IV YUGOSLAV-BELARUSSIAN SYMPOSIUM ON PHYSICS AND DIAGNOSTICS OF LABORATORY & ASTROPHYSICAL PLASMA

Belgrade, 23.-24. August 2002

Abstracts of invited lectures and posters

Faculty of Physics, University of Belgrade
Center for Science and Technology Development

BELGRADE, 2002

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AND DIAGNOSTICS OF LABORATORY & ASTROPHYSICAL PLASMA

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Belgrade, 23.-24. August 2002

PROGRAM OF THE CONFERENCE

23. 8. 2002. Friday

10:00 Opening ceremony
10:30 J. Purić,V.M. Astashynski, M.M. Kuraica, I.P.Dojčinović:
PLASMA ACCELERATOR EXPERIMENTS IN YUGOSLAVIA
11:00 V.K.Goncharov, A.F.Chernyavski:
THE ROLE OF THE BULK VAPOR FORMATION IN DYNAMICS OF METAL LASER EROSION JETS
11:30 V.I. Arkhipenko, S.M. Zgirouski, A.A. Kirillov, L.V. Simonchik:
DETERMINATION OF GAS TEMPERATURE IN He/N_2 MIXTURE ATMOSPHERIC PRESSURE GLOW DISCHARGE
12:00 Coffee pause
12:30 V.S. Burakov, H.-D. Kronfeldt, S.N. Raikov:
MEASUREMENTS OF OSCILLATOR STRENGTHS OF IONIC SPECTRAL LINES BY INTRACAVITY LASER SPECTROSCOPY OF LASER ABLATION PLASMA
13:00 A.N. Chumakov, A.M. Petrenko, N.A. Bosak:
OPTICAL DISCHARGE AS A SOURCE OF SHOCK WAVES AND ACOUSTIC RADIATION
13:30 B. Vujičić, S. Djurović, Z. Mijatović, R. Kobilarov:
T-TUBE, OLD "NEW" PLASMA SOURCE
14:00 Lunch
17:00 Poster section
20:00 Conference dinner

24. 8. 2002. Saturday

10:00 E. Ershov-Pavlov, K. Catsalap, K. Stepanov, Z. Mijatović, S. Djurović, D. Nikolić:
LOCAL PLASMA DIAGNOSTICS USING LINE PROFILES IN THE PLASMA EMISSION SPECTRUM
10:30 A. Brablec, P. Slavíček:
DIAGNOSTICS AND APPLICATION OF DISCHARGES BURNING AT ATMOSPHERIC PRESSURE
11:00 N.M. Sakan, A.A. Mihajlov, Z. Djurić, V.M. Adamyan:
THE METHOD OF DETERMINATION OF FULLY IONIZED PLASMA CHARACTERISTICS
11:30 Coffee pause
12:00 V.D. Shimanovich, I.P. Smyaglikov:
THERMAL FLUX TO A METAL MACROPARTICLE IN A SHORT ARC ARGON PLASMA
12:30 S. Jovičević, M. Ivković, N. Konjević:
PARAMETRIC STUDY OF AN ATMOSPHERIC PRESSURE MICROWAVE INDUCED PLASMA OF THE MINI-MIP-TORCH
13:00 I.R. Videnović, P. Oelhafen:
THIN FILM DEPOSITION BY MAGNETRON PLASMAS: SURFACE CHARACTERIZATION OF GOLD NANOCLUSTER-CONTAINING AMORPHOUS HYDROGENATED CARBON
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DETERMINATION OF GAS TEMPERATURE IN He/N_2 MIXTURE ATMOSPHERIC PRESSURE GLOW DISCHARGE

V.I. Arkhipenko, S.M. Zgirouski, A.A. Kirillov, L.V. Simonchik

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In this report the results of gas temperature measurements in negative glow region of atmospheric pressure glow discharge in He/N_2 mixture are presented. The temperature was determined by molecular spectra of N_2 first negative system and 0-0 OH band. The luminosity growth of N_2 second positive system bands is observed with increasing of nitrogen concentration. It is significantly complicates analysis of spectrum and calculation of gas temperature. Investigation shows that the growth of gas temperature is observed with increasing of nitrogen part in He/N_2 mixture. It can explain by rising of energy contribution in discharge.

The work was supported by BFFR (grant F01-093).

DIAGNOSTICS AND APPLICATION OF DISCHARGES BURNING AT ATMOSPHERIC PRESSURE

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In the last decade a rapid development of technologies working at atmospheric pressure has been observed. The use of atmospheric pressure non-equilibrium plasma, which replaces low-pressure plasma treatment of various materials, is a significant current trend in industrial plasma engineering. The crux is the availability of robust and low cost effective sources of atmospheric pressure plasmas capable of meeting the basic on-line treatment requirements. Thus, the discharges, working under different experimental conditions can be used for their great variety in different application like plasma chemistry, deposition of thin films, cleaning of surfaces, restoration of archaeological artefacts and many others.

In the contribution an overview of such discharges and their nomenclature are presented. In detail, optical diagnostics and application of selected discharges are discussed as follows:

Plasma pencil is a new plasma-generating device usually driven at rf that was developed when the non-standard problem of archaeological artefact treatment was solved. Special properties of this discharge offer many hopeful technological applications like deposition of thin solid films, cleaning and treatment of surfaces, restoration of archaeological artefact's, etc. It was also demonstrated that the discharges could burn under the liquid level. They can interact with the material and then new chemical compounds can arise. The discharges can be driven in argon, in air and other gases and they burn both in open space and in liquid environment, too.

