:50 - 17:10	**Electing new IPSTA Chair and Committee**	
17:10 - 17:30	**Samuel Goldsmith Best Student Presentation Awards**	
17:30 – 18:00	**Farewell party**	

Posters

1. L. Beilin, A. Shlapakovski, and Ya. E. Krasik, *Technion* - Two-frequency microwave pulse compressor with a magic-tee-based plasma switch.
2. Y. Katzir and A. Zigler, *HUJI* - High intensity laser optical manipulation by plasma channels for contrast ratio enhancement and high harmonic generation.
3. D. Mikitchuk , E. Kroupp, R. Doron, E. Stambulchik, H. Strauss, A. Fisher, A. Fruchtman, and Y. Maron, *WIS, HRS Fusion, Technion, and HIT* - Investigation of the compression of magnetized plasma and magnetic flux .
4. T. Queller, J. Z. Gleizer, and Ya. E. Krasik, *Technion* - Novel high current carbon composite capillary cathode.
5. B. Sagi, I. I. Beilis, V. Zhitomirsky, O. Margulis, and R. L. Boxman, *TAU* - Experimental Study of Cathode Spot Motion in a Vacuum Arc with a Long Rectangular Roof-shaped Cathode.
6. A. Sayapin and A. Levin, *Technion* - Relativistic magnetron with inbuilt magnetic block.
7. D. Tsimanis and R. L. Boxman, *TAU* - Microwave Plasma Excitation for a Lighting Application.
8. S. Yatom and Ya. E. Krasik, *Technion* - Spectroscopic research of the plasma parameters generated during nanosecond “runaway” discharge at atmospheric pressure.

INVITED

Dynamics of the K-radiating stagnating plasmas in z-pinch experiments: Implications for pressure and energy balance

Yitzhak Maron

Weizmann Institute of Science, Rehovot 76100, Israel
Yitzhak.Maron@weizmann.ac.il

The plasma properties at stagnation of two disparate z-pinches, inferred from spectroscopic diagnostics, are examined within a 1-D shock wave picture, and found to be in good agreement with this picture. A conclusion is that for a wide range of imploding-plasma masses and current amplitudes, in experiments optimizing non-planckian hard radiation yields, the magnetic field plays a minor role in the pressure balance and energetics of the stagnation of the leading edge of the imploding plasma responsible for the hard radiation.

The structure of a magnetic-field front propagating through low-resistivity, multi-ion species plasma

R. Doron[1], **B. Rubinstein**[1], **A. Fruchtman**[2], **R. Arad**[1], **J. Citrin**[1] **and Y. Maron**[1]

[1]*Weizmann Institute of Science, Re , Holon 58102, Israel*
ramy.doron@weizmann.ac.il

The study of low-resistivity plasmas interacting with transient electromagnetic fields is important for the understanding of a variety of fundamental phenomena. Previous research revealed intriguing phenomena, including the long-standing problem of rapid magnetic-field penetration into low-resistivity plasmas. Inconsistencies between observations and theories invoked the possibility that unexplored processes, occurring in scales that are beyond the experimental resolution, play a significant role in the interaction. In the present study, improved diagnostic capabilities allows for obtaining new insights into the plasma-field interaction. In the configuration studied, a pulsed current (rise-time 400 ns) generating the magnetic field (~ 1 T), is driven through a plasma that prefills the volume between two electrodes. The detailed structure of the propagating magnetic-field front is reconstructed and its width is used for estimating the plasma conductivity. The magnetic-field front structure and velocity are found to remain nearly constant when the field propagates over a length scale of the order of the front width. This observation allows for treating the magnetic-field front as an electric potential hill in the moving frame of the field. Using the properties of the potential hill, derived are the dynamics of the various ion-species. The inferred ion dynamics are used to predict the electron density evolution that is found to agree with the observed density.

Generation of converging strong shock wave by underwater electrical explosion of spherical wire array

O. Antonov, S. Efimov, D. Yanuka, V. Tz. Gurovich and Ya. E. Krasik

Physics Department, Technion, Haifa 32000, Israel
antonov@tx.technion.ac.il

Results of recent experiments on generation of converging strong shock wave by underwater electrical explosion of spherical Cu-wire array involving sub-microsecond (~300 ns, ≤500 kA, ~6 kJ) and microsecond (~1 μs, ≤ 300 kA, 4 kJ) timescales high-current generators are presented. Time of flight of the shock wave was measured and used in hydrodynamic 1D simulation to calculate the parameters of the water in the vicinity of the implosion origin. In the case of sub-microsecond timescale wire array explosion, it was shown that the pressure, temperature and compression of water reaches extreme values, namely, $\sim 2\times10^{12}$ Pa, ~8 eV and ~7, respectively. In the case of micro-second timescale wire array explosion, in spite of less initially stored energy, a superior implosion of the generated shock wave was obtained. The latter is explained by additional energy which is transferred to the imploded water flow due to implosion of wire array caused by the magnetic pressure which becomes significant in the microsecond time scale explosion.

Convergence of shock wave generated by underwater electrical explosion of ring-shaped wires

D. Shafer, **G. Toker, V. Tz. Gurovich, S. Gleizer and Ya. E. Krasik**

Physics Department, Technion, 32000, Haifa, Israel
dshafer@tx.technion.ac.il

Nanosecond timescale underwater electrical wire explosions of ring-shaped Cu wires have been investigated using pulsed generator with current amplitude of up to 50 kA. It was shown, that this type of wire explosion results in generation of a toroidal shock wave. Current and voltage waveforms, as well as shadow, Schlieren and overlaid fast-framing images of the converging part of the shock wave were acquired. Shadow and Schlieren images show that the shock wave preserves its circular front shape up to compression factor of 50, i.e., in the range of radii $100\mu m < R_{sw} < 5mm$. Another interesting finding is in time-of-flight measurements, which show that the shock wave propagates in the above radii range with a constant shock wave velocity of $v_{sw} = 1.2M$, where M is the Mach number. A calculation of the shock wave dynamics based on the Chester-Chisnell-Witham linearized theory is presented, explaining the constant velocity of the shock wave in spite of the increase of the pressure behind the shock wave front.

