On Abnormal Acceleration of Ions at Initial Stage of a Pulse Vacuum Arc

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Abstract – Results of experimental investigation of the pulse vacuum arc of the MEVVA type with different materials of the cathode are presented. It is shown that the Langmuir probe signals for both ion and electron components plasma jet for Al and Mg cathodes have a pronounce peak in the beginning of the pulse. The signals for Ti and Zr cathodes have the more rectangular form. In addition, it is shown that signals from the ion energy analyzer also have the similar peak at high energies. It is shown that the ion energy spectra are changed significantly through the discharge pulse. Namely, the spectrum of ions produced at the peak of discharge current has the most likely energy and a tail of high-energy particles as compared to ions produced at plateau of the discharge current. High-energy ions from tail of the spectrum are produced in front of the discharge current, these in vicinity of maximum of the spectrum are produced in maximum of the discharge current and the slow ions are produced at plateau of the current pulse.

1. Introduction

It is well known that the vacuum discharge plasma is produced at non-stationary cathode jets of micron-size, characterized by extremely high current density, power density and plasma density. Due to these parameters there are the microjets, where a production of ions of the cathode material at high charge states and acceleration of the ions up to high velocities occurs [1]. Experiments showed that both the charge state distribution and velocity of the ions in both steady-state and pulse vacuum arcs depend only on material of the cathode and vary just slightly with variation of the discharge current [2, 3]. Recent measurements performed in pulse arc of 250 μs duration showed that these parameters of ion flow for a wide range of cathode materials are close to the data of model hydrodynamic calculations of plasma parameters in the microjets [3, 4]. Nevertheless, the measurements demonstrated that parameters of the ion flow are not constant throughout the arc pulse. The ion velocity is markedly higher at the beginning of the arc pulse than at the steady state stage of the discharge burning so that the good agreement of the experimental and theoretical results was observed just 150 μs after beginning of the discharge pulse [5]. It was also observed that charge states of ions of plasma flow at the beginning of pulse arc exceeded significantly those at the steady-state stage of arc for a number of materials of cathode [6]. These findings permit them to suppose that besides of the conventional mechanism of plasma heating and acceleration in the cathode microjet there is an additional one, which occurs at the initial stage of the pulse and provides the observed enhancement of both energy and the average charge state of ions of the macroscopic plasma jet. Objectives of the present report are to establish the changes of parameters of plasma jet throughout a pulse of vacuum arc for a set of the cathode materials with different physical characteristics.

2. Experimental setup and results

The experiments were performed in a pulse vacuum arc of MEVVA type [5] with an electrode system comprising a cylindrical Zr cathode of 6 mm in diameter and the annular anode with an inner diameter of 13 mm; the anode was 9 mm apart from the cathode surface (see Fig. 1). The vacuum chamber was evacuated to a residual pressure of (4–6) 10^{-6} Torr. The discharge was initiated on the cathode surface by means of a high-voltage breakdown via a dielectric insert

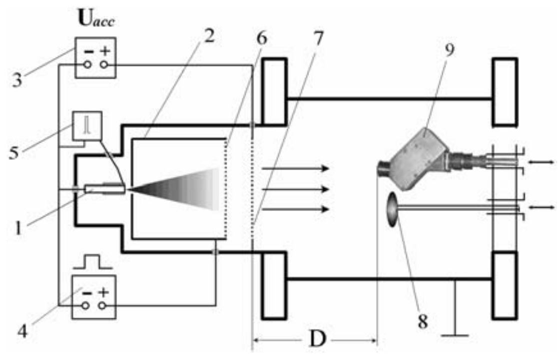

Fig. 1. Experimental setup: 1 – cathode, 2 – anode, 3 – accelerating voltage supply, 4 – arc power supply, 5 – tigger power supply, 6 – anode grid, 7 – accelerating grid, 8 – Langmuir probe, 9 – electrostatic analyzer

between the cathode and the igniter. The discharge was fed by a LC-pulse line resulting in pulses of up to 150 A amplitude, 30 μs rise time, and 200 μs duration. The plasma jet leaving the arc discharge region passed through the anode hole and expanded while streaming towards the anode grids. The ion beam had a diameter of about 10 cm, it passed through the anode grid and expanded into the equipotential drift chamber with a diameter of 20 cm and a length of 30 cm. The ion current density was measured using a movable flat Langmuir probe operating with the saturation regime. The plasma potential was measured by a moveable heated probe. An electrostatic ion energy analyzer with the entrance tube facing the accelerated ion beam was placed at the distance D = 20 cm apart the accelerating grid. The energy resolution of the energy analyzer was of $\Delta E/E \approx 0.1$.

