Israeli Plasma Science and Technology Association
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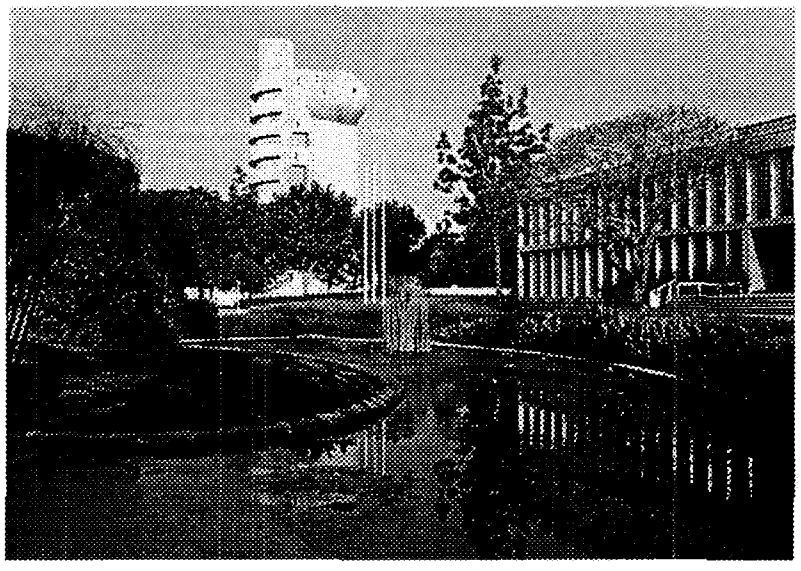
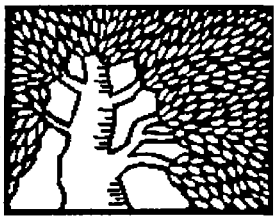
5th Israeli Conference on Plasma Science and Applications

March 5, 2002

Faculty of Physics, Weizmann Institute of Science

Rehovot, Israel





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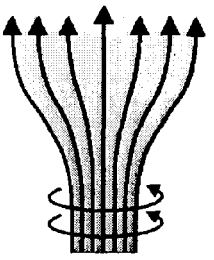

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Space Charge Effects in a Prebunched Beam Free Electron Maser (FEM)

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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.

The spectral properties of the radiated power depend on the electron beam current density (space charge effects). For a low density e-beam (tenuous beam) the monochromatic super-radiant emission power is maximal at a single frequency corresponding to the synchronizm condition. However, for a dense e-beam the space charge effects becomes dominant. Synchronizm can take place them with either the slow or the fast space-charge wave, which propagate on the e-beam with different phase velocities. Consequently radiated power maxima occur at two well separated frequencies.

We report a first experimental measurement of super-radiant power emission for a wide range of e-beam currents for which the influence of space charge can be investigated.

The measurements were compared to those predicted by an analytical model and by simulations for a wide range of frequencies and e-beam currents. Measurements are in a good agreement with theory and simulations.

Low-Pressure Plane Plasma Discharge Sputtering System

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Ultra-thin semiconductors and metal films have gained high technological importance in recent years. Sputtering is considered to be the preferable way for industrial thin semiconductor systems preparation. The main goal of our work was to develop a sputtering based method suitable for fine electronic and opto-electronic applications. The basic idea behind the developed method was to create a plane of gas discharge placed between the sputtering target and the growing film in order to enable the sputtered atoms to reach the substrate without collisions. Thus, the shape of the created plasma is viewed as a thin wall.

The work was devoted to the modeling and practical implementation of the novel sputtering method. The mean free path of the gas molecules in the vacuum chamber is chosen as the critical parameter that defines the type of the sputtered particle transport and the level of the gas pressure used in the vacuum chamber. The properties and behavior of the plane plasma are considered under the conditions of ballistics (collisionless) and boundary transfer of the sputtered atoms (taking into account the diffusion part as well).

The basic properties of the plane plasma were experimentally studied with the Langmuir probe introduced in plasma. The evaluation of electron temperature and ion concentrations was done using the Bohm approximation for collisionless conditions, which were created in the designed system. The measurements were taken in a gas pressure range from 0.2 mTorr up to 5 mTorr in various points of the vacuum chamber: along the plasma plane and in its vicinity. It was found that the electrons with the maximum temperature of about 7-7.5 eV occur along the plasma plane. Positive argon ion concentration was found to vary in the range from 3.5×10^{11} cm^{-3} to 6×10^{11} cm^{-3} on the plasma axis, depending on the gas pressure.

The substrate in the novel system is completely protected from the plasma and the electron irradiation. The substrate temperature does not exceed 60 °C during 1 hour of operation. Titanium and silicon were tested as sputtering targets. The deposition rates for these materials were 60 A°/min and 100 A°/min, respectively, with the applied power not exceeding 50 W. All of the electrical supplies were isolated from ground, to protect against parasitic discharges in the vacuum chamber.

This novel sputtering method enables one to independently vary the sputtering voltage and the ion current while sputtering. This is of course impossible in a conventional sputtering system such as magnetron sputtering systems. The following table shows the position of the proposed sputtering method in comparison with the other known methods:

Process Type	**Typical Particle Energy**	**Vacuum (Pa)**
Evaporation	< 1 eV	0.001
Triode (tetrode) Sputtering	**500 ... 3000**	**0.05**
Magnetron Sputtering	10 ... 100	0.5
Diode Sputtering	1000	10

Thermal Model of a Refractory Anode in a Vacuum Arc. Two-Dimensional Solution

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The hot refractory anode vacuum arc (HRAVA) is a discharge in which material transferred from the cathode is immediately re-evaporated from a refractory anode heated by the arc. In the present work, a thermal model for a cylindrical anode, predicting the transition of the arc from the cathode spot mode to the HRAVA mode, is proposed. The model includes the transient heat flux from the plasma to the anode surface, the radiation from the upper (faced to the heat flux), lower and lateral anode surfaces and the temperature dependent thermophysical coefficients of the anode material. A numerical finite-difference approximation of the non-linear, transient, 2D heat conduction equation and boundary conditions (in cylindrical coordinates) were used. Arcs having equipped with 32 mm diameter and 10-30 mm long graphite and molybdenum anodes, currents of 175 and 340 A, and duration up to 200 s were analyzed. The 2D results are compared with previous 1D calculations.

The 2D calculations show that the anode surface temperature is distributed relatively uniformly and the rate of anode temperature increase is larger for short (10mm) anodes than for long (30 mm) anodes. The lower surface temperature decreases by about 150C for 340 A and 100 C for 175 A with Mo anodes and 250C and 150 C for 340 A with graphite anodes when the anode length is increased from 10 to 30 mm, while the maximal upper surface temperature does not change substantially. The calculated results indicate that the anode surface temperature with short anodes (~15mm) in steady state is appropriate (2000-2300 K) for HRAVA operation.

Plasma Turbulence Suppression and Transport Barrier Formation by Externally Driven RF Waves in Spherical Tokamaks

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Turbulent transport of heat and particles is the principle obstacle confronting controlled fusion today. Thus, we investigate quantitatively the suppression of turbulence and formation of transport barriers in spherical tokamaks by sheared electric fields generated by externally driven radio-frequency (RF) waves, in the frequency range $\omega_A \pi \omega < \omega_{ci}$ (ω_A and ω_{ci} are the Alfvèn and ion cyclotron frequencies).