Measuring drift velocity and electric field in mirror machine by fast photography

I. Be'ery[1], **O. Seemann**[1], **A. Fruchtman**[2], **A. Fisher**[1] **and J. Nemirovsky**[1]

[1]*Physics Department, Technion - Israel Institute of Technology, Haifa 32000, Israel*
[2]*Faculty of Sciences, H.I.T. – Holon Institute of Technology, Holon 58102, Israel*
ilanbeery@gmail.com

The flute instability in mirror machines is driven by spatial charge accumulation and the resulting E×B plasma drift. On the other hand, E×B drift due to external electrodes or coils can be used as a stabilizing feedback mechanism. Fast photography is used to visualize Hydrogen plasma in a small mirror machine. Using incompressible flow and monotonic, local decay assumptions components of the velocity field are obtained from the evolution of the plasma cross section. The electric field perpendicular to the density gradient is then deduced from E=-V×B. Using these techniques, the evolution of the flute instability is investigated, as well as the coupling to externally biased electrodes.

,

INVITED

Conversion of laser energy to nuclear energy

Joshua Jortner

School of Chemistry, Tel Aviv University, Ramat Aviv, 69978 Tel Aviv, Israel
jortner@post.tau.ac.il

Compelling experimental and theoretical evidence emerged for nuclear fusion driven by Coulomb explosion of multicharged deuterium containing nanostructures generated by ultraintense, femtosecond, near-infrared laser pulses. Theoretical-computational studies of table-top laser-driven nuclear fusion of high-energy (up to 15 MeV) deuterons with ^{7}Li, ^{6}Li and D nuclei demonstrate the attainment of high fusion yields within a source-target reaction design. The reaction design attains the highest table-top fusion efficiencies (up to $4x10^{9}J^{-1}$ per laser pulse) obtained up to date. The highest conversion efficiency of laser energy to nuclear energy (10^{-2}–10^{-3}) for table-top fusion in the source-target design with a source of exploding large deuterium nanodroplets (initial size of 300nm) driven by superintense lasers (peak intensity $5x10^{19}$ Wcm^{-2}), is comparable to that for DT fusion currently accomplished for 'big science' inertial fusion setups.

References

1. I. Last, S. Ron, and J. Jortner, Phys. Rev. A **83**, 043202 (2011).
2. S. Ron, I. Last, and J. Jortner, Phys. of Plasmas **19**, 112707 (2012).

Enhanced Proton Acceleration by an Ultrashort Laser Interaction with Structured Dynamic Plasma Targets

E. Schleifer[1] , S. Eisenmann[1], M. Botton[1], E. Nahum[1] , Y. Pomerantz[1], F. Abricht[2], J. Branzel[2], G. Priebe[2], S. Steinke[2], A. Andreev[2], M. Schnuerer[2], W. Sander[2], D. Gordon[3] P. Sprangle[3], K. W. D. Ledingham[4], and A. Zigler[1]

[1]Racah Institute of Physics, Hebrew University, Jerusalem 91904, Israel
[2]Max Born Institute, Berlin, Germany
[3]Plasma Physics Division, Naval Research Lab, Washington, D.C. 20375, USA
[4]University of Strathclyde, Glasgow G4 0NG, Scotland, UK
eladschleifer@gmail.com

We experimentally demonstrate an order of magnitude enhanced acceleration of protons to high energy by relatively modest ultrashort laser pulses and structured dynamical plasma targets. Realized by special deposition of snow targets on sapphire substrates and using carefully planned pre-pulses, high proton yield emitted to narrow solid angle with energy of up 25MeV were detected from a 5TW laser.

We report on a promising alternative approach to the laser-based proton acceleration quest by using a moderate power (<10TW) laser systems, and carefully produced *microstructured snow targets*. Following previous experimental demonstration of improved laser absorption by snow targets and enhanced proton acceleration, we demonstrate here for the first time acceleration of proton bunches to 25MeV by a 5TW ultrashort (50fs) laser pulse. Our experimental results show that the energy of the accelerated protons scales with the power of the laser according to the $E_{protons} \propto (P_{Laser})^{1/2}$ rule which is obtained here for much lower laser power than the traditional schemes. Numerical 2D PIC code simulations of the interaction process reproduce the experimentally obtained scaling law and predict the possibility of accelerating protons to 150MeV with laser energy of about 100TW. This significantly increased proton energy is attributed to a combination of three mechanisms. First is the localized enhancement of the laser field intensity near the tip of the microstructured whisker. This cause increased electronic charge repulsion out of the whisker. Second is a mass-limited like phenomena, namely the absence of high density cold electron cloud in the vicinity of the whisker which can compensate for the expelled electrons. The heated electrons remain in the vicinity of the positively charged whisker, producing strong accelerating electrostatic fields and pulling the protons out. Third is the Coulomb explosion of the positively charged whisker, adding longtime acceleration to the protons.

SPECTROSCOPY OF A NITROGEN CAPILLARY DISCHARGE PLASMA AIMED AT A RECOMBINATION PUMPED X-RAY LASER

I. Gissis, A. Rikanati, I. Be'ery, A. Fisher, E. Behar

Department of Physics, Technion –
Israel Institute of Technology, Haifa, 32000, Israel
itaigiss@gmail.com

The recombination pumping scheme for soft X-Ray lasers has better energy scaling, than the collisional-excitation pumping scheme. Implementation of an H-like $3 \rightarrow 2$ Nitrogen recombination laser, at λ~13.4nm requires initial conditions of at least 50% fully stripped Nitrogen, kTe~140eV and electron density of $\sim 10^{20} cm^{-3}$. In order to reach population inversion, the plasma cooling to below 60eV should be faster than the typical three-body recombination time. The goal of this study is achieving the required plasma conditions using a capillary discharge z-pinch apparatus. The experimental setup includes a 90mm alumina capillary coupled to a pulsed power generator of ~60 kA peak current, with a rise time of ~60ns.