Barrier discharge is the discharge burning between two electrodes, from which at least one is covered with a dielectric layer. The presence of the dielectric leads to the formation of a large number of micro-discharges of nanosecond duration, which are distributed randomly distributed with respect to space and time. The dielectric barrier discharge burning at atmospheric pressure has usually filamentary non-homogeneous form. A uniform dielectric barrier discharge could be generated in helium, nitrogen and in the mixture of argon with acetone under specific conditions - atmospheric pressure glow discharge (APGD). The APGD is homogeneous, it burns in the whole volume of the discharge gap, and no filaments are observed. Besides this, there is only one current peak in the discharge current per half period of the power supply voltage, whereas the discharge current in DBD consists of many current peaks. This new discharge can be used not only for deposition of thin films (now, this possibility has been studied intensively) but also for ozone production.

Underwater pulse electrical diaphragm discharge is generated in the vicinity and inside a hole in the diaphragm made from a dielectrics which is inserted in the gap between two electrodes in conductive water based solution. The discharge can be succesfully used for surface treatment of fibrous polymeric materials polyester cord.

As diagnostic tools the optical and spectral diagnostics have been preferable used. Classical emission spectroscopy makes possible to estimate different temperatures and density of charged particles while for mapping of light conditions in the discharges CCD camera can be is used.

We recommend all who are interested in the subject specified here to visit our WWW page (URL http://www.sci.muni.cz/~physics) where we established a public domain archives for data, programs, texts related to plasma physics.

MEASUREMENTS OF OSCILLATOR STRENGTHS OF IONIC SPECTRAL LINES BY INTRACAVITY LASER SPECTROSCOPY OF LASER ABLATION PLASMA

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New measurements of probabilities of spectral transitions is especially important for ions of refractory metals, the quantitative data for which are frequently inconsistent and require systematic improvement. It is well known, that solar and stellar spectroscopists extremely need accurate oscillator strengths of strong and weak spectral lines for singly ionized 3d elements in the iron group, for example Ti II and V II. Therefore, it is important especially for weak lines to test and to improve tabulated oscillator strengths with the help of independent spectroscopic methods.

Measurements and calculations of oscillator strengths (*f*-values) for Ti II and V II were the subject of numerous experimental and theoretical publications of several scientific groups. The experimental data were obtained using solar and stellar spectra as well as spectra of laboratory plasmas.

At first, it is offered in the present work to use a spectroscopic method, new for such measurements, namely absorption intracavity laser spectroscopy (ICLS). The ICLS is similar to conventional continuum source absorption spectroscopy, but it is much more sensitive technique. In addition to extremely high sensitivity of the ICLS to small values of absorption coefficient, it is

characterized by high time resolution necessary for diagnostics of non-stationary plasma. The self-emission of plasma is unessential in the ICLS.

Secondly, source of ionic species, new for such measurements, was used. The complexity of the solving task is aggravated in rather high temperatures necessary for ablation, atomization and ionization of refractory metals and, in addition, for achievement of useful populations of ions at excited levels. The laser-produced plasma is, of course, a valuable medium to observe a large variety of spectral transitions up to the highly excited states of ions of the element present in the target.

The values of integral absorption in the Ti II and V II spectral lines between 375 and 475 nm have been measured and the relative oscillator strengths have been determined for the sets of spectral lines with the common lower level. The obtained relative values of oscillator strengths have been converted to an absolute scale by means of the most recent appropriate data obtained in emission and have been checked by measurements of atomic level populations.

OPTICAL DISCHARGE AS A SOURCE OF SHOCK WAVES AND ACOUSTIC RADIATION

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Amplitude, temporal and spectral characteristics of pressure pulses initiated by near-surface optical discharge in air are investigated by experimental and numerical methods. The agreement of experimental and computational amplitudes of shock wave outside initial breakdown regions is shown. Under conditions of near-surface air breakdown it is experimentally found out, that the recoil momentum weakly depends on target size. The results of momentum numerical simulation agree with experimental data for small target sizes and significantly differ from that one for large target sizes. Moreover, the gas-dynamic calculation based on Euler equations gives negative values of momentum for large target sizes. Besides it is revealed the difference of the real shape of pressure pulses from computational one. To explain such disagreements, the suggestion has been made that propagating shock-wave transforms into acoustic disturbance due to acoustic dispersion. The power-type relationship between dominant frequency of acoustic radiation and the energy of laser pulse, which is initiating near-surface air breakdown is found. The obtained results can be used for designing of laser-plasma source of shock waves with adjustable amplitude and controlled acoustic spectrum characteristics, and also for remote acoustic diagnostics of laser technological processes and diagnostics of other explosive phenomena in gases.

LOCAL PLASMA DIAGNOSTICS USING LINE PROFILES IN THE PLASMA EMISSION SPECTRUM

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The paper is devoted to a development of the techniques enabling to evaluate local parameters of inhomogeneous plasmas of high-pressure dc arcs and jets directly from recorded spectra of the observed plasma volume emission. The approach allows avoiding any common tomography technique, such as, e.g., Abel inversion procedure in the case of an axial symmetry of the plasma volumes. The results of the problem analytical approach are considered, as well as data of a numerical simulation of the line spectra formation are presented. Also some experimental results confirming the technique applicability are demonstrated.

Atomic line profiles in the recorded spectra are shown to depend strongly on a distribution of the plasma parameters along an observation line. So, they can serve as an information source to find the parameter local values. Here, the technique application is considered for the plasmas, which are close to LTE, optically thin and not changing in time. The plasma temperature distribution along the observation line is supposed to have one maximum and a monotone fall around it. For its evaluation, emision intensity, half-widths and shifts, as well as an asymmetry of spectral profiles for the chosen atomic lines in the recorded spectra have to be measured. These values are used to find parameters accounting for the temperature distribution: the temperature maximum value, the distribution half-width and the parameter determining the distribution shape. As an example, the results of the technique application at local temperature measurements of argon plasma of a cascaded dc arc are presented. A way of the technique optimal application is proposed relying upon use of the pre-calculated diagrams for a wide range of plasma parameters and atomic spectral lines. The resulting technique appeared to be rather simple, and it can be easily applied for diagnostics of different plasmas at their laboratory and (especially) industrial use.

