NANO-, SUBNANO-, AND PICOSECOND PROCESSES IN HIGH-POWER ELECTRICAL DISCHARGES IN GASES[1]

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Electrical discharges in gases are of great importance in pulsed power devices, such as gas lasers, in pulsed light sources, in production of short-term electric and magnetic fields, etc. To solve many problems in these areas, it is necessary to have switch-on times in the range 10^{-12}–10^{-9} s [1]. Such short times can be achieved by utilizing discharges of four types, namely (I) high-pressure gas discharges operating under static breakdown conditions, (II) discharges operating under the conditions of a relatively low overvoltage ($\Delta \le 3$) and ultraviolet initiation, (III) discharges initiated by an accelerated electron beam injected directly into the gas, and (IV) pulsed discharges in highly overvolted gaps. In experimental studies of all these types of discharge, a charged coaxial line is discharged into a two-electrode spark gap with a uniform electric field between the electrodes.

In studying the discharge under static breakdown conditions [2], the breakdown voltage is given by $U_s = F(pd)$ (Paschen's law), where p is the gas pressure and d the gap spacing. It was assumed that the conductivity of the gas-discharge plasma is proportional to its specific energy. In terms of this model, the current switch-on time can be estimated from the formula $p\tau = a(E/p)^{-2}$, where E is the electric field in the gap and a is a constant characterizing the gas. We have shown that this formula holds for air and nitrogen at $\tau \approx 10^{-10}$–10^{-9} s.

For pulsed discharges initiated in gaps with $d \le 1$ cm and overvoltage $\Delta = U_s/U \le 3$ by means of ultraviolet irradiation, we obtained that the switch-on time can be estimated as $\tau = A(\alpha v)^{-1}$ [3], where α and v are the impact ionization coefficient and the electron drift velocity, respectively; $A \approx 10$ for air. This formula was derived assuming multi-avalanche multiplication of the initiating electrons. The experimentally obtained time τ for atmospheric air at $\Delta = 3$ was $5 \cdot 10^{-10}$ s.

We have demonstrated that with direct injection of electrons into the gas, it is possible to obtain a discharge in a large volume with the switching time as short as and even shorter than 10^{-9} s due to the gas ionization by electron beam.

At high overvoltages, $\Delta \ge 10$, the electric field is so high that the electron runaway effect arises (for nitrogen and air, at $E/p \ge 600$ V/cm·Torr). We have shown that the duration of runaway electron pulses is 10^{-12}–10^{-11} s [4]. In this case, the runaway electron beam plays the same part in the discharge initiation as the externally injected electrons. The switch-on time with participation of runaway electrons lasts for $\sim 10^{-10}$ s. It has been demonstrated that discharges of this type also operate in a multi-avalanche mode.

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LOW-PRESSURE PULSED GAS DISCHARGES WITH HOLLOW CATHODE AND HOLLOW ANODE AND THEIR APPLICATIONS[*]

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This review deals with the fundamental properties of the low-pressure gas discharges with hollow cathode and hollow anode. The conditions of low pressures imply that the electron free path for ionization exceeds a characteristic size of the interelectrode gap. Then the discharge keeps an intermediate position between the classical glow discharge with an avalanche ionization and a pure vacuum discharge that burns in the cathode material vapor [1–3].

The single electrons appearing at the cathode surface cannot initiate the low-pressure discharge. The principal idea for interpretation of the discharge initiation mechanism is reduced to the following. At the stage of delay time to breakdown, a considerable electron current from the cathode is required. In spite of the fact that only a small fraction of the electrons enters into reaction of ionization, the excess space charge of positive ions builds up in the gap with time. As a result, the electric field is distorted in such a manner that the potential distribution along the discharge axis is no longer monotonic. A region of potential hump forms near the anode so that the electrons oscillating in this region assure the intense gas ionization and formation of the plasma column. This mechanism is confirmed for a wide interval of gas pressures. For example, when the pressure is at a level of 10^{-2} Torr a typical gap distance amounts to about 1 cm. On the other hand, the characteristic size of the gap can be increased to about 100 cm when the pressure decreases to 10^{-4} Torr.

