## SPARK DISCHARGE IMPEDANCE MATCHING FOR SHOCK WAVE GENERATION

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Shockwave generation by a plateËŮtoËŮplate spark discharge in water is difficult to reproduce due to high water dielectric strength. Advantage of using plate electrodes is their great "wear hardness" in comparison with pin electrodes. Therefore, the plate-to-plate configuration is proposed to be used for the shock wave lithotripsy. Spark discharge between the plate electrodes is initiated by a bubble injection into the electrode gap from the gas inlet in one of the electrodes. When the bubble dimensions are sufficient for the gas breakdown high voltage is applied to electrodes. Streamers emanating from the bubble then bridge the electrode gap and spark is created. Final plasma channel conductivity significantly depends on the channel formation between the electrodes. At certain conditions it is possible to achieve slow increase of the plasma channel conductivity, and thus, nearly perfect impedance matching of the shockwave generator to the pulse power supply.

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## ATMOSPHERIC HYDROGEN PLASMA REDUCTION OF FLEXIBLE GRAPHENE OXIDE ELECTRODES

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This study concerns a low-temperature method for dry hydrogen plasma reduction of flexible graphene oxide (GO) followed by fabrication of graphene electrodes, an approach compatible with processes envisaged for the manufacture of flexible electronics. The GO ink was deposited on various surfaces by spin coating and inkjet printing. A fundamental study of GO ink wetting of standard silicon and flexible polymeric surfaces was performed. Afterward, atmospheric pressure plasma generated in pure hydrogen was used to reduce the GO-ink thin layers. The reduced GO (rGO) layers showed excellent mechanical stability on flexible foils and significantly improved electrical performance. In this study, we investigated the influence of i) surface pre-treatment on GO ink wetting and ii) hydrogen plasma reduction on rGO performance and its application in flexible electronics.

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## DECREASE IN THE MOLECULAR WEIGHT OF VEGETABLE CROSSLINKING AGENT IN THE CONDITION OF RFI PLASMA

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It is proposed to decrease the molecular weight of the dry vegetable crosslinking agent in the condition of the radio-frequency induction (RFI) discharge at low pressure. The parameters of RFI plasma were: energy of plasma ions 10-15 eV; the ion current density $20\,\mathrm{A\,m^{-2}}$; pressure 30 Pa; Ar was used as plasma-forming gas. It was found that RFI plasma leads to a decrease in the molecular weight of the predominant fractions of the vegetable tanning agent: from 311.16; 545.13 to 255.23; 375.20. Application of the obtained crosslinking agent in the process of leather tanning allows improving its physical and strength properties.

## MECHANICAL PROPERTIES OF WNX FILMS AND THEIR OXIDATION RESISTANCE

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The paper reports on the structure, microstructure, mechanical properties and oxidation resistance of the WNx films; here $x = N/W$ is the stoichiometry of nitride films. The films were reactively sputtered from a W target of diameter of 100 mm on Si(100) substrates in a mixture of $Ar + N_2$ gases using an unbalanced magnetron powered by the AC pulsed power supply. It was found that (1) the sputtered WNx films are polycrystalline nanocomposites composed of a mixture (i) low-T $\alpha$-W and high-T $\beta$-W2N the phases at $0 < x < 0.6$ and (ii) high-T $\beta$-W2N and low-T $\delta$-WN phases at $0.6 < x \leq 1.5$ and (2) the as-deposited WNx films exhibit high values of the hardness H, ratio H/E*, elastic recovery We increasing with x up to 32 GPa, 0.12 and 77 %, respectively; here E* is effective Young's modulus and (3) annealing of WNx at temperature of 500 °C in air for 5.5 hour results in formation of $WO_3$ scale on the film surface.

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## CYTOTOXICITY AND OXIDATIVE STRESS IN NORMAL AND CANCER CELL LINES AFTER TREATMENT WITH COLD PLASMA

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Cold plasma-induced differential effects were compared between normal and cancer cells.The remarkable increase of specific intracellular ROS production only occurred in melanoma cancer cells and not in normal cells.The melanoma cells responded more strongly to cold atmospheric plasma treatment than homologous normal cells, with a greater rise in ROS and a higher consumption rate of $H_2O_2$.Cell viability reduced significantly more in cancer cells than in the gas-control and normal cells.To further investigate plasma-mediated anticancer mechanisms, the effects of plasma on the cellular response and mitochondrial function were examined using parental A549 cells and A549-ÏĄ0cells (depletion of mtDNA). We tested whether plasma caused a change in mitochondrial $Ca^{2+}$ levels in cells using the positively charged and cell-permeant $Ca^{2+}$ indicator Rhod 2-AM. We also examined the Akt activation status and caspase-3 activation in various cell types using multispecies In-Cell Western technology.

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## BORON POWDER SYNTHESIS IN THE DC 30KW PLASMA-ARC REACTOR

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The results of thermodynamic calculation of equilibrium composition of the $BCl_3 + H_2$ system are presented. It is shown that the maximum product output can be expected at temperatures close to T = 1800 K, and the excess of hydrogen exceeding 8 multiple rather stoichiometric. On the 30 kW laboratory plasmochemical setup at mixture of streams of bor tetrachloride and hydrogen plasma stream the bor powder having mixed (amorphous and crystal) structure is synthesized. Results of the complex analysis of the produced powder, including laser diffraction, X-ray, SEM, specific surface are presented. It is experimentally shown that increase in an enthalpy of a plasma stream up to 3.4 kWh/m$^3$ allows to increase a product output to theoretical value. Change of an enthalpy of a plasma stream and use of the quartz channel in experiments has allowed to change the specific surface of the produced boron powder in the range from 57 to 94 sq.m/g.

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## PRODUCTION OF SYNTHETIC RUTILE IN THE DC PLASMA ARC 100 KW FURNACE

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Plasma arc recovery melting of the quartz-leucoxene concentrate is investigated. Experiments were made in laboratory DC plasma arc furnace in various crucibles. The best results are reached in a cold copper crucible. The temperature field of a pool is calculated in hot graphite and cold copper crucibles. It is shown that in a graphite crucible diameter of an anode spot is more, and density of current and material temperature in a spot is less, than in copper that is the reason of the worst refinements in a graphite crucible.

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## INFLUENCES OF THE FLOW OF CHLORINE-CONTAINING GAS ON THE ANISOTROPY OF THE ETCHING PROCESS OF GALLIUM ARSENIDE BY THE PLASMA-CHEMICAL METHOD

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In the experiments on the etched surface of gallium arsenide were performed. We studied the effect of NBCl3 gas flow rate on the thickness of the etched layer. GaAs etching rate was: 537.4 nm/min, 28.7 nm/min, 2.6 nm/min, the values of the flow rate of NBCl3 15, 10, 5 cc/min, respectively. The influence of the anisotropy of the process on the geometry of the etched area. Revealed that the deflection angle for the samples treated with the working gas flow rate NBCl3 - 15 cc/min in the [110] direction was $\alpha[110] = 65.5°$ in direction [111] was $\alpha[111] = 45.58°$. For samples treated with the working gas flow rate NBCl3 - 10 cc/min in the [110] direction was $\alpha[110] = 20.94°$ in direction [111] was $\alpha[111] = 11.37°$. For samples treated with the working gas flow rate NBCl3 - 5 cc/min in the [110] was $\alpha[110] = 0.32°$ in direction [111] was $\alpha[111] = 0.21°$.

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## EFFECTS OF CARBON-CONTAINING GAS PRESSURE ON THE PARAMETERS OF CARBON NANOSTRUCTURES FOR CREATING HIGHLY EFFICIENT SOLAR PHOTOELECTRIC DEVICES

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This article deals with the manufacture of high-performance photovoltaic devices, solar cells. Improving the efficiency, this is achieved by using carbon nanomaterials. The use of carbon nanotubes increases the performance of solar photovoltaic through efficient charge transport in the device. Effective use of carbon nanomaterials in these devices is achieved by the formation of an ordered network of cross-walled carbon nanotubes. The work for the formation of such arrays chosen method of chemical vapor deposition plasma enhanced. The result shows that at an optimal pressure of the carbon-containing gas, vertically oriented carbon pipes grow. At pressures below, amorphous carbon grows on the surface. At pressures above optimal, cone structures with a low aspect ratio are formed instead of carbon nanotubes.

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## MORPHOLOGY AND CONTACT PROPERTIES OF POLYTETRAFLUOROETHYLENE-LIKE FILMS DEPOSITED ONTO TRACK-ETCHED MEMBRANE SURFACE IN VACUUM

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The morphology and contact properties of nanoscale polytetrafluoroethylene-like films deposited onto the surface of the poly(ethylene terephthalate) track-etched membrane by RF-magnetron and electron-beam sputtering of polytetrafluoroethylene in vacuum have been studied. It was shown that the morphology of the films obtained by these methods was differed drastically. This is due to the size of the deposited polymer particles. The particles produced by the electron-beam sputtering of polytetrafluoroethylene are much bigger in size. The study of the contact properties of the composite membranes formed in these processes was shown that the deposition of the polytetrafluoroethylene-like film onto track-etched membrane leads to hydrophobization of the surface. The water contact angle for the composite membranes significantly increases.

## PROPERTIES OF PLASMA POLYMER FILMS BASED ON CLASSICAL POLYMERS

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The structure of typical plasma polymer has unordered chemical structure and high degree of crosslinking. On the contrary, the classical polymers prepared by "wet" chemistry typically exhibit well-defined molecular structure and their crosslinking degree is much lower. Plasma-assisted vapour thermal deposition is a technique that allows preparation of thin films that have both well-defined molecular structure and controllable degree of crosslinking. Powder of classical polymer is heated under low pressure until the oligomeric fragments of the material are released and re-polymerized using an RF glow discharge.
Thin films based on poly-lactic acid, polyethylene oxide and polyurethane have been prepared and characterized in terms of chemical composition and molecular weight. The degradation/swelling properties of the films in dependence on the deposition conditions (heating temperature and plasma power) have been studied.

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## NANOSTRUCTURED MAGNETRON SPUTTERED C:F SURFACES FOR DROPLET COATING DEPOSITION RAMAN SPECTROSCOPY

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Droplet coating deposition Raman spectroscopy was recently reported to be a valuable method for sensitive bio-detection. This technique is based on spontaneous drying of liquid solutions. Under certain conditions drying droplet forms a well-defined "coffee-ring" structure after its complete evaporation. Biomolecules dissolved in the liquid are then concentrated only in a thin outer ring of dried pattern, thereby enhancing the Raman signal. In this study, we investigate a novel method for surface production that facilitates the "coffee-ring" formation. This method employs nano-structuring of magnetron sputtered C:F films by a base layer of nanoparticles that are fabricated by means of gas aggregation source. Influence of surface roughness of resulting coatings on properties of dried patterns is investigated using methylene blue dissolved in water at different concentrations as a model system.

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## SURFACE MODIFICATION OF FLEXIBLE POLYURETHANE IMPLANTS BY BIOCOMPATIBLE COATINGS OBTAINED BY PVD WITH ASSISTING RF FIELD AT LOW SUBSTRATE TEMPERATURE

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Thin Zr and Ti coatings (70 nm thick) have been obtained by vacuum-arc deposition with assisting RF-field on polyurethane surfaces (PUR) at low substrate temperature (60°C). The choice of Ti and Zr coatings on PUR is based on the idea of combining the properties of the polymer (e.g., elasticity, vessel-like) with those of a thin metal-coating (e.g., biocompatibility, corrosion, and degradation resistance). The surface morphology, structure, elemental and phase composition of the obtained coatings was examined by SEM, TEM, XRF. It was revealed that vacuum-arc method with RF-field allowed applying coatings on PUR flexible surfaces at (60°C, decreasing the formation of macro-particles, providing formation of $\alpha$-Zr and $\alpha$-Ti polycrystalline films of hexagonal modification with average grain size of 0.1 μm. The roughness of the obtained coatings has been measured.

