Israel Plasma Science
and Technology
Association

האגודה הישראלית
למדע וטכנולוגית
הפלסמה

affiliated with the Israel Vacuum society
חטיבת האגודה הישראלית לואקום

THE FOURTH ISRAELI CONFERENCE ON PLASMA PHYSICS AND ITS APPLICATIONS

BOOK OF ABSTRACTS

TECHNION – ISRAEL INSTITUTE OF TECHNOLOGY
32000 HAIFA, ISRAEL

15 FEBRUARY, 2001

Israel Plasma Science and Technology Association

האגודה הישראלית למדע וטכנולוגית הפלסמה

affiliated with the Israel Vacuum society

חטיבת האגודה הישראלית לואקום

THE FOURTH ISRAELI CONFERENCE ON PLASMA PHYSICS AND ITS APPLICATIONS

15/2/2001, Technion – Israel Institute of Technology, 32000 Haifa

Program Committee:

Dr. Yakov E. Krasik – Technion (Chairman)
Prof. Yitzhak Maron – Weizmann Institute of Sciences
Dr. Josef Shiloh - Rafael
Prof. Reuven Boxman – Tel-Aviv University
Prof. Enrique Gruenbaum – Tel-Aviv University
Prof. Michael Mond – Ben-Gurion University
Prof. Amnon Fruchtman – Holon Technological Center

Local Committee:

Prof. Joshua Felsteiner - Technion
Dr. Yakov Slutsker - Technion
Dr. Yosef Gleizer - Technion
Dr. Yakov Krasik - Technion
Mr. Alex Dunaevsky - Technion
Ms. Liz Yodim – conference coordinator, Ph.: 04-829-2608

Conference Sponsor:

The Department of Physics, Technion – Israel Institute of Technology.
Mark Technologies, Israel Scientific Instruments, El-Tan Technologies, Edwards Israel Vacuum Ltd., SPT, Rosh-Electro-Optics.

Program

I. Registration and Opening

8:15 – 9:00 Registration

9:00 – 9:20 General Meeting and Elections – Reuven Boxman

II. Basic Plasma Physics

Chairperson – **Joseph Shiloh (Rafael)**

9:20 – 9:25 Isaak Beilis (Tel Aviv University) "Igor Rutkevitch – Plasma Physicist"

9:25 – 9:45 Shalom Eliezer (Soreg NRC) and Jose Maria Martinez Val (Nuclear Fusion Institute, Spain) - Cumulation of Laser Induced Magnetic Field by a Z-Pinch Device - **In memory of Igor Rutkevitch**

9:45 – 10:00 Lazar Friedland (Hebrew University) and Arkadi Shagalov (Institute of Metal Physics) – Pattern Formation by Synchronization in Pure Electron Plasmas and 2D Vortex Dynamics

10:00 – 10:15 O. Sadot, A. Rikanati, D. Oron, G. Ben-Dor, and D. Shvarts (Nuclear Research Center Negev, Ben Gurion University) – Effect of Nonlinear Initial Conditions on the Shock Induced Richtmyer-Meshkov Hydrodynamic Instability

10:15 – 10:30 Y. Srebro, D. Oron, and D. Shvarts (Nuclear Research Center Negev, Ben-Gurion University), The Effect of Laser Imprint on Pertubaration Growth in Direct Drive Inertial Confinement Fusion

10:30 – 11:00 ***Refreshments and Posters***

III. Radiation sources – I

Chairperson – **Lazar Friedland (Hebrew University)**

11:00 – 11:30 Evgenii Stambulchik (Weizmann Institute of Sciences) – Polarization Spectroscopy Measurements and Theoretical Modeling at the WIS Plasma Laboratory

11:30 – 11:45 M. Fraenkel, Z. Henis, S. Eliezer (Soreq NRC), A. Zigler (Hebrew University), N.E. Andreev (High Energy Research Center, Russia) – Measurements of the Energy Penetration Depth into Solid targets Irradiated by Ultra-Short Laser Pulses

11:45 – 12:00 R. B. Baksht, A. V. Fedunin, A. Yu. Labetsky, V. I. Oreshkin, A. G. Russkikh, and A. V. Shishlov (High Current Electronics Institute, Russia) – Long Time Implosion Experiments with Gas Puff

12:00 – 12:15 D. Kaganovich and A. Zigler (Hebrew University) – Velocity Control and Staging in Laser Wakefield Accelerators Using Segneted Capillary Discharges

12:15 – 13:45 **Lunch (will be available on site) and Posters**

IV. Radiation sources – II

Chairperson – **Joshua Felsteiner (Technion)**

13:45 – 14:30 Yu. P. Bliokh (Technion) – Plasma Electronics. Theoretical and Experimental Investigations of Plasma Nonlinearity in Powerful Microwave Oscillators

14:30 – 14:45 A. Kesar and E. Jerby (Tel-Aviv University) - Spatial Steering Resonance Maser Array Antenna by Magnetic Field

14:45 – 15:00 M. Arbel, A. Abramovich, A. I. Eichenbaum, A. Gover, H. Kleinman, I.M. Yakover (Tel-Aviv University), and Y. Pinchasi (The College of Judea and Samaria) – Super-Radiant and Stimulated Super-Radiant Emission in a Pre-Bunched Beam Free Electron Maser

15:10 – 15:15 A. Yahalom, Y. Pinhasi, and Y. Lurie (College of Judea and Samaria) –Variation Principles of Electromagnetic Field Excitation in Waveguides

15:15 – 16:00 ***Refreshments and Posters***

V. Plasma Applications and Industrial Processes

Chairperson – **Rueven Boxman (Tel-Aviv University)**

16:00 – 16:30 A. Dunaevsky, Ya. E. Krasik, and J. Felsteiner (Technion) – Plasma Cathodes for Electron Beam Generation

16:30 – 16:45 A. Shahadi and S. Yatsiv (Hebrew University), and Y. Sintov and E. Jerby, (Tel-Aviv University) - Microwave-excited CO2 Lab-Laser with an Axially-Homogeneous Discharge

16:45 – 17:00 A. Pokryvailo and Y. Yankelevich (Soreq NRC) – High-Power Short Pulsed Corona: Investigation of Electrical Parameters, Abatement of SO2 and Ozone Generation

17:00 – 17:15 R. L. Boxman, V. Zitomirsky, and S. Goldsmith (Tel-Aviv University) – Influence of Oxygen Pressure on Filtered Vacuum Arc Deposition of Tin Oxude Thin Films

17:15 – 17:30 A. Cohen-Zur and A. Gany (Technion), A. Fruchtman and J. Ashkenazy (Holon Academic Institute of Technology), Parametric Study of Hall Thruster Performance Using a One-Dimensional Steady-State Model

17:30 – 18:15 ***Students Awards, Cocktail and Farewell***

Posters

1. R. Arad, K. Tsigutkin, Yu. Ralchenko, D. Osin, and Y. Maron (Weizmann Institute of Sciences), and A. Fruchtman (Holon Academic Institute of Technology) – Physics of the Interaction of Pulsed Magnetic Fields with Plasmas and Relevance to Applications

2. Yu. Ralchenko and Y. Maron (Weizmann Institute of Sciences) – Accelerated Recombination in Cold Plasmas with Metastable Ions Due to Resonant Deexcitation

3. G. Makrinich, J. Ashekanazy, and A. Fruchtman (Holon Academic Institute of Technology) – Study of RF-DC Voltage Plasma

