Investigation of Plasma Filter Influence on Ions Charge State of DC Vacuum Arc Plasma

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Abstract – At present time the Vacuum Arc Plasma Generators (VAPG) by the materials modification (plasma sputtering, ion implantation etc.) are most widely used. It is necessary to know the relative densities of the ions with various charge state in order to understand the obtained results and to choose treatment modes choice.

The presented work is dedicated to the investigation of the influence of the shutter type plasma filter (PF), designed in Nuclear Physics Institute, on the charge state generated by the DC vacuum arc plasma.

The investigations have been made using a new approach to the time-of-flight method realization. The experiments have been performed with cathodes of various types – both monopropellant and composite. The plasma charge state has been investigated with plasma filter operating both in passive and active modes.

The influence of the plasma filter operation modes (PF with magnetic field, PF with magnetic field and bias potential and passive PF) on the plasma ions charge state for various cathode materials has been detected. The possible mechanisms of charge state changing have been discussed.

1. Introduction

Numerous recent investigations showed, that for technological use of plasma flows and ion beams generated using these flows it is necessary to control not only their traditional parameters (namely density, average energy), but also specific ones, which contribute to the interaction of the flow with the target. These parameters are the plasma ion charge state, the presence of neutral and micro drops in the plasma flow etc.

There exists various methods of defining the charge state, such as time-of-flight method, based on the tangential ions deflection [1]; single pole magnetic spectrometer [2]; the method of inhibit grids [3]; Thomson spectrometer [3].

In this work the new approach to the time-of-flight method is described, which is based on the plasma ions acceleration in the quasi planar diode in the longitudinal direction and their consequent registration with the Faraday cup, placed at the certain distance from the diode gap. Charge state of plasma ions, generated by DC vacuum arc with plasma filter [4] operating in various modes was investigated using this method.

2. Experimental Setup

The scheme of experimental setup is shown in Fig. 1.

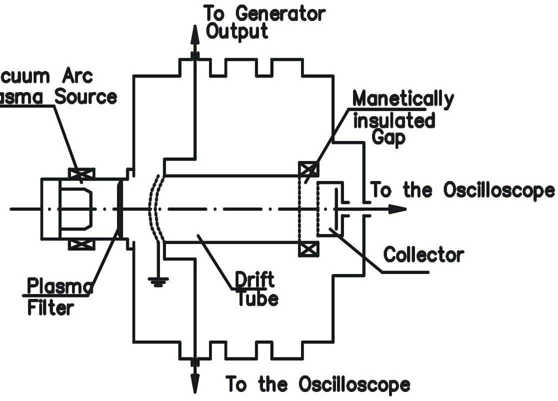

Fig. 1. The experimental setup

Both conventional source of NNV 6.6-1 (for titanium and zirconium cathodes) and modified one (for tungsten cathode) were used as a plasma source. In the first case the arc current was equal to 100 A and was about 500 A in the second one.

The drift tube was places in the vacuum chamber so that its axe coincided with the plasma flow motion direction. At the front edge of the drift tube the quasi planar diode was formed with the interelectrode gap of 10 mm, moreover that was near to the plasma source was grounded and the negative voltage pulse with amplitude of 500–1000 V and duration of 650 ns was applied to the drift tube. The generator internal resistance was 50 Ohm, its repetitive rate reached 20–30 Hz. In each run we collect the statistic of 1000 shots for measured data averaging. The Faraday cup was placed after the drift tube, the interelectrode gap between it and drift tube was magnetically insulated by the annular magnet in order to decrease the electron current to the sensor. We also apply the negative bias of 100 V to the sensor with the same purpose. The drift region was equal to100 cm.

We record the experimental data by the LeCroy-9354 scope with time resolution of 2 ns.

3. Experimental Results

The typical waveforms of accelerated voltage and Faraday cup signal are given in the Figs. 2a and b, respectively.

We obtained the negative signal from the Faraday cup at the start time, caused by the electron, accelerated from the plasma by applying the negative voltage to the drift tube. Then the positive signals appeared, corresponding to the ion time-of-flight.