THE ROLE OF THE BULK VAPOR FORMATION IN DYNAMICS OF METAL LASER EROSION JETS

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The experiments were carried out on an installation based on a neodymium laser (λ=1.06 μm). The installation allows to produce the laser radiation pulses of the different space-time form.

The influence of particles of condensed phase of the material of the laser target on a dynamics of the erosion laser jet has been experimentally investigated.

It has been shown that condensed-phase particles formed in course of bulk vapor formation move to meet the laser beam are additionally evaporated. They produce around themselves denser medium than an adiabatic scattering of the transparent vapor. Laser radiation losses in this jet is determined by an absorption and scattering on condensed particles. Some laser radiation intensity can be found when occurs the low-thresold plasma burst. This intensity is different for each metal. The burst is initiated by additionally evaporating particles of target material. From this moment the losses of the laser radiation are determined by losses mechanisms in plasma.

The ranges of laser radiation intensity for a precision and speed processing were determined. The ranges of laser radiation intensity were determined for some metals.

PARAMETRIC STUDY OF AN ATMOSPHERIC PRESSURE MICROWAVE INDUCED PLASMA OF THE MINI MIP TORCH

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The results of spatial distribution measurements of the electron number density, excitation and rotationl temperatures in an atmospheric pressure microwave induced plasma in argon are presented. Electron number density, n_e is determined from the width of the hydrogen H_β 486.13 nm line. The excitation temperature, T_{exc}, is determined from the Boltzmann plot of relative line intensities either of carrier gas argon or iron that is introduced in the form of aerosols. The rotational temperatures ,T_{rot},, are determined from the relative intensities of OH (R_2 and Q_1 branch) electronic band $A^2\square - X^2\square$ (0,0) and to N_2^+ first negative system $B^2\,\Sigma_u^+ - X^2\,\Sigma_g^+$ (P branch).The influence of the microwave input power in the range 80 W - 150 W on the spatial distribution of n_e, T_{exc} and T_{rot} is determined at first. For the selected input power of 100 W, the influence of molecular hydrogen in the wet and desolvated nebulizer and support gas and the corresponding changes in distributions are studied. The influence of potassium as a low ionization potential element on the spatial distribution of n_e, T_{exc} and T_{rot} is also studied.

PLASMA ACCELERATOR EXPERIMENTS IN YUGOSLAVIA

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Here is given an overview of the results obtained in the Plasma Accelerator Experiments in Belgrade, using quasi-stationary high current plasma accelerators constructed within the framework of the Yugoslavia-Belarus Joint Project. The unique complex of experimental set-ups has been constructed for the investigations of different types of quasi-stationary plasma dynamic accelerating

systems of new generation, capable to generate high energy directional plasma flows of required composition (gas - and erosion discharges) in the large range of plasma parameters in different media (vacuum, gas at low and high pressures). So far, the following plasma accelerators have been realized: Magnetoplasma Compressor type (MPC); MPC Yu type; one stage Erosive Plasma Dynamic system (EPDS) and, in final stage of construction, two stage Quasi-Stationary High Current Plasma Accelerator (QHPA). They were tested and appropriated experiments have been performed. The emphases were on their applications in (i) obtaining the materials with improved qualities, (ii) creation of sub micron highly oriented structures on silicon monocrystal due to compression plasma flow action. The influence of external magnetic field on dimensions of created structures has been also observed and discussed. Due to the unique set of parameters (discharge duration τ, flow velocity v_f, temperature T_e and plasma densities n_e) and maximum lowering of electrodes erosion, these systems have advantages in comparison with all of the existing systems for plasma acceleration in the world. Finaly are considered the capabilities of a new generation plasma accelerator – quasi-stationary high-current plasma accelerator (QHPA) – as plasma injector for stellarator and tokamak fueling.

THE METHOD OF DETERMINATION OF FULLY IONIZED PLASMA CHARACTERISTICS

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In this work we present the method of determination of HF electroconductivity, dielectrical permeability and refraction and reflection coefficients of fully ionized plasmas which is based on previously developed RPA theory of nonideal plasma transport processes. Here we have treated two-component plasma, which consists of free electrons and one kind of single charged atomic ions. This plasma is observed in the presence of spatialy uniform monochromatic external electric field with frequency ω. It is considered the case $\omega \ll \omega_p$, where ω_p is the plasma frequency. Considering this, plasma HF caracteristics are determined in long wave approximation. The developed method is applied here on dense plasmas with $1\cdot10^{19} \le N_e \le 1\cdot10^{21}$ and $2\cdot10^4 \le T \le 1\cdot10^6$.

THERMAL FLUX TO A METAL MACROPARTICLE IN A SHORT ARC ARGON PLASMA

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The heat flux to a metal macroparticle in plasma of atmospheric pressure short argon arc used for coating deposition is calculated. Extreme approaches of continuum regime and free molecular flow give comparable results ($\sim 6\cdot10^8$ W/m^2). At the same time the obtained values of Q are in good

agreement with an experiment ($\sim 4 \cdot 10^8$ W/m^2). The proposed technology for deposition of metallurgical coatings was found to have high efficiency for heating up metal powders including refractory ones.

THIN FILM DEPOSITION BY MAGNETRON PLASMAS: SURFACE CHARACTERIZATION OF GOLD NANOCLUSTER-CONTAINING AMORPHOUS HYDROGENATED CARBON

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The technique of nanocomposite thin film deposition by magnetron plasma-enhanced chemical vapor deposition is described using an example of gold-containing amorphous hydrogenated carbon (a-C:H/Au). Though being recently revisited from the applicative point of view, this material has been studied predominantly as a model system due to the lack of reactivity between gold inclusions and *a*-C:H surrounding. As a consequence, an absence of chemical shifts in x-ray photoelectron spectra (XPS) enables one to use XPS as a tool to investigate size and surface arrangement of gold nanoclusters embedded in the *a*-C:H matrix.