4. Yu. Bliokh, J. Felsteiner, Ya. Z. Slutsker, and P.M. Vaisberg (Technion) – Characteristics of a High-Power RF Oscillator Based on a Pulsed Hollow–Cathode Discharge

5. Ya. Z. Slutsker Yu. P. Bliokh, J. Felsteiner, and P.M. Vaisberg (Technion) – Bohm Criterion Failure in Non-Stationary Plasma

6. Yu. Dolinsky and T. Elperin (Ben-Gurion University) – Effect of Finite Thickness of the Transition Layer on Particle Localization in the External Field Near the Interface Boundary

7. S. Cuperman (Tel-Aviv University), C. Bruma, and K. Komoshvili (The College of Judea and Samaria) - Solution of the Full Electromagnetic Wave Equation for Arbitrary Aspect Ratio and Magnetic Shear Values, Non-Circular Cross-Section, Pre-heated Tokamak Plasmas. I. The Alfven Wave Frequency Range

8. A. Faingersh, Y. Yakover, and A. Gover (Tel-Aviv University) – Development and Characteriztion of a High-Q Remotely Controlled Quasi-Optical mm-Wave Resonator for FEL

9. K. Chirko, Ya. E. Krasik, A. Dunaevsky, and J. Felsteiner (Technion) – High-Frequency Electron Beam Modulation, Transportation and its Interaction with a Slow Wave Structure

10. J. Z. Gleizer, A. Krokhmal, Ya. E. Krasik, and J. Felsteiner (Technion) – Hollow-Cathode Electron Source with a Fast Gas-Puff Valve

11. A. Dunaevsky, Ya. E. Krasik, and J. Felsteiner (Technion) – Operation of Ferroelectric cathodes with a Control Grid

12. Ya. E. Krasik (Technion) – Novel Gaseous Plasma Gun for Plasma Opening Switches

13. I. I. Beilis (Tel – Aviv University) and M. Keidar (University of Michigan, USA) - Plasma Jet Expansion and Plasma Voltage in the High-Current Vacuum Arc in Axial Magnetic Field

ABSTRACTS

Oral - Basic Plasma Physics

- In memory of Igor Rutkevitch -

Cumulation of Laser Induced Magnetic Field by a Z-pinch Device

Shalom Eliezer
Plasma Physics Department, Soreq NRC, Yavne 81800, Israel

and

Jose Maria Martinez Val
Nuclear Fusion Institute, ETSII, c. Jose Gutierrez Abascal, Madrid 28006, Spain

A central filament is assumed to be axially positioned inside a cylindrical shell collapsing by the Z-pinch effect. Generating a high magnetic field between the cylindrical shell and the filament induces the cumulation (i.e. concentration) process. The initial magnetic field (of order of few Megagauss) is generated by a circular polarized laser light (CPLL).[1,2] The inverse Faraday effect induces an axial magnetic field between the shell and the filament. Assuming a dissipationless approach, it is shown that this problem is equivalent to two point particles moving in a potential.[3]

1. Y. Horovitz et al., Phys. Rev. Lett., **78**, 1707 (1997).
2. Y. Horovitz et al., Phys. Lett., **A245**, 329 (1998).
S. Eliezer and J. M. Martinez Val, Phys. Rev., **E62**, 7227 (2000).

Pattern Formation by Synchronization in Pure Electron Plasmas and 2D Vortex Dynamics

Lazar Friedland
Racah Institute of Physics, Hebrew University, Jerusalem, 91904

and

Arkadi Shagalov
Institute of Metal Physics, Ekaterinburg 620219, Russian Federation

Magnetized, pure electron plasmas trapped in Penning-Malmberg traps can be modeled (in the drift approximation) by two-dimensional Euler equations of ideal fluids. The plasma density in this approximation is analogous to vorticity, while the radial electric field potential to the stream function of the fluid velocity field. For instance, electron plasma cylinder aligned with the magnetic field is analogous to a circular vortex patch solution of an ideal fluid. We shall show that by starting in such a circular equilibrium, applying a weak external oscillating potential of appropriate symmetry, and slowly varying the frequency of these oscillations, one can excite and control m-fold symmetric interface (vortex) waves in two dimensions (V-states, discovered by Deem and Zabusky nearly 20 years ago. The phenomenon is due to continuos nonlinear resonance in the system as the excited plasma (vortex) boundary preserves its functional form despite the drive, but self-adjusts the aspect ratio to synchronize with the driving potential oscillations. A similar approach can be used in controlling interface dynamics subject to global constraints in many other fields of physics.

Effect of Nonlinear Initial Conditions on the Shock Induced Richtmyer-Meshkov Hydrodynamic Instability

O. Sadot[1,2], A Rikanati[1,2], D. Oron[1], G. Ben-Dor[2] and D. Shvarts[1,2]
1. Nuclear Research Center Negev 84190 ISRAEL
2. Ben-Gurion University of the Negev 84105 ISRAEL

The Richtmyer-Meshkov (RM) shock wave induced hydrodynamic instability [1,2] occurs when a shock wave passes through an initially perturbed two fluids interface. Under the instability, initially small perturbations on the interface grow into a formation of interpenetrating bubbles and spikes, causing the two fluids to mix. This instability, together with the gravity induced Rayleigh-Taylor [3] instability play a major role in achieving energy gain in Inertial Confinement Fusion. As was shown by Alon *et al.*[4], the evolution of a multi-mode random initial perturbations is strongly related to the evolution of the single-mode case. The Richtmyer impulsive model predicts constant growth rate at the linear stage for the single mode initial perturbation. The model prediction for the initial growth rate is:

$$U_{RM}=A^{*}\,k\,a^{*}\,\Delta U_{1D}$$

where k is the wave number, A^{*} is the post shock Atwood number, ΔU_{1D} is the one dimensional post shock interface velocity and a^{*} is the post shock amplitude. Recently, moderate and high Mach numbers experiments have shown a large reduction of the initial instability growth velocity from the above impulse model prediction [5,6]. Even though, the initial amplitude in those experiments was high such as $k\,a_0 > 1$. It was suggested by [7] that this reduction is mainly a consequence of the high Mach number that used in those experiments due to the fact that:

$$U_{RM} \approx U_{shock}-\Box U_{1D}$$

in order to clarify the causes to the reduction, we have performed similar experiments and simulations with $ka_0 > 1$ but at low Mach numbers (i.e. $M \approx 1.2$). The results of the experiments and simulations do exhibit similar reduction factor as a function of ka^{*}. We can conclude that in those experiments the dominant cause for the reduction is mainly due to high initial amplitude (i.e. geometrical effect) rather than Mach number effect.

1. Richtmyer R. D., Commun, Pure Appl. Math. **13**, 297 (1960).
2. Meshkov E. E., Fluid Dyn. **4**, 101 (1969).
3. Lord Rayleigh, Proc. London Math. Soc. **14**, 170 (1883); Taylor G. I., I. Proc. Roy. Soc. **A201**, 192 (1950).
4. Alon U., Hecht J., Ofer D. and Shvarts D. Phys. Rev. Lett. **74**,534 (1995).
5. Aleshin *et al.*, In the Proceedings of the Sixth International Workshop on Physics Compressible Turbulent Mixing, edited by G. Jourdan and L. Houas Marseille, France, p.1 (1997).
6. Dimonte G., Schneider M. B., Phys. Rev. E **54**, 3740 (1996).
7. Holmes *et al.*, J. Fluid Mech. **55** 389 (1999).

