Characteristics of the Plasma Flow of a Nanosecond Vacuum Flashover[1]

I.L. Muzukin, S.V. Barakhvostov

Amundsena St. 106, Ekaterinburg, 620016, Russia, im@iep.uran.ru

Abstract – The effect of the selective acceleration of hydrogen ions in high-voltage nanosecond flashover discharge over a dielectric combined with a breakdown of a vacuum gap is found out. Various schemes of such combined discharge investigated. It is detected, that ions of hydrogen may be accelerated up to the energies essentially exceeding an applied voltage. It is shown, that the effect of the selective acceleration is observed at a vacuum gap over 0.5 mm.

1. Introduction

One of the purposes of our experiments is development of ion sources with high parameters of plasma on the basis of new methods of plasma production and its acceleration. As one of variants of an ion source the electrode scheme with combination of the dielectric flashover with a vacuum spark was considered. The discharge on a dielectric gives an ion flow of high intensity and the high content of the multicharged ions [1]. The vacuum spark is a source of high-energy ions [2, 3]. Combining of these two discharges was considered us as interesting object for examinations.

2. Experimental setup and results

Experiments were carried out in vacuum of 10^{-4} Pa. Plasma was analyzed by the ion energy-mass Thomson spectrometer with computer analysis system, described in [1, 4]. In the beginning was decided to use the setup maximum approximate to the setup of a vacuum-tube diode (Fig. 1). On a central electrode A with diameter of 2 mm the dielectric cylinder with a hole in diameter of 1 mm mounted. A material of the cylinder – polyethylene of a high pressure. Distance from an edge face of an electrode A up to a face surface of the cylinder – 4 mm. The distance from a surface of a dielectric up to a grid grounded electrode C varied from 2 mm up to 15 mm. On a central electrode A the short high-voltage pulse of the positive or negative polarity was applied. The amplitude of a pulse was 150 kV duration 3 ns and front of 200 ps.

It was revealed two unexpected facts. At application of the negative pulse on a central electrode there were no any signal of the ion flow, though the detector has stored an ultraviolet luminescence of plasma in the field of a capillary. At application on an electrode A the positive impulse it was revealed a ion flow of hydrogen with energies up to 350 keV (Fig. 2), thus no carbon ions in the given setup was registered. Searching the ion signal in a range has high and low energies were carried out but a signal of ions of carbon was detected not.

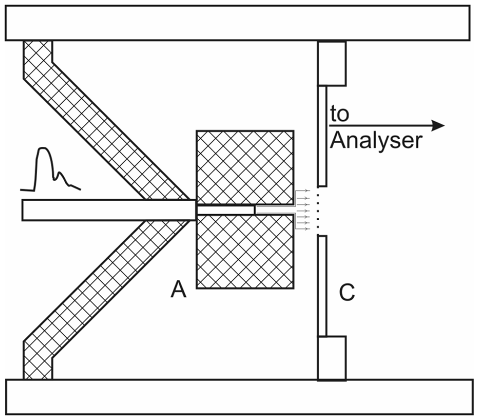

Fig. 1. Setup with combining the capillary discharge and a vacuum-tube diode

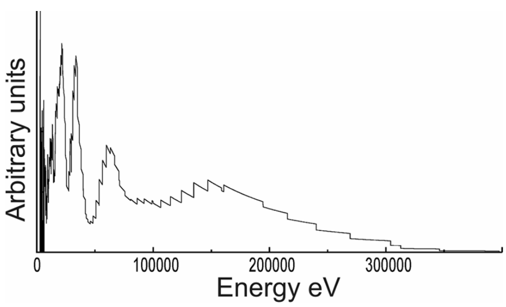

Fig. 2. Energy distributions of protons at an optimum gap the cathode – a dielectric surface in 7 mm for the electrode setup of a Fig. 1

It may be explained that according to measurements of angular dependence of parameters of a flashover ion flow [4] ions of carbon are sharply guided on a normal line to a surface. In case of the capillary discharge ions of carbon are collected on walls and do not leave from a capillary. Protons, which have wider sector of dispersion, may take off for a hole

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of a capillary. For proving of this hypothesis the electrode setup was essentially changed (Fig. 3).