Various diagnostic techniques are applied to measure the plasma conditions, including X-Ray diode, time-resolved pinhole imaging and time-resolved spectroscopy analysed with a multi-ion collisional-radiative atomic model. For optimization of the plasma conditions, experiments were carried out in different capillary radii and different initial N pressures. The results show a fast cooling rate to below 60eV, demonstrating the feasibility of capillary discharge lasers.

Experimental Characteristics of Dusty Plasmoids Excited by Localized Microwaves in Air Atmosphere

E. Jerby[1], Y. Meir[1], Z. Barkay[2], D. Ashkenazi[1], J. B. Mitchell[3], T. Narayanan[4], N. Eliaz[1], J. L. LeGarrec[3], M. Sztucki[4]

[1] *Faculty of Engineering, Tel Aviv University, Ramat Aviv, Israel.*
[2] *Wolfson Institute for Material Research, Tel Aviv University, Ramat Aviv, Israel.*
[3] *Université de Rennes I, Rennes, France.*
[4] *European Synchrotron Radiation Facility, Grenoble, France*
jerby@eng.tau.ac.il

This paper presents experimental investigations of plasmoids (fireballs) obtained by directing localized microwaves (~0.8 kW at 2.45 GHz) into a solid substrate in a microwave cavity. The plasmoid is blown up from the hotspot created in the substrate to the air atmosphere within the microwave cavity. The substrate materials employed in this study are mostly silicon and glass, but the method is applicable to various metals, powders and liquids as well. The experimental diagnostics include microwave scattering, optical spectroscopy, small-angle X-ray scattering (SAXS), and scanning-electron microscopy (SEM) with energy dispersive spectroscopy (EDS). Various characteristics of these plasmoids as dusty plasmas are drawn by combined analyses of the experimental results. Aggregations of macro-particles within the plasmoid are detected in nanometer and micrometer scales (by SAXS measurements and SEM observations, respectively). Both microwave scattering and SAXS results lead to dust density estimates in the order of $\sim 10^{16}\,\mathrm{m}^{-3}$. The resemblance of these plasmoids to natural ball-lightning (BL) phenomena is discussed in the aspects of nanoparticle clustering and slowly-oxidized silicon micro-sphere formation within the BL. Developments of potential applications, such as direct conversion of solids to powders, ignition of thermite mixtures, and material identification by microwave breakdown spectroscopy (MIBS), are presented. This paper presents experimental investigations of plasmoids (fireballs) obtained by directing localized microwaves (~0.8 kW at 2.45 GHz) into a solid substrate in a microwave cavity. The plasmoid is blown up from the hotspot created in the substrate to the air atmosphere within the microwave cavity. The substrate materials employed in this study are mostly silicon and glass, but the method is applicable to various metals, powders and liquids as well. The experimental diagnostics include microwave scattering, optical spectroscopy, small-angle X-ray scattering (SAXS), and scanning-electron microscopy (SEM) with energy dispersive spectroscopy (EDS). Various characteristics of these plasmoids as dusty plasmas are drawn by combined analyses of the experimental results. Aggregations of macro-particles within the plasmoid are detected in nanometer and micrometer scales (by SAXS measurements and SEM observations, respectively). Both microwave scattering and SAXS results lead to dust density estimates in the order of $\sim 10^{16}\,\mathrm{m}^{-3}$. The resemblance of these plasmoids to natural ball-lightning (BL) phenomena is discussed in the aspects of nanoparticle clustering and slowly-oxidized silicon micro-sphere formation within the BL. Developments of potential applications, such as direct conversion of solids to powders, ignition of thermite mixtures, and material identification by microwave breakdown spectroscopy (MIBS), are presented.

Electrode Erosion Effect on Decomposition of Methylene Blue in Aqueous Solutions

E. Faktorovich-Simon[1], N. Parkansky[1], V. Yacubov[1], B. Alterkop[1], O. Berkh[2], R. L. Boxman[1], Z. Barkay[3], Yu. Rosenberg[3], L. Burstein[3], A. Khatchtouriants[4]

[1] Electrical Discharge and Plasma Laboratory, [2] School of Electrical Engineering,
[3] Wolfson Applied Materials Research Center, [4] The Center for Nanoscience and Nanotechnology, Tel Aviv University, POB 39040, Tel Aviv 69978, Israel

simon.evelina@gmail.com

The pulsed submerged arc (SA) can decompose contaminant molecules in water. Recently, SA decomposition of Methylene Blue (MB) contamination was demonstrated. However, similarities and differences of the effect of particles eroded from Fe and Ti electrodes on the removal of MB from aqueous solutions have not been studied. The objectives of this research were to characterize and determine these effects on the MB decomposition efficiency in aqueous solutions. Electrode pairs of the same material (Fe, Ti) and combinations of these materials were used. The Fe and Ti electrodes were used without and with the addition of H_2O_2 into the treated solution, and followed by aging of the treated liquid. The treated solutions were examined by Raman, absorption and Fourier transform infrared (FTIR) spectroscopy. The produced particles were studied by SEM, XPS and XRD.

It was obtained that the electrode material defined the character of the MB decomposition. Periodic filtering of the particles during SA treatment with Fe electrodes exponentially decreased the MB concentration with time. Removal of the accumulated Fe particles during processing eliminated saturation, which occurred during processing without filtering. In contrast, eroded Ti particles positively influenced SA decontamination with Ti electrodes. Adding the particles produced by the SA in a solution without MB, into a solution containing MB, almost completely decontaminated the solution. Arcing with a Ti cathode and a Fe anode produced faster Ti erosion than the opposite polarity, as well as faster MB decomposition. SEM, XPS, XRD and Raman investigations revealed that titanium peroxide, strong oxidizer, was formed on the particle surfaces. The proposed mechanisms for SA MB decomposition are through the formation of the strongly oxidizing radicals during and after the SA treatment.