The Effect of Laser Imprint on Perturbation Growth In Direct Drive Inertial Confinement Fusion

Y. Srebro[1,2], D. Oron[2], and D. Shvarts[1,2,3]

1. Physics Department, Ben-Gurion University, Beer-Sheva, Israel

2. Physics Department, Nuclear Research Center - Negev, Israel

3. Department of Mechanical Engineering, Ben-Gurion University, Beer-Sheva, Israel.

Imprint of nonuniformities in the laser intensity into mass perturbations in the target is one of the major sources for geometrical distortions during direct drive Inertial Confinement Fusion (ICF) implosions. Small perturbations introduced by the target surface roughness and by the laser imprint grow due to the Rayleigh-Taylor instability, and may reduce significantly the efficiency of the nuclear fusion.

In the present work we present a numerical simulation based theoretical analysis of static and dynamic laser imprint. Using two-dimensional numerical simulations, the equivalence between laser nonuniformities and mass perturbations in the target is analyzed as a function of perturbation wavelength, laser intensity and pulse shape.

The reduction of laser imprint by temporal changes in the laser beam is analyzed by calculations of the integrated on-target nonuniformity, by comparisons to other models and to experiments and by full numerical simulations of dynamic nonuniformity imprint.

Applications of the resulting static and dynamic imprint efficiencies are presented. The spectrum of mass modulations which is equivalent to laser imprint is calculated, and its nonlinear growth due to the Rayleigh-Taylor instability is calculated using a Haan modal model for several experimental configurations.

Oral - Radiation sources – I

Polarization Spectroscopy Measurements and Theoretical Modeling at the WIS Plasma Laboratory

E. Stambulchik
Department of Particle Physics, Weizmann Institute of Science, Rehovot 76100

Plasma Polarization Spectroscopy (PPS) has recently become of an increasing interest. The idea behind PPS is that polarized light emitted by plasma should indicate the presence of an anisotropy such as electric or magnetic fields with preferable direction or anisotropy in the particle velocity distributions. Provided that the underlying processes can be well analyzed, the light polarization can thus be used to infer the fields and/or directionality of the particle trajectories in the plasma. In the WIS Plasma laboratory, spectroscopic methods implementing analysis of the polarization properties of the detected radiation has been in use for many years, including observations of fluctuating anisotropic electric fields in ion diodes [1], magnetic field measurements in plasma switches [2,3], interpretation of experimental data collected in the Particle Beam Fusion Accelerator II (PFBA II) diode [4,5]. Presently, a future work is planned on high-accuracy Doppler-free measurements of forbidden lines with different polarizations yielding the spatial distributions and orientations of the electric fields in the plasma [6].

1. E. Sarid, Y. Maron, and L. Troyansky, Spectroscopic investigation of fluctuating anisotropic electric fields in a high-power-diode plasma, Phys. Rev. **E 48**, 1364 (1993).
2. A. Weingarten, C. Grabowski, A. Fruchtman, and Y. Maron, The time-dependent electron density and magnetic field distributions in a 70-ns plasma opening switch, Proceedings of the 12th International Conference on High-Power Particle Beams.
3. R. Arad, K. Tsigutkin, A. Fruchtman, and Y. Maron, Magnetic field interaction with multi-component plasmas in sub-microsecond time scales, To be submitted to Physics of Plasmas.
4. J.E. Bailey, A.B. Filuk, A.L. Carlson, D.J. Johnson, P. Lake, E.J. McGuire, T.A.Mehlorn, T.D. Pointon, T.J. Rank, W.A. Stygar, Y. Maron and E. Stambulchik, Basic and applied atomic spectroscopy in high-field ion diode acceleration gaps, Laser Part. Beams, **14**, 543 (1996).
5. E. Stambulchik, Y. Maron, and J.E. Bailey, Polarization properties of excitation mechanisms in ion acceleration gaps. To be published.
6. K. Tsigutkin, Ph.D. thesis, Weizmann Institute of Science

Measurement of the Energy Penetration Depth into Solid Targets Irradiated by Ultra-Short Laser Pulses

M. Fraenkel, Z. Henis, S. Eliezer
Plasma Physics Department, Soreq NRC, Yavne 81800, Israel

A. Zigler
Racah Institute of Physics, Hebrew University, Jerusalem, Israel

N. E. Andreev
High Energy Density Research Center, Joint Institute for High Temperatures Russian Academy of Sciences, ul. Izhorskaya 13/19, Moscow, 127412 Russia

The energy penetration depth of a short pulse (100fs) Ti-Sapphire laser (0.8 □m) of intensity 31016 W/cm2, in solid density materials has been measured. High-Z (BaF2) and low-Z (MgF2) solid layers targets were used. The penetration depth was determined from the measurement of the x-ray emission spectra, as a function of the target thickness. The investigation of these spectra showed that in the low-Z case, solid density material to a depth of 50nm was heated to a peak electron temperature of ~ 150eV. For the high-Z material, the penetration depth corresponding to this temperature exceeded 100nm. This is the first experimental evidence of a larger heat penetration depths in a high-Z material in comparison to a low-Z material. A model based on electron heat conduction is used to estimate the energy penetration depth. It is suggested that the larger heat penetration in high-Z material is due to heating of the material, caused by the radiation flux, generated by the electron heat conduction.

Long Time Implosion Experiments with Gas Puffs

R.B.Baksht, A.V.Fedunin, A.Yu.Labetsky, V.I.Oreshkin, A.G.Russkikh, A.V.Shishlov
High Current Electronics Institute SB RAN, Tomsk, 634055, Russia

Long time implosion experiments with argon single and double gas puffs have been conducted on the GIT-12 generator at the current level of 2.22.4MA. The double gas puff was used as one of the alternative ways to provide a stable implosion at long implosion time. In the experiments the implosion time was in the range from 230 to 340ns. The results of the experiments were compared to the results of the 2D snow plow simulations. The experiments and the simulations show that the final pinch is sufficiently stable when the inner-to-outer shell mass ratio is greater than 1. The maximum argon K-shell yield obtained in the experiments is equal to 740J/cm with the radiation power of 220GW/cm. At the long implosion times, the K-shell yield obtained in the double gas puff implosion is twice as much as the K-shell yield of 4-cm radius single gas puff with the radiation power increased more than an order of magnitude.

Experiments with the single gas puff had shown that the portion of the plasma shell material confined in bubbles is accelerated much more rapidly than the rest of the material. Part of the experiments with single gas puffs were performed on the IMRI 4 generator(400kA, 800ns) with the Faraday rotation diagnostics. Experiments showed that inside the plasma column the toroidal bubbles appeared. The additional resistance delivered by the toroidal bubbles was about 0.1/cm that is near the theoretic estimates by A. L.Velikovich, L. I. Rudakov, J. Davis, J. W. Thornhill, J. L. Giuliani, Jr., and C. Deeney, Phys. Plasmas **7**, 3265-3277 (2000).

Velocity Control and Staging in Laser Wakefield Accelerators Using Segmented Capillary Discharges

D. Kaganovich, A. Zigler
Hebrew University, Jerusalem, Israel

To achieve multi GeV electron energies in the laser wakefield accelerator (LWFA) it is necessary to propagate an intense laser pulse long distances in a plasma channels while maintaining a proper phase with the accelerated electrons. We have demonstrated a new method that allows controlling the laser group velocity in long, multi-stage plasma channels. The control is achieved by modifying the index of refraction through variation of plasma density using a segmented capillary discharge.