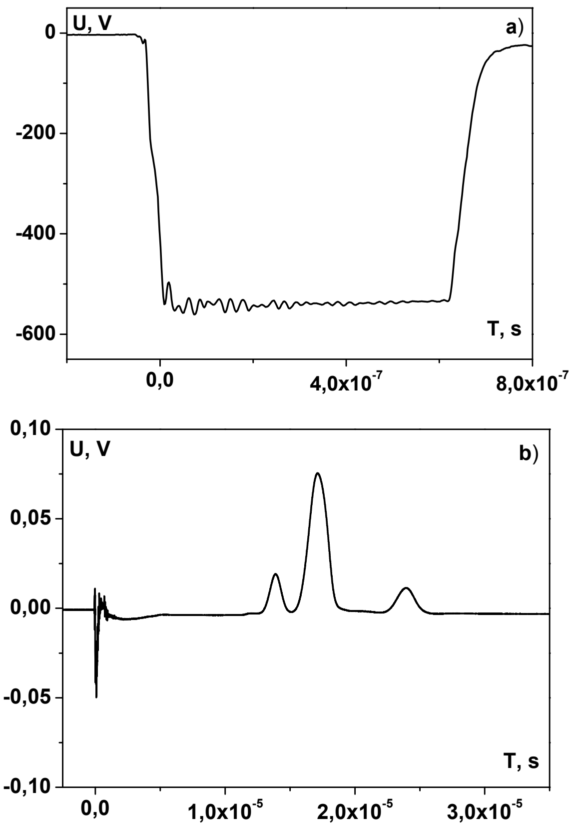

Fig. 2. Typical waveforms of diode (a) and Faraday cup (b) voltage

It must be noted, that the ions energy was lower then the applied accelerated voltage. This fact indicates the essential voltage drop on the plasma in the interelectrode gap.

The data summary of generated by titanium cathode charge state of plasma ions is given in Table 1.

Table 1. Data summary for titanium cathode plasma charge state

No	PF B	PFbias, V	Z1	Z2	Z3	⟨Z⟩
1	0	0	18.4	69.2	11.9	1.94
2	+	0	21.7	67.7	10.2	1.9
3	+	7.5	21.4	68.6	9.8	1.89
4	+	7.5	21.7	68.3	9.8	1.89
5	+	10.5	23.1	67.8	8.9	1.86
6	+	15.5	24.8	66.9	8.1	1.84
7	–	0	9.8	71.8	18.4	2.09
8	–	17	14.2	77.5	8.2	1.94
DC arc [5]			27	67	6	1.89
Reprate arc [6]			6	82	12	2.05

Here: PF B is the plasma filter magnetic field direction ("+" means that the magnetic field directions in the plasma filter and in the holding coil of the arc evaporator are codirectional, "–" means that they are opposite, "0" means zero magnetic filed in PF); PF bias is the positive bias potential, applied to the plasma filter; Zi, ⟨Z⟩ are the percentage of ions with charge state of "i" and average charge rate of plasma ions.

The ion waveforms corresponding to rows 1, 6 and 7 from Table 1 are shown in Fig. 3.