Inspired by the differences that direct imaging techniques (AFM and SEM) revealed in the samples deposited with and without applying dc substrate bias voltage, as well as clear difference in grazing incidence small angle x-ray scattering (GISAXS) patterns, we have performed several UV and x-ray photoelectron spectroscopy tests. *In situ* tests comprise as-deposited surface study, off-normal take-off angle XPS, and in-depth analysis by Ar ion etching. *Ex situ* study is performed by examining adsorption of sulfur-containing organic compound thiophene (C_4H_4S) onto the sample surfaces. All measurements provided consistent and convincing arguments that in the grounded case (deposition without substrate bias voltage), the topmost Au clusters are covered with a tiny layer of *a*-C:H. On the other hand, applying dc substrate biased voltage results in smaller and/or bald clusters on the sample surface, and affects *a*-C:H matrix which shows increase in sp^2-coordinated carbon content in comparison with the grounded case.

T-TUBE, OLD "NEW" PLASMA SOURCE

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The intention of this paper is to give the dynamical and spectral characteristic of the T-tube and new possibilities for it`s use as a plasma source.

The T-tube is a small electromagnetically driven shock tube. T-tube is energized by a 4 μF capacitor bank. Electron densities ranging from 2×10^{23} m^{-3} to 7×10^{23} m^{-3} were determined from the Stark widths of the H_β lines. The electron temperatures ranging from 17000 K to 33000 K are determined from line-to-continuum ratios for the H_β lines. The LTE conditions were also checked.

The technique of shock front and plasma flow velocity measurements is explained.

Besides the plasma repeatability for the shot to shot scanning of a spectrum, the main convenience is the plasma homogeneity, so no Abel inversion is required for local emissivity determination. The only possible inhomogeneity, apart from small gradients of temperature and electron densities along the tube axis and of course the shock front itself, is the boundary layer between the plasma and T-tube glass. The thickness of the boundary layer was measured and considerations and conclusions are given.

In order to find out how close was the expansion of the plasmas to the pure adiabatic expansion, we compared possible energy losses from the plasmas per unit time to the power $p\ \mathrm{d}V/\mathrm{d}t$ done by the plasmas during their expansion. Two possible energy loss mechanisms were considered: radiation and heat conduction through boundary layers.

Many various spectroscopic measurements were performed with T-tube plasma. We analysed the shape of the H_β line and He I 447.1 nm in different plasma conditions in presence and absence of external magnetic field. The H_β line shift was measured also.

The some new aspects of t-tube as plasma source are also considered. The possibilities for new spectroscopic measurements and usage the shock front energy for surface treatment.

FEATURES OF MICROSTRUCTURE AND PHASE COMPOSITION OF STEEL SAMPLES MODIFIED BY VARIOUS ENERGY PLASMA FLOWS

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The results of modification of carbon steel specimens by dense compression nitrogen plasma flows have been investigated. The treatment of specimens surfaces by compression plasma flows was carried out in conditions of so-called weak and strong interaction. As the result, a layered structure with the total depth up to 25 microns and up to 300 microns is formed on specimen surface in case of weak interaction and strong interaction, correspondingly. The structural changes result in an essential (by the factor of 3-5) microhardness increase as compared to microhardness of initial specimens. Investigations of the surface structure and its phase composition were carried out with the use of XRD, by optical microscopy techniques, along with studies of mechanical properties.

DYNAMICS OF REFLECTION PHENOMENA FOR POWERFUL LANGMUIR WAVE IN INHOMOGENEOUS PLASMA

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In this report the results of investigation of plasma-wave phenomena in region of linear conversion of powerful oblique Langmuir wave in magnetized inhomogeneous plasma are presented. The model experiment was performed at linear plasma device "Granit" in ECR argon plasma at pressure ~ 10^{-2} Torr, initial electron temperature 1-2 eV and maximal density 5×10^{12} cm^{-3}. The electron plasma wave (EPW) was excited in plasma by microwave pulses at frequency 2.84 GHz and power up to 200 W. It propagates along the magnetic field down the density gradient toward region of linear conversion, where condition $n_e = n_c$ is fulfilled. In this region the wave slows down and its field increases. According to the estimation, at power ~ 20 W the oscillatory energy of electrons is already close to the wave phase velocity. At this condition the wave-electrons resonance interaction and, as a consequence, the capture of electrons take place. Moreover the wave breaking can occur at a higher pump powers.

The relevance of above discussion is confirmed by experimentally observed acceleration of significant part of electrons at first moment. In first 0.2 μs of microwave pump pulse the current pulse with energy of electrons more than 300 eV is observed. Then the energy of electrons sharply falls down with time. The electron acceleration is accompanied then by reflection of launched

power. At pump power under 200 W in 1 μs from the start of pulse the satellite up-shifted by ~ 7 MHz appears in the reflected EPW spectrum. Its frequency shift increases with the pump power up to 20 MHz and decreases in time. A similar up-shifted satellite is observed in scattered spectrum of a small power probing wave as well. However after the pump pulse cutoff a 2–5 MHz down-shifted satellite appears in this spectrum. One of possible reasons for observed phenomena is a parametric decay instability excitation and generation of ion-acoustic waves at frequency 2 – 5 MHz, leading to frequency down-shift of reflected wave.

Taking into account the results of time resolved spectroscopy and cavity measurements and density profile calculations one can explain the observed frequency up-shift by reflection of EPW from border of plasma waveguide channel, which is formed by launched power and possesses much smaller cross-section than plasma waveguide existing in unperturbed plasma. This border is moving in density gradient direction at the high speed, thus leading to the reflected wave frequency up-shift due to the Doppler effect.

