METAL-VAPOR VACUUM-ARC ION SOURCE WITH AN ADDITIONAL ANODE *

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Abstract

For several years the investigations of MEVVA ion source and its modifications have been carried out in ITEP Moscow. From the highest charge state ions generation point of view, the e-MEVVA ion source (MEVVA with external electron beam and plasma source drift channel) is the most promising modification of MEVVA ion source. During experiments with e-MEVVA ion source it was found that this ion source can generate the ion beam with higher charge states than the common one when the external e-beam is off. To provide this effect, the two anode step-by-step high current discharge and axial high gradient magnetic field were used. The results of CSD (charge state distribution) measurement of uranium and lead beams generated by this ion source (MEVVA-M) with different discharge currents and different magnetic field distribution are presented.

1 INTRODUCTION

Metal Vapour Vacuum Arc (MEVVA) ion sources [1] are used to generate high current pulsed ion beams for both fundamental [2] and applied [3] research. The MEVVA is a prolific generator of highly ionized metal plasma from which metallic ions are extracted. During last years this source has investigated at the Institute for Theoretical and Experimental Physics (ITEP), Moscow with the purpose of increasing the charge states of the ions [4], [5], [6].

A generic MEVVA [4] consists of a series of electrodes (usually concentric) that are separated by ceramic insulators. The commonly used configuration is a solid electrode of the desired metal, followed by a trigger electrode, an anode, a suppressor, and an extractor system. Triggering of the vacuum arc is accomplished by applying a short high voltage pulse between the trigger electrode and the cathode across an insulating surface. Vacuum arc discharge occurs due to formation of cathode spots, which are micron-sized spots on the cathode surface characterized by extremely high current densities. In this spots the cathode material are vaporized and ionized, producing a plasma plume, from which ions are extracted. Although MEVVA plasma is characterized by a high degree of ionization, only low ion charge states are typically extracted. Depending on the cathode material used a conventional MEVVA ion beam has a mean charge state Q of about 2+.

For many applications [2,3], it is highly desirable to enhance the MEVVA ion charge states so that the ion beam energy can be increased without applying higher extraction voltage. Previous efforts demonstrated that the mean ion charge state in vacuum arc plasmas could be increased in a strong magnetic field [7,8], with high arc current [8], or by applying an additional short current ”spike” on top of the main arc current [9]. Most previous attempts to obtain higher charge states quickly reached saturation [10] at charge states only 1.5 to 2 times higher than the conventional MEVVA. For generation of high charge state ions, the E-MEVVA ions source (MEVVA with external electron beam and plasma drift channel) is the most promising modification of the MEVVA ion source and first confirming results were obtained [11]. During experiments with E-MEVVA ion source it was found that this ion source could generate the ion beam with higher charge states than the common one when the external e-beam is off.

In this report, results of CSD (charge state distribution) measurement of uranium beam generated by this ion source MEVVA-M (M for modernized) with different discharge currents and different magnetic field distribution are presented. It is shown that at 2.5 kA of discharge current copious amounts of U^{6+} and U^{7+} ions are extracted. Total ion beam extracted from this ion source is in the range of 100 –150 mA. In addition, measured CSD for lead ion beam generated by MEVVA-M is also presented.

2 EXPERIMENTAL LAYOUT AND SOURCE OPERATION

The ion source electrical layout is shown in Fig. 1. Unlike conventional MEVVA’s, this source contains a second anode. To trigger the discharge, as for usual MEVVA, a high voltage pulse is applied between the cathode and a trigger electrode separated by ceramic insulator. When the plasma plume reaches the first anode, anode-1, a discharge between the cathode and this anode is initiated. The discharge current in this circuit is 120 A with pulse length 150 µs. Then the plasma plume reaches the second anode, anode-2, and a discharge in the circuit

