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ACCELERATION OF IONS IN A VACUUM DIODE

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An investigation was made of the time, mass, and energy characteristics of the collective acceleration of ions in a vacuum diode. Acceleration of ions was observed only with the presence of surges on the oscillogram of the current density. The maximal energies of the ions in axial and radial directions are equal and depend on the multiplicity of the charge. It is shown that ions of the near-cathode plasma are drawn into acceleration conditions.

With a study of the explosive emission of electrons in a vacuum diode, two sets of current-takeoff conditions are observed: stable and unstable. Unstable conditions are accompanied by considerable surges on the oscillogram of the total current [1] and the density of the electron current [2]. The method of autographs has been used to find that, with unstable current takeoff, electron jets are formed, localized in space. With the presence of surges on the oscillogram of the total current, an acceleration of positive ions in the direction of the anode is recorded [1]. Since there exists an interconnection between these phenomena, it is necessary to study the time, mass, and energy characteristics of the accelerated ions, as well as the localization of the region of acceleration of the ions, in order to study the mechanism of unstable current takeoff.

A more detailed investigation of explosive conditions of electron and current-takeoff conditions was made with a voltage in the diode of $\sim 10^4$V. Due to their contradictory nature, it is practically impossible to bring in data on the collective acceleration of ions in a vacuum diode, obtained with higher voltages [1, 3-5]. Therefore, it is necessary to study the characteristics of the acceleration process with the abovementioned voltage.

Experiments were made with a pressure of 10^{-5} mm Hg. Breakdown was effected between a sharp cathode (Cu, W) and a flat anode (Cu, Ta, W). The interelectrode gap was established within the limits $d = 1$-5 mm. Single voltage pulses with an amplitude $U_0 = 25$ kV and a duration of 5-150 nsec were fed to the diode. The density of the electron current was investigated using a collector installed in back of an opening with a diameter of 0.1d at the center of the anode. The time characteristics were investigated by the method of a broken discharge. Provision was made for heating the anode up to a temperature of ~ 2000°C. The ion currents were recorded using a Thompson mass-spectrograph with an electron-optical recorder, whose sensitivity is $\sim 10^4$ times greater than with photographic recording. The resolving power did not exceed 25. The mass-spectrograph could be arranged at a distance of 20 mm from the axis of the diode, as well as along the axis of the diode behind an opening in the anode with a diameter of 1 mm, or behind an opening of the same diameter in the cathode holder.

In the experiments on study of the density of the electron current j_e at the center of the anode, it was observed that considerable surges on the oscillogram were recorded with a duration of the voltage pulse $\tau_p \geqslant 1/2t_k$ (t_k is the duration of the high-voltage stage of the vacuum discharge). The maximal increase in

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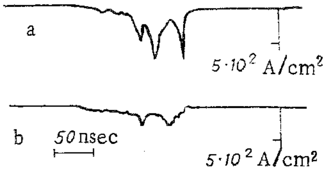

Fig. 1

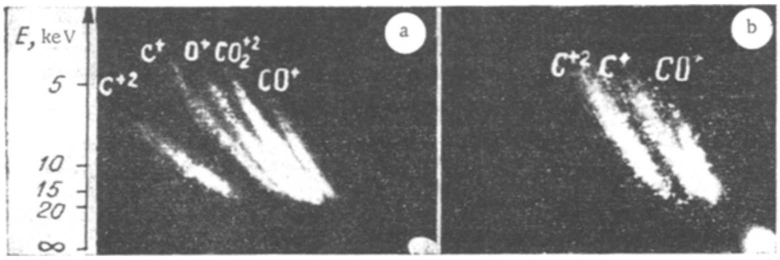

Fig. 2

the surges above the base level j_e reached F = 4-5; under these circumstances, there was recorded an intense ion current in the direction of the cathode, in whose composition ions of the material of the electrodes was not recorded. It was shown in [6] that the source of these ions is the near-anode plasma and that the beam is accelerated by the voltage applied to the diode during the high-voltage stage of the vacuum discharge. Heating the anode up to a temperature of ~1500°C led to a sharp decrease in the intensity of the ion beam, which pointed to the absence of plasma at the heated anode. Under these circumstances, the density of the electron current at the center of the anode fell by 1.5-2 times; however, the surges in j_e did not vanish, although F did not exceed two. Figure 1 gives oscillograms of j_e with d = 3 mm, $\tau_p = 150$ nsec, at cold (Fig. 1a) and heated (Fig. 1b) Ta anodes (cathode Cu).