Oral - Radiation sources – II

Plasma Electronics. Theoretical and Experimental Investigations of Plasma Nonlinearity in the Powerful Microwave Oscillators

Yu.P. Bliokh
Department of Physics, Technion, 32000 Haifa

During more than 50 years of Plasma Electronics development a great number of experimental and theoretical results have been achieved. These results allow understanding of physical processes which originate under charged particles beams interaction with a plasma. However, one essential aspect of such interaction remains insufficiently studied. The question is about a correlation between conditions of microwave excitation by a beam in plasma and plasma parameters. Each of these effects, namely the influence of plasma parameters on conditions of microwave excitation by a beam and plasma parameters variations under the influence of propagating microwave radiation are well known and investigated enough. However their common action under beam-plasma instability (BPI) development were not studied systematically, although the role of such reciprocal influence on character of these processes may be very large. The aim of this report is a review of recent theoretical and experimental investigations of such plasma nonlinearity in plasma-filled trawling-wave tubes. N.M.Zemlyansky and E.A.Kornilov have done experiments in Kharkov Institute of Physics&Technology (KhPhTI). Development of the theoretical model was started in KhPhTI (Yu.P.Bliokh, Ya.B.Fainberg, M.G.Lyubarsky, and V.O.Podobinsky) and continues by author in Technion. The developed theory takes into account two main reasons of the plasma density redistribution: high frequency pressure (HFP) force which "push out" plasma from the regions with increased microwave amplitude, or microwave discharge, which appears in the region where amplitude is large enough. Displaced (under HFP action) or additionally originating (under (BPD) development) plasma propagates from the disturbance source in the form of slow plasma waves (for example, ion-sound or magneto-sound waves), and the BPI develops in the nonhomogeneous plasma. It changes both magnitude and longitudinal distribution of excited microwave amplitude. As a result either new steady-state, or automodulation regime can appear. Developed theory predicts appearance of a deep low-frequency automodulation of microwave power when the beam current exceeds some threshold. This effect was observed experimentally and parameters of automodulation are close to calculated ones. The ion-sound waves, which are the reason of automodulation appearance, were also observed experimentally. It was shown theoretically and experimentally that non-stationary self-consistent plasma density and microwave power redistribution along the system can be the reason of microwave pulse shortening and power limiting mechanism in plasma-filled microwave radiation sources. It was shown also that the same mechanism leads to the stochastization of the microwave signal. Stochastic radiation, which is obtained by plasma-filled structure use, differs strongly by it spectral density homogeneity from stochastic radiation of analogous vacuum devices.

Spatial Steering of Cyclotron-Resonance Maser Array Antenna by Magnetic Fields

A. Kesar and E. Jerby

Faculty of Engineering, Tel Aviv University, Ramat Aviv 69978, ISRAEL

The novel concept of radiation lobe generation and steering by cyclotron-resonance maser (CRM) array is presented. In this scheme the gain and phase of each CRM-element in the array are tuned by magnetic fields which control the cyclotron synchronism condition and the pitch-ratio of each CRM-element. These operating parameters are controlled by the magnetic fields of the solenoid and the kicker, respectively. A numerical example of a CRM-array operating in a gyro-TWT mode is presented. The radiation pattern of a 10-element CRM phased array (15kV, 1A each) is calculated. The radiation lobe steering by the magnetic field controls is demonstrated in this analysis. A 40 lobe steering range is shown for the 10-element CRM-array at 7.3GHz. An experimental device is built in our laboratory to demonstrate the active CRM-array antenna concept. Preliminary experimental results of gain and phase-delay of a single CRM-element, as function of electron-beam parameters are presented. These results are compared to the numerical model.

Super-Radiant and Stimulated Super-Radiant Emission in a Pre-Bunched Beam Free Electron Maser

M. Arbel, A. Abramovich, A.L. Eichenbaum, A. Gover, H. Kleinman, Y. Pinhasi*, I.M. Yakover

Tel – Aviv University, Tel-Aviv – Dept. of Physical Electronics

* *The College of Judea and Samaria , Ariel - Dept. of Electrical and Electronic Eng.*

An electron beam prebunched at the synchronous free-electron laser frequency and passing through a magnetic undulator, emits coherent (super-radiant) synchrotron undulator radiation at the bunching frequency. If an input electromagnetic wave is introduced into the interaction region, at the same bunching frequency and at a proper phase, the radiation process will be stimulated (Stimulated Prebunched Beam radiation). We report first experimental measurements of stimulated super-radiant emission in a pre-bunched free-electron maser. Measurements are in a good agreement with theory.

Variational Principles of Electromagnetic Field Excitation in Waveguides

A. Yahalom, Y. Pinhasi and Y. Lurie
Faculty of Engineering, Dept. of Electrical and Electronic Engineering
College of Judea and Samaria, Ariel 44284, Israel

Interaction of radiation and plasma waves in many electron devices takes place inside an open or closed cylinder (waveguide) of some arbitrary cross-section. A well-known example is the free-electron laser, in which the electromagnetic field interacts with an electron beam in the presence of a periodic magneto-static wiggler field, generating high power coherent radiation. In order to achieve lasing, the radiation is being excited inside a resonator, dictating boundary conditions for both forward and backward waves.

Solution of the electromagnetic radiation field inside the resonator, requires simultaneous integration of the coupled excitation equations of forward and backward waves [1]. However, it becomes difficult to accommodate the different boundary conditions for both forward and backward modes in the same numerical integration scheme. Although the radiation power is built gradually in the direction of the electron beam propagation, the natural boundary conditions for the backward waves are given at the end of the interaction region. Thus it is desirable to develop a numerical procedure that allows non-local boundary conditions.

We suggest employing variational methods for calculating the total electromagnetic field, including excitation of forward and backward waves. Our developed variational principle is based on formulation of the electromagnetic field action in the space-frequency domain. Further more, the expression for the action is developed utilizing a modal representation of the total electromagnetic field in terms of the eigenmodes of the geometry in which the radiation is excited [2].

[1] N. Markuvitz and J. Schwinger, J. Appl. Phys, **22** 806 (1951).
[2] Y. Pinhasi, Yu. Lurie and A. Yahalom, "Model and simulation of wide-band interaction in free-electron lasers", accepted for publication in Nucl. Instr. and Meth. in Phys. Res. A (2000).

ORAL – PLASMA APPLICATIONS AND INDUSTRIAL PROCESSES

Plasma Cathodes for Electron Beam Generation

A. Dunaevsky, Ya. E. Krasik, and J. Felsteiner
Department of Physics, Technion- Israel Institute of Technology, 32000 Haifa, Israel

Generation of electron beams with a current amplitude of 105 – 106 A, and pulse duration of 10-9–10-7 s requires electron sources which can supply current density of 1-100 A/cm2. In addition, for many applications it is very important that the electron source should produce a uniform electron beam with a large area simultaneously with the beginning of the accelerating pulse and it should operate with a high repetition rate without significant decrease of the emission properties and without vacuum deterioration. Low transverse divergence of the generated electron beam is required in many othe applications as well. In this report we present a review of experimental studies of different types of plasma electron sources for the generation of electron beams under moderate accelerating electric fields (105 V/cm). The operation of different passive sources (i.e. sources where the plasma formation is caused by the application of the accelerating electric field) like metal-ceramic, velvet, corduroy, carbon fibers, and carbon fabric is described. The parameters of the electron beams generated by the passive cathodes are compared with the parameters of the electron beams generated by ferroelectric plasma cathodes which are active plasma sources (i.e. sources where the plasma is formed due to the application of a driving pulse from an additional power supply). All the investigated cathodes had the same diameter and were tested at the same experimental conditions. Different types of electrical and optical diagnostics were used to study the formation and parameters of the plasma, the potential distribution inside the anode-cathode gap, and the uniformity and divergence of the extracted electron beam and their dependence on the amplitude and rise time of the accelerating pulse. It was shown that for all the studied cathodes the electron emission occurs from a surface discharge plasma. Results of the lifetime of the investigated cathodes and their compatibility with vacuum requirements are presented as well.