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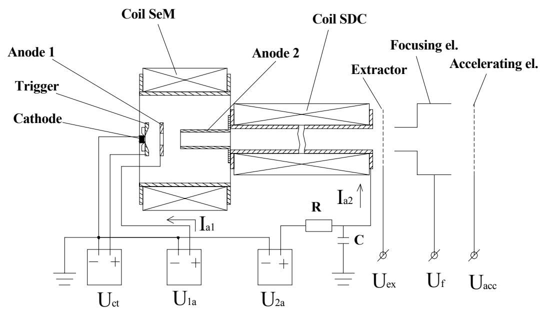

Figure 1: Electrical layout of MEVVA-M ion source.

cathode – anode-2 starts. The discharge currents in the circuit cathode – anode-2 of 54 A, 350A, 800 A and 2400 A were used during experiments. Discharge plasma drifts inside anode-2, which is a hollow cylinder with a length of 64 cm, to the grid extraction system. Past its entrance, this cylinder is effectively a drift tube like in E-MEVVA. To keep plasma near the source axis during this drift, an axial magnetic field is used. The SDC (Solenoid of Drift Channel) coil generates this axial magnetic field B_{a2}. The amplitude of this magnetic field always was 1 T. The coil SeM (Solenoid of E-MEVVA) provides the axial magnetic field in the main discharge area. It can be varied in range from 0 (when it is off) to 0.2 T.

To extract the ion beam, the grids ion optics is used. During experiments the extracting and focusing voltages were - U_{ex} = -7 kV, U_f = -3 kV with respect to the source cathode. The main accelerating voltage was U_{acc} = 54 kV.

To measure the ion beam Charge State Distribution (CSD), a magnetic analyzer was used. Bending angle and radius are 60° and 0.3 m correspondingly. To increase the resolution of the analyzer, two slits with 2 mm width were installed at the magnet input. The distance between slits was 180 mm. At the output of analyzer a current detector with slit of 3 mm was used. The resolution of analyzer is about 10^{-2} for specific mass in the measured range (12 – 90 a.m.u.).

2.1 CSD measurements for different discharge currents and magnetic fields in the anode-2 circuit

As it was mentioned above, the discharge current in circuit anode1-cathode always was 120 A. The magnetic field along the anode-2 cylinder (drift tube) also was kept the same (1 T) for all experiments. For different discharge currents in the circuit cathode – anode-2, the CSD were measured in two modes: with the coil SeM off and with the coil energized to provide a 0.2 T on its axis. For discharge currents of (or less than) 54 A, it was impossible to extract an ion beam with sufficient current for CSD measurements when SeM was off. Therefore, for this discharge current, the CSD was measured when the SeM provided 0.2 and 0.1 T at its axis.

Results obtained for different discharge current are shown in Table 1. It was found that for cases when the coil SeM is off, the ion source provides higher charge states compared with the mode when both coils are on.

Table 1: Maximum charge states of uranium beam for different operation modes.

I_{a2}	"SeM on" mode	"SeM off" mode
54 A	U^{5+}	U^{5+}
350 A	U^{5+}	U^{6+}
800 A	U^{5+}	U^{8+}

The result of the CSD measurements for SeM-off mode and discharge current of 2.5 kA in circuit cathode – anode-2 is shown in Fig. 2. Uranium ions with charge state from U^{3+} to U^{8+} can be easily identified. Moreover, the corresponding charge-exchange peaks (for ions undergoing charge reduction during their flight path in the analyzing magnet) can be identified easily.

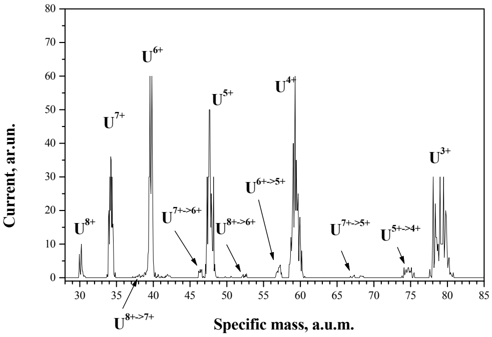

Figure 2: Uranium beam CSD for discharge current of 2.5 kA in circuit cathode – anode-2.