The acceleration of ions toward the side of the anode and in a radial direction was recorded only with a duration of the voltage pulse $\tau_p \geq 1/2t_k$. The mass composition and energy characteristics of the radial ion currents did not vary as a function of whether there was fed to the anode a voltage pulse of positive polarity, with a grounded cathode, or to the cathode a pulse of negative polarity, with a grounded anode. The ions C^{+2}, C^+, O^+, CO_2^{+2}, and CO^+ were recorded (Fig. 2); ions of the material of the electrodes were not observed. To clarify the question of whether or not there is acceleration of the ions in the plasma of an anode flare which, under the conditions of the experiment, has approximately the same mass composition [6] as in a beam of collectively accelerated ions, the anode was heated up to a temperature at which there was no plasma at the anode (~1500°C); under these circumstances, the acceleration of ions, both toward the side of the anode and in a radial direction, did not vanish. This points to a cathode origin of the accelerated ions.

The maximal energies of the ions $E_{i,max}$ in axial (Fig. 2a, N = 100 pulses) and radial (Fig. 2b, N = 300 pulses) directions are equal and amount to ~20 keV. From the mass spectrograms (d = 1.5 mm, τ_p = 75 nsec, cathode Cu, anode Cu) it can be seen that, in the given case, the maximal energies of the ions depend on the multiplicity of the charge. The value of the efficiency of the acceleration process, defined as $k = E_{i,max}/eU_g$, is equal to 2-3.

On the basis of the experimental results, the following conclusions can be drawn:

1. The collective acceleration of ions in axial and radial directions, in the absence of a plasma at the anode, indicates that the ions of plasma of the cathode flare are accelerated.

2. The presence of surges in j_e, in the absence of the plasma of an anode flare, bears witness to the fact that the instability of an electron beam in a vacuum diode is determined by processes in the near-cathode plasma.

3. The dependence of the maximal energy of the ions on the multiplicity of the charge points to a potential character of the mechanism of the collective acceleration of ions in a vacuum diode.

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AN UNCONSTRICTED POSITIVE COLUMN OF A HIGH-VELOCITY FLOW OF GAS

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The creation of a homogeneous unconstricted discharge in large-diameter tubes with high pressures of the gas is of importance for a number of problems in quantum electronics, plasma physics, etc.

It is well known that, with pressures of the gas greater than 10 mm Hg, the positive column of a glow discharge is constricted, i.e., it is forced toward the axis. In [1-9] various mechanisms for explaining this phenomenon are discussed. The general criterion for a strongly compressed current pinch is inhomogeneity of the temperature over the radius of the tube. Article [10] gives the results of an investigation of the constriction of a positive column in a longitudinal flow of gas.

An unconstricted discharge in a flow of gas was obtained in [11] in a supersonic nozzle located between the cathode and the anode. It is assumed that a uniform discharge is achieved as a result of the development of shock waves in the discharge.

In [12] an unconstricted discharge in a tube was set up thanks to a nozzle made of metal, which at the same time served as the cathode. The gas entered the discharge tube through the nozzle. An unconstricted discharge, uniform over the cross section, was observed under the most greatly differing flow conditions of the gas, with both subsonic and supersonic nozzles. From this the conclusion is drawn that turbulence of the flow is of very little importance in the formation of a uniform discharge.

The present article reports the conditions necessary for obtaining a uniform, unconstricted discharge at high pressures of a high-velocity flow of gas (without a nozzle). It is shown that the unconstricted character of the discharge is due to the appearance of a turbulent flow of gas. The experiments were made in a glass water-cooled tube with an inside diameter of 10 and 15 mm and a length of from 10 to 30 cm, with cylindrical electrodes. The gas was introduced radially into the anode section.

In a tube with an inside diameter of 10 mm, in a flow of He a velocity of 250 m/sec was achieved by connecting a pump with a capacity of 0.0183 m^3/sec to the cathode section. The value of the gas velocity increased by 5-10% with the ionization of the discharge gap by a current of 30 mA. The temperature of the gas, measured with a thermocouple, increased by 3-5°C on the average. The velocity of the flow was measured with a Pitot tube, introduced into the middle of the discharge tube. A velocity of the gas of 40 m/sec was achieved by connecting-in a pump with a capacity of 0.0033 m^3/sec.

The positive column was investigated with discharge currents of 0.01-0.075 A. Electrical breakdown occurred at a gas pressure of 10^{-1} mm Hg. With a direct current, the pressure in the tube increased. Up to p = 3 mm Hg, the luminescing region of the positive column fills the whole volume of the tube (a diffusion discharge). A further increase in the pressure of the gas leads to a constriction, as a result of which the

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