This investigation consists of the solution of the full-wave equation for a spherical tokamak in the presence of externally driven fast waves and the evaluation of the power dissipation by the mode-converted Alfvèn waves. This in turn, provides a radial flow shear responsible for the suppression of plasma turbulence. Thus, a strongly non-linear equation for the radial sheared electric field is solved, the turbulent transport suppression rate is evaluated and compared with the ion temperature gradient (ITG) instability increment.

For illustration, the case of START-like device (Sykes 2000) is treated. Thus, (i) the exact D-shape cross-section is considered; (ii) additional kinetic (including Landau damping) and particle trapping effects are added to the resistive two-fluid dielectric tensor operator; (iii) a finite extension antenna located on the low-field-side of the plasma is considered; (iv) a rigorous 2½D finite elements numerical code (Sewell 1993) is used; and (v) the turbulence and transport barrier generated as a result of wave-plasma interaction is evaluated.

Enhanced Emission Mode of a Ferroelectric Plasma Cathode

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An enhanced emission mode of a ferroelectric plasma cathode based on $BaTi0_3$ ceramics with an area of 100 cm^2 has been observed. The enhanced emission is achieved due to the generation of a dense plasma ($10^{13} - 10^{14}$ cm^{-3}) by the application of a second driving current pulse to the ferroelectric cathode. The formation of dense and uniform plasma occurs due to the ionization of the thin neutral layer which was formed by a desorption process caused by the first driving pulse. Fast framing photographs of the light emission from this plasma and results of spectroscopic research are reported. The generation of an electron beam with a current amplitude up to 2.5 kA under the application of an accelerating pulse of 15 - 300 kV amplitude and 350 ns pulse duration is demonstrated. The same ferroelectric cathode was used for ion beam generation. Ion beam generation with a current amplitude up to 150 A is demonstrated in the plasma pre-filled mode of the diode operation. It was found that the generated ion beam consists of light (H^+, C^+, O^+) and heavy (Ti^+, Cu^+, Sr^+) ions. In addition, it was shown that the application of a reflex triode scheme with a negative grid cathode allowed us to separate effectively the light ions from the generated ion beam.

Heat Flux Inhibition by Whistlers: Experimental Confirmation

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Heat flux in weakly magnetized collisionless plasma is, according to theoretical predictions, limited by whistler turbulence that is generated by heat flux instabilities near threshold. Observations of solar wind electrons by Gary and coworkers appear to confirm the limit on heat flux as being roughly the product of the magnetic energy density and the electron thermal velocity, in agreement with prediction ((Pistinner and Eichler 1998).

Energy Conversion in Imploding Z-Pinch Plasma

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Due to important applications, Z-pinches became a subject of extensive studies. In these studies, main attention is directed towards improvement in efficiency of electric energy conversion into high-power radiation burst. At present, knowledge available on physics of Z-pinch operation, plasma motion, atomic kinetics, and energy conversion is mainly knowledge of numerical simulation results. We believe further progress require (i) *experimental* determination of spacial distribution and time history of thermodynamic parameters and magnetic field, as well as (ii) utilization of this data for *experiment-based* calculation of r,t-distribution of driving forces, mass and energy fluxes, and local energy deposition rates due to each of contributing mechanisms, what provides an insight into a process of conversion of stored electric energy into radiation burst. Moreover, experimentally determined r,t-distribution of parameters may serve for verification of computer programs developed for simulation of Z-pinch operation and optimization of radiation output.

Within this research program we performed detailed spectroscopic study of plasmas imploding in modest-size (25 kV, 5 kJ, 1.2 μs quaterperiod) gas-puff Z-pinch. This facility has reasonably high repetition rate and provides good reproducibility of results. Consistent with plasma ionization degree in the implosion period, measurements are performed in UV-visible spectral range. Observation of spectral lines emitted at various azimuthal angles φ showed no dependence on φ. Dependence on axial coordinate z is found to be weak in near-anode half of the anode-cathode gap. Based on these observations and restricting the measurements to near-anode half of the gap, an evolution of parameters is studied in time and radial coordinate r only.

In present talk we report on determination of radial component of plasma hydrodynamic velocity $u_r(r,t)$, magnetic field $B_\varphi(r,t)$, electron density $n_e(r,t)$, density of ions in various ionization stages $n_i^{+q}(r,t)$, and electron temperature $T_e(r,t)$. We also show that local ion temperature $T_i(r,t)$ is close to $T_e(r,t)$. These distributions are used for experiment-based insight in dynamics and energetics of imploding plasma. In particular, we calculated and compare (i) plasma acceleration by local pressure gradient and local Lorentz force, (ii) local energy deposition rates provided by Joule heating, compression, and heat conduction; (iii) local growth rates of plasma internal energy and kinetic energy of radial motion. These results are used for analysis of conversion of discharged electric energy $E_C(t) = C(U_0^2-U_t^2)/2$.

Formation and Control of Nonuniform Vortex States in Nonneutral Plasmas

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Uniform, m-fold symmetric, rotating vortex patches (V-states) in *2D* ideal fluids were discovered by Deem and Zabusky two decades ago [1]. Analogous structures can be formed in pure electron plasmas trapped in Penning-Malmberg traps [2], where plasma density plays the role of vorticity. Here we consider excitation and control of nonuniform V-states in nonneutral plasmas, the problem related to recent studies of inviscid vorticity symmetrization of *2D* vortices [3]. It will be shown that a family of stable, nonuniform, m-fold symmetric, nonneutral plasma structures in two dimensions (nonuniform V-states) can emerge by subjecting an axisymmetric plasma with a sharp density edge profile to a weak oscillating external potential of appropriate symmetry. The phenomenon is due to nonlinear synchronization (autoresonance) in the system, as the plasma density distribution self-adjusts to equate the rotation frequency of the plasma structure with slowly varying oscillation frequency of the external perturbation. The synchronization is induced by passage through resonance with the isolated eigenfrequency of the linearized problem, provided the driving potential amplitude exceeds a threshold. We shall present a quasilinear theory of excitation of nonuniform V-States by synchronization and compare the predictions of this theory with contour dynamics simulations.

Work supported by US-Israel Binational Science Foundation grant 98-474 and INTAS grant 99-1068.

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Particle and Energy Balance in a Helicon Plasma Source

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The plasma density and the electron temperature in a helicon source are measured with a Langmuir probe in various radial and axial locations. The measurements are compared with equilibrium calculations that are based on particle and energy balance. The employed momentum equation includes the ion inertia, as well as nonlinear ion mobility due to ion-neutral collisions. As in other models, particle balance should determine the electron temperature, while energy balance should determine the plasma density. The experimental results are not explained by a straightforward application of the model. For example, the measurements show that at a fixed wave-power the density increases when the magnetic field is increased. However, the expected improved confinement by the magnetic field could indeed be the reason for density increase only if a large anomalous conductivity is invoked. Other intriguing observations are the increase of the electron temperature with the increase of the magnetic field intensity, instead of the decrease predicted by the model, and the nonlinear dependence of the plasma density on the wave power. Possible explanations for these observations are discussed. Such are neutral depletion and a dependence of the wave-plasma coupling on the intensity of the magnetic field.