A great interest to the discharges under discussion is associated with their applications. One of the fields of application is related to specific type of discharge with extremely high total current and respectively with extremely high current density. Similar systems are used in a novel type of the high-current switching devices often named the grounded-grid thyratrons or pseudospark switches [2, 3]. At the current time, these thyratrons are used for parallel switching with nanosecond stability of a large number of devices in the linear electron accelerators [4, 5]. The state of art as applied to this problem is mainly considered in the present paper.

The other field of application is related to generation of a uniform plasma in a large volume of the cathode or anode cavity. Such discharges are often used for surface modification, when the samples are immersed in plasma. The discharges with hollow anode constitute the basis for the sources of the charged particles with plasma emitter. The method of extraction of the particles from plasma allows obtaining the high-energy electron or ion beams with a large cross section. This directions of application is also partly considered in the review.

One of the conclusions of the paper is that the mechanisms of the discharge initiating and sustaining turn out to be general in spite of the seemingly different conditions of the discharge burning.

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ELECTRON BEAM EXCITED PLASMA AND BEAM PLASMA DISCHARGE IN PLASMA PROCESSING TECHNOLOGIES [*]

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The report addressed the following issues:

History of discovery, research and applications of a beam-plasma discharge (non-relativistic and relativistic plasma electronics; active geophysical experiments; plasma processing technologies).

The physical mechanism of discharge, the main characteristics, features of manifestation at qualitatively different external conditions.

Principles of non-equilibrium plasma chemistry.

Electron beam excited Plasma (EBEP): physics, basic characteristics, LAPPS installation, applications for nanoelectronics.

Beam plasma discharge with a plasma cathode: main characteristics; technological applications.

Beam-plasma reactor of FIRE RAS: design; features of operation in the presence and in the absence of a magnetic field.

Computer modeling of processes in the reactor of FIRE RAS: features of the development of beam instability in a plasma resonator; energetic parameters; ion distribution function.

BPR reactor applications:

Low energy etching of materials and structures for nanoelectronics.

Deposition of nanoscale carbon films.

Restructuring of carbon films, obtaining graphene.

Prospects for the development of BPR reactor.

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ATMOSPHERIC PRESSURE PLASMAS TREATMENT OF AL$_2$O$_3$-FILLED EPOXY RESIN FOR ACCELERATING SURFACE CHARGE DISSIPATION [*]

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Al$_2$O$_3$-filled epoxy resin (Al$_2$O$_3$-filled Epoxy Resin) is widely used as an insulating material in electric power and pulsed power systems. Investigations on its surface characteristics, especially the surface insulating property are continuing hotspots in high voltage engineering [1-2]. In this paper, plasma etching and plasma deposition were used for the modification of the Al$_2$O$_3$-ER surface at atmospheric pressure. The evaluation comparison of surface charge dissipation was compared. The experimental results showed that both treatments could suppress the surface charge on the Al$_2$O$_3$-ER surface. The maximum surface potentials after plasma etching and plasma etching decreased to 60.09% and 23.37%, respectively, compared to that of the untreated sample. The decay rates of the surface charges on the DBD deposited exceeded 98%, while the decay rates were 35.91% and 0.75% on the plasma etched and untreated samples (Figure 1). Surface morphology illustrated that the surface roughness of the plasma deposited sample was smaller than the of the plasma etched sample. A flat surface improved the uniformity of electric field, thereby reducing the surface charge accumulation. The surface conductivity after plasma deposition increased three orders of magnitude higher than that of the untreated sample, which effectively improved the surface charge dissipation on the Al$_2$O$_3$-ER surface. Ageing effects of the both treatments were evaluated. Results showed that there were no obvious ageing effects after plasma deposition, making a stable surface charge dissipation in five-day storage. However, the plasma etched samples showed a significant ageing effect because the oxygen-containing functional groups introduced after plasma etching reoriented towards the interface when the ageing time increased.