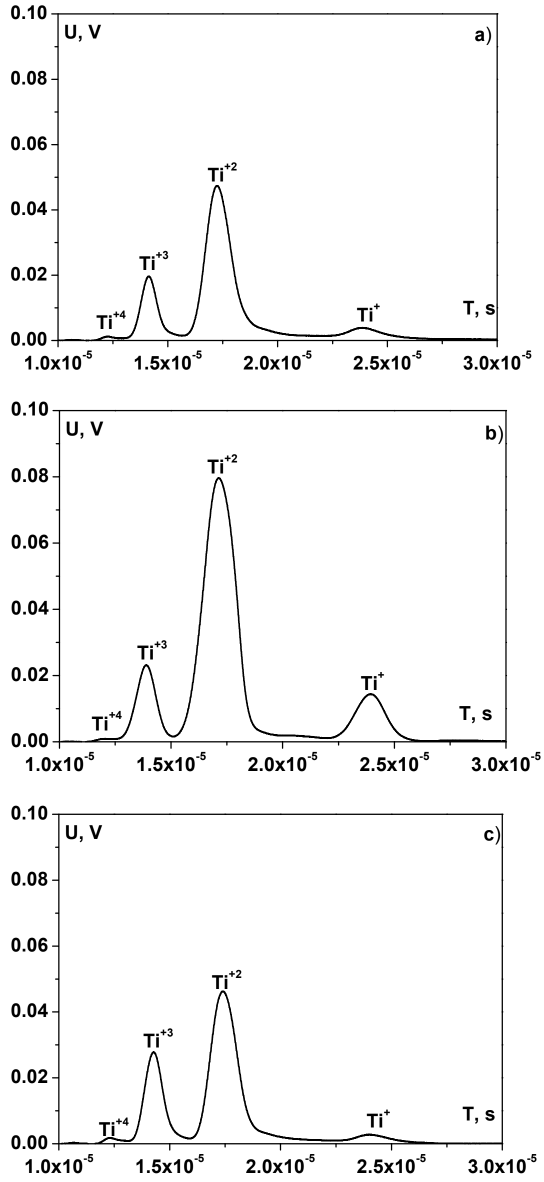

Fig. 3. Ion waveforms for various regimes of plasma filter operation

The more detailed examination of these waveforms indicates the presence of peaks corresponding to the titanium ions with charge state of +5 and +6 (Fig. 4). The cases a) and b) correspond to the Table 1 rows 1 and 7.

The relative percentage of ions with charge state of +5 and +6 can be estimated as 0.4, 0.2 and 0.6, 0.06 for cases a) and b) correspondingly.

The data summary for the generated by zirconium cathode plasma ions charge state is given in Table 2, and in Fig. 5 – the typical waveforms of ion signals.

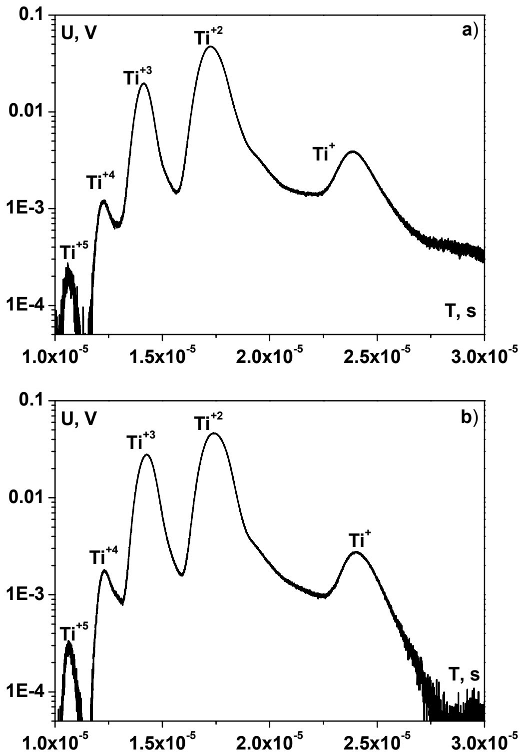

Fig. 4. Ion waveforms in logarithmic scale

Table 2. Data summary for zirconium cathode plasma charge state

No	PF B	PFbias, V	Z1	Z2	Z3	Z4	⟨Z⟩
1	0	0	11.6	61.6	23.7	2.9	2.18
2	+	0	16.5	61.3	28.8	3.4	2.29
3	+	7	6.6	58.4	31.1	3.9	2.32
4	+	10	6.3	58.4	31.4	3.8	2.33
5	+	15	7.3	58.8	30.4	3.6	2.31
6	+	20	7.1	59.9	29.4	3.5	2.3
7	–	17	4.7	59	33	3.2	2.35
DC arc [5]			14	60	21	–	1.94
Reprate arc [6]			9	55	30	6	2.33

As in the case of titanium cathode we obtained ions with charge high state (+6) at the level lower than 1%.

The experiments performed with the composite cathode (50% Ti and 50% Zr) did not allow us to separate velocity ions with the low velocity difference (Ti^{+} и Zr^{+2}, Ti^{+2} и Zr^{+4}). This fact is shown in Fig. 6.