Theoretical Modeling of High Pressure Argon Arc Radiation

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A one-dimensional, axisymmetric theoretical model of a high pressure Argon arc was formulated, based on a combined solution of the energy conservation and the radiation transfer equations. For a pressure of P=15 atm, the coefficients of absorption in Argon were calculated for the continuum and line spectra. The coefficient of radiative heat conductivity was found, subject to the assumption that the continuum optical depth is much less then unity while the spectral line optical depth is much more than unity. The general heat conductivity was found by neglecting convection, but taking into account radiative conductance and kinetic conductance by ions, electrons and neutral atoms. The radial distributions of the temperature, ionization degree and electrical conductivity were found for arc currents of I = 880, 990 and 1250 A in a transparent tube of radius R = 0.01 m. The degree of ionization was claculated assuming local thermodynamic equilibrium. For I=880 A and 1250 A, the continuum and line spectra of the arc plasma radiation were calculated under the assumption that in the continuous spectra the optical thickness of the arc body is $\tau_{cont} < 1$ for its own thermal radiation while in spectral lines the optic thickness is $\tau_{line} >> 1$. An effective temperature was calculated in the range of (300-3000) nm. For I=880 A the effective temperature was found to be T_{eff} = 7500 K and for I=1250 A T_{eff} = 8700 K. For these two values of the arc current, a spectral radiant emmitance in the maximum point of the spectra were found to be $W_\nu \approx 7.5\times10^{-8}$ W m^{-2} Hz^{-1} and $W_\nu \approx 10.5\times10^{-8}$ W m^{-2} Hz^{-1} respecdtively.

Shock Front Formation at Vacuum Arc Anodes

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A vacuum arc plasma jet (VAPJ) between copper electrodes is considered as a supersonic hydrodynamical jet (the *primary plasma* jet) that bombards the anode and sputters and/or reflects material which forms a *secondary plasma*. An initial primary ion jet velocity of $v_0 = 1.5\times10^4$ m/s is assumed. A time-dependent interaction between primary and secondary ions is considered for primary ion concentrations of $n_0 = 10^{18}$ and 10^{19} m^{-3} and for a Cu-Cu self-sputtering yield coefficient of $\beta = 0.2$. It is found by numerical calculation that the primary jet is decelerated by the collisions with the secondary ions. In the case where the mean free path in the primary plasma is much less than the interelectrode gap ($\ell_{11} << L$) and the mean free path for the primary-secondary ion collision is much more than the interelectrode gap ($\ell_{12} >> L$), the primary jet deceleration to subsonic values depends on time. For a primary ion concentration of $n_0 = 10^{18}$ m^{-3} and an initial secondary ion velocity $\approx 0.1\times v_0$, a shock front appears at time $t\approx245\times L/v_0$ while for $n_0=10^{19}$ m^{-3}, at $t\approx135\times L/v_0$.

High-Current Plasma Electron Sources

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In this report we present the design, electrical schemes and preliminary results of a test of 4 different electron plasma cathodes operating under high-voltage pulses in a vacuum diode. The first plasma cathode consists of 6 azimuthally symmetrically distributed arc guns and a hollow anode having an output window covered by a metal grid. Plasma formation is initiated by a surface discharge over a ceramic washer placed between a W-made cathode and an intermediate electrode. Further plasma expansion leads to a redistribution of the discharge between the W-cathode and the hollow anode. An accelerating pulse applied between the output anode grid and the collector extracts electrons from this plasma. The operation of another plasma cathode design is based on Penning discharge for preliminary plasma formation. The main glow discharge occurs between an intermediate electrode of the Penning gun and the hollow anode. To keep the background pressure in the accelerating gap at $P \leq 2.5\times10^{-4}$ Torr either differential pumping or a pulsed gas puff valve were used. The operation of the latter electron plasma source is based on a hollow cathode discharge. To achieve a sharp pressure gradient between the cathode cavity and the accelerating gap a pulsed gas puff valve was used. A specially designed ferroelectric plasma cathode initiated plasma formation inside the hollow cathode. This type of the hollow cathode discharge ignition allowed to achieve a discharge current of 1.2 kA at a background pressure of 2×10^{-4} Torr. All these cathodes were developed and initially tested inside a planar diode with a background pressure $\leq 2\times10^{-4}$ Torr under the same conditions: accelerating voltage 180 – 300 kV, pulse duration 200 – 400 ns, electron beam current ~ 1 – 1.5 kA, and cross-sectional area of the extracted electron beam 113 cm^2.

Plasma-Like Collective Instabilities in Stellar Disks of Galaxies

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There is a formal analogy between the collective oscillations in a rotating stellar disk of spiral galaxies and the oscillations of a hot collisionless plasma in a magnetic field [1,2]. The collisionless Boltzmann equation governing the evolution of a stellar disk resembles the Vlasov equation for a plasma; thus, the technique of plasma kinetic theory may be applied. The conception of unstable oscillations already played a remarkable role in understanding of many processes occurring in galaxies such as the spiral structure [3-4].

We treat a disk of stars by employing the well elaborated mathematical formalisms from plasma perturbation theory using normal-model analysis [5-8]. Although both plasmas and gravitating disks are collective systems, in fact plasmas are significantly different from galactic disks (the sign of interaction, etc.). A principal difference between plasmas and gravitating systems is that the latter ones because of the nature of the gravitation force, are *always spatially inhomogeneous. This point is essential: quasi-stationary gravitational disks* must be essentially nonuniform. We include the effects of disk inhomogeneity, i.e., the effects of surface density, angular velocity, and random velocity dispersion (square root of ``temperature") spatial gradients in the study of disk's instabilities.

To describe the ordered behavior of a medium near its quasi-equilibrium state a general dispersion relation that connects the frequency of excited oscillations with the wavenumber throughout the disk is obtained. Using the dispersion relation, a gravitational Jeans-type instability is discussed. In plasma physics an instability of the Jeans type is known as the negative-mass instability of a relativistic charged particle ring or the diocotron instability of a nonrelativistic ring that caused azimuthal clumping of beams in synchrotrons, betatrons, and mirror machines. We show that the Jeans instability of gravity disturbances is one of the most frequent and most important instabilities in the galactic dynamics.

Similar to bunching instabilities in plasmas, e.g., pinch instabilities or a firehose instability, the instability is driven by a strong interaction of the gravity fluctuations with the bulk of the particle population, and the dynamics of Jeans perturbations can be characterized as a fluidlike interaction. The almost aperiodic Jeans instability does not depend on the behavior of the particle distribution function in the neighborhood of a particular speed, but the determining factors of the instability are macroscopic parameters like the random velocity

spread, mean density, and angular velocity of regular rotation. The Jeans instability associated with departures of macroscopic quantities from the thermodynamic equilibrium is hydrodynamical in nature and has nothing to do with any explicit resonant effects. The instability is due to the nature of the galactic system: the free kinetic energy associated with the rotation and the gravitational potential energy are possible sources for the growth of the average wave energy.

This work was partially supported by the Israel Science Foundation, the Israeli Ministry of Immigrant Absorption, and the Academia Sinica in Taiwan.