2.2 CSD changing during the beam pulse

One can see from Fig. 2 that the charge state distribution of uranium ions does not have a "bell" shaped form, as might be expected. It could be a result of pulse-to-pulse variation that exists in some ion sources and it is well-known to occur in MEVVA sources. However, it is shown next that the particular shape of the uranium CSD in Fig. 2 is the result of CSD changing during the discharge pulse. As it was mentioned above, the maximum current that was measured for each step of magnetic field was independent of its time during the beam pulse. Therefore, if the CSD of generated beam changes during the pulse, the maximums for different charge states occur at different times, and, as result, the CSD has the measured form. To investigate this effect, we have carried out the measurements of CSD only for uranium ion, and we averaged the data result for ten pulses per each magnetic field step. CSD measurements were performed on two equal halves (time wise) of the beam pulse. Results are shown in Fig. 3, for the first and last part of the beam pulse respectively. It is necessary to note that for either case, the CSD is bell shaped. For beginning of the pulse the maximum corresponds to U^{7+} and U^{6+} ions and for end of the pulse, the CSD looks like one measured for conventional MEVVA with high discharge current. Also it is necessary to note that if for both half are superimposed (see Fig. 3), a CSD with a

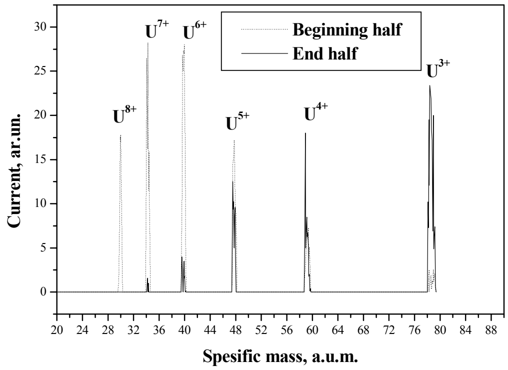

Figure 3: Uranium beam CSD for beginning and end half of beam.

local minimum at the peak of U^{5+} ions is obtain, just like it is in Fig. 2. Therefore, the observed departure of uranium CSD from bell-shaped in Fig. 2 can be explained by the time-evolution of the CSD, as charge states vary from high values at the beginning of the pulse to smaller ones in the end of beam pulse.

2.3 Lead beam CSD

The CSD measurements with lead cathode for both "SeM off" and "SeM on" mode were carried on. The both spectra were measured simultaneously – at each step of magnetic field, first the measurement with "SeM off" was taken and then the measurement with "SeM on" was taken. The result of that measurement is shown in Figure 4. One can see that the lead CSD has the same feature as the uranium one. The CSD has two maximums, which is a result of CSD changing during beam pulse. The second maximum is observed at the Pb^{4+} ions for "SeM off" mode meanwhile for "SeM on" mode the maximum corresponds to Pb^{2+} ions only.

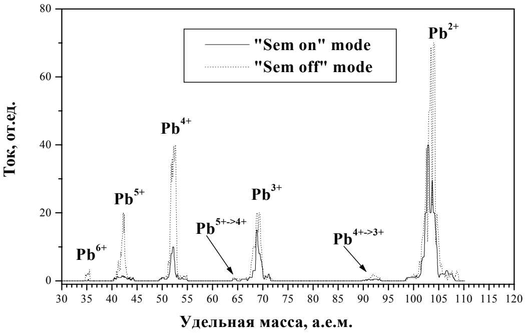

Figure 4: CSD measurements for lead cathode. "SeM off" and "SeM on" mode

3 CONCLUSION

CSD measurements of ion beams generated by the MEVVA-M ion source have shown that a two-step discharge in a region with a magnetic mirror results in an increase of both mean and highest generated charge states. For a 2.5 kA discharge current in the cathode – anode-2 circuit, uranium ion beams of 150 mA of total current with a high content of U^{6+} and U^{7+} ions are obtained. For MEVVA-M with the lead cathode under similar conditions the Pb^{4+} and Pb^{5+} ions dominate in the extracted ion beams.

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