Microwave-Excited CO2 Slab-Laser with an Axially-Homogeneous Discharge

A. Shahadi, Y. Sintov, E. Jerby, and S. Yatsiv

Tel Aviv University, Ramat Aviv 69978, Israel
RedC LTD, Tel-Aviv, Israel
Racah Institute of Physics, the Hebrew University, Jerusalem, Israel

A slab laser-head configuration has been proved to be most suitable for RF or microwave excitation of slow-flow and sealed CO2-lasers. These laser schemes are characterized by their high average and peak powers. When excited by microwave radiation in a pulsed regime, a high peak-to-average power ratios can be obtained. In this regime the microwave-excited CO2 slab-laser proves advantageous comparing to RF excited lasers or combined RF and DC pumped schemes.

Two main mechanisms impairing the CO2 slab-lasers operation are investigated:

- Thermal-instabilities occurance, due to the absence of a stabilizing dielectric strip inside the laser discharge-zone.
- An axially inhomogeneous discharge formation due to the relatively short excitation-wavelength.

In the presented research, we find adequate solutions for these difficulties. We investigate and optimize the operation of microwave excited CO2 slab-lasers regarding thermal-instabilities and the discharge homogeneity, and support the presented theory by experimental verifications. An axially homogeneous discharge in a CO2 slab-laser excited by a magnetron is obtained in a low gas-flow regime operation. Coupling a slab laser parallel to the electric-field of a rectangular resonator operated near cutoff, where the laser head is axially shorter than the resonator, forms an axially-uniform discharge field. The laser head employs a 40 cm long double-ridged waveguide, with an axially-unvaried crossection. For a slab surface of 80 cm2 and discharge heights of 1.5 or 2 mm, a maximal average laser-power of 40W is measured. A peak laser-power of ~580W is measured with an overall efficiency of 6 %. A maximal overall efficiency of 9 % in a duty cycle of 5% (PW=10s) is measured for a non-optimized device. This first prototype is proposed as a means to develop a highly efficient, compact sealed microwave-excited CO2 slab-laser exploiting the benefits of an axially homogeneous-discharge.

High-Power Short Pulsed Corona: Investigation of Electrical Parameters, Abatement of SO2 and Ozone Generation

A. Pokryvailo and Y. Yankelevich
Propulsion Physics Laboratory, Soreq NRC, Yavne, Israel

Electrical performance and chemical activity of a 50MW, 100kV, 22ns pulsed corona was studied in simulated air-SO2 gas mixture in a coaxial reactor. Infrared and mass spectrometers and electrochemical sensors were used for gas diagnostics; solid byproducts were identified using X-ray fluorescent spectrometry. Electrochemical methods of gas diagnostics were not sufficiently reliable in view of the cross-influence of different gases, especially in ozone presence.

The removal efficiency of SO2 decreased at lower pollutant concentration and higher frequency, while the pulse energy was kept invariant. Removal efficiency in dry mixture was 25g/kWh; in humid air, it was several times greater, which is attributed to the influence of OH radicals. In dry SO2-air mixture, the removal efficiency was much higher at positive polarity.

Traces of many compounds were found and identified in treated gas. The precipitation of a yellowish powder identified as sulfur was observed. This effect was not previously noted in literature. It is ascribed to direct breaking of atomic bonds of the SO2 molecule by energetic species.

PSpice-based engineering model of corona-generator system is proposed. It was found that preliminary simulation results are in fair agreement with experimental data. The simulation revealed that surprisingly small part of the energy is coupled to plasma.

Influence of Oxygen Pressure on Filtered Vacuum Arc Deposition of Tin Oxide Thin Films

R.L. Boxman, V. Zhitomirsky, S. Goldsmith
Electrical Discharge and Plasma Lab, Tel Aviv University

Tin oxide is a conducting material which is transparent in the visible region, reflective in the infra-red, and absorbing in the ultraviolet. Applied as a thin film, it is used for transparent electrodes for solar cells and in energy conserving coatings on architectural glass. This paper presents the results of experiments in which tin oxide films were deposited using filtered vacuum arc deposition.

A plasma jet of ionized Sn vapor was produced by cathode spots on a 93mm diam Sn cathode by a 160 A d.c. arc. The plasma jet was directed through a quarter torus duct using a magnetic field, while droplets of liquid Sn collided with the duct walls and were thus filtered from the plasma stream. The plasma jet was directed either to a probe or to a substrate placed downstream from the duct outlet, and where an oxygen atmosphere was maintained at a pressure p of 0-6mTorr. Arc voltage, ion current, coating transmission and coating conductivity were measured as a function of the oxygen pressure.

It was found that the arc voltage was ~ 30V, and relatively independent of p for p<4mTorr. With higher pressures, the arc increasingly operated in a high voltage mode, with an arc voltage typically 10V higher than in the low voltage mode. The change from the low to the high voltage mode is likewise associated with a trebling in the extracted ion current, from ~250 to ~750mA. The deposition rate decreased linearly from 14 to 5nm/s when the pressure was increased from 3 to 5mTorr. The optical extinction length had a maximum value of 2.6m in the pressure range of 3.9-4.3mTorr, while minimum electrical conductivities of 410-3-cm were obtained for 3.8-4.1mTorr.

Parametric Study of Hall Thruster Performance Using a One-Dimensional Steady-State Model*

Abraham Cohen-Zur[1], Amnon Fruchtman[2], Joseph Ashkenazy[2],**, and Alon Gany[1]

1*Faculty of Aerospace Engineering, Technion – Israel Institute of Technology Haifa 32000, Israel*

2*Holon Academic Institute of Technology, 52 Golomb st., Holon 58102, Israel*

The Hall thruster is an attractive candidate for various space applications such as orbit control, orbit raising and interplanetary missions. Similar to other electric propulsion devices, the Hall thruster utilizes electric energy to generate and accelerate a plasma jet to exit velocities that may be an order of magnitude or more higher than the exhaust velocities attained by conventional chemical rockets. The Hall thruster1 utilizes a combination of an axial electric field and a transverse magnetic field in order to accelerate a heavy ion plasma (usually Xenon). The plasma is generated by electrons emerging from a cathode/neutralizer at the thruster exit, their mobility being impeded by the transverse magnetic field.