Figure 2 shows the typical waveforms of the Langmuir probe signals of both ion (I_i) and electron (I_e) saturation currents for different cathode materials. One can see that there are recorded significant peaks at the beginning of the discharge. Note that the peaks are clearly pronounced for materials of cathode as metals with low melting points, i.e. for Al and Mg and are seen rather less for refractive metals, namely, for Ti and Zr. Note also that the peaks are present at both ion and electron signals. This implies that the peaks are rather due to more value of plasma density at the initial stage than the plasma (i.e. ion) velocity.

Now let us consider results of the analyzer measurements. Fig. 3 presents signals of the analyzer for different recorded ion energies. One can see that at low energies the signal has near rectangular shape, whereas at more energy the pronounced peak is

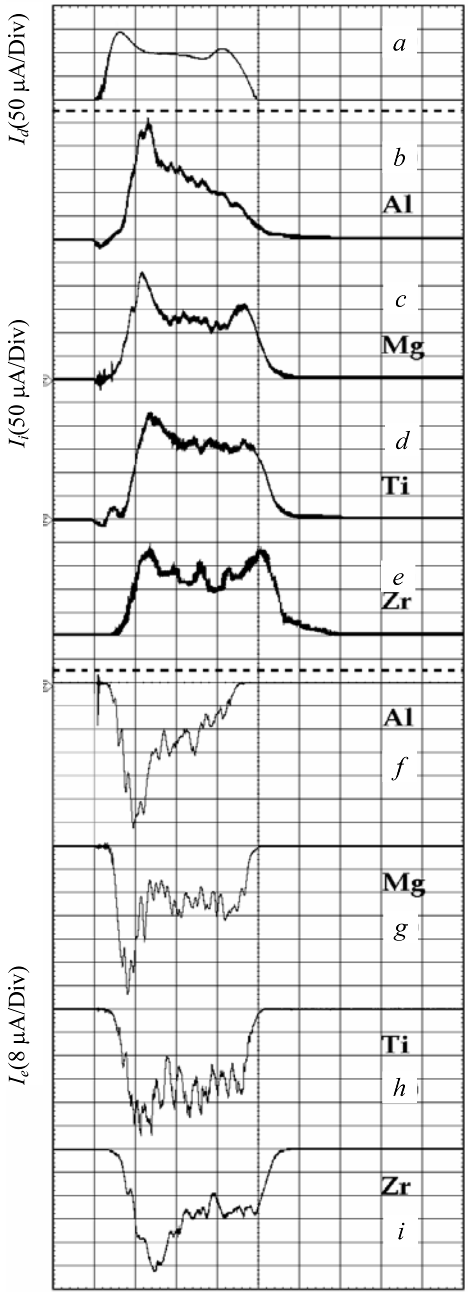

Fig. 2. Typical waveforms of the discharge current (*a*) and the ion (*b–e*) and electron (*f–i*) probe currents for different materials of the cathode