INVITED

Wave Compression in Plasma

Nathaniel J. Fisch

Princeton University, Princeton, NJ 08543, USA
fisch@princeton.edu

This talk reviews wave compression in plasma. The next generation of laser intensities may well be obtained using plasma-based effects to compress laser pulses, since using plasma overcomes the limitations of materials in conventional compression gratings. The compression effect occurs through irradiating plasma by a long pump laser pulse, carrying significant energy, which then releases its energy to a short counter-propagating pulse, through a resonant nonlinear Raman process. Aspects of this compression effect have been demonstrated experimentally. Recently, it was shown theoretically that, by proper chirping of the seed pulse, the group velocity dispersion may in fact be used to advantage. The seed chirping effect is distinguished from the pump chirping effect in a density gradient, which is also useful in a complementary way in that it may be used to eliminate premature backscatter from noise or to avoid deleterious precursors.

However, for very different applications, waves might also be compressed in plasma through adiabatic changes in time of the plasma medium. In particular, waves with small group velocity, such as Langmuir waves, might be compressed in plasma as the plasma itself is compressed. As the plasma wave grows, the ratio of the field energy to the plasma kinetic energy changes, which can in turn govern a variety of interesting plasma processes. Among the processes governed is the growth of coherent plasma waves through adiabatic compression, followed by the sudden loss of this energy to plasma ions or electrons, which can result in sudden heating of electrons or ions or sudden current and magnetic field generation or voltage drops. These kinds of effects are now becoming more relevant in view of the very large investment now being made in compression facilities for inertial confinement fusion.

Resonant excitation of plasma waves via formation of holes in phase space

P. Khain and L. Friedland

Racah Institute of Physics, Hebrew University, Jerusalem
pavelkh_il@yahoo.com

Resonant wave interactions play a major role in plasmas and other nonlinear media. Resonantly driven waves may exhibit autoresonance, i.e. a continuous nonlinear phase-locking despite variation of system parameters. In my talk, I will analyze the autoresonant excitation of a longitudinal plasma wave (PW) in a nonuniform plasma, driven by a constant frequency ponderomotive wave resulting from beating between two laser beams [1] (the process known as Stimulated Backward Raman Scattering).

Whitham's averaged variational principle [2] will be applied in studying dynamics of formation of autoresonant PW. A flat-top electron velocity distribution will be used as a simplest model allowing a variational formulation within the water bag theory. The corresponding Lagrangian, averaged over the fast phase variable, yields evolution equations for the slow field variables. The theory allows uniform description of all stages of excitation of the driven PW and predicts modulational stability of the associated nonlinear phase space structures (phase space holes). The adiabatic multi water-bag extension of the theory for applications to autoresonant PW for more general initial distributions will be also discussed. Numerical solutions of the system of slow variational equations will be compared with Vlasov-Poisson simulations.

[1] P. Khain, L. Friedland, A.G. Shagalov and J. S. Wurtele, Phys. Plasmas 19, 072319 (2012).
[2] G. B. Whitham, Linear and Nonlinear Waves (Wiley, New York,1974).

Aharonov-Bohm Constraint for Fusion

Asher Yahalom[1,2]

[1]Isaac Newton Institute for Mathematical Sciences
20 Clarkson Road, Cambridge CB3 0EH, United Kingdom
[2]Dept. of Electrical and Electronic Engineering, Faculty of Engineering
Ariel University Center of Samaria, Israel
asya@ariel.ac.il

It was shown that an Aharonov-Bohm (AB) effect exists in magnetohydrodynamics (MHD). This effect is best described in terms of the MHD variational variables. If a MHD flow has a non trivial topology some of the functions appearing in the MHD Lagrangian are non-single valued. Some of those functions are analogue to the phases in the AB celebrated effect. While the manifestation of the quantum AB effect is in interference fringe patterns, the manifestation of the MHD Aharonov-Bohm effect is through a new dynamical conservation law. This local conservation law will be shown to constrain the dynamics of MHD flows including fusion scenarios.

[1] Asher Yahalom and Donald Lynden-Bell "Simplified Variational Principles for Barotropic Magnetohydrodynamics". [Los-Alamos Archives - physics/0603128], Journal of Fluid Mechanics Volume 607 pages 235-265 (2008).

[2] Asher Yahalom "A Four Function Variational Principle for Barotropic Magnetohydrodynamics", EPL 89 (2010) 34005, doi: 10.1209/0295-5075/89/34005 [Los-Alamos Archives - arXiv:0811.2309].

Radial ion dynamics in a cylindrical hollow cathode

Jorge H. Palacio Mizrahi and Yakov Krasik

Physics Department, Technion, Haifa 32000, Israel
jorpalac@techunix.technion.ac.il

Plasma electron temperature and radial distribution of density, ion velocity, and potential for the plasma within a cylindrical hollow cathode are estimated through modeling of the ion dynamics in the radial direction taking into account ion inertia and nonzero ion temperature. The model considers an ion-neutral collision frequency more general than that considered in the well-known variable mobility model, allowing its application in a broad range of pressures commonly used in hollow cathode operations.

Enhanced momentum delivery by electric force to ions due to collisions of ions with neutrals

G. Makrinich and A. Fruchtman

H.I.T. - Holon Institute of Technology, Holon 5810201, Israel
gennady@hit.ac.il

Ions in partially-ionized argon, nitrogen, and helium gas discharges are accelerated across a magnetic field by an applied electric field, colliding with neutrals during the acceleration. The momentum delivered by the electric force to the ions, which is equal to the momentum carried by the mixed ion-neutral flow, is found by measuring the force exerted on a balance force meter by that flow exiting the discharge. The power deposited in the ions is calculated by measuring the ion flux and the accelerating voltage. The ratio of force over power is found for the three gases while the gas flow rates and magnetic field intensities are varied over a wide range of values, resulting in a wide range of gas pressures and applied voltages. The measurements for the three different gases confirm our previous suggestion [1], that the momentum delivered to the ions for a given power is enhanced by ion – neutral collisions during the acceleration, and that this enhancement is proportional to the square root of the number of ion-neutral collisions.