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## INVESTIGATION OF THE METHOD OF DYNAMIC MICROWAVE POWER REDISTRIBUTION IN A RESONATOR-TYPE PLASMATRON

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The investigation results of a dynamic microwave power $f_{microwave} = 2.45 \pm 0.05\,\mathrm{GHz}$ redistribution in a $9\,000\,\mathrm{cm}^3$ reaction-discharge chamber of a microwave resonator-type plasmatron are presented. In order to redistribute the microwave power, a rotating metallic four-blade L-form dissector placed above the reaction-discharge chamber was used. The microwave power in the local points at the axis of the chamber with plasma and without it was measured applying the "active probe" method. During the experiments the chamber contained silicon plates. Periodical interchange of maximum and minimum microwave power values along the chamber axis was established experimentally. Note, when the dissector was rotating, the range of maximum and minimum "active probe" values dispersion decreased. It has been established that during the dissector rotation the microwave power in the local discharge areas changes with periodic repetition every quarter of revolution.
Keywords: microwave plasma, microwave power, redistribution, dissector.

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## DEVELOPING AIR QUALITY IMPROVEMENT SYSTEM OF A SWINE HOUSE USING PLASMA SYSTEM

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The study was set to develop an air purification system for a swine house. This system was used to sterilize disease and improving the air quality inside and outside the swine house. The plasma with oxygen was mixed to produce the ozone gas with raging 4 - 10 ppm that active for the sterilize performance. The vacancy time is reduced from 7 days to 4 days. This show that 42 percent was reduced in this system The weight of pigs increased from 100 kilograms per one pig to 104 kilograms, rising by 4 percent. Pig house It was found to be more satisfying compared to pre-installed plasma systems for disinfection and improved air quality.

## NANOPARTICLES AND NANOCOMPOSITE FILMS DEPOSITED USING A TOROIDAL PLANAR HOLLOW CATHODE DEPOSITION SYSTEM

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Sometime ago researchers developed the Gas Flow Hollow Cathode (GFHC) Sputter Deposition where a relatively high gas flow was used to entrain the sputtered atoms along the cathode axis towards the substrate. We have developed a modified hollow cathode design based on the planar system, a combination of a toroidal electrode and the GHFC; Toroidal Planar Hollow Cathode (TPHC). The "hollow cathode" discharge occurs between the upper and lower electrode surfaces. We have used the system to deposit bismuth and aluminum based thin films and nanoparticles as a function of the experimental parameters. The size of the nanoparticles mainly depends on the gas pressure and plasma power. Nanocomposite coatings have been made by using the plasma plume at the exit of the TPHC to remotely decompose acetylene or methane and deposit a combination of the nanoparticles and an a-C:H film.

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## THE EFFECT OF TEMPERATURE SET-UP AND PLASMA GENERATOR INSTALLATION POSITION ON THE SPLIT-TYPE AIR CONDITIONER

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This plasma system was developed by AC high voltage - 10 kV with a frequency of 10-30 kHz of Flyback. The research was conducted by installing the plasma generator in wall-mounted type air conditioners with three types of installation: air flow out, air flow in, and room center. The result showed that the plasma generator installed in split type air conditioners could purify the air as efficiently as the plasma system available at present. The result of an experiment in the efficiency of installations revealed that the air flow out installation worked the most efficiently at 24 degree Celsius and the installation had to be done at the position where air flowed out in front of the cold coil of the air conditioner. The air flow out installation provided the highest average of o-zone quantity at 172.5 mg/h. This type of installation provided the highest efficiency of air quality improvement.

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## PLASMA POLYMER DEPOSITION ON HOLLOW OBJECTS BY ELECTRICAL PLASMA GENERATED FROM LIQUID SURFACE

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Recently, plasma deposition at atmospheric pressure has become a promising technology due to its reduced equipment costs and its possibility of in-line processing. The main aim of this work was to show a process for the deposition of plasma-polymerized layer inside and outside of polytetrafluoroethylene tube by plasma discharge generated above the liquid electrolyte. In principle, this process is based on the surface dielectric barrier discharge, where the plasma is generated from the boundary line of liquid precursor and dielectric surface. HMDSO was chosen as a model precursor compound for deposition on external and internal wall surface of PTFE tube.

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## ALUMINIUM AND TITANIUM ALLOYS SURFACE BEHAVIOUR UNDER ARGON AND HELIUM ION EXPOSURE

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Samples of aluminum alloy Al(2024) and titanium alloy Ti-6Al-4V have been irradiated with 2 keV helium (He) and argon (Ar) ion fluxes using FALCON ion source. Cone-like structures are found to be formed on the surface of two Al(2024) samples due to both irradiation conditions: Ar and He exposure reaching total charge 150 Coulomb per sample. Ar exposure of Ti-6Al-4V causes cones formation. He exposure causes only physical sputtering morphology at the same total charge. Chemical composition of grown structures has been obtained from energy dispersive spectroscopy (EDS). Surface roughness and roughness profile have been investigated with confocal microscope. Hardness of irradiated surfaces has been obtained from results of whiskers hardness test. Residual stresses after irradiation and phase composition have been measured by X-ray Diffraction spectroscopy (XRD). Free surface energy measured with drop test.

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## THE FORMATION OF CHITOSAN-SILVER COMPOSITE IN PLASMA SOLUTION SYSTEM

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Bactericidal potential of chitosan can be enhanced by the modification of this well-known biopolymer with an antibacterial agent, Ag for example. Plasma-solution treatment allows to produce such hybrid materials in a single-stage process. In this work, a 1 % (w/v) acetic solution of chitosan with the addition of 0.13 % (w/v) of $AgNO_3$ was used either as a cathode or an anode in an atmospheric pressure plasma-solution cell. The decrease of the molecular weight of chitosan was observed for both polarities. The formation of Ag particles in the treated solutions was confirmed by the development of a plasmon absorption band at 410 nm. The hybrid composite foils were produced by the evaporation of the solvent. UV-Vis, FTIR, XRD, SEM and EDX analyses found that the incorporation of Ag particles into chitosan is mediated by the OH-groups.

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## FABRICATION OF PALLADIUM NANOPARTICLES BY A GAS AGGREGATION CLUSTER SOURCE

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Over the last few decades, there has been a growing interest to develop a replacement of traditional fossil fuels due to risks of environmental contamination and the limitations they imply. Fuel cells have proven to be efficient, environmentally friendly and useful in a wide range of applications. Recent works showed promising results of using palladium nanoparticles (Pd NPs) as anode catalysts in fuel cells. For example, the improvement in performance of direct formic acid fuel cells is expected due to the increased surface area of the catalyst. Here, we focused on the synthesis of Pd NPs by aggregation in a cool buffer gas. DC magnetron sputtering was used in the configuration of a gas aggregation cluster source. Two sets of the operational parameters allowed tuning the NP size from 6 nm to 14 nm and adjusting the deposition rate. The NPs were deposited onto a carbon cloth and silicon substrates. AFM, SEM and XPS were used to characterize the NPs.

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## PARAMETERS OF PLASMA TORCH OPERATING ON A MIXTURE OF METHANE AND AIR

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The main methods for obtaining syngas are solid fuels gasification, natural gas catalytic reforming and water electrolysis. In recent decades, the partial oxidation of natural gas is developing (exothermic process). However, to ensure the necessary reaction temperature this is not enough, so the $O_2/CH_4$ ratio is increased. This leads to a decrease in H2/CO ratio, so that the arc energy can be used to increase the temperature $H_2O + CO_2$ methane reforming was previously studied. At the same time, methane conversion was 99.8 %, hydrogen selectivity was 98 %, and specific energy consumption was 38 MJ/kg of methane.

The report considers the AC plasma torch with two plasma-forming gas feeding zones: the electrode zone and the arc zone. Air is supplied to the electrode zone (4 g/s), and a mixture of air (1.13 g/s) and methane (1 g/s) is supplied to the arc zone. The plasma torch power is 74 kW, the idling voltage of the source is 10 kV, and the current is 50 A.

## PLASMA SPHEROIDIZATION OF POWDERS OF METAL-CERAMIC COMPOSITE MATERIALS OBTAINED BY SHS FOR ADDITIVE TECHNOLOGIES

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Plasma spheroidization of powders is one of the most effective and productive ways of obtaining high-quality raw materials for additive technologies. Particularly promising in this direction are devices and structures that use high-frequency gas heating. The absence of electrodes makes it possible to obtain a high-frequency plasma that is extremely pure, not contaminated by the products of their destruction.
Powders of metal-ceramic composite materials were obtained by the self-propagating high-temperature synthesis method (SHS). The structure and phase composition of powders are studied. Investigations of the spheroidization of the obtained powders with the use of a high-frequency induction plasmatron were carried out. Powders of spherical shape are obtained. It has been established that plasma spheroidization does not affect the internal structure and properties of the powders. The powders obtained were successfully tested using them in the additive technology of direct laser growth.

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## MULTI-ELECTRODE SEQUENTIALLY PULSED COPLANAR BARRIER DISCHARGE FOR THE TRANSPORT OF BULK MATERIALS

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The natural tendency of fine powders to concentrate outside the microfilament plasma channel was utilized to induce their unidirectional drift across the active plasma zone. A coplanar barrier discharge with multiple (i.e. 3 and 4) individually driven electrodes was devised, together with two different types of high-voltage power supplies. Discharge plasma was sequentially ignited between the given electrode pair, forming a travelling wave of active plasma zone. The presence of bulk material transport was demonstrated on stained glass microbeads of 100-200 µm average diameter. Two important constrains were identified: (1) only a thin powder layer can be effectively manipulated; (2) driving frequency is inversely proportional to the mass of transported powders. The 3-electrode system exhibited the strongest transport properties for the tested material. The 4-electrode system simplified the design of multiphase HV power supply, with still reasonably strong powder transport.

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## METALLIC NANOPARTICLES GENERATION BY REPETITIVE PULSED LASER FOR APPLICATIONS IN BIO-MEDICINE

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A Nd:YAG pulsed laser operating at the 1064 nm wavelength, the 3 ns pulse duration, the $10^{10}$ W/cm$^2$ intensity and the 10 Hz repetition rate is employed to irradiate biocompatible metallic targets based on Au, Bi and Ag placed in water. The laser-matter interaction produces nanometric spherical particles. The concentration of the solution with nanoparticles is controllable by the laser parameters, the ablative emission process, the irradiation time and the water's volume. Generally, nanoparticles of about 10 nm in size and concentrations of the order (0.1 - 10) mg/ml are prepared to be injected in cell cultures or in living systems (mice). The nanoparticles introduction in the extra and intra cellular liquids improves the bio-imaging of the tissue and organs by using fluorescence techniques. Moreover, if these nanoparticles are concentrated in tumour cells, they make possible high efficiency radio-therapy and thermal-therapy treatments, as it will be presented and discussed.