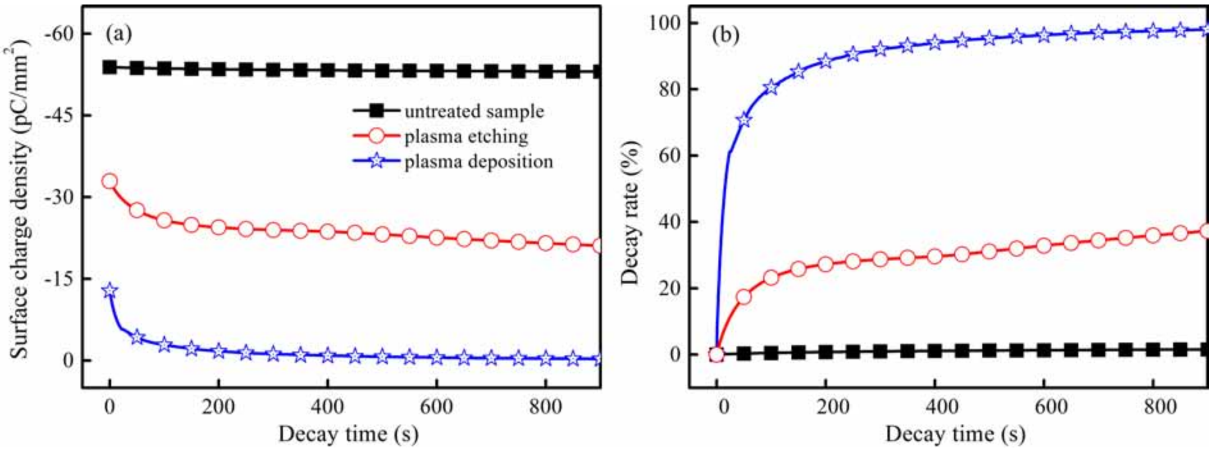

Fig. 1. The dependence of surface charge density and the decay rate on the decay time

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INTERACTION OF COLD ATMOSPHERIC PLASMA JET WITH DIELECTRIC TARGET[*]

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Non-thermal atmospheric plasma jets are powerful instruments successfully used for different applications in medicine, agriculture and material surface manufacturing. Streamers originated near the powered electrode in a dielectric tube of plasma device propagate over an inert gas jet to a treated target. The streamers deliver to the surface the high density plasma, high electric field, surface bombardment by ions and initiate chemical reactions in the mixture of nitrogen, oxygen, water. Plasma devices generating a sequence of streamers over an inert gas jet in ambient air are recently widely used in anticancer therapy. An enhancement of electric field carried by the streamers to the target surface is a way to intensify the plasma jet impact on a cell life cycle.

In this work, in the experiment and in numerical simulations we study of the dynamics of plasma jet, plasma chemistry over a zone of plasma-target contact and the interaction with the cancer cells in vitro. The calculated spatial distribution of electric field and electron temperature are input parameters for plasma enhanced chemical model in a mixture of He/Ar and ambient air (N2, O2, H2O). The calculated optical spectra are compared with measured ones over a range of wavelength 250–750 nm. The dynamics of the streamer propagation over helium and argon is compared in the experiment and 2D fluid model simulations with the model developed in Ref. [1]. The electric field penetration in cancer cells covered by water layer is calculated. Two stages of the ionization process induced by the streamer near the plasma-target interface are observed in the experiment and simulations. The first stage is related to the streamer approaching the surface and lasts 100-200 ns. The second stage is the stationary self-sustained ionization and lasts much longer during a positive cycle of sinusoidal voltage applied to the electrode inside of the plasma device.

The viability of cancer cells plated in 96 well with flat-bottom plates is studied and compared for different regime of plasma jet generation.

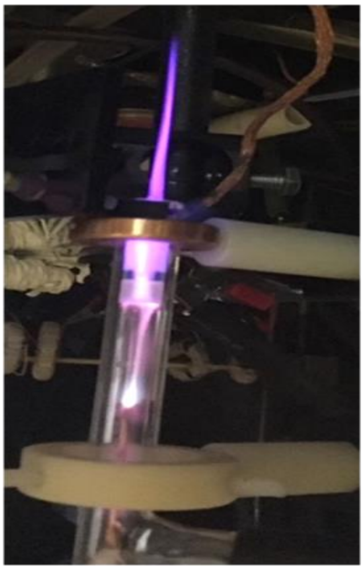

Fig. 1. Photo of experimental setup

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