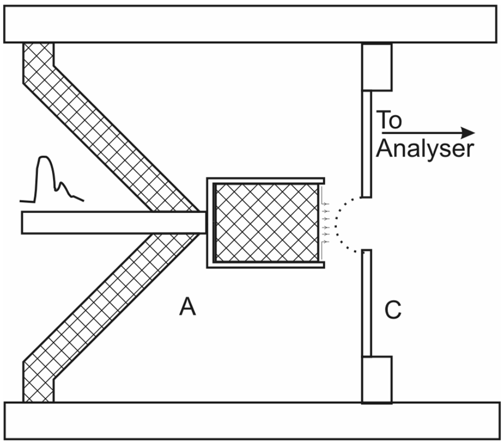

Fig. 3. Setup with the vacuum flashover, which is taking place in direct visibility of the analyzer

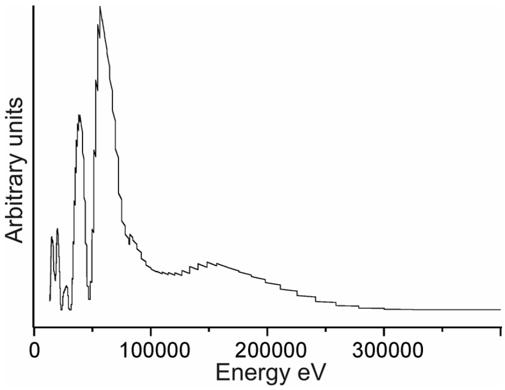

Fig. 4. Energy distribution of protons at a gap the cathode – dielectric in 7 mm for the setup of a Fig. 3

In this case the surface of a dielectric on which the discharge burn, was turned to the analyzer. The arrangement of an arc-shaped grid C ensured that the discharge was spread over all surface of a dielectric. The results for the second setup had no the significant difference from the first setup. Also for the negative pulse no ion signal was detected. In case of the positive pulse the signal of the accelerated protons was revealed. Apparently from figures 4 and 2 energy distributions of protons also are similar. And in both cases a signal of carbon ions was not detected. The searching of a C ions signal was undertaken by changing an aiming point of a Thomson analyzer, but search gave no results for all accessible ranges of energies.

Modification of the setup used in [1] (Fig. 5) is the one more discharge setup where the effect of the selective acceleration of protons was detected. This was setup with linear flashover of a dielectric with a vacuum gap between a peripheral electrode and a wall of the chamber. The gap was 5 mm. Results of measuring of ion flow parameters in basic similar to those for the first two setups. Signal of a C ion flow was not detected. At application of the negative pulse no ion signal was detected. In this case energies of protons appeared much less, those than in the first two electrode setups (Fig. 6).

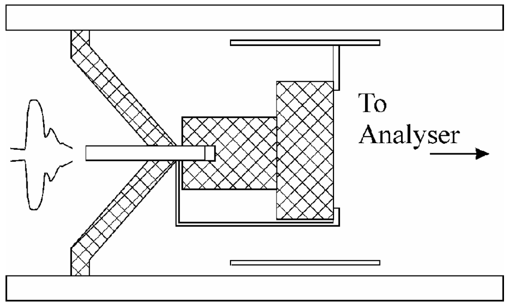

Fig. 5. Setup of vacuum flashover with a gap between a peripheral electrode and a wall of the chamber

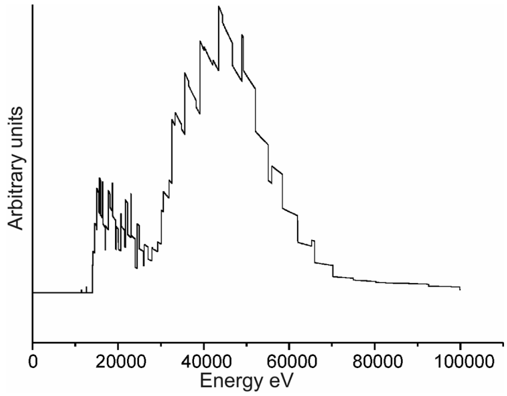

Fig. 6. Energy distribution of protons at a gap the peripheral electrode – a wall of the chamber in 5 mm for the setup of a Fig. 5

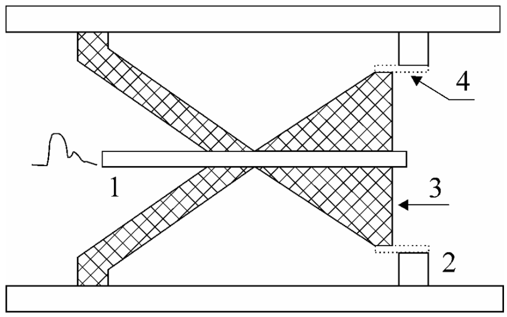

Fig. 7. Coaxial setup of a flashover discharge

At the further examinations of a dielectric flashover combined with a vacuum gap it was revealed, that occurrence of a small vacuum gap between a dielectric and the cathode chamber wall conducts to the smoothly varying diminution of the relative content of heavy ions and to occurrence of high energy tail on energy distribution of H ions. In these experiments the coaxial setup similar to that in [5] (Fig. 7) was used. Diameter of the dielectric cylinder 3 made 20 mm. The vacuum gap between a dielectric and a peripheral electrode 2 made 0.5 mm, which might be eliminated by a metal ring 4.

