Characteristics of Metal Ions Acceleration in Pulsed Vacuum Arc

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Abstract – Results of measurements of ion energy distribution in cathode plasma jet of pulsed vacuum arc source MEVVA are presented. Measurements were performed with a Langmuir probe and a small-size energy analyzer of the "plane capacitor" type and the ion distribution was averaged through the ion charge states. The current pulse was of near rectangular shape of 200 μs length and of 100 or 300 A amplitude. Different cathode materials (Al, Zr) were used. It was found that shape of the ion energy distribution was changed significantly in progress of the discharge. Very early in the discharge a gross peak of ions with a wide energy dispersion, namely with high energy 'tail' up to 400 eV was recorded. Maximum of these ion distribution lies near of 50 eV for all metals studied and the energy averaged over the distribution was of about 150 and 170 eV for Al and Zr, respectively. These ions present the bulk (60–80 %) of total yield of the ions in the pulse. In 150 μs after the discharge onset the averaged ion energy decreases down 140 and 50 eV for Al and Zr, respectively. We suggest that the high energy ions in the early stage of the discharge burning are due to the transition processes when the drastic changes of discharge current occurs. Also it was found that the averaged ion energy near hold with for Al cathode and is enhanced from 50 up to 90 eV for Zr cathode with increases of distance from the anode from 18 up to 36 cm.

1. Introduction

Vacuum arc is widely used as a source of metal ions. An important characteristic of the ion flow is the ion energy distribution of the cathode plasma jet. Ion spectra are well studied for a wide set of cathode materials in a steady state vacuum arc. It was established that the average energy of the ion flow for most of materials is between 20 and 150 eV [1]. These properties have importance for synthesis of dense coating with the controllable structure. Also, it was found that in steady state arcs the energy is nearly independent on parameters of the discharge [2]. Nevertheless, the picture in pulse discharges is more complicated. In particular, it was found that in the initial stage of the discharge running, flows of ions of the cathode material with energies that exceed the values obtained in steady state arcs were produced [3]. After a few tens of microseconds the ion energy relaxed toward the steady state values. This result was of a qualitative character and it was not studied in detail. The objective of the given paper was the detailed study of evolution of the ion spectra in the course of a pulse in vacuum arc.

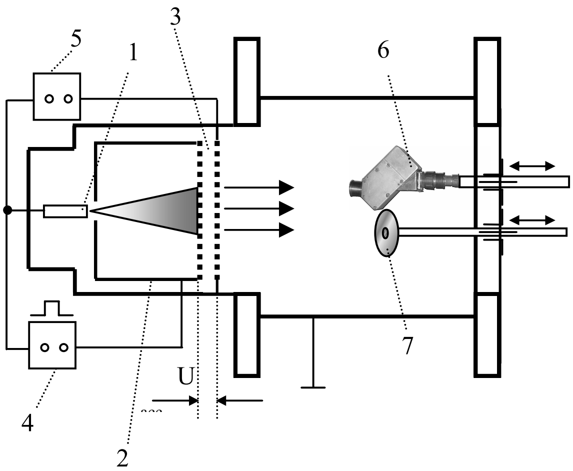

Fig. 1. Experimental setup 1 – cathode, 2 – anode, 3 – accelerating gap, 4 – arc power supply, 5 – accelerating voltage supply, 6 – electrostatic analyzer, 7 – Langmuir probe

2. Experimental

Researches were performed in pulsed vacuum arc of 'MEVVA' type [4]. The initiating high voltage pulse (20 μs length, 20 A current) was applied between the igniter and the cathode of 6 mm in diameter, which were separated with a dielectric insert. That resulted in a breakdown through surface of the insert that, in turn, initiated a pulse vacuum discharge between the cathode and anode (see Fig. 1). We used two types of materials of cathode with low and high atomic masses, e.g. Al and Zr, respectively. The length and amplitude of the discharge current pulse were controlled with the supply circuit and were of 200 μs and 100–300 A, respectively. The cathode plasma jet went through the annual anode with of 10 mm diameter hole that was spaced 10 mm from the cathode and expanded into the vacuum chamber. We used two types of diagnostics. First one was a movable Langmuire probe as a disc of 3 cm in diameter, placed perpendicular to the discharge axis.

The second diagnostics was a small-size electrostatic energy analyzer of a 'plane capacitor' type with a microchannel plate as a detector. Energy resolution of the analyzer was $\Delta\varepsilon/\varepsilon \approx 0.1$ and temporal resolution of the recording circuit was about 10 μs. The analyzer also could be moved along the discharge axis therewith its entrance tube was oriented along the axis. The analyzer lets to derive, virtually, the ion distribution over energy per the mean ion charge state $\varepsilon/\overline{Z}$. We imply just that parameter as the 'ion energy' below in the report. Analyzer signal at the given value of energy had a wide dispersion from shot to shot, hence, to obtain a statistically justified result the signal was averaged over 10 shots.