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## USING LOW TEMPERATURE PLASMA FOR FORMATION OF NANOSCALE RELIEF ON THE SURFACE OF STRUCTURES BASED ON GAAS

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In this exploratory work, the precision profiling technology of structural GaAs surfaces based on chemical etching in low temperature plasma for further epitaxial growth.
This method is consistent application of local oxidation and plasma chemical etching. GaAs plates have been subjected to standard liquid polishing for improvement its geometric characteristics. By the method of local anodic oxidation oxide nanostructures were obtained on surfaces of plates. Oxide structures were used as masks for further plasma chemical processing. For this processing two types of discharge: capacitive and inductively coupled were used. BCl3was applied as working reaction gas and the total etching time varied from 0.5 to 2 minutes.
As a result of the experimental session, samples were obtained with surface reliefs, that depending on the formation stress, as well as the etching time of the near-surface layer of GaAs plates.

*This research has been supported by the Russian Science Foundation Grant No. 15-19-10006.*

## FIELD EMITTERS BASED ON CARBON NANOTUBES OBTAINED BY THE METHOD OF PLASMA CHEMICAL VAPOR DEPOSITION

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During the implementation of experimental studies, the structure of the field emitter model based on vertically oriented carbon nanotubes obtained by the method of plasma chemical vapor deposition was developed and fabricated.
Experimental layout was chemical cleaned silicon substrate, on which vanadium and nickel layers were deposited by magnetron sputtering. Nickel was used to metal, that forms catalytic centers. Further, on this structure, by the method of plasma chemical vapor deposition, an array of carbon nanotubes oriented perpendicular to the substrate was obtained.
The obtained structure has the following characteristics: the field gain $\beta = 7.9 \times 10^7$, the threshold field strength of the field emission field beginning $E = 6.7 \times 10^8\,\mathrm{V/m}$, the current density $j = 3.2\,\mathrm{mA/cm^2}$. The obtained field emission characteristics make it possible to judge the high efficiency of field emission.

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## SW CNT BY HYDROGEN-VHF PLASMA ETCHING INVESTIGATION

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In this work, consecutive hydrogen irradiation doses are applied to single walled carbon nanotube (SW CNT) film for 0.5, 1, 2, 3, and 4 hours in vacuum. After the irradiation the samples were studied with the visible-ultraviolet and near-infrared spectroscopy, the scanning electron microscopy, Raman spectroscopy, terahertz time-domain, and Fourier-transform infrared spectroscopies.
We found that both the electrical conductivity and the loss tangent of the film in the terahertz range decreases as radiation time increases supporting the conclusion about the CNTs cutting due to the plasma etching. Using the scanning electron microscopy we obtained one more confirmation of the tube length reduction in the samples. Direct-current conductivity of the films was also shown to decrease with increasing time of irradiation.

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## PORTABLE “UPOV-001” TYPE OZONE GENERATOR BASED ON DBD FOR WATER TREATMENT

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In this paper we present a device for obtaining ozonated water equipped with generator based on a DBD. The device is compact and portable, able to quickly saturate the water with ozone to the concentration necessary for its disinfection and further use. The design of the ozonizer allows directly receiving ozonized water in a capacity of 20 liters, which is part of the device. The ozone concentration in this device is controlled by the built-in spectroscopic ozone meter. Experiments on ozone saturation have been carried out. The dependences of water saturation with ozone are obtained depending on the time and volume of water. It was found that the residual amount of ozone in the water, after switching off the generator, for more than 2 hours was more than 1 mg/l. This dose is sufficient for the disinfection of water. The device can be used for disinfection of various surfaces in the room with the help of ozonated water, as well as in emergency and purulent surgery, food processing.

## MATURED ESCHERICHIA COLI LAYER TREATMENT BY LOW TEMPERATURE PLASMA GENERATED USING DIFFERENT TYPES OF DISCHARGES

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The basic model of many *in vitro* experiments with microorganisms is set with a sample of precisely defined species of observed microorganism diluted in an appropriate ratio, so an untreated (control) sample grows as one single homogenous layer covering the growth substrate. Despite many advantages for many basal experiments, such a model situation does not correspond to the usual *in vitro* conditions. In presented basic experiments we have focused on the situation where the microorganism species grows into a submillimetre layer which gives slightly similar conditions as can be found in healing infected wounds. The grown layer was afterward consequently treated by low-temperature plasma (via corona and dielectric barrier discharges) eventually with a combination of other agents, e.g., essential oil. It was approved that microorganisms grown into a more complex structure are much more resistant compared to a single individual of its species.

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## TRIBOLOGICAL PROPERTIES OF TUNGSTEN NITRIDE FILMS AT TEMPERATURES UP TO 500 °C

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The paper reports on tribological properties of WNx films with a stoichiometry $x = N/W$ varying from 0 to 1.5 and measured at temperatures ranging from RT up to 500 °C. The WNx films were reactively sputter deposited in an $Ar + N_2$ gas mixture using an unbalanced magnetron powered by the AC pulsed power supply. It was found that (1) WNx films are polycrystalline nanocomposites composed of a mixture of (i) low-T$\alpha$-W and high-T $\beta$-W2N phases at $x \leq 0.56$ and (ii) high-T $\beta$-W2N and low-T $\delta$-WN phases at $0.56 < x \leq 1.5$, (2) the friction coefficient µof WNx films increases with increasing x from $0.26 - 0.42$ at RT to 0.751.23 at 150 °C and decreases to about 0.50 with temperature increasing above 150 °C up to 400 °C due to the growth of a WOy scale on the film surface, and (3) the wear rate k of WNx films increases from about $10^{-8}$ mm$^3$/Nm at 150 °C up to about $2.5 \times 10^{-6}$ mm$^3$/Nm at 400 °C.

*This research has been supported by the project LO1506 of the Czech Ministry of Education, Youth and Sports under the program NPU I.*

## BACTERICIDAL EFFECT OF HELIUM DIELECTRIC-BARRIER DISCHARGE PLASMA JET IN VIVO

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Atmospheric pressure plasma jets based on a dielectric-barrier discharge (DBD) are known to be able to kill bacteria and inhibit their growth on different surfaces including wounds. The results of the study on the effect of helium DBD plasma jet on a bacterial growth in mice wounds have been obtained. The plasma jet was produced from a helium flow. An average discharge power was equaled to 160 mW. The gas outlet velocity was 2 m/s. A model of complicated course of wound process against the background of hydrocortisone-induced immunosuppression was used to provide the investigation of wounds in mice skin. The mouse was placed on a wooden substrate 4.5 cm from the plasma jet generator. The duration of treatments was 4 minutes. Bacterial composition in wounds was estimated using biopsy material inoculated on agar in Petri dishes. Plasma jet treatments result in the significant reduction of the amount of Staphylococcus aureus colonies in comparison with a non-treated wound.

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## FUNCTIONALIZED PLASMA POLYMER NANOPARTICLES FABRICATED BY A GAS AGGREGATION CLUSTER SOURCE

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Plasma polymer nanoparticles (NPs) are of great interest due to their applicability in different fields of science, for example, in medicine and bioengineering. Nowadays, different strategies have been developed for fabrication of polymer NPs but gas aggregation cluster sources (GAS) take special place because of their effectiveness and environmental friendliness. This work is focused on the preparation of plasma polymer NPs functionalized with electrophile nitrogen-containing or nucleophile oxygen-containing groups with a purpose of their potential use for biomolecule attachment. GAS was used to exploit either plasma polymerization of volatile monomers such as n-hexane (mixed with $N_2$) and acrylic acid or RF magnetron sputtering of nylon. The NPs were characterized by AFM, SEM, XPS and FTIR spectroscopy. Tuning of the parameters inside the GAS (e.g. working gas mixture, pressure or discharge power) allowed to control the chemical composition, the size and the flux of the NPs.

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## COATINGS FROM NON-EQUILIBRIUM LOW TEMPERATURE PLASMA FOR CORROSION PROTECTION OF ELECTRONIC ASSEMBLIES

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The usage of circuit boards in industrial atmosphere or harsh environment requires protective coatings to prevent corrosion and to ensure safety and functionality. Common coating technologies for electronics, such as varnishing, are characterized due to their cost of material and expenditure of time. In contrast the deposition of flawless films from plasma processes is well known. Therefore coatings from a non-equilibrium low temperature plasma process are investigated to determine their protective properties. Further efforts are made to evaluate the integration of these processes in common electronic production lines. In general the deposited coatings are characterized in terms of their chemical, physical and electrical properties. In detail the influence of moisture is of vital importance for corrosion mechanisms. Thus the change of coating properties were described by fourier transform infrared spectroscopy, drop shape analysis and measurements of surface resistivity on test boards.

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## BIOCIDAL EFFECT OF CORONA DISCHARGE IN SYNERGY WITH ESSENTIAL OILS

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Oregano essential oil (OEO) has a considerable biocidal effect caused by thymol and carvacrol presence. The synergetic effect of plasma activated OEO suspended in 5 % Polysorbate 80 in distilled water on a set of model organism (*Escherichia coli*, *Staphylococcus aureus*). A dilution series was performed on the set of microorganisms (*Escherichia coli*, *Staphylococcus aureus*) and subsequent treatment with non-thermal atmospheric pressure plasma. Partial biocidal factors were considered, namely combination of plasma, OEO an floating potential electrode. The higher density of the mesh has a negative influence on the treatment result. The oregano essential oil has a positive impact on the inhibition process.

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## EFFECT OF GAS FLOW RATE ON PLASMA-CATALYTIC METHANATION REACTIONS

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To generate methane for rocket fuel from $CO_2$ on Mars, the key issue is to promote the methanation reactions at low temperature and low pressure. We are developing such methanation method at the pressure and temperature of the Martian atmosphere by non-equilibrium capacitively coupled plasma. QMS was used for gas composition measurements. With increasing the gas flow rate, the methane production rate increases in a low flow rate region and then it decreases with in a high flow rate region. We will discuss the results based on the rate equations.

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## OPTIMIZATION OF THE PROCESS OF PLASMA-CHEMICAL SYNTHESIS OF POWDERS OF METAL OXIDES: THEORY AND EXPERIMENT

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A set of theoretical and experimental works was carried out to optimize (dispersity and morphology) the process of plasma-chemical synthesis of metal oxide powders from the corresponding initial salts (precursors). A physico-mathematical model of the evolution of a precursor in an evaporating drop of a metal salt solution in a gas flow of a plasma chemical reactor was developed. A double continuum physical and mathematical model of evolution of precursor in a vaporizing droplet of low-concentration solution of metal salt in the process of its heating in the flow of heat transfer medium of a plasma chemical reactor is represented. Using the special block in the "cold experiments" mode, the dispersion of droplets in a spray flare was studied. The droplet size was studied using aqueous solutions of aluminum nitrate of various concentrations. Taking into account the theoretical and experimental data obtained, nanosized aluminum oxide powders were synthesized and studied.

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## LASER-INDUCED FLUORESCENCE IN NANOSECOND DISCHARGES FOR THE $CO_2$ CONVERSION

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The massive utilisation of solar (renewable) energy is limited by its intermittency and non-uniform spatial availability. An option to overcome these problems is energy storage that allows decoupling supply and demand. A promising way to convert renewable electricity into chemical energy is the use of non-thermal plasmas (NTP) for converting $CO_2$ into C-neutral fuels. The non-equilibrium properties of NTP can be used for channelling energy in the molecular dissociation rather than in heating the gas, thus affording a high energy efficiency. The development of such technology requires a deeper understanding of the chemical kinetics and the detection of transient species in the discharge. To this purpose, one needs a non-invasive, time- and space-resolved diagnostic. Laser-induced fluorescence (LIF) is the technique of choice. However, in discharges operating at atmospheric pressure, the critical role of the collisional processes has to be taken into account because the energy-transfer processes depopulate non-radiatively the state initially pumped by the laser. In fact, the interpretation of the LIF outcome requires the knowledge of the proper collisional rate coefficients. Recently, we have demonstrated the possibility to estimate the time dependence of the $CO_2$ dissociation by analysing the LIF spectra of the OH radical produced in a $CO_2/H_2O$ discharge (Collisional Energy Transfer, CET-LIF) (L.M. Martini, N. Gatti, M. Scotoni, G. Dilecce and P. Tosi, Plasma Physics and Controlled Fusion, 60, 014016 (2018)). This communication discusses the CET-LIF technique, its limits and future perspectives.