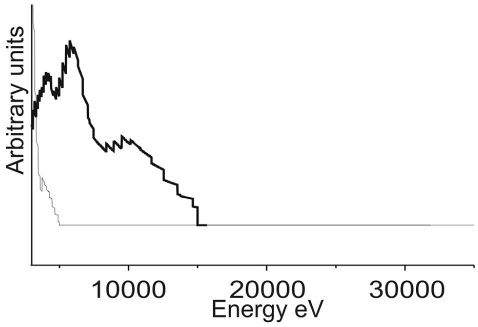

Fig. 8. Energy distribution of H ions in a high-energy region without a vacuum gap for the setup of a Fig. 7. A thick line – the positive pulse polarity, thin line – the negative polarity

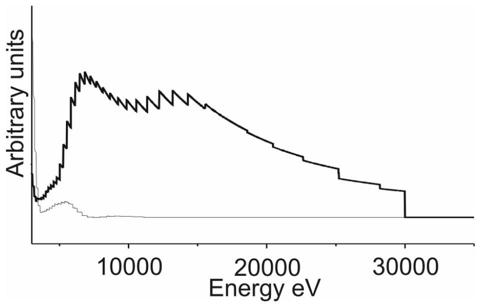

Fig. 9. Energy distribution of H ions in a high-energy region with vacuum gap D=0.5 mm for the setup of a Fig. 7. A thick line – the positive pulse polarity, thin line – the negative polarity

Table. Plasma flow composition

Polarity	Gap	Ion fraction %				
		H^+	C^+	C^{2+}	C^{3+}	C^{4+}
+	D=0	50	9	7	8	26
	D≠0	76	3	2	3	16
–	D=0	42	5	5	8	40
	D≠0	40	3	4	7	46

Four variants of vacuum dielectric flashover – were explored at application on a central electrode of pulses of the positive or negative polarity, and also at presence and absence of a vacuum gap between a dielectric and a peripheral electrode. As a result of the experiments performed it was revealed, that from four described variants of discharge the variant with presence of a vacuum gap and applying positive pulse on a central electrode is essentially different. In this case the composition of plasma sharply varies aside magnifications of a share of H ions (Table 1), and also there is a high-energy tail in ion energy distribution (Fig. 8 and 9).

3. Discussion

The later series of measuring in part uncovers the mechanism of effect of the selective acceleration. Time of activity of a pulse of a voltage together with reflections (the presented electrode setup is the unmatched load for the high-voltage generator) approximately 20 ns. Propagation velocity of flashover discharge frontline from the anode toward the cathode on a dielectric is $3 \cdot 10^6$ m/s [1]. Time of distribution of the discharge on a dielectric surface in the setup in a Fig. 7 makes approximately 3 ns. Hence, the considerable time (about 17 ns) in case of absence of a gap the discharge burns at the high current about 3 kA. In a case of presence of a gap for the discharge overlapping it is necessary that plasma from an edge of the cylinder has reached a peripheral electrode. All this time plasma of the discharge remains under potential, the close to potential of a central electrode. In assumption, that velocity of plasma frontline is not in strong difference with propagation velocity of explosive emission plasmas – $2.5 \cdot 10^4$ m/s [5] the vacuum backlash of 0.5 mm will be, overlapped in time approximately equal to 20 ns. After that occurrence of a high discharge current is possible. Thus, it is possible to draw a conclusion, that time of overlapping of the discharge essentially influences both a plasma composition, and on process of acceleration of ions. Thus in case of the negative pulse of a voltage presence of a gap does not play an essential role. The basic feature of a mode of the selective acceleration is the long-lived presence of discharge plasma under the high positive potential. Such state of plasma leads to preferred acceleration of light ions, as during activity of a voltage pulse, heavy ions, because of the inertia, have not time to be accelerated up. Thus, the mode of the selective acceleration of light ions is implemented. In a case when plasma the considerable time is under potential the close to zero or the negative potential the common mechanism of collective acceleration of ions by electronic gas apparent is implemented both in case of a vacuum spark, and in case of plasma expansion in vacuum obtained by a radiant of laser radiation.

4. Conclusion

Thus, it is revealed, that combination in one discharge of vacuum flashover of a dielectric and a vacuum gap breakdown with use of the high voltage nanosecond pulse generator lead to appearance of effect of polarity and effect of the selective acceleration of H ions in case of the positive pulse applied on a potential electrode.

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