At higher pump powers, the time of reflection onset decreases down to 0.2 – 0.4 μs. The sharp aperiodic droppings of the signal are then observed in the reflected pulse envelope. They are apparently related to the wave breaking in the vicinity of conversion region.

The work was supported by RFBR and BFFR (collaborative grant 02-02-81033 Bel 2002_a, F02R-092).

NEAR-SURFACE PLASMA PARAMETERS DURING THE ACTION OF COMPRESSION PLASMA FLOWS ON TARGET

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Dynamics of interaction of compression plasma flows generated by magnetoplasma compressor (MPC) of compact geometry with target surface was investigated. Action of supersonic compression plasma flows on the target results in formation of shock-compressed layer near the target surface. The velocity of plasma spreading throughout the surface, according to measurements by high-speed cinematographic methods, was about 10 km/s. The energy absorbed by the target surface was measured by calorimeter methods. Values of this energy were shown to decrease by no more than 20% as the distance from the accelerator tip increases from 8 cm up to 12 cm. The temporal dependence of plasma pressure on the target surface during the action of compression plasma flow on specimens was measured by optical sensor in various modes of MPC operation. It was shown that depending on experiment conditions, the peak pressure of plasma in near-surface layer might reach up to 10-20 Bar.

INVESTIGATION OF CYLINDRICAL STRUCTURES FORMATION ON SILICON SURFACE UNDER CONDITIONS OF RADIAL CONFINEMENT OF PLASMA LAYER

V.M. Astashynski[1], S.I. Ananin[1], V.V. Askerko[1], E.A. Kostyukevich[1], A.M. Kuzmitski[1], J. Purić[2,3], M.M. Kuraica[2,3], I. Dojčinović[2], V.V. Uglov[4], V.M. Anishchik[4], V.V. Astashynski[4], N.T. Kvasov[5], A.L. Danilyuk[5]

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Submicron regular cylindrical structures on silicon surface were formed by the action of compression plasma flow. Exposed to plasma flow were specimens of monocrystalline silicon of (100) orientation. Compression plasma flows were generated by quasi-stationary plasma accelerator of magnetoplasma compressor type of compact geometry. Microreliefs of silicon surfaces were recorded by means of high-resolution scanning microscopy. The action of the compression plasma flow on the sample results in melting and subsequent modification of silicon material. As the result, submicron-size regular cylindrical structures are formed on silicon surface. Cylindrical fragments are 50 to 100 μm in length and 0.7-1 μm in diameter. These fragments are located on surface of the samples at intervals of 1-2 μm with surface density ~ $(2\text{-}6)\cdot 10^6$ cm^{-2}. Characteristics of cylindrical structures formation under conditions of radial confinement of near-surface plasma layer are described.

INVESTIGATION OF PLASMA FLOW IN EROSIVE PLASMADYNAMIC SYSTEM BY SHADOW METHODS

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Investigations into capabilities of obtaining high-energy compression plasma flows of predetermined composition in dense gases are of great scientific and practical interest. Such flows were first obtained in the air at atmospheric pressure by the use of custom-built erosion

plasmadynamic systems. The compression plasma composition in such systems depends on the inner electrode material. Shadow methods were used for both studying dynamics of plasma streams and measurement of plasma parameters. In particular, visualization of gas-dynamic nonuniformities by high-speed shadowgraphy in experiments on incidence of a compression flow on a thin wedge with sharp leading edge enabled the plasma temperature to be determined. Obtained in such a way plasma temperatures are in good accordance with values found by other methods.

DYNAMICS OF MONOCRYSTALLINE SILICON MELTING AND CRYSTALLIZATION PROCESSES UNDER THE ACTION OF COMPRESSION PLASMA FLOWS

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To find out the mechanism of formation of cylindrical structures of submicron sizes on monocrystalline silicon surface formed under the action of compression plasma flows (CPF), it is necessary to consider processes of silicon melting and crystallization under conditions, characteristic of experiments. In this work, the model of melting and crystallization of monocrystalline silicon taking into account phase transformations kinetics on the basis of Kolmogorov's equation is presented. The temporal form of energy density has been taken close to one observed in experiment. As calculations have shown, within several microseconds after the beginning of CPF action with power density, reaching in maximum $W = 10^5$-10^6 W/cm^2, melting of surface layer begins and a two-phase zone moving into the sample is formed. The overheating value at the melting front reaches 40 K. In the course of CPF action, the front of two-phase zone propagates into the sample to depths 3-10 microns depending on the pulse form and on a kind of boundary conditions. After energy density of the flow on sample surface starts falling, propagation of interface of two-phase zone stops and the process of crystallization on the maximal depth of zone penetration begins. For maximal pulse energy density of ~10^6 W/cm^2 and duration of action ~100 microseconds, silicon sample crystallization time is ~ 300 microseconds after initiation of CPF action.

COMPLEX FOR SPECTROSCOPIC PLASMA DIAGNOSTIC WITH TEMPORAL AND SPATIAL RESOLUTION

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V.Chimanowich, N. Naumenko, S.Tugarinov

No abstract.

LIGHT INDUCED COOLING OF ACTIVE MEDIUM OF CW TEA CO_2 LASER

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Laser local treatment of materials surfaces using a CO_2 laser is based upon the requirements to high quality of the laser beam. It is known that beam parameters of electric discharge laser depend on a spatial distribution of plasma gas kinetic temperature T_g in resonator.