[1] G. Makrinich and A. Fruchtman, Appl. Phys. Lett. **95**, 181504 (2009).

Review of MagnetoPlasmaDynamic Thrusters

D. Lev

Rafael, Israel
Dan.R.Lev@gmail.com

MagnetoPlasmaDynamic thrusters (MPDTs) are a subclass of plasma thrusters with an overwhelmingly electromagnetic acceleration mechanism involving the interaction of a current between an anode and a cathode and a magnetic field which could be applied or induced by the current itself. This interaction gives rise to a Lorentz force density ($f = j \times B$) that accelerates propellant downstream and out of the thruster.

The thrust generation mechanism of the self-field MPDT is well understood and was characterized by Maecker[1] and Jahn[2] and analyzed by Choueiri[3]. High thrust and thrust density are also the big advantages that MPDTs have over other types of electric propulsion devices, such as the Hall thruster or the ion thruster.

MPDTs promise a wide range of thrust levels (100 mN - 100 N) that depends on the power level, along with high specific impulse (1000-5000 s) high thrust efficiency, (10%-25% with argon and up to 60% with lithium propellant), and the ability to process 100's of kW in a single compact device.

It has been well established that the addition of an applied magnetic field to the thruster increases its performance significantly. This is often necessary at low power levels (below 100 kW) where the current is too low for the self-induced magnetic field to be sufficient. Thrust, efficiency and specific impulse tend to increase with the applied magnetic field intensity. It has been observed4 that the thrust increases linearly with the product JB, where J is the total current applied to the thruster and B is the value of the applied magnetic field measured at the solenoid's center. The detailed physics behind the acceleration mechanism in applied magnetic field MPDT (AF-MPDT) is not yet fully understood and further experimental research is needed.

The presentation given at the IPSTA will give a general overview of the MPD thruster technology and the present research challenges and efforts to improve MPD thruster performance. An emphasis will be given on the speaker's research experience with applied-field MPD thrusters at the electric propulsion laboratory at Princeton University.

References

1. H. Maecker, "Plasma jets in arcs in a process of self-induced magnetic compression." Z. Phys., 141:198{216}, (1955).
2. R. G. Jahn, "Physics of Electric Propulsion," (McGraw-Hill, New York, 1968).
3. E. Y. Choueiri, "The scaling of thrust in self-field magnetoplasmadynamic thrusters," Journal of Propulsion and Power, 14(5):744{753}, (1998).

95GHz gyrotron with ferroelectric cathode

Moshe Einat, Moritz Pilossof, Roey Ben-Moshe, Haim Hirshbein and Dmitri Borodin

Faculty of Engineering, Ariel University Center of Samaria, Ariel, Israel
einatm@ariel.ac.il

Ferroelectric cathodes were reported as a feasible electron source for microwave tubes. However, due to the surface plasma emission characterizing this cathode, operation of millimeter wave tubes based on it remains questionable. Nevertheless, the interest in compact high power sources of millimeter waves and specifically 95GHz is continually growing. In this experiment a ferroelectric cathode is used as an electron source for a gyrotron with the output frequency extended up to 95GHz. Power above 5kW peak and ~0.5μs pulses are reported; duty cycle of 10% is estimated to be achievable.

Effective Cathode Voltage Increase in a Vacuum Arc with a Black Body Electrode Configuration

I. I. Beilis, **Y. Koulik, and R. L. Boxman**

Electrical Discharge and Plasma Laboratory, School of Electrical Engineering, Faculty of Engineering, Tel Aviv University, P.O.B. 39040, Tel Aviv 69978, Israel

beilis@eng.tau.ac.il

A Vacuum Arc Black Body Assembly (VABBA) was studied to produce a directed plasma jet. In the VABBA, the cathode material is emitted into a closed vessel formed by a water-cooled cylindrical Cu cathode and cup shaped W or Ta anode heated by the arc. Material eroded by the cathode spots as plasma and MPs impinges on the hot anode, and is re-evaporated from it, forming a dense, high-pressure plasma within the volume. The closed vessel operated as a 'black body' for the MPs, trapping them within it, while plasma was emitted through a single small anode aperture or a shower head aperture array. The emitted plasma can be used to deposit metal films. Arc currents were I=150-250 A and the arc duration was 120 s. The effective cathode voltage U_{cef} was determined calorimetrically using a thermocouple probe.

It was observed that U_{cef} increased with time from ~6.5 V when the anode was cold, agreeing well with literature data for conventional cathodic arcs. When the anode was sufficiently hot, U_{cef} increased with time and reached a steady state value of ~11-12 V. The increase of U_{cef} was explained by additional heat flux to the cathode from the plasma in the closed electrode assembly. In contrast, it should be noted that U_{cef} = 6-7V was invariant in vacuum arcs with different open electrode geometries and experimental conditions. With open geometries, a large portion of the generated plasma expands freely from the interelectrode gap.

Steady-State Plasma Bubbles Excited by Microwave Radiation

E. Gidalevich and R. L. Boxman
Electrical Discharge and Plasma Laboratory, Tel-Aviv University
boxman@eng.tau.ac.il

Supplying safe drinking water is a global problem. Plasma disinfection of water is currently investigated as an alternative to conventional water treatment. While pulsed submerged-arc plasma treatment has been demonstrated to effectively kill bacteria and destroy contaminating organic molecules, it also produces nano- and micro-particles from the electrodes. This paper considers an alternative submerged plasma for treating water, based on an electrodeless microwave discharge which will form plasma bubbles in the water, and will not produce eroded electrode particles.