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Autoionization Level Shifts as an Estimator for Local Field

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Direct estimation of the electric field in the cathode discharge zones is achieved by optogalvanic spectroscopy. Stark level shifts above 12 cm^{-1} have been calculated in Ne and Ar noble gas atoms near the cathode walls in Ne and Ar hollow cathode discharge tubes. Fields of the order of 5 kV/cm are estimated.

Experimental Research of Methane Conversion is Activated By Electron Beam: Measurement with a Molecular-Beam Mass-Spectrometery

V. Kantsler and V. Gagachev

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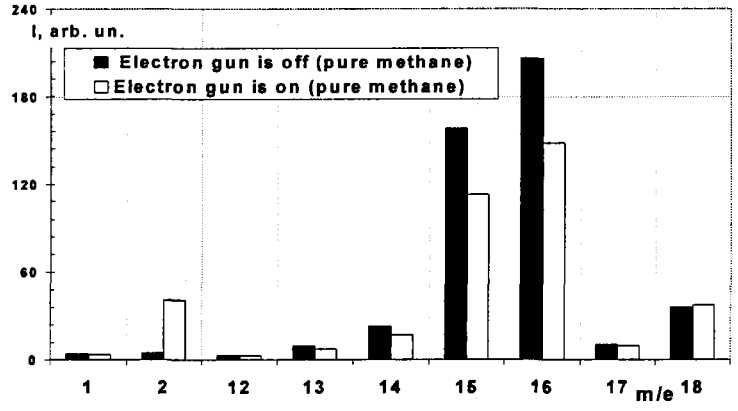
This work is about research conditions of methane conversion to molecular hydrogen. The experimental set-up includes annular nozzle as a gas source, electron gun with plasma cathode that generates electron beam, flow reactor (length = 330 mm, i.d. = 28 mm). Probe is picked as a neutral molecular beam by earthed skimmer (d = 3 mm) from the end of reactor. Then the molecular beam reaches monopole mass-spectrometer where ionization occurs.



Part of pure methane mass spectrum is shown on the figure. Average energy of activating electrons was about 2,5 keV, electron current ~ 200 mA. The conversion ratios K, R were calculated. R shows number of hydrogen molecules produced by one molecule of methane spent,

$$R = \frac{n(H_2) - n_0(H_2)}{n^0(CH_4) - n(CH_4)} = \frac{I(H_2) - I^0(H_2)}{I^0(CH_4) - I(CH_4)} * \frac{\sigma_{CH_4^+}(CH_4)}{\sigma_{H_2^+}(H_2)}$$

$$K = \frac{n(H_2) - n_0(H_2)}{n^0(CH_4)} = \frac{I(H_2) - I^0(H_2)}{I^0(CH_4)} * \frac{\sigma_{CH_4^+}(CH_4)}{\sigma_{H_2^+}(H_2)}$$

where n(i) is the concentration of compound i after activation, $n^0(i)$ – one before activation, I(i) – current of ions i after activation, $I^0(i)$ – one before activation, $\sigma_{i+}(k)$ – partial cross section ionization of *k* molecule for *i*th fragment.

In addition to pure methane we have used $10\%CO_2+90\%CH_4$ mixture. Dependences K and R on the entering energy to the mix are shown in the table. The results provide the possibility to create arrangement of syngas produced by electron-beam plasma conversion.

ε, J/G	1,92	3,53	7,22
K	0,14	0,31	0,58
R	0,28	1,05	1,92

The work was partially supported by Russian Foundation for Basic Research grant (project № 00-03-33021), and Ministry of an Industry, Science and Technologies of Russian Federation (project № 06-05).

Electron-Drift and Transit-Time Instabilities in Hall Thrusters

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Hall thrusters (HT) are being used more and more for producing thrust aboard spacecraft. Widely known peculiarities of this type of plasma thrusters (magnetization of electron component, strong electric field, non-equilibrium character of ionization process, non-uniformity of plasma and field parameters over the channel length) are favorable for various types of plasma instability arise. A wide spectrum of oscillations in the channel ranging from a few kHz to GHz gives a clear evidence of these. The instabilities affect the thruster performance in many ways, predominantly deteriorating it.

We propose the theoretical models of two types of plasma instability in HT. In the first type only the electron component participates, while the second type involves the ions as well. Relevant mathematical models are based on linearized MHD equations. Electron instability at realistic non-uniformities of electric and magnetic fields were studied numerically by solving the corresponding boundary-eigenvalue problem.

At the non-uniformity of the electric field much more than the one of the both magnetic field and plasma concentration, the system of the equations and boundary conditions, which describe the electron perturbations in the thruster, can be reduced to Rayleigh problem well known in the dynamics of ideal liquids. In this case the uniformity of the electric field causes the fast growth of the perturbations of electron velocity; typical increments have the same order of magnitude as drift frequency. Positive gradient of magnetic field along the channel exerts a suppressing effect on the instability, reducing its increment. But the practically attainable steepness of magnetic profiles in HT is yet insufficient to suppress the instability completely.

The second theoretical model concerns the nature of so-called "transit-time" oscillations in the accelerating channel, well known from experimental studies of HT. Within the scope of slightly non-uniform plasma approximation it was analytically demonstrated that the possible reason for the instability of these oscillations is existence in the channel of two ion flows: the fast one consisting of ions born relatively close to anode; and the slow originating in the zone of maximum magnetic field. In this situation, the transit-time oscillations are the two-dim potential perturbations wave-vector of which is orthogonal to the magnetic field.

Excessive Yield of Second Charged Ions of Heavy Elements in Laser Plasma Expansion Process

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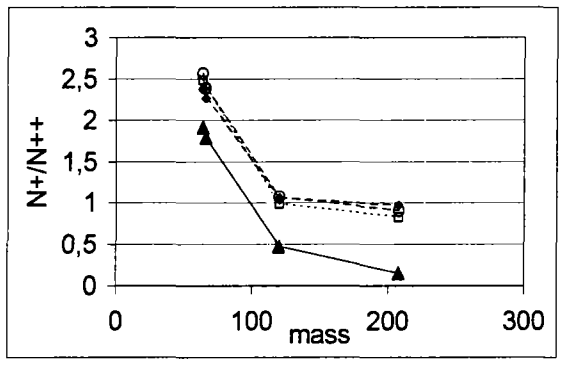
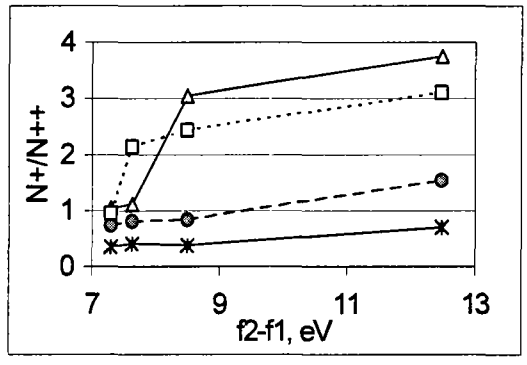
LAMAS-10M TOF-MS that was recently designed for inorganic quantitative analysis is also well suitable for investigation of laser irradiation interaction with solids. This feature allows one to analyze plasma on early stage and gives an excellent possibility to complete existent physical model. This work is dedicated to investigation of yield doubly charged ions for different elements.