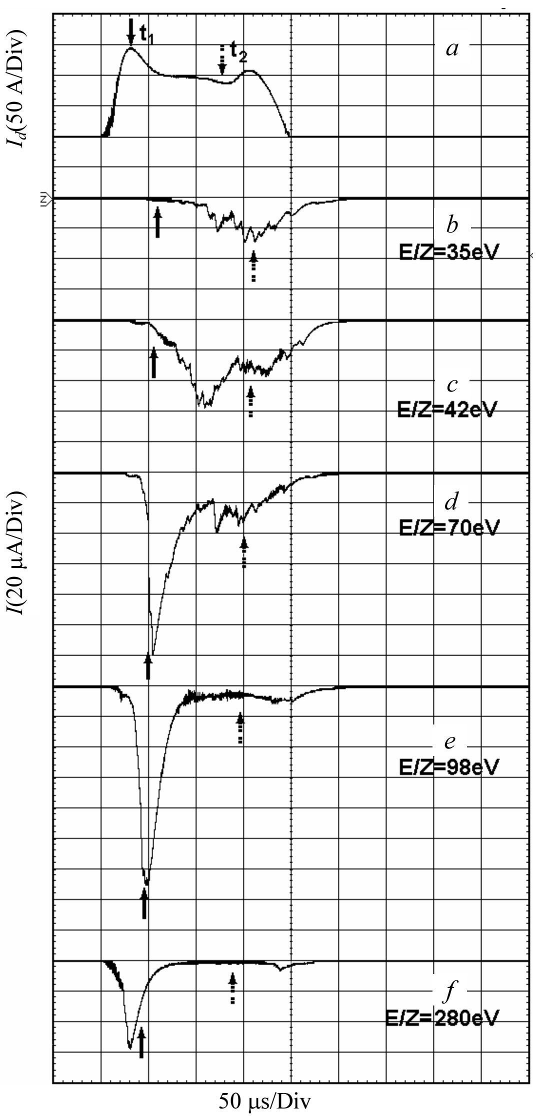

Fig. 3. Typical waveforms of the discharge current (*a*) and signals of ion analyzer for different recorded energies (*b–f*). The arrows in (*a*) point the moments at the discharge current for which the energy spectra are built up. The arrows in (*b–f*) note the calculated moments of recording of ions with corresponding energies which were produced at moments t_1 and t_2

recorded in the beginning of the pulse, like that at the probe signal.

To demonstrate changes of parameters of plasma jet through the discharge pulse, we built up the energy spectra for different moments of the discharge burning, which are noted with arrows in Fig. 3, *a*. We calculated the moment of recording of these ions for the given length of ion flight trajectory (it is, approximately, equal to *D* in Fig. 1) and each energy value. These moments for group of ions, which were produced in moments t_1 and t_2 are marked with the corresponding arrows in Fig. 3. Then to obtain a statistically justified result, we averaged the analyzer signal at these moments over 10 shots with parameters of the discharge hold. This procedure was repeated through the range of the measured energies and in this way, the energy spectra for ions produced at the noted moments were built up. Fig. 3 shows that ions with low energies are principally produced at late stage (t_2) of the discharge pulse. As the energy increases, the peak at the signal becomes more pronounced and it is shifted toward beginning of the pulse, so that ions with high energies from the tail of energy spectrum are recorded in the form of the pulse. This implies that at the moment t_2 just the ions with rather low energies are produced.

Figure 4 shows that, in fact, amplitude of spectrum of the ions produced in moment t_1 exceeds significantly that for ions that were produced in moment t_2.

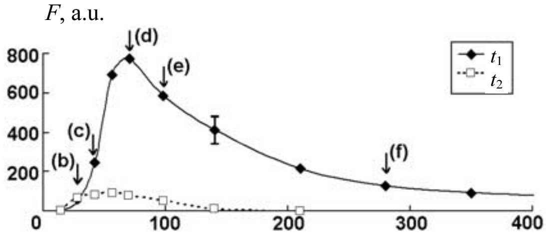

Fig. 4. Energy spectra for moments t_1 and t_2

The question arises: “When ions of different energies are principally produced?” To establish the reply, we calculated the moments, when ions with the specified energies that are produced at peak of the discharge current are recorded with the analyzer. The result is depicted in Fig. 5 and it is compared with the moments of recording of peaks of the analyzer signal. One can see that ions of low energies are, in fact, produced later than peak of the discharge current is attained; ions from the peak of the current correspond to peak of the analyzer signal; ions of high energies from the tail of spectrum are produced at front of the current pulse.

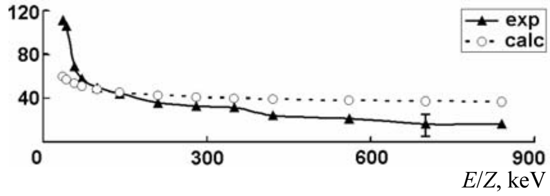

Fig. 5. Moments of recording of peaks at the analyzer signals in Fig 3 vs the specified analyzer energy and the same dependence for calculated moments of recording of ions produced at peak of the discharge current (noted as t_1 in Fig. 3, *a*). All the moments were measured from beginning of the discharge current

3. Discussion

The results presented demonstrate that there is observed a significant difference between parameters of the plasma jet at the transient stage of the discharge and these at plateau of the pulse, when parameters of the plasma jet relax to the steady-state values. Elsewhere we shall consider the latter in detail and show that these energies are close to the convenient ones adopted as the governed with the mechanisms that are valid in cathode microjets [3, 4].

References

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