We employ a simple one-dimensional, steady-state model,2 to calculate the profiles of the plasma flow and electric potential along the acceleration channel, requiring a smooth acceleration from subsonic to supersonic velocity. The performance parameters, such as the propellant, current, and energy utilizations, and the total efficiency are calculated. In a previous study3, where for simplicity we assumed that the flow is supersonic along the whole channel, we have shown that there is a distinct region of the parameter space where steady state solutions exist, while in the other region no solution exists. The highest efficiency has been found to be at the boundary between these two regions. Here we extend the parametric study to the more general case in which there is a smooth sonic transition. We also examine the effect of an ion backflow towards the anode4 on the plasma density profile. The theoretical results are compared to the measurements of the Soreq Hall thruster. 5

* Partially supported by Israel Space Agency

** On sabbatical from Soreq NRC

1. A. I. Morozov, Yu. Esinchuk, G. Tilinin, A. Trofimov, Yu. Sharov, and G. Shchepkin, "Plasma Acceleration with Closed Electron Drift and Extended Acceleration Zone", *Sov. Phys. Tech. Phys.* 17, 38 (1972).
2. A. Fruchtman, N.J. Fisch, J. Ashkenazy, and Y. Raitses, "Scaling Laws for Hall Thruster Performance", IEPC 97-022, 25th International Electric Propulsion Conference, Cleveland, Ohio, Aug. 1997.
3. A. Cohen-Zur, A. Fruchtman, and J. Ashkenazy, "Steady Acceleration in the Hall Thruster", IEPC 99-108, 26th International Electric Propulsion Conference, Oct. 17-21 1999, Kitakyushu, Japan.
4. E. Ahedo, and M. Martinez-Sanchez, "One-Dimensional Plasma Structure in Hall Thrusters", AIAA 98-8788, 34th AIAA/ASME/SAE/ASEE Joint Propulsion Conference and Exhibit, July 13-15, 1998, Cleveland, OH.
5. J. Ashkenazy, Y. Raitses, and G. Appelbaum, "Parametric Studies of the Hall Current Plasma Thruster", *Phys. Plasmas* 5, 2055 (1998).

POSTERS

Physics of the Interaction of Pulsed Magnetic Fields with Plasmas and Relevance to Applications

R. Arad, K. Tsigutkin, Yu.V. Ralchenko, D. Osin, and Y. Maron
Department of Particle Physics, Weizmann Institute of Science, Rehovot 76100

and

A. Fruchtman
Holon Academic Institute of Technology, Holon, Israel

Spatially and temporally resolved spectroscopic measurements of the ion velocities, electron density and temperature, non-thermal electric fields, and the magnetic field evolution in a current-carrying plasma, show that ion separation occurs in which a light-ion plasma is pushed ahead of a magnetic piston while a heavy-ion plasma lags behind the magnetic piston. The velocities of the heavier ions are determined from Doppler shifts and the proton velocity is obtained using charge-exchange spectroscopy. The width of the current channel, calculated from the spatial distribution of the magnetic field, determined from Zeeman splitting of doped helium lines, is significantly broader than expected from classical diffusion. A large electron and ion heating is observed during the field penetration, as predicted theoretically. Moreover, the formation of non-thermal fast electrons, associated with the field penetration is experimentally studied. Turbulent electric fields with a 10(2 kV/cm amplitude are inferred from Stark broadening of hydrogen and helium lines. Explanations for the observed rapid magnetic field penetration into the heavy-ion plasma in the context of EMHD theory or turbulence-induced collisionality are discussed. It is shown that the presence of the light ions in the plasma significantly modifies the dissipated-magnetic-field-energy partitioning between electrons and ions. Furthermore, understanding the dynamics of different ion species allows for improving the switch opening and coupling to various loads. Relevance to astrophysics and magnetic fusion will also be discussed.

Accelerated Recombination in Cold Dense Plasmas with Metastable Ions due to Resonant Deexcitation

Yuri V. Ralchenko and Yitzhak Maron

Department of Particle Physics, Weizmann Institute of Science, Rehovot 76100

In a recombining plasma the metastable states are known to accumulate population thereby slowing down the recombination process. We show that a proper account of the doubly-excited autoionizing states, populated through collisional 3-body recombination of metastable ions, results in a significant acceleration of recombination. 3-body recombination followed by collisional (de)excitations and autoionization effectively produces deexcitation via the following chain of elementary events:

$$X_Z^*(\alpha_0) + e + e \to X_{Z-1}^{**}(\alpha_0 nl) + e$$
$$X_{Z-1}^{**}(\alpha_0 nl) + e \to X_{Z-1}^{**}(\alpha_0 n'l') + e, \ldots$$
$$X_{Z-1}^{**}(\alpha_0 n''l'') \to X_Z(\alpha_1).$$

A fully time-dependent collisional-radiative (CR) modeling for stripped ions of carbon recombining in a cold dense plasma demonstrates an order of magnitude faster recombination of He-like ions. The CR model used in calculations is discussed in details.

Study of a Hybrid RF-DC Voltage Plasma*

G. Makrinich, J. Ashkenazy**, and A. Fruchtman
Holon Academic Institute of Technology, 52 Golomb st., Holon 58102, Israel

A plasma source that operates in a radio-frequency (RF) wave mode, in a DC voltage mode, and in a hybrid RF – DC voltage mode has been developed.1 The RF source, that operates mostly as a Helicon plasma source,2 is composed of a vacuum chamber, a gas flow controller, solenoids that generate a DC magnetic field, a radio frequency generator with matching units, and an antenna. The plasma is generated inside a Pyrex tube, 52cm in length and 10cm in diameter. The radio-frequency generator radiates at 13.56 MHz with a power of up to 1 kW. The magnetic field intensity is up to 900G. The working pressure is between 0.5 mTorr and 10Torr. Argon and nitrogen are used, both separately and as a mixture. The antenna is a helix of six turns of a 350mm total length and a 100mm diameter. Employing a Langmuir probe we have measured the plasma density for various wave power levels, magnetic field intensities and gas pressures. We have developed a method to measure the particle velocities. The method is based on a simultaneous measurement of the thrust of the plasma flow per area unit and the ion flux per unit area. From these two measurements we obtain both the plasma density and velocity. A model based on particle and energy balance has been developed and is used to calculate the plasma density and temperature. The calculated density and temperature are in good agreement with the measurements. In the DC voltage mode of operation no wave power is deposited. The discharge is sustained by a DC voltage that is applied between two cylindrical concentric ring electrodes. In such a configuration the motion of the electrons between the electrodes is impeded by the applied DC magnetic field. An argon DC discharge is ignited when the applied voltage is above 60V. At about 100V the plasma density at the exit of the Pyrex tube is higher than 1010cm-3. The hybrid RF-DC voltage mode of operation has demonstrated a significant improvement at a certain regime of parameters.

* Partially supported by the 0.25 μm consortium and by Israel Science Foundation
** On sabbatical from Soreq NRC

1. G. Makrinich, A. Fruchtman, and J. Ashkenazy, Bull. APS **45**, 227 (2000).
2. R. W. Boswell and F. F. Chen, IEEE Trans. Plasma Sci. **25**, 1229 (1997).

Characteristics of a High-Power RF Oscillator Based on a Pulsed Hollow-Cathode Discharge

Yu. P. Bliokh, J. Felsteiner, Ya. Z. Slutsker, and P. M. Vaisberg
Department of Physics, Technion, 32000 Haifa, Israel

The characteristics of a very simple high-power pulsed RF oscillator are presented. This oscillator is based on the use of a low-pressure pulsed hollow-cathode discharge during the periods when its cathode sheath becomes unstable. A set of four different oscillators has been studied in different operating regimes for various values of load resistance. The materials and the design of the oscillators were found to be suitable for commercial production. These oscillators were tested to produce pulse power of over 100 kW at frequencies up to 50 MHz and efficiency exceeding 20%. The tests were performed done with pulse duration of 14 □s and repetition rate up to 100 Hz. Equivalent circuits of the oscillator for RF loading and for pulsed power are described. The requirements for the device power supply as well as recommendations for the oscillator use are presented.