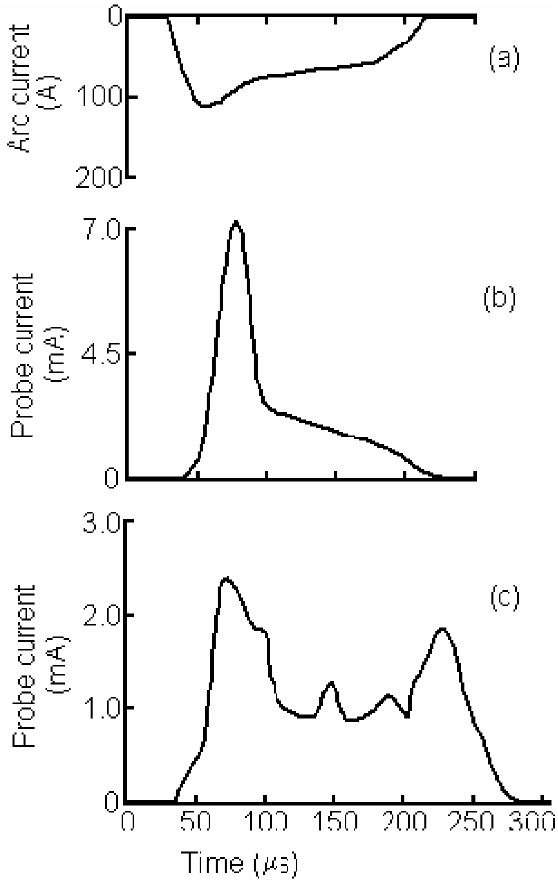

Fig. 2. Waveforms of the discharge current (a) and signals of the probe located at the distance 22 (b) and 44 (c) cm from the anode for Al cathode

The following results were obtained after experiments. Fig. 2 presents typical waveforms of the discharge current and corresponding signals of the probe located at two distances from the anode for *Al* cathode. One can see that both the amplitude and the shape of the probe signal change significantly with the distance being enhanced. At short distance the signal exhibits a pronounced peak in the initial stage whereas at large distance the signal takes more rectangular form. Note that the probe signal that was obtained with the *Zr* cathode is of the rectangular form at both distances of the probe from the anode (see Fig. 3). One can see also for both cathode materials decrease in the signal amplitude when the probe is moved off the anode, which, apparently, is due to expanding of the cathode jet into the vacuum ambient.

Now let us consider results of measurements with the ion energy analyzer. Fig. 4 presents signals from the analyzer at two different energies of ions Zr^{n+}. One can see that there is a considerable burst of ions in the initial stage of the discharge. For low energy ions the burst relaxes to a plateau in, approximately, 50–100 μs (Fig. 4, *b*), but for high energy ions the plateau, if exists, lies under the threshold of recording. This means that the energy spectra of ions also change significantly in course of the discharge running. Fig. 5 illustrates this effect. One can see that in the initial stage there (instant T_1) the ion energy distribution has a maximum at, approximately, 50 eV and a broad 'tail' that attains 400 eV. Ion energy averaged over the distribution here is 170 eV at 18 cm distance from the anode. The same value for more late instant T_2 is 50 eV. Fig. 5 exhibits also effect of acceleration of the ion flow when its expansion into vacuum ambient. Actually, the averaged ion energy increases both in the instance T_1 (up to 180 eV) and, significantly, in the instance T_2 (up to 90 eV) with distance from the anode increasing from 18 up to 36 cm. Note, that the similar measurements with the *Al* cathode did not reveal a significant enhancement of the averaged ion energy.