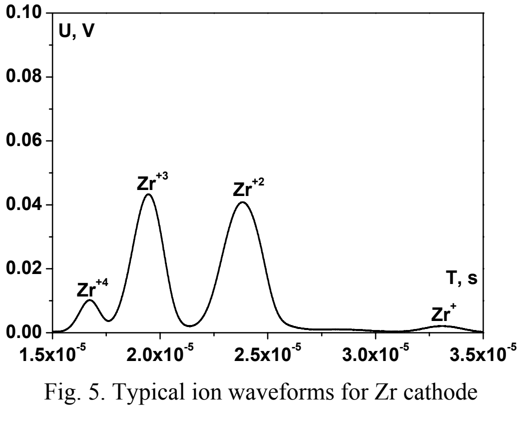

Fig. 5. Typical ion waveforms for Zr cathode

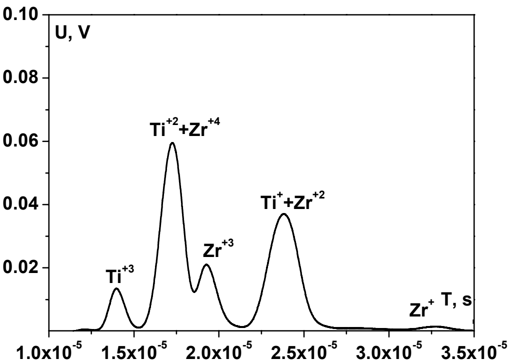

Fig. 6. Ion waveforms for composite cathode

Finally, we performed several runs with the tungsten cathode. In Fig. 7 the typical waveform of ion signals from the Faraday cup is given.

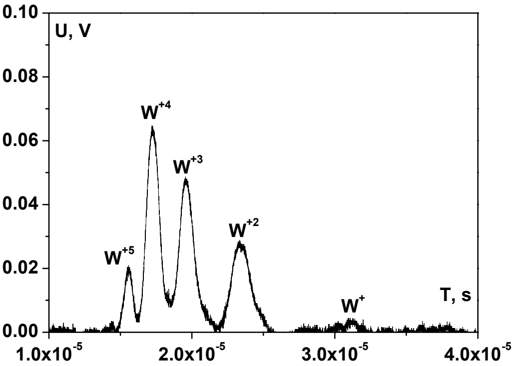

Fig. 7. Ion waveforms for tungsten cathode

4. Analysis

The carried out investigations have shown, that at the passive plasma filter (with zero magnetic field and bias potential) a god accordance with the other authors data, received for titanium DC vacuum arc, is observed. The experimental data for zirconium cathode are placed between data of other experiments for DC and reprate vacuum arcs. This fact can be explained by the difference of physical-mechanical properties of the cathode material.

By the activation of PF the behaviors of titanium and zirconium are also different: by the increase of bias potential the average charge rate of Ti plasma drops homogeneously and has a feebly marked maximum for zirconium.

The situation changes essentially at switching PF mode from optimal to less effective (here must be explained that PF has a higher flow capacity when the magnetic field directions in the plasma filter and in the holding coil of the arc evaporator are codirectional). This effect can be used in some applications, when the high plasma ion charge rate is needed.

The carried out investigations have shown the high sensitivity of the proposed method, which allows to reveal the ion charge state presence at very low level – less than the tenth part of percents. It is possible by sufficiently long drift region and by taking special actions to decrease the plasma concentration in the sensor placement region (the presence of drift tube etc.).

The experiments with composite cathode have shown that the drift region is too short for ions resolution with similar Z/M ratio. It also must be noted, that for good peaks resolution the accelerating generator must have a short leading edges. The smearing of the ion signals may be caused by:

– energy dispersion of plasma ions;

– duration of the double layer formation in the diode;

– duration of the applied voltage leading edges.

The carried out experiments with the other generator with long leading edges have shown that the latter cause is most essential.

5. Conclusion

Performed investigations have shown the possibility of plasma ions charge state measurements with the new approach to time-of-flight method. This method has a good time resolution to reveal single-sorted ions of different charge state (the 5 and 6 charge states were resolved).

Moreover, this method has a high sensitivity, that allows to indicate the components with relative concentration less than the tenth part of percents. It can be useful in some special investigations.

The investigations of the plasma filter influence on the average charge rate demonstrate the possibility to control this parameter; it can be used in practical applications.

References

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