In the present paper a gas kinetic temperature change of active medium of high-power TEA CO_2 laser, that is conditioned by a self-influence of laser radiation on plasma parameters, is investigated. The active medium was pumped by a self-sustained transverse glow discharge. The discharge chamber was a rectangular flow channel with a solid equipotential anode of dimensions 800 x 300 mm and a segmented cathode. The electrode gap was 40 mm. Operation conditions were as follows: working mixture composition - $CO_2/N_2/He=1/10/10$; mixture pressure $P=42$ Torr; input discharge power density $W=1.9-4.4$ W/cm^3; laser output power - 5 kW, mass flow velocity - 100 m/s. The gas kinetic temperature T_g of plasma has been deduced from the half-width of rotationally unresolved spectral bands of the (2+) N_2. It is shown that the laser radiation propagation through the inverse medium causes a cooling of the active medium. The degree of the gas mixture cooling δT_g increases with the input power density rise: $\delta T_g \approx 5$ K at W~2.2 W/cm^3 and $\delta T_g \approx 60$ K at W~4.4 W/cm^3. We suppose that the effect of the active medium cooling is connected with the change of a kinetic of V-T relaxation in asymmetrical mode of vibationally-excited CO_2 molecule when the lasing takes place in the laser resonator. Analytical estimation of the light-induced temperature change of fast-flow TEA CO_2-laser active medium is compared with the experimental one.

FEATURES OF PULSE NEAR-SURFACE OPTICAL DISCHARGE IN AN EXTERNAL ELECTRICAL FIELD

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The influence of target electrical potential on dynamics of pulse near-surface optical discharge is experimentally investigated. Optical discharge was initiated by action of YAG:Nd^{3+}-laser radiation on aluminium target in a mode when laser periodically generated series of pulses (λ= 1,064 μm, τ = 20 ns, E < 0.3 J, spot of irradiation ~200 μm, pulse repetition frequency $f \approx$ 50 kHz). Optical discharge was studied by photographic methods. The change of target potentials and additional electrical probe was recorded, the deposition of condensed disperse phase on a transparent substrate was assessed under changes of constant voltage on the aluminium target from 0 up to 11 kV.

The growth of erosive plasma formation and liquid disperse phase flow going from a target surface in optical discharge as target potential increases for more than 6 kV was found. The action of the second laser pulse it was accompanied by much more essential increase of current from the target and current on the probe, than the action of first one. The growth of quantity of liquid phase deposited on a substrate is detected as target potential increases. The obtained results can be of practical value for laser technologies optimization of materials processing and for technologies deposition of thin films.

PULSATION OF A DC PLASMA JET PARAMETERS

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A pulsation of a plasma jet parameters generated a DC coaxial plasmatrons with contracted arc are investigated using probe and optical methods. A spatial and temporal structure of a plasma jet flowing out from a nozzle shows a multymodal character of a acoustic field existing in a plasmatron. A transversal oscillations of a jet with a frequency f ≥ 15 kHz are caused a rotary movement of a plasma jet and a spasmodic displacement of a anode spots in a conical part of a nozzle channal. A part of a current-conducting arc channal are blew out from a nozzle and participate in a plasma jet forming.

DEPENDENCE OF STRUCTURE CHANGES OF MONOATOMIC METALS ON THE REGIME OF THEIR LASER TREATMENT

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No abstract.

STARK WIDTHS IN THE S III SPECTRUM

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Stark widths of six doubly ionized sulfur (S III) spectral lines in the $3d-4p$ transition have been measured in a SF_6 plasma created in the linear, low pressure, pulsed arc discharge at about 35 000 K electron temperature and about $2.8\cdot10^{23}$ m^{-3} electron density. Mentioned widths have been calculated, also, using the semiclassical perturbation formalism (SCPF) and the semiclassical theory (G) taking into account the configuration interactions. Calculation have been performed for electron temperatures between 10 000 K and 150 000 K.

INFLUENCE OF THE WORKING GAS COMPOSITION ON THE MAGNETOPLASMA COMPRESSOR PROPERTIES

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Plasma compression flows from Magnetoplasma Compressor of Compact Geometry (MPC-CG) operating in different gases (argon, hydrogen, nitrogen and air at various pressures from 0.1 up to 200 mbar) within the voltage range from 2.5 up to 4.1 kV were studied. Discharge current and the voltage between the MPC electrodes were measured using the Rogovski coil and the voltage RC-divider, respectively. Using IMACON 790 high speed camera operating in frame and streak mode, the development of breakdown, shock wave, formation of compression plasma flow and after glow discharge were registered; and the velocity of shock wave front, and velocity and frequency of compression plasma flow, were determined.

TIME-RESOLVED SPATIAL DISTRIBUTION OF BALMER ALFA LINE RADIATION FROM MAGNETOPLASMA COMPRESSOR

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This paper deals with time and spatial resolved spectroscopy of hydrogen Balmer alfa line radiation from MPC plasma using a HR320S spectrometer - IMACON 790 high speed camera system connected with appropriated CCD camera and computer. The camera speed was $1 \cdot 10^5$ frames/s. Plasma was observed with a set of 10 fibers distributed along z axis starting from the outlet of the cathode with 9 mm separation up to 6.3 cm distance. From the registered time and spatially resolved Balmer line images, the Stark profiles of H_α lines were obtained and from them temporal and spatial electron density distribution of MPC plasma was determined.

EXTENSION OF QUASI-STATIONARY PLASMA FLOW LIFE TIME FROM MAGNETOPLASMA COMPRESSOR

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Time extension of quasi-stationary plasma flow from Magnetoplasma Compressor (MPC) has been obtained and discussed. The operation has been performed in nitrogen at 5 mbar pressure using condenser bank of (i) 800 μF, 2.6 kV and (ii) 1200 μF, 2.7, 3.2 and 4 kV. Using the corresponding number of coils, with properly chosen inductivity, and number of connections with MPC electrode system, it was possible to obtain the desired shape of the current pulse (appropriate life time and ratio of the first to the second current maximum). In the case of (ii) it was shown that time extension of current pulse was obtained from 163 μs to 363 μs; first half period from 94 μs to 176 μs. Current maximum in this case was decreased only from 68.4 kA to 46.2 kA. Life time extension of quasi-stationary plasma flow in MPC was verified using high speed IMACON 790 camera. In different material processing by plasma flows action the time elongation of compression plasma flow is very important.