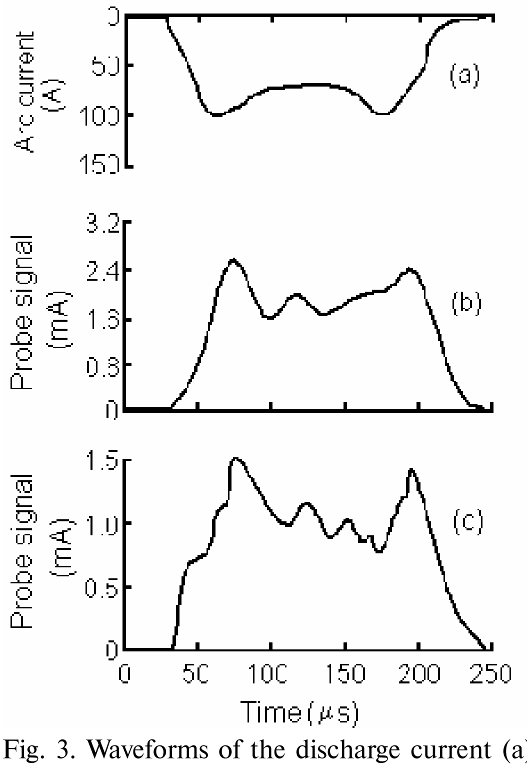

Fig. 3. Waveforms of the discharge current (a) and signals of the probe located at the distance 22 (b) and 44 (c) cm from the anode for Zr cathode

3. Discussion

The results presented show a significant difference between parameters of a cathode plasma jet in a steady state and pulsed vacuum arc. Probe measurements show that in specific mode of the device operation the significant fraction (near 50 %) of plasma of cathode jet is emitted just in the initial stage of the discharge running, less than in 50 s after the discharge onset. Evolution of the probe signal with the distance from anode and dependence of its shape on the cathode material require detailed additional measurements.

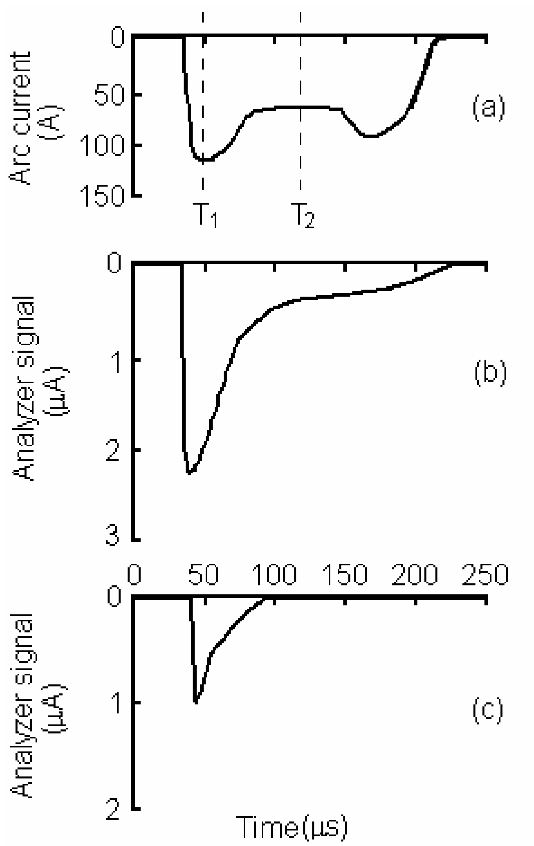

Fig. 4. Waveforms of the discharge current (a) and signals of the analyzer for $\varepsilon/\bar{Z}$=40 eV (b) and 120 eV (c) for Zr cathode

Let us consider now the results of ion energy measurements. They show that the averaged energy of the ions in the middle of the discharge pulse is close to that was measured earlier in pulsed vacuum arcs by the time-of-flight technique [5]. Nevertheless, the averaged energy of ions in the initial stage of the discharge running significantly succeeds this value. Note, it is well known that in this stage also a significant increases in the mean ion charge state as compared to the steady state arc was found in a pulse vacuum arc [6]. We suggest that both effects are of a common nature and connected with transient processes that occurred in the initial stage of the discharge running.

Rather unexpected result is the observing acceleration of ions when motion of the cathode plasma flow beyond interelctrode gap. This effect also requires the additional studies.

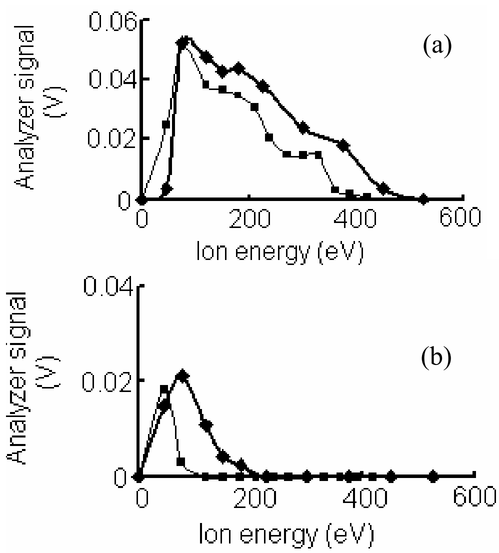

Fig. 5. Ion energy distribution with Zr cathode for instances T_1(a) ant T_2 (b) at the distances 18 cm (thin line) and 36 cm (solid line) from the anode Discharge current was 100A

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