A theoretical model is formulated for plasma in water vapor bubbles within liquid water, subjected to an electrical field which varies sinusoidally with time at microwave frequency. Vapor in the bubble is ionized by the field, producing plasma. Joule heating of the plasma is balanced by thermal conduction to the bubble boundary which is at the water boiling temperature. For the bubble to be stable, the heat flux from the plasma must be equated to the thermal flux into the water, which determines the bubble radius R. R varies with the field strength E. Steady-state solutions were found for two ranges of E, (0.8 - 5) kV/m and (35 - 60) kV/m, with considerably different bubble properties. For (0.8 - 5) kV/m, $R < \delta$, where δ is the skin depth of the plasma bubble. In this case, E inside the bubble is almost homogeneous. Ionization equilibrium is obtained by balancing the impact ionization and electron diffusion to the bubble border. The electron temperature T_e is considerably higher than the heavy component temperature T_a: $T_e \approx 15\times10^3$ K, $T_a \approx (1 - 5)\times10^3$ K. The temperature difference decreases with increasing E. In contrast, bubbles produced by E~(35 - 60) kV/m are characterized by $R > \delta$. The electromagnetic field is absorbed and attenuated in a thin layer in the bubble. In the internal region surrounding the center of the bubble, E is negligible. The plasma in the internal region is isothermal, and $T_e \approx T_a$. Ionization equilibrium is maintained by the balance between impact ionization with both 2- and 3-body recombination. R is found to be ≈ (2.8 - 0.2) mm for applied E of (0.8 - 5) kV/m, and R ≈ (32 - 7) mm for E of (35 - 60) kV/m; i.e. in both cases, R surprisingly decreases with increasing E. In both cases, the maximum power density σE^2 (where σ is the electrical conductivity) increases, while the total absorbed power in the bubble decreases with applied E. Maximum total absorbed power for E=(0.8 - 5) kV/m ($R < \delta$) is $P_{max} = 31$ W, while for E = (35 - 60) kV/m ($R > \delta$), $P_{max} = 5$ kW.

POSTERS

Two-frequency Microwave Pulse Compressor with a Magic-tee-based Plasma Switch

L. Beilin, A. Shlapakovski, and Ya. E. Krasik
Physics Department, Technion 32000 Haifa, Israel
leonidus@tx.technion.ac.il

Plasma switches are widely used in research on microwave pulse compression for the fast release of electromagnetic energy accumulated in a compressor storage cavity. Initiation of the plasma discharge in a gas-filled cavity drastically decreases the cavity Q-factor that actually results in opening of the cavity. In a traditional compressor configuration [1], a waveguide H-plane tee with the shorted side-arm is used as an interference switch. A switch must be in the closed state during energy storage, so that the length of the shorted arm of the tee is chosen to provide equality of its closing frequency and the eigenfrequency of the cavity. Therefore, traditional compressors typically operate in a single frequency, since for any frequency change, mechanical tuning is required. Meanwhile, for a Magic-tee with shorted side-arms, the closing state is provided if the arms are identical, *i.e.*, the necessary condition for energy storage in a compressor with a Magic-tee-based switch is frequency-independent. Hence, for such compressor, the operation in different cavity eigenmodes is possible without any mechanical tuning, which is important if a frequency variation is needed.

In this work, the two-frequency S-band compressor with a Magic-tee-based plasma switch is studied. It has been shown in numerical simulations using the 3-D code MAGIC [2] that the RF electric field amplitude in the place where the plasma discharge is to be triggered (quarter guide wavelength from the shorting wall in one of the Magic tee side-arms) can differ rather significantly for the frequencies of two neighboring eigenmodes of the cavity. Moreover, it can be higher or lower than the amplitude of the RF field in the antinodes of the excited standing wave in the cavity; this is of crucial importance for the proper operation of the plasma switch. Two kinds of optimal geometry were found in simulations: one providing a maximal field in the place of plasma discharge in only one frequency (it turns out to be ~1.24 times as much as the maximal field in the cavity), and another one providing the highest possible and equal fields for both operating frequencies (they turn out to be ~1.1 times as much as the maximal cavity field). In all cases, the cavity gain obtained in the simulations is in the range 14.5-15.5 dB. The release of microwave energy from the system was simulated by setting the ionization in the scope of the MAGIC code in the region of plasma discharge with the variable ionization rate and time. Experiments with the compressor charging by the input pulses of up to 2.5 μs duration generated by the magnetron of 200-400 kW power at 2.8 to 2.9 GHz frequency confirmed the simulation results concerning the stage of energy storage. Output pulses at both resonant frequencies (2.801 and 2.866 GHz) were obtained in the self-breakdown mode using conical discharge initiators to form the plasma at that location. In the geometry optimized for the frequency of 2.801 GHz, it has been shown that a higher cavity field is required to trigger a plasma discharge in 2.866 GHz frequency, in agreement with the simulations. Also, the duration of the output pulse in 2.866 GHz (~20 ns) is longer than that in 2.801 GHz, which was approximately equal to the cavity double transit time, ~11 ns. Experiments with plasma discharge triggering by the Surelite laser are planned.

1. J. Benford, J. A. Swegle, and E. Schamiloglu, *High Power Microwaves*, 2nd Ed., Taylor & Francis, New York, London, 2007.
2. B. Goplen, L. Ludeking, D. Smithe, and G. Warren, “User configurable MAGIC code for electromagnetic PIC calculations,” Comput. Phys. Commun., **87**(1/2), pp. 54–86, 1995.

High Intensity Laser Optical Manipulation by Plasma Channels for Contrast Ratio Enhancement and High Harmonic Generation

Y. Katzir and A. Zigler

Racah institute of Physics, Hebrew University, Jerusalem, Israel
yiftach.katzir@mail.huji.ac.il

Nowadays laser intensities are on a scale of terawatts ($10^{12}W$) and can reach focused intensities of $10^{21}W/cm^2$. Such intensities open up new frontiers in laser-matter interaction research, such as particle acceleration, high harmonic generation, and high energy density physics. Albeit tremendous progress in laser power since the invention of chirped pulse amplification (CPA), certain limitations have not been removed on par. These limitations include damage thresholds of optical components and unsatisfactory contrast ratio between the laser pulse and any preceding residual amplified radiation. To date the major means for overcoming these limitations are the use of perishable optics (e.g. plasma mirrors), large optical surfaces and short laser interaction lengths. In order to overcome these limitations we have created a small $F^{\#}$ ~3 durable lens which could withstand high laser intensities. This lens was used for suppression of the prepulse and increased contrast ratio by an order of magnitude. In addition, spatial tailoring of plasma channels for increased of laser-matter interaction lengths and created of quasi phase matching conditions for these interactions, yielding third harmonics at laser intensities as low as 10^9W/cm^2.