PARTICULARITIES OF LASER TREATING OF METALS WITH LOW PRESSURE OF SURROUNDING GAS

T.S. Glebovich, A.Yu. Ivanov, E.V. Kudryavkin, V.I. Nedolugov, S.V. Vasiliev

No abstract.

CHARACTERISTICS OF DIAMOND-LIKE CARBON FILMS DEPOSITED BY LASER-PLASMA METHOD

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The production and investigation of the diamond-like carbon (DLC) films attract an interest of many researches due to these films have properties close or similar to a diamond. Such properties as a high transmission in the visible and infrared range, chemical inertness, high microhardness, high electrical resistance can be used in microelectronic and optic industry, medicine.

The diamond-like carbon films were deposited by laser ablation of graphite, using Nd-glass laser (λ=1.06 μm). Films were deposited on silicon and glass substrate in vacuum. The pressure was 10^{-3} Pa. The pulse duration was 50 ns. A spectroscopic ellipsometry and thermal wave inspection system (photothermal reflection investigations) have been used to analyze the film property.

Measurements have shown that film has a different thickness alone an erosion flame of the graphite target. This difference in a film thickness can be connected with a partial overlap of the erosion flame with the action laser radiation. The overlap area alone a flame section is inhomogeneous. This causes an offset of the maximum of the decay flame diagram, the modification flame form and a formation of the area with high-energy ions in the flame.

Side by side with a measurements of the films thickness the gap layers have been brought out which can be refereed to SiC or SiO_2. The additional researches are necessary to solve this problem.

It has been obtained that the index refraction decreases with a wavelength increasing. Such behavior has a nature diamond. However, refraction index of the diamond-like film has the less value. It can be explained that film has another carbon modifications together with diamond bond.

The experiments have been shown that diamond-like films can be produced by the laser method with high transmission coefficient. The optic properties of films considerably depend on energy of the action laser radiation.

KINETICS OF THE LIQIUD-DROP PHASE OF THE TARGET MATERIAL IN THE LASER PLASMA

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The liquid-drop phase was formed by action of pulse neodymium laser radiation on lead target. The interacting radiation was in form of the near-rectangular pulse of 400 μs duration. This pulse had space-time nonuniformity of no worse than 5%. The intensity of the laser radiation on the target surface was $q=3\times10^5$ W/cm^2. The monitoring of sizes of the liquid-drop phase in real time scale was performed at a different distance from a target surface perpendicularly to the erosion jet axis by the radiation of the auxiliary ruby laser.

The experiments have shown that the diameter of the liquid-drop phase decreased from 70 nm to 45 nm for the same time interval at a distance from target surface in a process of the laser action. It is caused the additional evaporation due to an overheating.

The erosion plasma jet is some time after the action of the laser pulse. In this time interval the particles sizes increase at the distance from target surface because of condensation. The particles sizes decrease at an increasing of the intensity of the action laser radiation because of more intensity of the additional evaporation. The minimum diameter reaches 35 nm at $q=4\times10^5$ W/cm^2.

These researches are necessary for determination of the laser action regimes to produce the nanosize particles.

CAPABILITIES OF OPTICAL PRESSURE SENSOR IN PLASMA EXPERIMENT

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The issues of pressure measurements in the presence of strong electrical/magnetic fields and high levels of light emission are considered. Under such conditions specific of plasma flows generated by electric-discharge accelerators, such as magnetoplasma compressor (MPC), implementation of piezoelectric pressure sensors is practically impossible. In optical sensors on the basis of Michelson interferometer with He-Ne laser as a light source, the useful signal is too weak when compared to background strays induced by both electric discharge of capacitor bank and light emission from plasma. The suggested sensor based on a design of laser interferometer makes it possible the above negative effects to be minimized: due to a considerable length of an optical element, the signal from the pressure sensor is recorded with time delay, when background noise reduces significantly. The application of such sensor enabled the temporal dependence of pressure on the surface exposed to the MPC plasma compression flow to be obtained.

RESEARCH OF SOLAR PLASMA AND COMETARY ATMOSPHERES FOR RESULTS OF COMETARY OBSERVATIONS

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Comet Hale-Bopp images were obtained in optical range of spectrum. Plasma-dust structures are revealed in comet head. The motions of plasma and dust structures of comet Hall-Bopp are studied. The time scale of the comet nuclear activity is estimated. Diagnostic methods of solar wind plasma and the strength of coronal magnetic fields are represented. The methods are based on the process of interaction of solar wind with gas-dust envelopes of comets.

ION CONTRIBUTION TO THE 667.82 nm He I SPECTRAL LINE

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Ion characteristics of the astrophysical important Stark broadened 667.82 nm He I spectral line profiles have been investigated at electron densities between $4.4 \cdot 10^{22}$ and $8.2 \cdot 10^{22}$ m^{-3} and electron temperatures between 18 000 and 33 000 K in plasmas created in five various discharge conditions using a linear, low-pressure, pulsed arc as an optically thin plasma source operated in a helium-nitrogen-oxygen gas mixture. On the basis of the observed asymmetry of the line profiles we have obtained their ion broadening parameters A caused by influence of the ion microfield on the line broadening mechanism and also the influence of the ion dynamic effect D on the line shape. Our A and D parameters represent the first data obtained experimentally by the use of the line profile deconvolution procedure. We have found stronger influence of the ion contribution to this He I line profile than the semiclassical theoretical approximation provides. This can be important for some astrophysical plasma modelling or dia-gnostics.