The analyses of reference samples with LAMAS-10M TOF-MS show excess of the relative yield of doubly charged ions for heavy elements. Obtained data may be selected between two groups. First group shows decreasing a value N^{+1}/N^{+2} vs. mass, second group shows decreasing a value N^{+1}/N^{+2} vs. the value f2-f1 (f2 and f1 are the ionization potentials).





For example, the relative yield of ^{208}Pb ions with charge +1/+2 is equal to 1-0.5, whereas for ^{63}Cu the yield amounts to 2-2.5. The electrons, being lighter than ions, at first move from the center of the plasma cloud to the rim. It results to "uncovering" of uncompensated positive charge. The electric field arising by this way returns the electrons to the center of the cloud, and accelerates them up to significant energy E ~ 100 eV. Since in this case the flight of ions depends on mass, the concentration of heavy ions in the center of the cloud is higher then the concentration of light ions. This fact results in more effective ionization for heavy ions and appearance of the secondary ions with the charge +2. At long plasma lifetime, the processes of recombination begin that result in distribution of charges. However, in this case, a destruction of plasma occurs at early stage and non-equilibrium

distribution of ions and charges remains. Indeed, practically in all spectra an excess of doubly-charged ions is registered.

Experiments carried out on reference sample "bronze 663" confirm introduced above supposition: increase of yield ions is registered at increasing mass of element. The dependence of relative yield of ions upon the mass is approximated by the function $N+1/N+2=m1/n$.

High-Voltage, High-Current Switch Driving by a Ferroelectric Plasma Cathode

Ya. E. Krasik, K. Chirko, J. Z. Gleizer, A. Krokhmal, A. Dunaevsky, and J. Felsteiner

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The parameters of two types of high-current switches based on ferroelectric $BaTiO_3$ ignition are presented. Both types of switches showed a reliable and controllable operation with a repetition rate of several Hz. The first type is a vacuum two-electrode switch ignited by the plasma which is generated by a $BaTiO_3$ cathode. This type of switch was tested in the voltage range of 3 – 25 kV and switched current amplitude of 2 – 15 kA with either negative or positive polarity of the high-voltage electrode. The second type is a $BaTiO_3$ surface flashover strip-like switch ignited by a driving pulse which has an amplitude of several kV. It was shown that the application of the driving pulse (>10 kV) leads to the appearance of many non-complete surface discharges which transform further to a multi-channel discharge. This type of switch was tested in the voltage range of 1 – 25 kV and current amplitude of 0.5 – 15 kA. The design of the switches, their lifetime, the time jitter and the parameters of the switched current for different discharge conditions are presented.

X-Ray Laser in an Ablative Capillary Discharge Driven by an m=0 Instability

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The development of EUV and soft-X ray lasers made great progress during the last decade. In most cases powerful primary lasers in the UV-, visible and near-infrared spectral regions are employed to produce the dense hot plasmas needed as active media for the lasers. Widely spread applications require small table-top systems and here capillary discharges offer an alternative approach and are being studied by several groups. By selecting properly the transient discharge conditions, collisional excitation or three-body recombination are the effective mechanisms to achieve population inversion. At the Ruhr-University a different approach is pursued where charge exchange between different ions in colliding plasmas is utilized. The plasmas are produced in a small ablative capillary discharge made of polyacetal. In the second half cycle an m=0 instability develops and results in hot plasmas in the neck regions which stream into the cold plasma outside and create overpopulation of the n=3 level of hydrogenic carbon leading to lasing on the Balmer-alpha line at 18.22 nm. A waved structure of the inner capillary wall induces reliably the instability and pinhole pictures give the clue why not all materials are useful. Double pass experiments using a multilayer mirror give an effective gain-length product of GL=4.3 for a 3 cm long capillary and a life-time of the inversion layers of 400 ps.

Generation of Vorticity and Turbulent Cooling of "Hot Channels" in Gases

Yair Kurzweil, Eli Livne and Baruch Meerson

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A wide class of physical phenomena can be cast into the paradigm of a "strong gasdynamic explosion". Examples are numerous and include lightning in the atmosphere, dynamics of laser-induced plasma in gases and in front of condensed matter, entry of a comet/asteroid into the atmosphere, supernova explosions and many others. All these phenomena are characterized by a rapid and localized energy release in a gas, generation of shock waves and creation of strong density and temperature gradients. The weakly-ionized "hot channels" (HCs), formed by a rapid energy release in a gas, exhibit turbulent mixing and cooling, and their life time is usually several orders of magnitude shorter than the molecular heat conduction time scale. Picone and Boris [1] suggested that turbulent mixing results from the vorticity generation (caused by asymmetries in the energy deposition) during the early, shock-wave dominated stage of the dynamics. More recently, alternative scenarios of vorticity generation in the HCs were suggested. We investigate the vorticity generation and turbulent cooling of the HCs by hydrodynamical simulations in two dimensions [2]. We also present some preliminary results of three-dimensional simulations. Assuming small perturbations of the cylindrical shape of the energy release region, we follow the evolution of several HCs and determine their mixing/cooling time. We identify the details of vorticity generation which results in turbulent flow and fast mixing of the cold ambient gas into the HC. Overall, the simulations support, with some modifications, the Picone-Boris scenario. The simulated cooling time is in good agreement with experimental results. The cooling process can be described as turbulent diffusion. The width of the mixed region shows dynamic scaling and compares well to experimental data.

This work was supported by a grant from the Israel Science Foundation, administered by the Israel Academy of Sciences and Humanities.

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High-Current Capillary Discharge with Pre-Pulse Ablative Plasma

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Racah Institute of Physics, Hebrew University, Jerusalem, 91904

Generation of dense long scale axisymmetrical plasmas is important for the study of physics of inertial confinement fusion driven by high-intensity laser and ion beams. Another area of interest is a soft X-ray laser, which require long plasma medium with electron densities in range $10^{19} - 10^{20}$ cm^{-3}. Such plasmas can be created by a slow capillary discharge with evaporated wall and current period $\tau >> l/v$, where l is the length of the capillary, and v is the velocity of the plasma jet blown out from the capillary. Using such discharges, stable dense plasma at temperatures of 1–3 eV has been obtained [1–3]. Typical lifetime of such discharges is higher than one microsecond. Much faster and powerful capillary discharges (τ = 10–100 ns) produced plasma densities in range of $10^{18} - 10^{20}$ cm^{-3} and higher temperatures on the order of tens of eV [4]. However, intensity of the radiation emitted by such plasma exhibits strong shot-to-shot variation [5, 6], and the conclusion that the plasma inside the channel was homogenous is not evident [7].

We report here of the production of dense ($n_e \sim 10^{19}$ cm^{-3}) axisymmetric stable plasmas with temperatures 7–8.5 eV, obtained in a high-current capillary discharge with a pre-pulse ablative plasma. The plasma was produced in vacuum by a discharge with evaporated wall through polyethylene $(CH_2)_n$ capillary which had the diameter 2 mm and the length 10 mm. The discharge had two stages. In the pre-pulse stage, a discharge was held for a few microseconds, the current density being 50 kA/cm^2. In the main stage, the current consisted of a few oscillations with the half-period ~ 1 μsec, the peak current density being 1000 kA/cm^2. The discharge energy in the main stage was 270 J. The temperature and the electron density of the CH_2 plasma were measured by spectroscopic methods.