In order to generate the plasma we used two apparatuses: 1) Laser ablation by a *5*ns (*1*ns=10^{-9}sec.) pulsed Q-switch Nd:Yag laser carrying an energy of ~25mJ, used to ablate a face of short tube. This apparatus was used to create a plasma distribution fit for plasma lensing effect. 2) An electric discharge capillary ablation. This apparatus was used to create a plasma channel for the increase in laser-matter interaction length and generation of quasi phase matching conditions for third harmonic generation.

Investigation of the compression of magnetized plasma and magnetic flux

D. Mikitchuk[1] , E. Kroupp[1], R. Doron[1], E. Stambulchik[1], H. Strauss[2], A. Fisher[3], A. Fruchtman[4], and Y. Maron[1]

[1]*Faculty of Physics, Weizmann Institute of Science*
[2]*HRS Fusion*
[3]*Faculty of Physics, Technion-Israel Institute of Technology*
[4]*H.I.T. - Holon Institute of Technology*

dimitry.mikitchuk@weizmann.ac.il

This research investigates the phenomena of magnetic field flux and magnetized plasma compression by plasma implosion in a gas-puff z-pinch. The experiment differs from a standard z-pinch by the inclusion of an axial magnetic field component, in addition to the azimuthal magnetic field. This system is relevant to many studies in laboratory and space plasmas, and recently gained particular interest due to theoretical work describing its potential application for controlled nuclear fusion. In the experiment, we employ a cylindrical configuration, in which an initial quasi-static axial magnetic field (<1 T) is applied. A gas column is then injected into the anode-cathode gap, followed by an electric discharge (350 kA, 1.6 μs). The discharge ionizes the gas and also generates the azimuthal magnetic field that compresses the plasma and the axial field embedded in it. Spatially resolved spectra and 2D visible images of argon plasma self-emission are presented for different initial axial magnetic field values at different times of compression. These data allow for studying the instability and density dependence on the initial conditions. The axial magnetic field has been thought to stabilize Rayleigh Taylor instabilities. The visible images show perturbations, which are evidently aligned with the magnetic field. MHD instabilities, such as those observed in Tokamaks, are typically magnetically aligned. The data may indicate the presence of MHD instabilities driven by the current flowing parallel to the magnetic field, which are not possible in a standard z-pinch.

Novel high current carbon composite capillary cathode

T. Queller, J. Z. Gleizer and Ya. E. Krasik

Physics Department, Technion, Haifa 32000, Israel
quellertal@gmail.com

A carbon-epoxy multi-capillary cathode, providing a long duration, high-current and uniform emission electron beam was studied experimentally. The beam was generated in a planar vacuum diode, supplied by high-voltage generators, with and without the application of a guiding external magnetic field. The diode parameters were obtained using the measured voltage and current waveforms and time resolved visible light emission measurements. Two cathodes were investigated: (1) a cathode with a small emission area (~7 cm^2), generating an electron beam with electron energy of ~200 keV, current density of ~300 A/cm^2 and a pulse duration of ~450 ns. (2) A cathode with a larger emission area (~30 cm^2) generating an electron beam of ~300 keV, current density of ~500 A/cm^2 and a pulse duration of ~700 ns. It was found that in both cases, the source for electrons is the plasma formed as a result of a flashover inside the capillaries. It was shown that both cathodes sustain thousands of pulses without any degradation in their emission properties. Time- and space-resolved spectroscopic measurements were used to determine the cathode plasma density, temperature, and expansion velocity. It was found that for both cathodes, the density of the cathode plasma decreases rapidly with respect to the distance from the cathode. For the small emission area cathode, it was also found that the main reason for short-circuiting of the accelerating gap is the formation and expansion of the anode plasma. In addition, it was shown that when an external guiding magnetic field is present, the injection of the electron beam into the drift space with current amplitude exceeding its critical value, changes the radial distribution of the current density of the electron beam because the inner electrons are reflected from the virtual cathode.

Experimental Study of Cathode Spot Motion in a Vacuum Arc with a Long Rectangular Roof-shaped Cathode

B. Sagi, I. I. Beilis, V. Zhitomirsky, O. Margulis, and R.L. Boxman

Electrical Discharge and Plasma Laboratory, School of Electrical Engineering, Faculty of Engineering Tel Aviv University, P.O.B. 39040, Tel Aviv 69978, Israel

beilis@eng.tau.ac.il

The vacuum arc is widely used as metal plasma source. In filtered vacuum arc deposition (FVAD), the plasma is filtered from droplets of molten cathode material, known as macro-particles, by magnetic separation. Typical FVAD systems have a relatively small plasma output beam cross-section. However many applications such as wafer metallization, transparent conductive coatings for large flat panel displays and energy conserving coatings on architectural glass require uniform coatings over large areas. Therefore operation with a large cathode area is important. Controlled motion of the cathode spot using a magnetic field is commonly used to influence erosion uniformity on the cathode surface, and plasma beam uniformity.

In the present work the spot motion was investigated for a novel “roof-shaped” aluminum cathode. This design is a conceptual elongation in one direction of the commonly used truncated cone cathode, so that a wide plasma beam can be generated, and eventually coupled to a magnetic filter with a rectangular cross-section. The roof shaped cathode had sloped surfaces along the sides and ends, terminating at a flat upper surface. The cathode length, height and width (including side slopes) were 37.2; 7.4; and 5.2 cm, respectively. The arc was initiated by a trigger which contacted one end of the flat top surface of the cathode. The effect of the "roof slope" on cathode spot motion was tested.

Cathode spot behavior was observed with a high speed camera having 256X1280 pixel resolution, and a frame rate of 6000/s. The arc current was 200A. Each movie was analyzed using motion analysis software.