Bohm Criterion Failure in Non-Stationary Plasma

Yu. P. Bliokh, J. Felsteiner, Ya. Z. Slutsker, and P. M. Vaisberg
Department of Physics, Technion, 32000 Haifa, Israel

The Bohm criterion, generally used as a boundary condition at the plasma-sheath edge, does not fit the temporal evolution of the voltage fall across the collisionless cathode sheath in pulsed hollow-cathode discharge. Similarly this criterion is not valid for the interpretation of probe measurements of the plasma in this discharge. The discrepancy disappears only when the discharge reaches its steady state. The duration of this invalidity is much larger than the ionization time needed to fill the device with plasma and than the time needed for the sheath formation. It is shown that our measurements can be explained quantitatively by assuming a monotonous growth of the ion speed from an initial low value up to the ion sound velocity.

Effect of a Finite Thickness of a Transition Layer on Charged Particle Localization in the External Field near the Interface Boundary

Yu. Dolinsky and T. Elperin
The Pearlstone Center for Aeronautical Engineering Studies
Department of Mechanical Engineering
Ben-Gurion University of the Negev, P. O. Box 653, Beer-Sheva 84105
Israel

Behavior of charged particles near the boundaries between regions with different electric permittivities ε_1 and ε_2 is of interest in view of numerous applications. Models with a piece-wise homogeneous medium allow to determine the field of the point charge at least in the cases with simple geometries However, since in these models the thickness of the transition layer is assumed to be equal zero the potential $\varphi(\vec{r},\vec{a})$ caused by the particle located at $\vec{a}$ has a discontinuity of the second kind when a particle crosses the boundary between different media. The latter restricts the possibility to study various phenomena using classical electrodynamics. We showed that when the finite thickness of the transition layer is taken into account, the effective potential of repulsion from the surface for a charge located in the region with $\varepsilon_1 > \varepsilon_2$ has a finite maximum. Similarly, the effective potential of attraction to the surface for a charge located in the region $\varepsilon_2 < \varepsilon_1$ has a finite minimum. The external electric field changes the distribution of the effective potential. We investigated the effect of the thickness of the transition layer on electric resonance for a particle localized in the vicinity of the interphase boundary, demonstrated a nonmonotonic dependence of the resonance frequency vs. the amplitude of the external field and investigated the dependence of this frequency on different parameters of the problem.

Solution of the Full Electromagnetic Wave Equation for Arbitrary Aspect Ratio and Magnetic Shear Values, Non-Circular Cross Section, Pre-Heated Tokamak Plasmas. I. The Alfven Waves Frequency Range

S.Cuperman[1] , C.Bruma[1,2] and K.Komoshvili[1,2]
1 School of Physics and Astronomy Tel Aviv University
2 The College of Judea and Samaria

Low Aspect Ratio Tokamak (LART) configurations represent a promising approach to thermonuclear fusion. They require auxiliary non-ohmic power for heating, current drive and turbulent transport suppression. This paper pioneers the pre-requisite for the quantitative evaluation of these effects, namely the formulation and solution of the wave equation for pre-heated LART's; the case of mode-converted Alfven waves is illustrated.

For this, the full electromagnetic wave equation for arbitrary aspect ratio tokamaks and magnetic shear with non-circular cross section is consistently formulated and solved for waves in the Alfven frequency range; the mode conversion of externally launched fast RF waves is properly considered. This general approach includes, as a particular case, that of low aspect ratio (spherical) tokamaks

The problem is formulated in terms of the vector and scalar potentials $(\mathbf{A},\Phi)$, thus avoiding the numerical pollution occurring in the case of $(\mathbf{E},\mathbf{B})$ formulation. Adequate boundary conditions at the vacuum-metallic wall interface and regularity conditions at the magnetic axis are enforced.

For pre-heated stage, a quite general two-fluid, resistive dielectric tensor-operator able to describe the anisotropic plasma response in spherical tokamaks is derived and used; except for its linear character, no physical or geometrical limitations are imposed on it. Consistent equilibrium profiles including effects of neo-classical conductivity and bootstrap current are used.

Possible applications of the procedures developed and results obtained in this paper to recently operating LART devices, e.g., START, MAST and NSTX, are indicated.

Development and characterization of a high-Q remotely controlled quasi-optical mm-wave resonator for FEL

A.Faingersh, Y.Yakover, A.Gover
Tel-Aviv University

G.Denisov
Institute of Applied Physics, Nigniy Novgorod, Russia

We describe development and characterization of a novel mm-wave quasi-optical resonator for the Israeli Free Electron Laser. The first version was installed in the FEL accelerator tank, and its RF characteristics were evaluated on site.

The resonator is based on a unique configuration comprised of a special "Talbot effect" out-coupling reflector attached to an over-moded parallel plates waveguide. The reflector is composed of two perpendicular rectangular waveguide sections and a 90 degree perforated Mitter Bend, which permits good transmission of the electron beam through the hole (as confirmed by careful electron beam transport simulations). At the same time high radiation losses at the perforated Mitter Bend are avoided due to the Talbot optical imaging effect. At the end of the reflector an adjustable reflection coefficient mirror is installed. This mirror is composed of a system of three parallel wire grid polarizers. The out-coupling coefficient is controllable by varying the polarization direction of the center grid. The transmission of the radiation from the resonator, situated in the vacuum enclosure, into the low loss corrugated waveguide transmission line situated in the high-pressure tank, is achieved by using a special off-axis curved matching mirror and a wide-band RF-transparent corrugated dielectric vacuum-window.

The resonant characteristics of the resonator were evaluated by measuring the Fabri-Perot resonance "comb", recording the reflectivity as a function of frequency when the resonator is illuminated from the output side. A data processing and numerical filtering procedure was developed in order to reveal the resonant comb out of the background of parasitic reflections and noise. The Q-factor of the resonator at frequency 100 GHz was found to be 12000, when the outcoupling coefficient was set to 10% transmission. The measured high Q-factor is in good agreement with our theoretical simulations and calculation. It provides a good basis for successful operation of the FEL as an oscillator.

High-Frequency Electron Beam Modulation, Transportation and its Interaction with Slow-Wave Structure

K. Chirko, Ya. E. Krasik, A. Dunaevsky, and J. Felsteiner
Department of Physics, Technion, 32000 Haifa, Israel

We present experimental results of a high-frequency (HF) modulated electron beam generated in a diode with a plasma cathode. The plasma was prepared by an incomplete surface discharge which was ignited by applying a driving pulse to a ferroelectric sample. The sample was made of a BaTiO3 disk placed inside a cathode box with an output window covered by a stainless steel grid. The experiments were carried out with an accelerating voltage in the range of 40-120 kV and pulse duration up to 30 s. Data concerning the influence of the accelerating voltage and the diode geometry on the parameters of the modulated electron beam and its power are presented. We also present data concerning the electron energy and the total current of the beam in the diode as a function of the applied voltage. The maximum amplitude of the modulated beam current reaches 65A which corresponds to the beam power of 4.5 MW. The transport of the HF electron beam in a guiding external magnetic field as well as the beam interaction with a helical slow-wave structure (SWS) were demonstrated. The beam modulated at 190 MHz with the amplitude up to 25 A was transported in the magnetic field 0.9-1.8 kG along a distance of 50 cm. In addition, it was shown that the modulated beam could be efficiently transported through the SWS without any external magnetic field. A backward–wave oscillator regime at an operating frequency ~ 1 GHz with a non–modulated electron beam emitted by the ferroelectric cathode is demonstrated as well.