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## CONVERSION OF SUSTAINABLE ELECTRICITY INTO CHEMICAL POTENTIAL ENERGY - A PLASMA PERSPECTIVE

G. van Rooij

A promising option to mitigate intermittency and to achieve sector integration is plasma synthesis of chemicals and artificial fuels using sustainable energy. This is illustrated on basis of a common microwave reactor approach that is evaluated experimentally with laser Rayleigh and Raman scattering and Fourier transform infrared spectroscopy. For example, 50% energy efficiency was observed in pure $CO_2$ (forming CO and $O_2$) in a thermodynamic equilibrium conversion regime governed by gas temperatures of $\sim 3500$ K. These results are interpreted on basis of Boltzmann solver based plasma dynamics estimates, indicating that intrinsic electron energies are higher than what is favorable for preferential vibrational excitation. Pulsed experiments (1-5 kHz) in which gas temperature dynamics are revealed confirm this picture. In pure $N_2$, vibrational temperatures are observed in excess of 10 000 K and up to five times higher than the gas temperature. Overpopulation of higher levels is confirmed. These observations are promising in view of economic localized production of fertilizer. An outlook is given to novel reactor approaches that tailor the plasma dynamics to optimally promote vibrational excitation and to achieve the desired non-equilibrium.

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## NANO-SECOND ELECTRICAL DISCHARGE PLASMA IN GAS-LIQUID REACTORS FOR CHEMICAL AND ENVIRONMENTAL APPLICATIONS

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Electrical discharge plasma generated in contact with liquid water is under intensive investigation for a wide range of applications in chemical, electrical, biomedical, environmental, and materials science and engineering. Of particular significance is the generation of highly reactive chemical species such as hydroxl radicals from water in non-thermal plasma. Plasma channels that propagate along the interface between a flowing gas and a flowing liquid within a small chamber provide a very suitable configuration for analysis of chemical reactions and plasma properties. In addition, the nature of the electrical discharge pulse can play an important role on the formation of the plasma and the subsequent chemical reactions. In this contribution we report on the use of nano-second pulsed discharges propagating along the surface of liquid water and assess the plasma, electrical, and chemical properties of such discharges.

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## KEY CHALLENGES TO BIO AND MEDICAL APPLICATIONS OF PLASMA SCIENCE

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Non-thermal plasmas have demonstrated many potential applications in sterilization, wound healing, and blood coagulation and so on. We invented plasma activated medium (PAM) and plasma activated Ringer's lactate solution (PAL) for the new cancer treatment option. Both PAM and PAL exhibited anti-tumor effects on cancer cells. We found that cell death mechanisms of PAM-treated and PAL-treated cancer cells are different, and it also depends on the type of cells. On the other hand, by controlling the PAL concentration, we have applied it to the various kinds of performances of agriculture field. Plasma activated solutions generally exhibits not only cell death, but also cell growth. In this presentation, the systematical results obtained by analyzing the behaviors of species in the gas phase, those of chemical species in the liquid and their reactions on the cells were mentioned. The mechanism of key reactions is also discussed from the point of view of plasma sciences.

# ELASTIC MICROWAVE SCATTERING FOR DIAGNOSTICS OF NON-EQUILIBRIUM ATMOSPHERIC PRESSURE MICROPLASMAS

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Electron number density measurements in small-size and atmospheric-pressure plasmas are very challenging. Many traditional diagnostic tools developed for application in gas-phase plasma cannot be used. Electrostatic probes introduce very strong perturbation and are associated with difficulties at application in strongly-collisional atmospheric conditions. Microwave interferometry require a reconstruction algorithm such as an Abel inversion to produce spatially resolved data and often fails due to diffraction and a very small phase shift acquired on the small size plasma. Laser Thomson scattering has limited sensitivity, namely, plasma ionization degree of at least about $10^{-6}$ (or $\sim 10^{13}\mathrm{cm}^{-3}$ for atmospheric pressure discharges) is required. In addition, extremely long accumulation of the signal (typically, $10^5 - 10^6$ laser pulses) is needed in order to achieve the appropriate signal level.

Elastic scattering of microwaves from the plasma volume offers ultimate solution for diagnostics of small-size atmospheric-pressure plasmas. The method is based on the measurement of the amplitude of the signal scattered from the plasma volume. The scattered radiation is created as the result of polarization of the plasma channel in the external microwave field. Overall, such a process is analogous to elastic Rayleigh scattering of light, when radiation wavelength significantly exceeds the scatterer size (Rayleigh Microwave Scattering or RMS).

RMS technique has been applied in the first direct measurement of electron numbers generated in a multiphoton ionization (MPI) of air. Multiphoton ionization (MPI) is a fundamental first step in high-energy laser-matter interaction and is important for understanding of the mechanism of plasma formation. However, with the discovery of MPI more than 50 years ago, no reliable data is available until today on MPI cross-sections and ionization rates. This is due to inability to conduct absolute measurements of plasma electron numbers generated by MPI. Total numbers of electrons in the plasma volume were measured vs. the intensity in the femtosecond laser pulse. Subsequently, a cross-section of eight-photon ionization of an oxygen molecule by 800 nm photons was determined: $\sigma_8 = (3.3 - 0.3) \times 10^{-130}\,\mathrm{W}^{-8}\mathrm{m}^{16}\mathrm{s}^{-1}$. The proposed method establishes a general approach to directly measure and tabulate basic constants of the MPI process for various gases and photon energies.

RMS technique has been applied to measure the electron number density produced in nanosecond repetitive pulsed discharges. The experiments were conducted with pin-to-pin electrode configuration, and breakdown was initiated by a high voltage pulse with the amplitude of 20 kV and duration of 55 ns. The peak electron density decreased from $1 \times 10^{17}\,\mathrm{cm}^{-3}$ down to $7 \times 10^{14}\,\mathrm{cm}^{-3}$ when increasing the gap distance from 2 to 8 mm (total electron numbers in the plasma volume decreased from $2 \times 10^{13}$ down to $5 \times 10^{11}$ respectively). Electron number density decayed on the timescale of about several microseconds due to dissociative recombination.

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## FROM STANDARD TO SMART: THE USE OF PLASMA FOR MEDICAL TOOLS AND IMPLANTS

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To improve the mechanical and chemical resistance of surfaces exposed to wear Diamond-like Carbon (DLC) coatings were successfully used in a broad range of machinery. To achieve similar effects in load-bearing body implants such as hip, knee and spinal disc prostheses, quite a few attemps were made to establich DLC for medichal applications. However, several clinical studies using DLC coatings on articulating joints showed severe problems due to partial coating delamination after several yearsin vivo, which had dramatic effects for the affected patients. Such observations obviously affected the use of DLC in the MedTech field.

Here, we present an overview of the main known failure mechanisms of DLC coated medical alloys and their impact on the lifetime of the coated implant, along with means to predict thein vivosurvival time - especially the long-term adhesion stability of the coating. The formation of a few atomic layers of reaction products at the interface, usually metal carbides, can make the differenc between succes or catastrophic failure. Any contamination from residual gas or any cross-contamination will result in a different reactively formed interface compound with different properties. Plasma monitoring is needed to ensure a long lieftime of these coatings.

The most promising interlayer candidate was tested in a spinal disc simulator and maintained stable for a simulated mechanical equivalent of over 100 years of articulation whilst Rockwell-indentation based corrosion tests indicate a corrosion resistance up to 60 years in vivo.

In addition to this particular research topic, several applications for Plasma based coatings are given. How a coating can change an instrument from standard to smart.

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## CALCULATION OF THERMAL CONDUCTIVITY COEFFICIENTS OF ELECTRONS IN MAGNETIZED DENSE MATTER

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The solution of Boltzmann equation for plasma in magnetic field, with arbitrarily degenerate electrons and non-degenerate nuclei, is obtained by Chapman-Enskog method. Functions, generalizing Sonin polynomials are used for obtaining an approximate solution. For non-degenerate and strongly degenerate plasma the asymptotic analytic formulas are obtained. We obtain in three polynomial approximation analytical expressions for the heat conductivity tensor for non-degenerate electrons. Account of the third polynomial improved substantially the precision of results. For strongly degenerate electrons we obtain an asymptotically exact analytical solution for the heat conductivity tensor. This solution has considerably more complicated dependence on the magnetic field than those in previous publications, and gives several times smaller relative value of a thermal conductivity across the magnetic field at $\omega_\tau \approx 0.8$.

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## RAYLEIGH-TAYLOR INSTABILITY WITH FINITE SKIN DEPTH

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In this work, the Rayleigh-Taylor instability is addressed in a viscous-resistive current slab, by assuming a finite electron skin depth. The formulation is developed on the basis of an extended form of Ohm's law, which includes a term proportional to the explicit time derivative of the current density. In the neighborhood of the rational surface, a viscous-resistive boundary-layer is defined in terms of a resistive and a viscous boundarylayers. As expected, when viscous effects are negligible, it is shown that the viscous-resistive boundary-layer is given by the resistive boundary-layer. However, when viscous effects become important, it is found that the viscous-resistive boundary-layer is given by the geometric mean of the resistive and viscous boundary-layers. Scaling laws of the time growth rate of the Rayleigh-Taylor instability with the plasma resistivity, fluid viscosity, and electron number density are discussed.

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## INFLUENCE OF GAS FLOW ON SURFACE-WAVE DISCHARGES SUSTAINED AT ATMOSPHERIC PRESSURE

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The performance of an argon atmospheric pressure argon surface-wave discharge sustained at atmospheric pressure in a capillary tube has been investigated for different total gas flows (0.5 - 20 slm). A thorough study of gas temperature and plasma column length as function of this parameter shows total gas flow can be used to control and modify plasma parameters and kinetics. By acting on gas flow, residence time and the efficiency of chemical processes taking place within the discharge can be varied. Moreover, experimental evidence of the impact of gas flow on the physical mechanisms responsible for surface-wave discharge sustainment has been provided.

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## EFFECT OF EXCHANGE CORRELATION POTENTIAL ON DISPERSION PROPERTIES OF LOWER HYBRID WAVE IN RELATIVISTIC DEGENERATE PLASMA

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The propagation characteristics of lower hybrid waves are studied in electron-ion relativistic degenerate plasma considering exchange-correlation effect. The quantum hydrodynamic equations are used to obtain the dispersion relation of the lower hybrid wave, which is discussed considering three different regimes i.e., non-relativistic, relativistic and ultra-relativistic regime respectively. It is found that the relativistic effects modify the plasma current density and degenerate pressure, thus introduces correction terms in the dispersion relation, which in turn give rise to a new lower hybrid mode. The presence of Bohm force and exchange potential also alter the dispersion properties of lower hybrid waves.The analytical and numerical results explicitly show the influence of Bohm force, exchange-correlation potential, relativistic velocities of electrons and kinetic pressure of ions on the frequency of the lower hybrid wave.