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Hall Instability of Plasma Flows in Channels

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The Hall instability (HI) of a perfectly conducting plasma is studied. The two-dimensional magnetohydrodynamic (MHD) equations for systems with large Larmor radius for a two-fluid model, in which the Hall term is taken into account in Faraday's law, are investigated. The flow regimes and the plasma parameters where the magnetic field penetrates into plasma are investigated. By using a linearized theory it is shown, that the plasma may become unstable under small perturbations propagating in some directions. The most unstable perturbations propagate in the direction where the wave vector is orthogonal to the magnetic field. In that respect, the HI looks like the Rayleigh-Taylor instability. However, unlike the latter, the HI is compressional and may lead to the density clumping instead of rippling. The growth rate for short-wavelengths HI is obtained by using the frozen-coefficients approach. The non-evolutionarity (i.e. the ill-posedness of the initial-value problem) first mentioned by Brushlinskii and Morozov in their numerical studies of flows in Hall plasma accelerators is analyzed. The dependence of the HI on the steady-state plasma parameters of the plasma flow in the channel, and the conditions for existence of the HI are discussed in detail. It is shown that the condition for HI may be satisfied for typical values achieved in various plasma flows such as plasma accelerators and MHD generators and some problems related to fusion reaction, geophysics, astrophysics, etc.

Pulsed Magnetic Accelerators – Simulation and Practice

Yuri Livshitz, Oren Gafri and Amit Izhar

Pulsar Ltd.

This paper presents an overview summary of several research works conducted at PULSAR Ltd., concentrated on improving the efficiency, stability and durability of pulse-power systems, with emphasis on high magnetic field generation.

Our systems employ magnetic repulsion concept to accelerate a solid continuum, rather then free particles. This dictates very short acceleration travel (several tenths of a mm). Suitable measurement systems were developed for the high-speed measuring of small translation.

Two-dimensional time-dependent model for simulating and optimizing the Electro-Magnetic-Mechanical coupled process of magnetic pulse acceleration was developed heaving total-system simulating capacity, taking into consideration physical dimensions, electric and mechanical properties of all materials comprising the system: coil, field shaper, accelerated part, and the impacted part. Several methods for pulse power diagnostics & health monitoring were also developed, which also serves to verify and support the simulation predictions and modeling.

Systems composed of a kA to MA current pulse generators with capacitor energy storage in the 10-100 kJ range, MA-level pulse transformers, and 10-40 Tl (100-400 kGauss) Coils and Field-shaper (flux concentrators) have been made and designed to withstand several 10,000 s pulses at 4 PPM repetitive operation without fail.

Electromagnetic and Mechanical phenomena regarding the behavior of Field Shapers (FS) and mono-wind trapezoidal coils during core collapse were identified, leading to improved designs.

Current-Augmentation Transformer efficiency in driving coil loads was improved using industrial-grade transformer cores, with good agreement with mathematical projection.

Stoichiometry Control During Deposition by Ion Beam Sputtering

Jaya P. Nair, Ilya Zon, Matti Oron, Ronit Popovitz-Biro, Yishay Feldman,
and Igor Lubomirsky

Dept. of Materials & Interfaces, Weizmann Institute of Science, Rehovot 76100

Ion Beam Sputtering of chemical compounds is in general non-stoichiometric. The problem is especially severe for inorganic insulators because target charging and ionic emission render sputtering rates unstable. This study reports on the influence of target charging on Ion Beam Sputtering of Al_2O_3 and $LiNbO_3$ films on Si and Al_2O_3/Si substrates. It was found that undesirable ionic emission could be minimized by eliminating target charging, controlled via electron to ion neutralization ratio of the incident beam. Experimental data suggest that the stoichiometric sputtering corresponds to zero target charging and thus can be used as an effective feedback parameter during deposition. When the target charging was minimal, high quality stoichiometric Al_2O_3 films were obtained without the need for oxygen supplied to the deposition chamber. The dependence of refractive index, residual stress and specific resistance on neutralization ratio showed abrupt change in the vicinity of zero target charging.

In a separate experiment, minimization of the target charging helped to maintain stoichiometry during ion beam sputtering of $LiNbO_3$, suggesting that this method is also beneficial for sputtering of ternary compounds.

AMBDAS: A New WWW Bibliographic Database for Atomic, Molecular and Plasma-Material Interaction Data

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[2]*International Atomic Energy Agency, Vienna, Austria*

We report here on a new Web-based version of the IAEA bibliographic database on atomic and molecular physics and plasma-material interaction. The existing bibliographic information from the telnet-accessible AMBDAS system was incorporated into a free-source object-relational database management system PostgreSQL v. 7.1.3 [1]. The newly developed WWW interface to the database can be freely accessed at URL **http://www-amdis.iaea.org/AMBDAS/**. This interface provides various search options over, e.g., author names, keywords, publication years, categories and processes, reactants and surfaces, ion charges, isoelectronic sequences, etc. Nested searches over author names are allowed as well. The data output contains direct links to the corresponding journal home pages to facilitate the access to the original sources of data. The numerical data on energy or temperature limits and types of reactants and surfaces is provided where available. The interface is self-explanatory, with help information available for the user. The AMBDAS presently contains about 40,000 references relevant to atomic, molecular and plasma-material-interaction data and is updated twice a year.

[1] URL http://www.postgresql.org/.

Electromagnetically Induced Transparency of Magnetized Plasma

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[2]*University of California, Berkeley, CA 94720*

It is well known that electromagnetic radiation with a frequency equal to the cyclotron frequency of plasma electrons is strongly absorbed by magnetized plasma. It is shown here that this absorption does not occur in the presence of a second, properly detuned, electromagnetic pump pulse. The plasma can thus be made transparent at the cyclotron frequency. The pump is detuned from the probe by the plasma frequency. Transparency occurs because the currents induced at the cyclotron frequency by sideband of the pump can cancel the currents induced by the probe. This effect is very similar to electromagnetically-induced transparency (EIT) of atomic vapours. The essential difference is that the plasma considered here is completely classical, and no quantum mechanical effects are invoked to produce the EIT. The plasma system is significantly more complex than the three-level quantum system--in particular, a non-local interaction, the plasma oscillation, corresponds to one of the levels. Potential applications of the EIT in plasma will be discussed.

Plasma Physics at Terakelvin Temperatures

B. Svetitsky

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The quark-gluon plasma being sought in high-energy accelerator experiments may bear some resemblance to electromagnetic plasmas. I will review signals by which the former might be (or may have been) detected.

Diagnostics of Electric Fields in Current-Carrying Plasmas

K. Tsigutkin, V. Bernshtam, Yu. V. Ralchenko, and Y. Maron

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

The study of non-equilibrium current carrying plasmas is important for the understanding of basic phenomena in laboratory plasmas, astrophysics, and various other applications. A fundamental question underlying the various attempts to describe a current carried through the plasma concerns the formation of non-neutral regions and generation of strong electric fields. Theories and numerical simulations, predicting the development of these regions with turbulent and quasi-DC electric fields in pulsed plasmas, use assumptions that limit the validity of such theories for experimental systems. We investigate experimentally the phenomenon of electric field generation, to determine characteristics and the spatial distribution of these fields, to study the formation of non-neutral regions, the acceleration of charged particles and generation of instabilities. This study is performed in a Plasma Opening Switch (POS) configuration. Non-intrusive spectroscopic methods, including Laser Induced Fluorescence and plasma doping methods, are implemented to achieve high temporal, spectral, and spatial resolutions simultaneously.