CONTRIBUTION OF ION TO THE ASTROPHYSICAL IMPORTANT 471.32 nm He I SPECTRAL LINE BROADENING

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Ion contribution of the astrophysical important Stark broadened 471.32 nm He I spectral line profiles have been measured at electron densities between $4.4 \cdot 10^{22}$ and $8.2 \cdot 10^{22}$ m^{-3} and electron temperatures between 18 000 and 33 000 K in plasmas created in five various discharge conditions

using a linear, low-pressure, pulsed arc as an optically thin and reproductive plasma source operated in a helium-nitrogen-oxygen gas mixture. On the basis of the observed asymmetry of the line profiles we have obtained their ion broadening parameters A caused by influence of the ion microfield and also the influence of the ion dynamic effect D to the line shape. Our A and D parameters represent the first data obtained experimentally by the use of the line profile deconvolution procedure. We have found stronger influence of the ion contribution to this He I line profiles than the semiclassical theoretical approximation provides. This can be important for some astrophysical plasma modelling or diagnostics.

HYDROGEN BALMER LINE SHAPES IN SPHERICALLY CONVERGENT BEAM FUSION EXPERIMENT

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Profiles of H_α and H_β spectral lines emitted from spherically convergent beam fusion plasma source were measured and analyzed. Effects of the cathode voltage on the hydrogen Balmer line profiles were studied. It was found that measured profiles are broadened due to Doppler effect. Doppler width dependence on the voltage applied between electrodes has been found and discussed.

DETERMINATION OF THE PHYSICAL PROPERTIES IN ACTIVE GALACTIC NUCLEI USING BALMER LINES

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We have studied the Balmer line shapes of several Active Galactic Nucleus (AGNs) in order to find the physical parameters of the emitting plasma. Using well known method for laboratory plasma diagnostic, the Boltzmann plot, we estimated the electron temperature and electron density of two AGNs; NGC 3516 (Seyfert 1) and 3C 273 (quasar).

APPLICATION OF THE HIGH-VOLTAGE DISCHARGE PLASMA OF ATMOSPHERIC PRESSURE FOR CARBON NANOMATERIAL SYNTHESIS

A.E. Shashkov, I.F. Buyakov, S.A.Zhdanok, A.P.Solntsev, A.V. Krauklis

No abstract.

GRAPHITE PARTICLES MELTING ON A SURFACE OF CATHODE DEPOSIT IN CARBON ARC

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From considering structure of a cathode deposit growing in a carbon arc at fullerene synthesis mode it was revealed that deposit is formed from 20–50 μm quasispherical particles arisen from coalescence of smaller particles in plasma flow. The smallest size of characteristic details of the deposit surface relief is about 2–3 nm. With use of obtained data on plasma parameters the velocity of 20 μm particles near the cathode was found to be higher than 50 m/s. The deposit formation mechanism based on physicochemical transformations taking place at collision of macroparticle with a cathode surface is proposed. It was shown that raising of temperature and pressure within the collision boundary layer amount to 40 K and 10^8 Pa, respectively, that results in melting graphite in correspondence with a carbon phase diagram.

EXPERIMENTAL STARK WIDTHS OF SEVERAL F III SPECTRAL LINES

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Stark widths of five prominent doubly ionized fluorine (F III) ultraviolet spectral lines (311.358 nm 311.567 nm, 312.152 nm 312.476 nm and 313.421 nm) in $2p^2 3s - 2p^2(^3P)3p$ transition have been measured in the linear, low-pressure, pulsed arc discharge created in SF_6 plasma at 30400 - 33600 K electron temperatures and at $(2.75-2.80)\cdot 10^{23}$ m^{-3} electron densities. The obtained broadening parameters have been compared to the available experimental and theoretical data.

NUMERICAL SIMULATION OF RADIATION TRANSFER IN PLASMA TAKING INTO ACCOUNT OF REAL SPECTRUM

Yu.A. Stankevich, K.L. Stepanov, L.K. Stanchitz

No abstract.

MODEL OF X-RAY SOURCES IN ACCRETION DISKS

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The model of accretion disk in active nucleus of the radio galaxy is constructed. Basing on the analysis of X-ray spectrum of the galaxy, viscosity parameter, included in stationary equations of the disk structure in Shakura and Syunyaev approximation, is determined. The rate of accretion, the internal and the external boundaries of the disk are determined. Depending on a ratio between pressures of gas and radiation, its separation into two areas is carried out. For the whole disk the relations are found and its three-dimensional model is constructed. Making an assumption about a non-stationary rate of a substance inflow, the quasiperiodic changes of X-ray luminosity with characteristic periods of ~1 hour and ~1 day accordingly, are explained.

APPLICATION OF THE HIGH-VOLTAGE DISCHARGE PLASMA OF ATMOSPHERIC PRESSURE FOR CARBON NANOMATERIAL SYNTHESIS

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Carbon nanomaterials (CNM) are synthesized in a gas-phase non-equilibrium plasma process. The present paper describes basically new approach to carbon nanotubes synthesis. This method has the possibility of scaling under atmospheric pressure without any catalyst and with use of not expensive carbonic gaseous fuels (methane, propane, etc.). The proposed technique of carbon nanomaterials manufacturing consists in performing a disproportionation reaction with participation of vibrationally excited molecules of carbon oxide by electric impact in nonequilibrium plasma of

Atmospheric Pressure High-Voltage Discharge (APHVD). A mixture of a natural gas (methane) with air is an initial raw material for final product generation. Technique implementation is possible both at direct treatment of methane-air mixture by APHVD plasma and with preliminary process of catalytic methane conversion and further treatment of conversion products (CO and H_2) by the discharge.

Influence of different synthesis terms of CNM by its phase composition was studied.