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## EQUATIONS OF STATE FOR DENSE METALLIC PLASMAS AT HIGH ENERGY DENSITIES

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Modeling of properties of structural materials under extreme conditions of high energy densities is of both fundamental and practical interests. Equations of state for metals over wide range of pressures and densities are required for numerical simulations of hydrodynamic processes in plasmas under intense pulsed influences. In this report, a semiempirical equation-of-state model is presented. Wide-range equations of state for chromium, molybdenum and tungsten are constructed on the basis of model developed. Calculation results are compared with available data from experiments on shock compression as well as isentropic and isobaric expansion of the metals at high pressures and internal energies. The equations of state obtained can be used efficiently in simulations of different processes in dense metallic plasmas at high energy densities.

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## SURFACE WAVES IN SEMICONDUCTOR DEGENERATE PLASMA WITH SPIN POLARIZATION

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In recent years, quantum effects have proved to play a crucial role in ultra-small electronic devices. All the prevalent models considered electrons as a single fluid of macroscopically averaged spin-1/2 plasma. Very recently, a modified separate spin evolution (SSE) treatment of electrons in accordance with Pauli equation has been developed. In this paper, we propose a scheme of stimulated SPW excitation in magnetized quantum plasma via stimulated electron-hole recombination in the proximity of the guiding surface using the modified SSE-QHD model taking into account the spin polarization produced due to difference in concentration of spin-up and spin-down electrons. The quantum effects of Bohm potential and Fermi electron pressure have also been included in the analysis. The dispersion relation and Poynting flux of the SPW in magnetized quantum plasma has been obtained. The optical gain has been calculated and analysed graphically.

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## DEVELOPMENT OF DRY PLASMA POLISHING TECHNOLOGY

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Mechanical polishing cause SSD(sub surface damage) of several micrometer due to physical removing of material. The SSD could be generated even in CMP process. The SSD could be removed by plasma etching.
In semiconductor manufacturing process, backside of wafer is thinned to be stacked in packaging process. As the thickness of wafer becomes smaller than 100 μm, the SSD become critical problem on chip strength. To reomve the SSD of thin wafer, we developed a plasma polishing process.
In space optics, sintered SiC is used as a body and dense SiC film is formed thereon by chemical vapor deposition method and polished to be used as a mirror. We investigated application of plasma etching for SiC compensation cutting and ultra fine polishing.
Atmospheric pressure plasma of dielectric barrier discharge has been developed for correction cutting process and vacuum plasma etching has been tested for ultra fine figuring process which dose not cause SSD.

## INVESTIGATION ON A 2.45 GHZ SURFATRON IN ARGON FLOW AT ATMOSPHERIC PRESSURE IN TERMS OF OPTICAL EMISSION AND MASS SPECTROMETRY

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Microwave excited plasmas exhibit distinctive characteristics compared to low frequency generated plasmas (kHz) pertaining to electron density, reactive species and electrode-less feature. Several research groups have shown differed plume formation at atmospheric pressure between microwave discharge and plasmas generated in kHz range. Thus, relevant species inherent to high-end applications - such as surface processing, bio-medicine or even potential use in analytical chemistry - are of concerns. In this work, a 2.45 GHz surfatron sustaining plasma plume in a 4 mm quartz tube with a permanent argon flow by a solid state generator has been characterized by optical emission spectroscopy (Oceano Optics HR2000+) and time-of-flight mass spectrometer (TOF-WERK). Focus has been made on typically cited reactive oxygen and nitrogen species (RONS) generation for bio-medicine applications by means of these diagnostic tools at different positions and operating conditions.

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## PLASMA-CHEMICAL SYNTHESIS AND PLASMA PROCESSING TECHNOLOGY OF VARIOUS POWDER MATERIALS

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Optimal technological parameters for the plasma-chemical synthesis of powder materials, which provide the specified dispersion and morphology, are determined. Synthesis of powders had been consisted of spraying aqueous salts through a special nozzle block into a low-temperature plasma. Investigations of powder materials included studies of morphology by the method of scanning electron microscopy and measurement of dispersion by the device Mastersizer. The samples of ceramic materials from alumina powders had been synthesized and their physicomechanical properties had been studied. The obtained data on the optimal technological parameters were projected on the plasma processing technology (for the production of spherical powders) of metal boride powders and metal-matrix powder materials for additive direct laser technologies. The resulting spherical powders of metal borides had been studied as components of high-energy materials.

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## TUBULAR MAGNETRON - TOOL FOR NANOPARTICLE MODIFICATION?

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Tubular magnetron (TMG) was used for in-flight sputter deposition of Cu onto Ag nanoparticles produced by Gas Aggregation Source (GAS). The GAS based on planar magnetron was connected via nozzle directly to the TMG. The magnetic field of the TMG was realized by an external coil in order to set independently the electric and magnetic fields of the magnetron. Although the deposition rate of copper onto Ag NPs increased with increasing current in the TGM the fraction of Cu in the resulting NPs was due to the relatively high velocity of Ag NPs and their short residence time in the TGM rather low ($< 50$ %). However, it was found that at certain combination of TMG current and magnetic field the Ag NPs stayed trapped inside the TMG which leads to substantial increase of Cu fraction in the NPs (up to 90 %). Janus type nanoparticles were observed in all cases due to immiscibility of Ag and Cu.

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## PLASMA DEPOSITION OF FUNCTIONAL COATINGS ONTO PCL NANOFIBROUS MATS

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In this contribution we present different approaches towards functionalization of nanofibrous polycaprolactone (PCL) mats by plasma coating. In the first approach we achieved homogenous and reproducible amine coating of PCL mats by thin film deposition from cyclopropylamine/argon mixture at low pressure capacitively coupled discharge. By tuning the experimental conditions, we were able to deposit stable thin films while maintaining relatively high concentration of amines. The second approach utilized atmospheric pressure dielectric barrier discharge in mixture of maleinanhydride, acetylene and argon for coating of PCL mats by carboxyl/anhydride groups. It was found that this coating conformally covers individual nanofibers within penetration depth of tens of micrometres. Regardless the plasma process, the deposition of functional plasma coatings onto the PCL mats sufficiently improved the cell adhesion and viability, as was evidenced by microscopy observations and ATP assay results.

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## OXIDATION OF CHLORIDE ANIONS BY O ATOMS FROM MICRO-SCALE ATMOSPHERIC PRESSURE PLASMA JET

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The COST Reference Îij-atmospheric pressure plasma jet operating with $He/O_2$ gas provides reactive oxygen species (ROS) free of charged particles, being an excellent tool for studying interactions of ROS with matter. In plasma-biomedical applications, usually the treated liquid or tissue are in the environment containing high concentration of $Cl^-$ ions. Thus, their interaction with ROS may eventually lead to the formation of new chlorine compounds. In this work, NaCl solution was treated by a µ-APPJ operating with the $0.6\%O_2$ in He mixture under controlled environment, hindering cross-interactions with nitrogen compounds. Suitable chemical diagnostics for analysis of several produced chlorine compounds were developed and reaction kinetics of the system was discussed. The observations support new studies of plasma-liquids reactivity highly relevant to plasma-biological research.

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## MAGNETICALLY CONSTRCITED ANODE PLASMA SOURCE FOR NANO PATTERNING

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Magnetically constricted anode is found to exhibit a droplet shaped fireball at the center of the anode. The role of pressure is studied using ions having different collision cross section. The stability and basic plasma properties is explored and found that it exhibits a double layer structure at the visible boundary of the fireball. The size of the fireball in our case is found larger than usual, this is due to the reduced pressure operation of the device made possible using the special arrangement of the magnets on the surface of the anode. Application of the said device is explored using the high voltage cathode sheath dynamics, whereas a substrate is biased at the cathode potential to draw almost mono energetic ion beam at reduced pressure. The current and the fluence of the ions is estimated and self-organized dot pattern on the GaSb surface is demonstrated as the proof of concept.

## ELECTRICAL AND OPTICAL PROPERTIES OF A DIELECTRIC COPLANAR SURFACE BARRIER DISCHARGE

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In this paper, the results of experiments on the electrical and optical properties of a dielectric coplanar surface barrier discharge are presented. The current voltage characteristics show capacitive character with phase current shift of approximately 90°. The results of optical emission spectroscopy showed the presence of the second positive ($N_2$ (Đą-ĐŠ)) and the first negative ($N_2$ +(B-X)) systems in the emission spectrum of DCSBD. The experiments were carried out at different powers from 81 W to 300 W. The results showed that with increasing power, the number of microdischarges increases, gradually filling the surface. The experiments were carried to measure the temperature of surface of the experimental setup out at various powers from 200 W to 260 W, with step of 20 W. The results showed that with increasing power the temperature rises, at the power of 200 W the surface temperature was 58 ° C, and at the maximum power of 260 W the temperature reached 63 ° C.

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## PLASMA TREATMENT OF POLYETHYLENE TUBES IN CONTINUOUS REGIME USING SURFACE DIELECTRIC BARRIER DISCHARGE WITH WATER ELECTRODES

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A new type of SDBD generating thin layers of plasma which propagate along the treated polymer surfaces was developed. This technique was aimed to achieve uniform atmospheric pressure plasma treatment of inner and/or outer surfaces of polymeric tubes and other hollow bodies.
Such configuration could be used for continual treatment of polymers without wariness about the metal contamination. Generating the plasma and executing the plasma surface treatment at atmospheric pressures have an additional advantage in the faster surface treatment due to higher active species densities, which can lead to higher productivity.
Though, it has been proven already that this kind of discharge could be used for treatment of different polymer materials, the challenge of continual treatment of long objects was still present. The results presented will show the possibility of such system to treat outer and inner surfaces of polymer materials in a continuous mode.

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## INVESTIGATION OF PLASMA-THERMAL PROCESSING MODES OF GLASS-CERAMICOPTICAL SURFACE

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The thermal modes of the ICP argon stream (13.56 MHz) were investigated with the respect of macroscopic parameters. The pressure in the vacuum chamber can be vary from 10 to 80 Pa, and RF generator power from 500 to 2500 W. Thus, the radial temperature distribution in the stream was studied on the several lengths cut, with different generator power and pressure. It was established that the temperature of the plasma-forming gas can reach 900 °Đą at the center of the stream and smoothly decreases to the periphery. However, regimes with pronounced skin-layer were observed. It was suggested that the skin effect is blurring with the distance from the inductor due to the gas dynamics of the plasma flow. Specific heat capacity and the heating rate of two-phase glass-ceramic material were investigated in the plasma stream with different plasma parameters.

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## COLD ATMOSPHERIC PRESSURE PLASMA AS AN INSTRUMENT FOR ACTIVATING DIELECTRIC SURFACES IN ORDER TO HARDENING THEIR OPTICAL CONTACT

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The connection of glass-ceramic details of laser gyroscopes is based on the optical contact technology. This technology means a careful polishing of the contacting surfaces that gives them an ability to approach each other on distances about tens an angstrom. Forces of an intermolecular interaction providing a high-strength coupling of the contacting bodies act on such distances. There are different films on the contacting surfaces that weaken optical contact, there was a need for their activation.

The development of low-temperature hardening of an optical contact by plasma activation was carried out by measuring its mechanical strength and estimating the leakage flux through compounds by the method of emission spectral analysis. The control samples were separated from each other at a force equal to approximately 300 N. In this case, the strength of the optical contact has increased twofold and the micro-leakage flux in the resonators assembled from these parts decreased several times.