Collisionless Shock Breakout in Type II Supernovae: TeV Neutrinos and GeV Photon Emission

Eli Waxman

Department of Condensed Matter Physics, Weizmann Institute, 76100 Rehovot

We show that, contrary to the common view, the radiation dominated shock, which propagates through a type II supernova progenitor, becomes collisionless as it approaches the stellar surface. Inelastic nuclear collisions of protons accelerated in the shock produce a ~1 hr long flash of TeV neutrinos and 10 GeV photons, about 10 hr after the thermal (10 MeV) neutrino burst from the cooling neutron star. A Galactic supernova in a red supergiant star would produce a neutrino flux easily detectable by km-square neutrino detectors under construction, and a photon flux well above the detection threshold of gamma-ray satellites.

Transport of Plasma Produced by a Compact Vacuum Arc Source in a Straight Magnetized Duct

V.N. Zhitomirsky, O. Zarchin, R.L. Boxman, and S. Goldsmith

Electrical Discharge and Plasma Laboratory, Tel-Aviv University, POB 39040, Tel-Aviv 69978

The transport of plasma produced by a vacuum arc plasma gun in a straight plasma duct in which an axial magnetic field was imposed, was studied experimentally. The plasma gun consisted of a truncated cone cathode with a base diam. of 17 mm and 10 mm height, a 17 mm i.d. water-cooled annular copper anode, a spacer, and a trigger electrode. The cathode materials were Sn, Al, or Cu. A D.C. arc current I_{arc} was in the range of 30-200 A was applied between the cathode and the anode. A focusing magnetic field of up to 30 mT was applied in the vicinity of the cathode-anode gap. Part of the plasma produced by the gun passed through the anode and entered into the 160 mm diameter, 500 mm long straight duct. Three magnetic coils positioned co-axially with the duct axis produced a guiding magnetic field B of up to 17.5 mT generally parallel to the duct walls. A 130 mm diam. planar disk probe positioned normal to the duct axis, was used to measure the saturation ion current I_{probe}, and the ion current loss to the duct wall I_{duct} was also measured. The probe and the duct floating potentials φ_{probe} and φ_{duct} were also measured as functions of the axial distance between the probe and the duct exit L, B, and I_{arc}. The measurements were performed in vacuum, at a residual pressure of $3\text{-}5.10^{-5}$ Torr.

Generally, the ion currents at first increased with I_{arc}, reached a maximum, and then decreased. For an Al arc, maximum I_{probe} and I_{duct} were observed at I_{arc}=40-50 A, while increasing I_{arc} to 100 A decreased these by a factor of 2-2.5. I_{probe} decreased while I_{duct} increased with increasing L, while the sum of total current $I_{probe}+I_{duct}$ was independent of L. I_{probe} increased with B, but the increase became less significant with increasing L. φ_{probe} and φ_{duct} were negative relative to the grounded anode. With increasing L or B, φ_{probe} became more negative. However there was no significant influence of B on φ_{duct}.

Properties of Coatings Deposited Using a Filtered Vacuum Arc Carbon Plasma Source

V.N. Zhitomirsky, O. Zarchin, R.L. Boxman, and S. Goldsmith

Electrical Discharge and Plasma Laboratory, Tel-Aviv University, POB 39040, Tel-Aviv 69978

A filtered vacuum arc plasma source with an adjustable cathode-anode gap was used to produce a carbon plasma for deposition of coatings on various substrates. The deposition apparatus consisted of a plasma gun, a toroidal plasma duct, a deposition chamber, and a cooled substrate holder. The plasma gun consisted of a cylindrical graphite cathode, an annular graphite anode, and a mechanism providing axial movement of the cathode to the anode. The arc was ignited in vacuum by momentarily contacting the cathode with the anode, while applying a d.c. current of 100 A between the cathode and the anode, and then withdrawing the cathode away from the anode in the axial direction, forming a cathode-anode gap of 12 mm. A carbon plasma jet passed through the anode into the toroidal duct and then to the substrate. The substrates were stainless steel and polycarbonate coupons, glass slides, and glass and polycarbonate substrates with a SnO_2 coating.

It was shown that the structure of the coatings deposited on stainless steel substrates depended on the negative bias voltage (V_{bias}) applied to the substrate. With V_{bias}=0, the coatings were not adherent, at V_{bias}=-10 V the coatings were porous, but the pore density decreased with increasing negative V_{bias}. At V_{bias}=-20-25 V the adhesion of the coating was good, and dense, hard (HV~34-60 GPa) DLC coatings were formed. At $V_{bias} \geq 35$ V, the formation of graphite phase was observed whose area increased with increasing $|V_{bias}|$. Coatings deposited on polycarbonate surfaces were adherent without applying bias. However, the substrate surface was damaged due to heat flux to the substrate produced by the plasma, after a deposition duration which depended on the magnetic field strength.

Accurate Measurements of Unloaded and Loaded Q-factors of Quasi-Optical Resonators for MM-Wave FEL Applications

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[1]*Applied Electromagnetics Department, Siberia State University of Telecommunicatoins, Russia*

[2]*Department of Physical Electronics, Tel Aviv University*

High-power mm-wave sources based on relativistic electron beams require high Q resonators for providing single-frequency and single-mode operation. Such a resonator can be realized on the basis of quasi-optical configurations, for example concave parallel plates waveguides and Talbot reflectors. A critical problem in the practical study of such resonators is an accurate measurement of unloaded and loaded Q-factors. This is needed in order to estimate the electron beam parameters required to reach lasing threshold and mm-wave FEL generation.

In this paper we report a new approach for measurement of unloaded and loaded Q-factors using mm-wave HP-Network Analyzer and a procedure of curve-fitting between the model developed and the experimental data. To simulate the measurement results, a model, consisting of a lossy 2-port device and lumped parameters of a parallel resonant circuit, has been developed in an analytical form. One of the possible realization of such a 2-port circuit is a lossy transmission line representing the coupling to the mm-wave source. So that variation of the attenuation and length of the lossy line as well as the equivalent lumped parameters of the resonator can be used to match the measured data and the simulated results via standard curve-fitting procedure. When the matching is reached, the actual unloaded Q_U and loaded Q_L factors are reconstructed from the model directly.

Since the resonance curve of a single-mode is uniquely determined by its equivalent R-C-L parameters, only a part of this curve can be employed for curve-fitting reconstruction. As a result, we can match the measured data and the simulated curves even with very small coupling between the resonator and the transmitting system. There is no need to determine a 3-dB level of attenuation as required in conventional methods.

To validate the method proposed several experiments have been carried out with the quasi-optical mm-wave resonator of the Israeli Tandem FEL. Using a parabolic spline approximation, a curve-fitting procedure was employed to extract the resonator Q-factors. The details of the method suggested and its further development will be reported at the conference.