Preliminary result showed that on an Al cathode with a slope angle of 17^0 in a 5mT axial magnetic field (i.e. perpendicular to the flat surface of the roof), retrograde spots motion occurred on the sloped surfaces. The first spots started at the trigger location and then moved to the slope area, where there was a component of magnetic field parallel to the sloped surface, enabling retrograde motion along the length of the cathode. The cathode spot motion on the sloped surfaces was along a circuital track along the length of the cathode one side, continuing across the width on the end slope, and returning along the sloped surface on the other side of the cathode, to the other end slope, with an average velocity of 0.9m/s. This velocity agrees with that observed in "race track" motion on flat circular cathodes subjected to a radial magnetic field.

Relativistic magnetron with inbuilt magnetic block

A. Sayapin and A. Levin

Physics Department, Technion, Haifa 32000, Israel
sayapin@physics.technion.ac.il

Radial power output of relativistic magnetron (magnetron with radial output – MRO) allows one to distribute generated microwave radiation among several waveguide channels which are connected to the anode resonator cavities. In the case of sufficiently large quantity of resonators, the MRO could be successfully used as a multi-channel source of coherent microwave radiation, for example, to supply an antenna array. But with the increase in the number of resonators, technical difficulties arise related to generation of external insulating magnetic fields in the range 0.2 - 0.3 T. In the case of commonly used MRO, this magnetic field is produced by Helmholtz coils and the interaction space (IS) of electron flow with generated microwave field is only a small part of the magnetic field space (MFS).

The present work considers a design of magnetic system of the MRO [1-2] in which IS volume and MFS volume are at most approximate. In our design, an axial magnetic field in the anode-cathode gap is formed by a cylindrical magnet placed coaxially inside a hollow cathode and by cylindrical magnets inbuilt in the hollow slats of the magnetron anode block. The results of calculation and measurement of the magnetic field of the six- and twelve-resonator S-band relativistic magnetron are presented. The uniformity of the magnetic field in the radial direction is accomplished by selection of an optimal ratio between diameters of the cathode and anode magnets. Also, it was shown that a decrease in the length of the cylindrical magnets leads to increase in the magnetic field. However, in this case, the axial length of the MFS with an insignificant gradient of magnetic field becomes only a part of the anode-cathode axial length.

In our research it was shown that a decrease in the axial length of the IS can be achieved using the cathode with explosive electron emission mainly from its central part made in the form of projecting finned surface. Indeed, fast framing images of the light emission from the cathode, showed that the explosive emission plasma is formed at that location. Moreover, the results of experiments with relativistic MRO having a cathode with limited emitting surface (≤30% of the total cathode surface), show the increase by ~ 10% in the generated microwave power. Thus, these results allows one to achieve the required magnetic fields B_z = 0.22÷0.3 T using Neodymium (NdFeB) magnets with a remaining magnetization $B_0 = 1.4T$ in the design of the magnetron with large number of the anode resonators.

1. A. Sayapin, Y. Hadas, and Ya. E. Krasik, Appl. Phys. Lett. **95**, 074101 (2009).
2. A. Sayapin and A. Shlapakovski, J. Appl. Phys. **109**, 063301 (2011).

Microwave Plasma Excitation for a Lighting Application

Daniel Tsimanis and Reuven Boxman

Electrical Discharge and Plasma Laboratory, Tel Aviv University
danielt3@post.tau.ac.il

Lighting consumes 19% of worldwide electricity generation. High power outdoor lamps mostly use electrical discharge plasmas. Generally the lifetime of these lamps is limited by effects associated with electrode erosion, and most of these lamps include Hg vapor. This paper explores a scheme for microwave excitation of an electrodeless discharge, which ultimately can be applied to a lamp having longer life and no Hg vapor. The scheme is based on excitation of a circular TE_{01} microwave mode having only an azimuthal magnetic field, and coupling it into a cylindrical discharge vessel having a transparent conductive coating. The research includes theoretical and computer simulated calculations of the electromagnetic field, and experimental measurements using an uncoated discharge vessel housed in a cylindrical waveguide which simulates the transparent conductive coating; the experimental measurements will be presented in the present paper.

Experiments were conducted with a set-up including a 2.45 GHz magnetron microwave generator with a nominal power of 1 kW, a loop antenna, a 15 cm diameter Al waveguide, a cylindrical glass discharge vessel equipped with ports for gas entry and pumping and a quartz window for spectroscopic observations, and a gas flow system including a mass flow controller and rotary vacuum pump. Discharges were excited in Argon with a pressure of 1.5 – 10 mbar. The spectral irradiance of the plasma was measured with a spectrometer. The total power absorbed by the material surrounding the discharge was determined from the temperature rise of the vessel and waveguide.

It was found that the temperature of the discharge vessel rose by about 25 C during 150 s of operation. Approximately 250 W was absorbed by the surrounding vessel and waveguide. The emission spectrum in the ultraviolet and visible regions consisted of typical Ar lines, whose intensity increased with pressure.

Spectroscopic research of the plasma parameters generated during nanosecond “runaway” discharge at atmospheric pressure

S. Yatom, and Ya. E. Krasik

Physics Department, Technion, Haifa 32000 Haifa, Israel

E. Stambulchik

Physics Department, Weizmann Institute of Sciences, Rehovot 76100, Israel
shurikyatom@gmail.com

Optical Emission Spectroscopy was employed to study the parameters of the plasma generated in nanosecond time scale discharge in He gas at atmospheric pressure. This discharge was initiated by runaway electrons, generated by the application of high voltage pulse with amplitude up to 150 kV and 5 ns duration, to the cathode made of stainless steel blade. The parameters of the plasma were studied with fine temporal and spatial resolution using imaging spectrometer with intensified fast framing camera at its output. The obtained results imply a presence of two different plasmas with different densities and possible geometrical model of the discharge channel is suggested. Explosive emission nature of generation of the discharge channel in He gas is shown according to the spectroscopy and fast-framing optical photography results.

INDEX