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## INVESTIGATION OF HIGH POWER IMPULSE REFLEX DISCHARGE

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The parameters of the multicomponent gas-metal plasma were investigated at the device "MAKET", where a high-power impulse reflex discharge ($P \leq 10\,\mathrm{MW}$) in crossed $\mathbf{E} \times \mathbf{B}$ fields was realized. The gas-metal plasma was produced in the mixture of the igniter gas (Ar) and the sputtered cathode material (Zr). To study the plasma parameters a variety of diagnostic techniques were used and following measurements were performed: the time dependence of the average plasma density in the range $10^{12} - 7 \times 10^{13}\,\mathrm{cm}^{-3}$ was monitored using a microwave interferometer; the plasma rotation velocity; the charge and elemental compositions of plasma; the time behavior of plasma radiation intensity. Experimental results attests that the reflex discharge is an efficient instrument for producing a multicomponent gas-metal plasma in the considerable volume, with a high-density, highly ionized, and effective introduction of a metal component into the plasma.

## ATMOSPHERIC PRESSURE PLASMA ASSISTED CW LASER DESORPTION FOR IMAGING MASS SPECTROMETRY APPLICATIONS

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We report a high spatial resolution atmospheric pressure mass spectrometry (AP-MS) system that allows us to sensitively image live tissues at ambient environment. The method is based on an efficient desorption by continuous wave (CW) laser assisted with nanoparticles and a subsequent ionization step by applying nonthermal helium plasma. The desorption of molecules from the tissues was found to be greatly enhanced by the strong photothermal effect of gold nanorods and CW laser. The subsequent ionization process with nonthermal atmospheric helium plasma jets enabled production of sufficient amounts of molecular ions of important molecules from live hippocampal tissues of an adult mouse. Combining the AP-MS with microscopic sample scanning, MS imaging with micrometer spatial resolution could be obtained with a sampling depth down to several tens of µm. This technique enables the advancement of AP-MS imaging technology into future clinical applications.

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## GAS TEMPERATURE DISTRIBUTION IN CATHODE FALL REGION OF GRIMM GLOW DISCHARGE

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Optical emission spectroscopy technique is used to measure gas temperature along the axis of cylindrical abnormal glow discharge parallel to the copper cathode surface (side-on) in hydrogen-argon mixture at low pressure. The rotational temperature of excited state of $RH_2$ was determined from the rotational structure of Q branch of Fulcher-$\alpha$ diagonal bands using Boltzmann plot technique while the obtained of the vibrational ground state temperature is assumed to be equal to gas temperature.

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## NANOSECOND BARRIER DISCHARGE AS A TOOL FOR CHEMISTRY APPLICATIONS

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Non-thermal plasma of dielectric barrier discharge (DBD) is characterized by high enough electrons temperature compare to the ions one. Hence, chemical processes that can be stimulated by the DBD depends upon it's electrons energy spectra.

A number of experiments with CH4conversion by DBD were carried out. It was expected that the concentration of final products would be nonlinearly dependent on the energy input, because at low energy inputs the discharge mode changed (it was more homogeneous). However, the linear dependence on reaction resultants concentration was obtained. This fact can be explained by dominant role of gas thermal stimulation when charge transferred onto dielectric surface. The electrons spectra are shifted into low energies region that leads to vibrational and rotational excitation of molecules. Thus it is ought to reduce of charge transfer stage at a low value of electric field strength for better efficiency of DBD chemical applications.

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## GC-MS AND GC-FID ANALYSIS OF PRODUCTS FROM GLOW DISCHARGE IN $N_2 + CH_4$ MIXTURE

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This work extends our previous investigation of nitrogen-methane atmospheric glow discharge for the simulation of chemical processes in prebiotic atmospheres. Also reactions on surfaces of solid state bodies can be important. So in presented experiments the electrodes with different shapes and different surface areas were used. Exhaust products of discharge in this gas mixture were analyzed by Gas Chromatography - Mass Spectrometry (GC-MS) and Gas Chromatography - Flame Ionization Detector (GC-FID). The major products identified in chromatograms were hydrogen cyanide and acetylene.

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## GAS PHASE PLASMA DIAGNOSTICS OF CYCLOPROPYLAMINE/ARGON PLASMA POLYMERIZATION PROCESS

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Surface modifications by deposition of thin films with amine groups are studied for potential application in many bio-related fields already for more than a decade. Our groups recently started to promote precursor cyclopropylamine, an isomer of widely used allylamine, as a promising candidate for deposition of amine-rich coatings thanks to the low toxicity, excellent stability of prepared coatings and relatively high content of amine groups. However, for further optimization and up-scaling of the process a deeper understanding is essential. The presented work investigates some fundamental aspects of the deposition process by plasma diagnostics and discusses it within scope of the macroscopic kinetics. The gas phase processes are investigated by mass spectrometry and optical emission spectroscopy, whereas surface processes, mainly the ion bombardment, are studied by retarding field energy analyzer. Experiments are complemented by simulations of deposition by molecular dynamics.

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## CHARACTERISTICS OF A DUSTY PLASMA PRODUCED IN A PLASMA EXCITED AT ELECTRON-CYCLOTRON RESONANCE

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Dusty plasmas produced at electron cyclotron resonance (ECR) were studied. Using a movable Langmuir probe, the spatial distributions of plasma characteristics were obtained in argon and acetylene plasma, the latter leading to the formation of dust particles.
In argon, the spatial distribution of electron and ion densities are, as classically described in the literature, with a maximum in the high magnetic field regions. This behavior is classical and related to the efficient magnetic confinement of charged species.
In acetylene, the spatial distribution is highly modified. Indeed, in contrast with argon, the plasma densities reach minimal values in the high magnetic field region, the maximal one being shifted to the walls. In addition, the electron density is about one decade less than the ion density. This behavior suggests that chemical processes such as nucleation and growth of dust particles take place in the high magnetic field region.

## LOW TEMPERATURE, HIGH DENSITY PLASMA FOR NEGATIVE HYDROGEN ION PRODUCTION IN HELICON EXPERIMENT FOR NEGATIVE ION SOURCE (HELEN-I)

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In Helicon wave heated plasmas, very high plasma densities can be attained with electron temperatures (Te) as low as 1 eV. These conditions favour production of negative hydrogen ions and lower their destruction due to reduced cross-section for negative ion destruction (electron-detachment). In the HELEN device at IPR, a $H_2$ helicon plasma is produced in a diverging magnetic field by applying RF Power of 13.56 MHz at 800-1000 W using a Nagoya-III antenna for exciting $m = \pm 1$ mode. The plasma is confined by a multi-cusp field in the expansion chamber. The characteristic density jump from inductively coupled mode to Helicon mode is observed at Prf 800W with plasma density $\approx 10^{18}\,\mathrm{m}^{-3}$ and $T_e \approx 1\,\mathrm{eV}$. The H-density is measured by Laser photodetachment diagnostic using a 1064 nm Nd:YAG laser and an RF compensated Langmuir probe. This result is validated by Cavity Ring Down Spectroscopy. Measured values of negative hydrogen ion is of the order of $10^{14}\,\mathrm{m}^{-3}$at $10^{-2}$ mbar.

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## ELECTRICAL PARAMETERS OF A DIELECTRIC BARRIER DISCHARGE - COMPARATIVE STUDY

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Dielectric barrier discharges have become one of the most powerful ways for generation of various active species. The measurement of power is a critical issue for evaluation of the energy efficiency of the plasma processes. The power is determined by different methods. First, the average power is calculated as the integral of the product of instantaneous discharge voltage and current. The current is determined from the current monitor. The second method uses a relatively large capacitor, which is inserted between the counter electrode and the ground. The voltage drop on this capacitor is used to calculate the current. The power is calculated on the basis of current obtained in this way or from the transferred charge-voltage Lissajous figures. Finally, current can be calculated from the voltage drop on a resistor in series with the discharge. We performed a comparative study of power measurement for the discharge by all these methods, and we compared obtained values.

*This research has been supported by the Technology Agency of the Czech Republic under contract No. TH03030432.*

## FORMATION OF IONIZATION SENSOR OF GASES SENSITIVE ELEMENT BY THE METHOD OF LOW TEMPERATURE PLASMA

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In the presented work, a model of a sensitive element of an ionization-type gas sensor with a surface having a complex structure was manufactured and investigated. The sensing element was formed as graphene films obtained by plasma chemical vapor deposition.
This structure was received on chemical cleaned silicon substrate, which has modify topology of massive vertically oriented nickel nanowhiskers. Nickel nanowhiskers were obtained by combination of methods magnetron sputtering and plasma chemical etching. Thanks to the use of chemical etching in low temperature plasma, it is possible to control the geometric parameters of the array with high accuracy.
According to the experimental estimates, this sensor has a significant sensitivity to $CH_4, CO_2, CO$ at an operating temperature of 300 K and a concentration of 0.01 mole/liter, the sensitivity was 63, 135, 5468, respectively, the response time was 0.1 s; recovery time 1.0 sec.

*This research has been supported by the Southern Federal University (grant VnGr-07/2017-02).*

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## RELATION BETWEEN ETCH PROFILE AND V-I SIGNAL OF SINTERED SIC ETCHING BY ATMOSPHERIC PRESSURE PLASMA

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Sintered SiC substrate was etched by a DBD source. A high voltage unipolar pulse was used with helium-NF3 mixed gas for the plasma generation. As the NF3 concentration increased, the width and depth of the etch profile became narrower and deeper. I-V analysis results expresses that the plasma in the positive phase of the pulse voltage etched the SiC substrate relatively wide and less deep volume and the plasma in the negative phase was vice versa. Additionally, these different etch characteristics being caused by the voltage polarity induced bad profile stability. All the maximum current in the negative phase was higher than the other. As the ratio of the positive phase current to negative phase current approached to 1, the removed volume of SiC substrate increased, while the profile stability was less stable. However, as the NF3 increased, the decrease of the profile width difference and the weakening of the positive phase plasma, the etch profile was stabilized.

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## COMPARATIVE ANALYSIS OF THE REFRACTION OF MICROWAVES AT DIFFERENT FREQUENCIES IN AN INHOMOGENEOUS PLASMA OF A HIGH POWER IMPULSE REFLEX DISCHARGE

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In the paper, numerical and experimental the studies on the refraction of microwaves at two frequencies (36 and 71 GHz) by an inhomogeneous plasma of an impulse reflex discharge in longitudinal magnetic field were carried out. Inclined probing was realized on account of microwaves rays which fall to the plasma at oblique angle relatively to the plasma column. The microwave signal transmitted through the plasma was registered by a horn antenna shifted at the angle of 60 degrees with respect to the radiating antenna axis. At frequency 36 GHz the minimal amplitude of receiving signal was registered when plasma density in the layer achieved the density Nc. In contrast, for the same conditions, the maximum signal amplitude was observed when probing frequency was 71 GHz. The experimental results are in satisfactory agreement with results of the numerical model.

## THE DETERMINATION OF THE CONTENT OF METAL IONS IN WATER SOLUTIONS BY USE OF A DC-CURRENT DISCHARGE WITH A LIQUID CATHODE

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The emission-spectral analysis of water and aqueous solutions on the content of metal ions is one of the promising applications of plasma-solution systems. High sensitivity (up to $10^{-9}$ gl$^{-1}$), low power consumption, no need for expensive equipment are the advantages of this method. However, it is established that the composition of the electrolyte-cathode affects the emission intensities of the lines of metal atoms. A possible solution to this problem is presented in this study. We suggest adding an aliquot of a solution of a metal salt with a known concentration to the analyzed solution and further determining the number of atoms of the analyzed metal in the plasma by the actinometry method. In this case, the metal atoms, whose cation concentration in the solution is known, is an actinometer. The concentrations of the corresponding cations in the solution are determined from the known number of atoms of the analyzed metal in the plasma, using the transfer coefficients.