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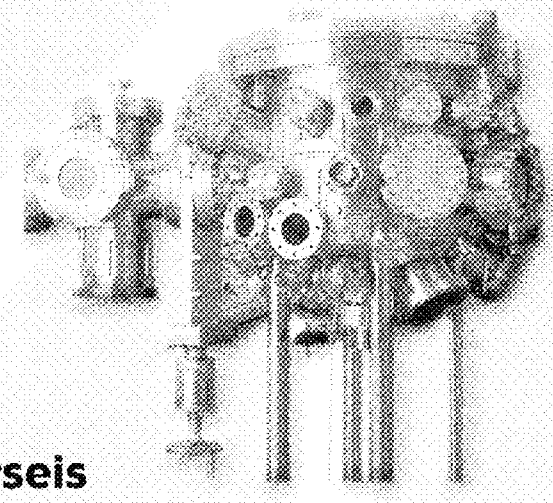

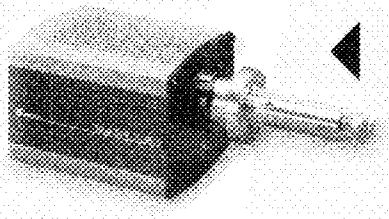

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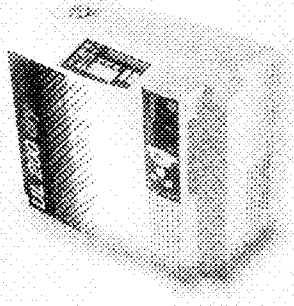
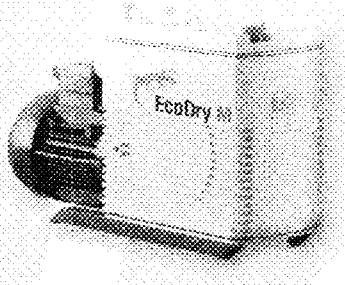


◀ Helium Leak Detector



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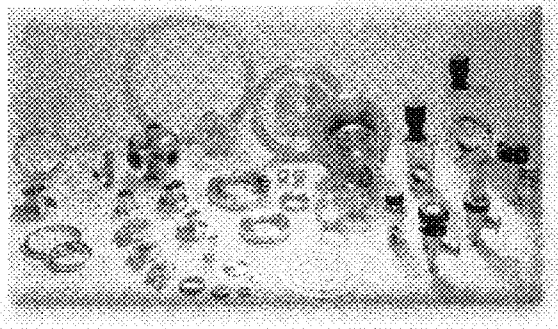

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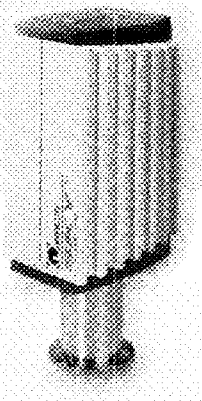

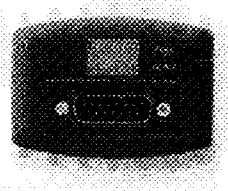

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החברה המובילה בעולם לציוד ואקום

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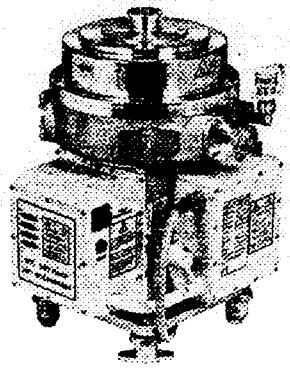
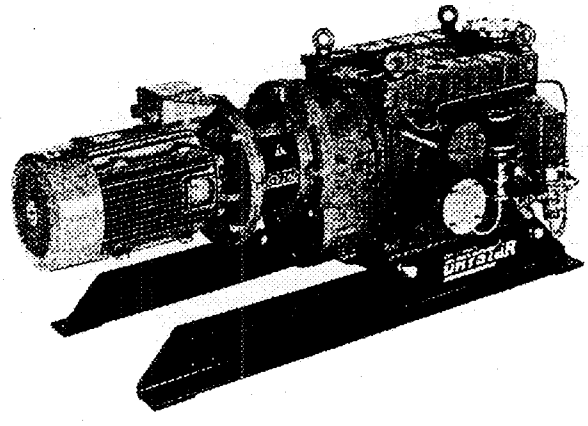
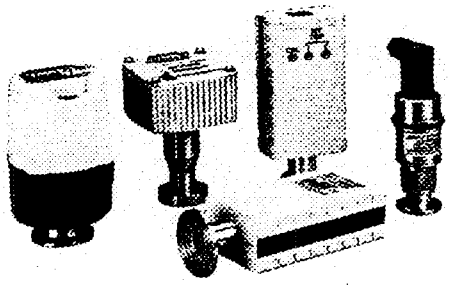
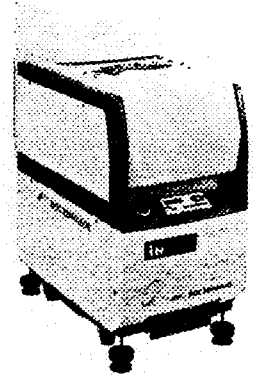
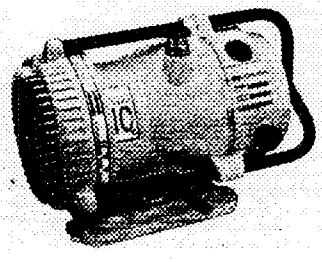
- משאבות למעבדות
- משאבות לתעש"ה
- משאבות דיפוזיה
- משאבות "טורבו"
- משאבות יבשות לתעש"ה הכימית
- ציוד מדידה ובקרה
- ציוד לגילוי דליפות
- ציוד לציפוי בואקום











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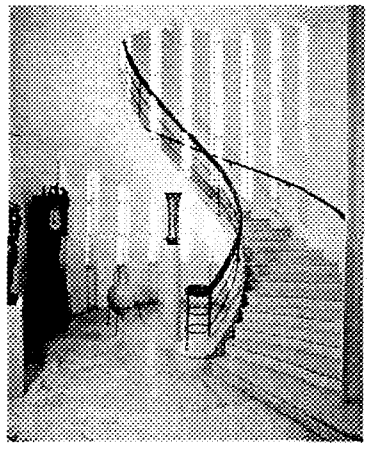

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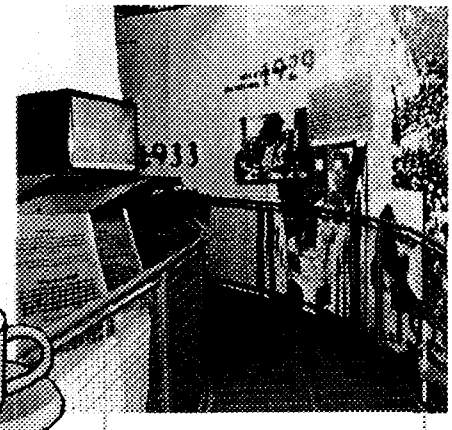

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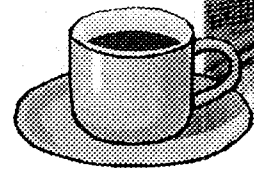

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