Hollow-Cathode Electron Source with Fast Gas-Puff Valve

J. Z. Gleizer, A. Krokhmal, Ya. E. Krasik, and J. Felsteiner
Department of Physics, Technion, 32000 Haifa, Israel

In this paper the design and characteristics of a hollow-cathode electron source are presented. A pressure gradient between the cathode cavity and the drift region which is necessary for simultaneous operation of the hollow cathode discharge and the microwave generation is provided by a gas-puff valve. To produce a plasma inside the hollow cathode we used a pulse forming network (PFN) generator with output parameters of 10 kV, 10 לs and 5 Ù. For reliable operation and the ignition of the hollow cathode discharge a mesh keep-alive electrode was used. Generation of high-current electron beams was provided by PFN generator: 30 kV, 300 ns and 7 Ù. To protect the power supplies from the high-voltage accelerating pulse decoupling inductances were used. The gas distribution inside the cathode was measured by two fast Penning probes. The plasma temperature and density were studied by floating electric probes. It was found that at a discharge current amplitude of 130-470 A the potential drop between the hollow cathode and the output grid is 140-160 V. Inside the hollow cathode the density of the helium plasma is (2-3)1012 cm-3 and the plasma electron temperature is 8±1 eV at a discharge current 120-270 A. It was shown that the plasma from the cathode cavity penetrates into the anode-cathode gap prior to the application of the accelerating pulse. Therefore, the observed amplitude of the electron current exceeds the value predicted by Child-Langmuir law.

Operation of Ferroelectric Cathodes with Control Grid

A. Dunaevsky, Ya. E. Krasik, J. Felsteiner
Department of Physics, Technion – Israel Institute of Technology, 32000 Haifa, Israel
and
A. Sternlieb
DDR&D/IMOD, 61909 Tel-Aviv, Israel

Results of experimental investigation of the generation of electron beams in a planar diode with a ferroelectric plasma cathode with control grid are investigated. The plasma is formed at the surface of BaTiO3 ferroelectric sample as a result of incomplete surface discharge when a driving pulse is applied to the sample. It is shown that in the case of the plasma formation prior to the application of the accelerating voltage, the diode is operated in plasma prefilled mode. This mode of the diode operation occurs because of the formation of fast plasma flows which fill the anode-cathode gap during the first 100-200 ns from the beginning of the driving pulse. We present results of experimental studies of the plasma parameters produced by a large area ferroelectric cathode and of the generation of electron beams by the ferroelectric plasma cathode with a control biased grid. The use of the control grid allows a suppression of the fast plasma flows. Measurements of the density of the plasma and its direct velocity allows the prediction of the control grid biased potential which is required for the suppression of the plasma flows. The measurements of the decrease of the plasma density of these flows on the grid potential showed the efficiency of the control grid operation. The successful operation of the electron diode with the ferroelectric plasma cathode with the biased control grid, when the plasma prefilling of the AC gap was almost avoided, is demonstrated.

Novel Gaseous Plasma Gun for Plasma Opening Switch

Ya. E. Krasik
Department of Physics, Technion, 32000 Haifa, Israel

Experimental and theoretical research of the plasma opening switch (POS) phenomenon showed that the plasma parameters (plasma density, composition, plasma flow velocity, plasma density distribution) determine the POS operation and its impedance.1 In the majority of the previous investigations the plasma formation was achieved by erosion type plasma guns, namely by different type of coaxial plasma guns and flashboards. These types of plasma sources provide a non-uniform plasma with a multi-ion composition. There have been a few experiments with gaseous plasma guns which produced a pure plasma.2,3 However, in the experiment described in Ref. 2 the plasma formation was achieved by several gaseous plasma guns which did not allow to obtain a uniform plasma in the POS region. In Ref. 3 a gaseous plasma gun was installed inside the cathode which determines the plasma injection towards the anode which, in fact, is not a preferable mode of the POS operation. In this report we present a design and results of a microsecond POS investigation (*IPOS* = 50 kA, *T1/4* = 950 ns) with a novel coaxial gaseous plasma gun. The operation of the plasma gun is based on the azimuthally uniform radial gas injection between two knife-type electrodes. An application of the high-voltage pulse between these electrodes causes formation of a plasma shell. This plasma shell is accelerated by the magnetic pressure gradient radially toward the POS the anode and cathode electrodes. Parameters of the pulsed gas vent and of the neutral and plasma flows are presented. Successful operation of the POS is demonstrated.

1. V. M.Bystritskii, A. A.Kim, Ya. E. Krasik, B. M. Koval'chuk, and G. A. Mesyats, Microsecond plasma opening switches, Physics of Elementary Particles and Atomic Nuclei, **23**, 19 (1992).
2. P. S. Anan'in, V. B. Karpov, Ya. E. Krasik, I. V. Lisitsyn, A. V. Petrov, and V. G. Tolmacheva, Investigation of plasma opening switches with pulsed gas guns, Sov. J. Phys. Tech. Phys., **36**, 894 (1991).
3. J. J. Moschella, R. C. Hazelton, C. Vidoli, E. J. Yadlowsky, B. V. Weber, D. D.Hinshelwood, B. Moosmann,, and S.J.Stephanakis, POS experiments on Hawk using an inverse pinch, gas plasma source, Proc. 12th International conference on High-Power Particle beams, Haifa, Israel, edited by M. Markovitz and J. Shiloh, (1998), Vol.1, pp.306 – 309.

Plasma Jet Expansion and Plasma Voltage in the High-Current Vacuum Arc in Axial Magnetic Field

I. I. BEILIS* and M. KEIDAR**,
*Department of Interdisciplinary Studies, Faculty of Engineering,
Electrical Discharge and Plasma Laboratory, Tel Aviv University
**Department of Aerospace Engineering, University of Michigan, USA

This work is a development of our previous investigations of the cathode plasma jet expansion and current density distribution in axial and self-magnetic fields in the case when the boundary conditions may be changed due to effect of interaction of many plasma jets originated from the cathode spots. The high-current vacuum arc plasma expansion is investigated using a two-dimensional model. The plasma and current flow are modeled using the sourceless steady-state hydrodynamic equations. The model considers the free boundary of the plasma jet, which is determined by a self-consistent solution of the gas-dynamic and electrical current equations. The electron temperature distribution is calculated from the equation of plasma energy conservation. An influence of the starting condition at the cathode side (electron temperature and directed velocity) on the interelectrode plasma parameter distribution is studied. It was found that the high current constriction leads to plasma compression, which accompanied by electron temperature grow. Plasma jet mixing leads to decrease of the directed plasma jet velocity that in turn affect potential distribution in the interelectrode gap. For instance, the decrease of the plasma velocity by factor of 2 (from 104 m/s to 5.103 m/s) leads to decrease of the plasma voltage on 10 V in the gap with distance 5-10 mm when the axial magnetic field is 0.05T and arc current is 3 kA and to 7 V for magnetic field 0.01T and current 1 kA. The plasma voltage decreases from 7.5 to 4 V with electron temperature increasing from 1.5 to 2.5 eV in case of 1 kA arc. In the case of 1 kA electron temperature increases by factor of 1.2 while in the 0.5 A this effect is negligible. These results are discussed in order to understanding the experimental potential drop behavior in high-current vacuum arcs.

I. I. Beilis, M. Keidar, R. L. Boxman, and S. Goldsmith, J. Appl. Phys. 83, 709

(1998).