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## SPATIAL DISTRIBUTION OF A NON-EQUILIBRIUM LOW TEMPERATURE PLASMA GENERATED BY AN ECR PLASMA SOURCE

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Non-thermal plasmas have shown relevant results in agriculture thanks to its low temperature, the relatively important reactive species and biocidal agents. In this study, the spatial distribution of a coaxial microwave plasma source in a 90 litres vacuum chamber was assessed in order to provide a homogeneous treatment on seeds in future work. The plasma source (SAIREM SAS) conception was based on Electronic Cyclotron Resonance (ECR) to sustain the plasma in the low-pressure range (air, $10^{-4} - 10^{-1}$ mbar). A 2.45 GHz solid-state generator (SAIREM SAS) was used as power feeding for the source while ensuring minimal power-losses and perfectly matched impedance. The parameters of the discharge were measured by a Langmuir probe (Impedans) at various positions in the vacuum chamber. In parallel, optical emission spectroscopy measurements have been performed at various positions with a Horiba Jobin Yvon iHR320 spectrometer in order to identify the plasma species' spatial distribution.

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## INVESTIGATION OF PECULIARITIES OF THE DISCHARGE EXCITATION WITH HOLLOW CATHODE EFFECT IN $N_2$ IN A TUBE ELECTRODE

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The influence of some constructive discharge system elements on the electric excitation modes and stable maintaining of pulse glow discharge plasma in $N_2$ in a hollow tube cathode has been investigated. The following discharge system changes have been performed: the position of a hollow electrode-cathode in the dielectric tube-holder; the method of plasma forming gas feeding to the discharge area; the distance between the electrode-cathode and counter-electrode (grounded anode). The investigation has been carried out within 50 - 700 Pa $N_2$ pressure range. The obtained results may be used in the design of gas discharge systems with hollow cathode effect.

# ON THE LOW ELECTRON DENSITY OF AN ATMOSPHERIC PRESSURE RADIO FREQUENCY PLASMA

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A low temperature atmospheric pressure radio frequency plasma with planar electrodes structure is studied in terms of electron density for the use in biomedical applications. In the experiment, plasma can be ignited at power of 10 W and sustained in homogeneous Îś mode from 10 W to 30 W. Gas temperature is estimated based on determination of the rotational temperature of OH radicals. OH ($A^2\Sigma+ \rightarrow X^2\Pi$, 0-0) band from 306-312 nm is detected and compared with simulated spectrum, giving the gas temperature as low as $375 \pm 25$ K under the input power of 30 W, helium flow rate of 2 slm. Line profile analysis is adopted to characterize the Stark broadening for $H_\beta$ line, further to obtain the electron density. Since we meet a situation of low electron density plasma, profiles with and without consideration of fine structure components are simulated, giving the estimated electron density around $8.3 \times 10^{19}$ m$^{-3}$ and $8.7 \times 10^{19}$ m$^{-3}$, respectively.

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# EXCITATION OF SURFACE WAVE ALONG A POSITIVE COLUMN OF GAS DISCHARGE

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The excitation and propagation of a surface electromagnetic wave (SEW) along a positive column of a gas discharge are studied. 80 and 58W fluorescent tubes of 16 and 25 mm diam. and 145 cm lengths, respectively, is investigated. The discharge in the tubes is excited and maintained by external pulsed periodic sources. The SEW on the first tube is excited by a rectangular waveguide connected to a microwave oscillator 2.5 GHz. On the second tube, the SEW is excited by means of a coaxial resonator as an applicator connected to an RF oscillator 446 MHz. The probe method is used to measure the distributions of the electric field strength components. The spatial decrement of the wave is measured. The length of the SEW is determined by two methods: the interferometric method and the standing wave method. According to the measured ratio $\lambda_s/\lambda_0 < 1$ (where $\lambda_s$ is the SEW length), the plasma concentration in both tubes is determined from the SEW dispersion characteristic.

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## INFLUENCE OF METAL VAPOURS ON RADIATION CHARACTERISTICS OF AIR ARC PLASMAS

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The presence of metallic vapours substantially modifies the properties of thermal plasmas, including radiation heat transfer. This paper deals with the evaluation of radiation properties of air arc plasma with various admixtures of Cu, Ag, and Fe, respectively. Under assumption of isothermal plasma cylinder, the net emission coefficients were calculated for various arc radii (0.01 to 10 cm) as a function of the plasma temperature up to 25 000 K. For plasma with prescribed temperature profile, the equation of radiation transfer was solved in both the P1 and SP3 approximations, and.the radiation flux and its divergence were calculated. The complicated frequency dependence of absorption coefficients has been simplified using the Planck and Rosseland mean absorption coefficients. The influence of various metals on radiation characteristics was compared.

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## ABSORPTION PROPERTIES OF ARC PLASMAS WITH VARIOUS ADMIXTURES OF COPPER VAPOURS

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This paper presents the results of a theoretical prediction of radiation transfer in electric arc plasmas with various admixtures of copper vapours. The method of spherical harmonics (P1-approximation) has been used as the way to solve the equation of radiation transfer. The frequency variable in the equation of transfer was handled by means of multigroup method. Due to very complicated frequency dependence of absorption coefficients, Planck and Rosseland mean absorption coefficients have been derived from calculated absorption spectrum.

Main radiation quantities have been determined for cylindrical arc plasmas. Calculation of radiation characteristics has been performed for thermal plasma in temperature range (300 - 35000) K for different splitting of the whole frequency interval $(0.01 - 10) \times 10^{15}$ Hz. Results could be used for a modelling of the radiation transfer in the switching arc, including vaporization from Cu contacts.

*This research has been supported by the Centre for Research and Utilization of Renewable Energy under project No. LO1210- "Energy for Sustainable Development (EN-PUR) ".*

## UPDATED VERSION OF THE SIMPLIFIED MODEL OF INTENSIVELY BLASTED ELECTRIC ARC

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The contribution deals with an improvement of a simplified model of intensively blasted electric arc burning in argon in an anode channel of a modular-type arc heater. Gradually gained experience in application of the model with various input data has revealed that some refinement is needed. The contribution focuses especially on the process of searching an optimum combination of the state variables, which are the exponent determining the arc radius development along the anode channel axis, the current density at the cathode, and the arc temperature at the end of the near-cathode layer. Limiting relations for the state variables are set and discussed. Three constituent parts of the used objective function are analyzed and compared. The procedure is demonstrated on a chosen set of experimental data. Further computations with many sets of measured data are necessary to test the designed procedure and to confirm the determination of the state variables' range.

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## THERMAL PLASMA OF ELECTRIC ARC DISCHARGE BETWEEN EVAPORATED ELECTRODES

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It is known that the arc discharge may occur between electrodes and/or contacts during switching of electrical circuits. So, it can lead to contacts' erosion, which, in turn, results in decrease of service time of switches, contactors, etc.
Combination of high-melting (Mo, Cr, W) and high-conductivity (Cu, Ag) components allows to obtain materials with high exploitation characteristics under conditions of electric arc. The investigation of electric arc discharge plasma with admixtures of metal vapours of electrode origin allow to increase the erosion resistance of electrodes due to optimization of material's composition and development of new technologies of their fabrication.
This study deals with optical spectroscopy of thermal plasma of free-burning electric arc discharge between asymmetric copper and composite Ag-Ni electrodes at arc current of 3.5 - 30 A.

## TREATMENT OF FLY ASH BY THERMAL PLASMA: SIMULATION OF TOXIC ELEMENT VOLATILITY DURING TREATMENT

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Treatment of fly ash collected from power plants using thermal plasma technology was investigated. The fly ashes treated in this work are collected from the power plants using heavy fuel oils in Saudi Arabia. An analysis carried out by (CHNOS) analyzer, and ICP showed that the fly ash was composed essentially by carbon and other metals. A Plasma reactor was used to separate carbon from metals by pyrolysis/combustion plasma system and also to immobilize the toxic element in a non-leaching glassy slag by vitrification. A computer code was developed to study the volatility of toxic elements during treatment, such as lead and arsenic. This model bases on the calculation of system composition using the free enthalpy minimization method, coupled with the equation of mass transfer at the reactional interface. Using the developed model, the effects of plasma temperature, plasma current, and presence of oxygen in the carrier gas on the volatility of lead and arsenic were determined.

*This research has been supported by the King Abdulaziz City for Science and Technology (KACST).*

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## NUMERICAL INVESTIGATION OF GLOW-TO-ARC TRANSITION IN HOLLOW CATHODE DISCHARGES

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In Stationary Plasma Thrusters hollow cathodes are used as electron sources for neutralization of ion beams emitted from the thruster. Although arc discharge, ignited within a hollow cathode for creating electrons, is self-sustaining, an intial heating of the cathode surface is required for discharge ignition. Typically, the initial heating is carried out using induction currents. An alternative approach would be to use a glow discharge which can provide natural transition to arc. In this work we carried out numerical investigation of glow-to-arc transition in the case of a hollow cathode discharge in order to determine the main factors influencing the transition and estimate efficiency of such thruster ignition mechanism. For this purpose, a 2D-axisymmetric model of a hollow cathode discharge was built using Comsol Multiphysics, on the basis of extended fluid model supplemented with the equations of thermal conductivity for gas and cathode material.

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## STATIONARY AND TRAVELING PLASMA SHEATHS

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A sheaths formation in bounded and unbounded weakly ionized free plasmas is revising in a framework of a unified model that includes the time dependent ion movement equations, the equation for the ambipolar field, and the equation of heat conductivity of electrons. Calculations carried out numerically for both electropositive and electronegative gases in the cylinder geometry. Two main problems are investigated: the free expansion of an initially created plasma in the unbounded background gas; and the case of permanently acting heat sources distributed in a certain region of the expanded plasma. Also, the wall bounding the plasma is considered in the last case. The data obtained are discussed along with known plasma sheaths models.

## SIMULATIONS OF PLASMA CHANNEL FORMATION BY KNIFE-LIKE NS-LASER BEAM

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The results of the simulations performed in KIAM RAS are presented. Formation of channels in gas targets using a ns-laser is considered in ELI-BL relevant regimes: output energy is hundreds of Joules, from 1 to 10 PW main pulse power. The MHD codes NPINCH and MARPLE are used for 1D and 2D simulations of plasma channel formation in the region of elongated focus of knife-like ns-laser beam in under-critical gas density. Such plasma channel can be applied to transport high power fs-laser beams over large distances. The 2D simulations are performed to investigate the process of symmetrization when the asymmetry of initial channel is caused by asymmetric deposition of the laser energy due to spatial structure of a plane focus of the laser beam. The simulations show how to reach the regimes of symmetric plasma channel formation. With 1D simulations the parameters of plasma channels for various cases under the condition of channel symmetrization are obtained.

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## POTENTIAL FORMATION IN FRONT OF A PLANAR ELECTRON EMITTING ELECTRODE STUDIED BY PIC SIMULATION

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Thermionic electron emission from a wall is a very important topic, due to its impact to the plasma. Because of the fact of being heated, a hot metal emits electrons, according to Richardson Law. This fact modifies the plasma properties, including the potential.
In order to analyse this phenomena, BIT1 code has been used, an electrostatic Particle In Cell + Monte Carlo (PIC + MC) code for plasma edge simulations. Plasma is created by volume ionization in the entire space between two planar electrodes. First, a system with no emission has been simulated until it reached the steady state. Then, the impact of the emitted electrons has been studied. The left electrode emits a flux of electrons with a drifting Maxwellian. The effects of drift velocity, temperature and flux of the emitted electrons on the potential profile are analysed. Transitions between monotonic, space charged limited and inverted sheath are observed.

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## HOW STREAMERS PROPAGATE ON A DIELECTRIC BEAD SURFACE

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Geometrical complexity of a catalyst is one of the major effects affecting the plasma generation observed in the plasma-catalyst interacting phenomena. We will explain the streamer propagations on a dielectric bead surface by 2-D simulation of simplified single pellet geometry. When a positive voltage is applied, the plasma was initiated at the anode electrode - top surface of the bead, and is propagated toward the cathode electrode. Two distinct streamers were observed - fast primary streamer and slow secondary streamer. When a negative voltage is applied, typical cathode-directed streamer (CDS) was observed after a glow-like discharge at the bead-cathode electrode contacting point. The initiation of CDS was triggered by abundant positive ions on the local spot. We will further compare the ADS and CDS characteristics by spatial species variations discussing the interacting phenomena between plasma and catalyst.

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## ITERATIVE ALGORITHM FOR INTERFEROMETRIC MEASUREMENT OF CONSIDERABLY INHOMOGENEOUS PLASMA DENSITY BASED ON RAY TRACING

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Abel Inversion can be used in interferometric measurements of axially symmetric objects to retrieve spatial distribution of, e.g., plasma density. Here the probing beam propagation along the straight line is assumed. In inhomogeneous media, however, the rays are considerably refracted and the initial assumption is thus not valid. To reconstruct the plasma density of the probed object with higher accuracy, an improved method for solving the inverse problem is required. An iterative algorithm based on calculating the light propagation in inhomogeneous media is proposed. Instead of finding the inverse transformation to reconstruct the plasma density from the phase shift, the problem is solved using succesive solutions of wave propagation through inhomogeneous medium using the ray tracing method.
Iterative algorithm was tested on simulated data with different configurations of plasma density, showing the function of the algorithm and its comparison to Abel Inversion.

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## HYBRID MODEL OF THE PLASMA ACCELERATOR WITH GAS WALLS AND CLOSED ELECTRON DRIFT

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The accelerator with gas walls and closed electron drift were not research till now in contrast to the well known accelerators with anode layer and accelerators with dielectric walls of channel. But this type of the accelerator has some advantages since the walls absence leads to absence of the wall material inclusion into the ion beam and to exclusion of the secondary electrons formation due to emissions and thus to plasma electron dynamics conservation. Early, we created one dimensional hydrodynamic model and found exact analytical solutions describing electric potential distribution and generalization condition of self sustained discharge in crossed ExH fields. Here we describe cylindrical hybrid model. The performed simulation showed converging towards axis accelerating ion beam forms. Ions moving to the system center and then along the axis in both directions are able to create space charge. The potential drop forms at the axis that could be used for ion beam accelerating.

## SIMULATION OF THE ATMOSPHERIC PRESSURE DBD FOR TREATMENT OF CHRONIC WOUNDS

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A one-dimensional numerical code modelling the Dielectric Barrier Discharge (DBD) $He + O_2$ plasma is developed to investigate the treatment effect of atmospheric pressure plasma to the chronic wound forming biofilm. For the simplification, we assumed the target biofilm as a thin water layer which has certain dielectric constant and the vapour is released from this according to the saturated vapour pressure. In addition, the simplified chemical models capable of capturing the main physicochemical processes are used, while the gas flow perpendicular to the electric field and sputtered reactive species from the water layer are not considered. This simulation is validated by comparing the discharge conditions with the experiments conducted under the same conditions. Finally, based on the fixed inter-electrode distance and the oxygen concentration value, the major reactive species distribution depending on the applied voltage and frequency are obtained.

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## STUDY OF HIPIMS-BASED DEPOSITION SYSTEMS BY ADVANCED DIAGNOSTICS TOOLS

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High power impulse magnetron sputtering (HiPIMS) belongs among sputtering-based ionised physical vapour deposition (IPVD) systems. During the last decade, various hybrid HiPIMS systems have been developed in order to increase deposition rate, reduce working pressure or increase ionisation of sputtered particles. Investigation of spatial and temporal evolution of the plasma parameters could contribute to better understanding of physical mechanisms responsible for deposition of thin films with improved properties in comparison with conventional sputtering techniques. The aim of this paper is to present recent advances in in-situ diagnostics of the HiPIMS-based systems. Attention will be paid to precise time-resolved Langmuir probe measurement allowing a detailed investigation of reactive HiPIMS process or qualitative determination a degree of ionisation of sputtered particles. On the other hand, invented so-called modified Katsumata probe is able to reveal angular distribution of the ion velocity distribution function in HiPIMS systems. Together with the time-resolved and energy-resolved mass spectroscopy, it was observed that energy of ions is enhanced by about 30 eV when combination of ECWR and HiPIMS discharge is used in comparison with the hybrid HiPIMS combined with pulsed-DC or RF discharge. Since the magnitude of ion flux on substrate is crucial for influencing of thin film properties developed Sobolewski probe allowed to estimate the ion flux even on dielectric substrates. The Sobolewski probe provides also the magnitude of the space charge sheath impedance allowing for determination of regime of operation in the reactive HiPIMS with potential to be used for the reactive process control. Application of obtained experimental results from HiPIMS-based systems for benchmarking of global semi-empirical model of internal plasma parameters of HiPIMS will be discussed too.

## COMA PLASMA CHEMISTRY: CHEMISTRY GENERATION AND CROSS SECTION CALCULATIONS WITH QUANTEMOL

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It is often a cumbersome problem to build and validate the set of reactions relevant for specific conditions in plasma, and estimate the reactions rate. In [2] the authors emphasized the need for the electron scatterring cross sections data for Rosetta mission. They listed molecules identified on the comet 67P nucleus, and we chose some of the molecules from the list for our calculations. Using small molecules such as $CH_4, H_2O$ and HCN for validation, we have also computed e-CH3NH2, e-HNCO and e-CH3CN cross sections from the list theoretically with the use of Quantemol-N software based on the sophisticated UKRmol code. We have generated a chemistry set relevant for the problem, and used it to suggest a 0D plasma model.

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## COLD ATMOSPHERIC PLASMA INTERACTION WITH LIQUIDS AND BIOLOGICAL SUBSTRATES: CHARACTERIZATION OF ISOLATED AND COMBINED RADICAL, PHOTON, AND ION EFFECTS

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Atmospheric non-equilibrium plasmas are an effective source of reactivity since they generate large densities of reactive radicals, metastables, ions and high fluxes of (V)UV photons. Especially important for therapeutic applications in plasma medicine is the fact that several or all of these components and electric fields are acting at the same time, very often in a synergistic way. Especially important for the understanding plasma effects is to obtain absolute fluxes of all plasma components to the surface and to study their isolated or combined effects. In this contribution, the mass spectrometry for detection of neutral and ionized species and the windowless VUV spectroscopy for the plasma analysis of a reference atmospheric plasma jet, which serves as a reference in several plasma medicine studies, will be discussed in detail. Additionally, the way in which in isolated or combined effects of plasma-generated radicals, photons and even ions can be studied will be presented.

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## CONTROL OF NANOPARTICLE FORMATION IN REACTIVE PLASMAS AND ITS APPLICATIONS

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We discuss nucleation, growth, coagulation, and transport of nanoparticles in reactive plasmas, in which nanoparticles and plasmas are interact strongly with each other. A cloud of nanoparticles can act as a size selective filter for the nanoparticles. Based on the formation mechanism of nanoparticles, we demonstrate control of size, structure, transport, and sticking of nanoparticles. We show some applications of such control to fabrication of Li-ion batteries, porous films, quantum-sensitized solar cells, dye-sensitized solar cells, and thin film Si solar cells.

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## RELATION BETWEEN ELECTRON INSTABILITIES AND SPOKES IN HIPIMS: MODELING AND EXPERIMENTAL EVIDENCES

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HiPIMS has emerged as one of the most interesting magnetized systems to study the instabilities driven by the complex field structures, namely very strong electric and magnetic fields with strong gradient. The present contribution focuses on the understanding the role of coupled electron instabilities arising at different scales as precursors for the self-organized plasma phenomena, commonly called spokes.
First, Thomson scattering gave the electron density fluctuations, but also the time variation of the electron density and temperature during the pulse as well as the group velocity of electrons in the $\mathbf{E} \times \mathbf{B}$ direction. Second, particle modeling (OHiPIC - Orsay High density Particle in Cell) has provided HiPIMS plasma evolution and it has been extended, non-selfconsistent, to the third azimuthal direction by a novel algorithm calledPseuod-3D. Numerical results provide insights on the spoke formation and the driven mechanism, and support the experimental findings.

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## NON-CONVENTIONAL DIAGNOSISTICS FOR PLASMA PROCESSING

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For an optimization of plasma-based processes as thin film deposition suitable diagnostics are required. In addition to well-established plasma diagnostic methods (e.g. emission spectroscopy, mass spectrometry, Langmuir probes, etc.) we perform examples of "non-conventional" low-cost diagnostics which are applicable in technological plasma processes. Examples are the determination of energy fluxes by calorimetric probes (Gauter, S., FrÃűhlich, M., Garkas, W. Polak, M., Kersten, H., Plasma Sources Sci. Technol.26(2017), 065013) and the measurement of momentum transfer due to sputtered particles by force probes (Trottenberg, T., Spethmann, A., Kersten, H., Eur. Phys. J. Techniques and Instrumentation5(2018), 3).

# PARTICLE TRANSPORT AND SPUTTERING DYNAMICS: TOWARD A CONSISTENT PLASMA-SURFACE MODEL

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The layout of sputter deposition processes may be guided by quantitative theoretical models to provide optimal design suggestions. For this purpose, however, a comprising consideration of the plasma and the bounding surfaces is essential. Knowledge of their respective state and a close coupling of the pertinent volume and surface dynamics is particularly important in reactive sputtering. In this work, initially, the sputtered particle transport is approached by means of a Monte Carlo simulation for a variety of exemplary sputtering discharges. If required (e.g., in the high power impulse magnetron sputtering regime; HiPIMS), the particle dynamics of all relevant heavy species (i.e., neutrals and ions) are unifiedly considered. The electron density and energy distribution is provided from external electron models (S. Gallian, J. Trieschmann, T. Mussenbrock, R. P. Brinkmann, and W. N. G. Hitchon, J. Appl. Phys. 117, 023305 (2015)) (S. Kondo and K. Nanbu, J. Phys. D: Appl. Phys. 32, 1142 (1999)). In addition, the sputter yield and the sputtered particle energy/angular distribution is obtained from TRIDYN simulations for the specific discharge conditions (W. Möller and W. Eckstein, Nucl. Inst. and Meth. B 2, 814 (1984)). Such a stationary approach is not suitable, however, if the bombardment conditions transiently vary during operation. In this situation (e.g., during a HiPIMS pulse), a selfconsistent approach taking into account this change (e.g., a varied sputter yield) as well as the state of the respective surface is necessary. For this purpose, subsequently, an approach for transiently interfacing pre-calculated sputtering data with the proposed transport model based on an artificial neural network (ANN) is devised. It is demonstrated that a multi-layer perceptron trained with TRIDYN results is able to predict the sputter yield and the sputtered particle energy/angular distribution for arbitrary energy distributions of projectile particles incident onto the surface. Finally, it is argued that the combination of both preceding submodels leads toward a consistent plasma-surface model for sputter processing.