Vacuum Arc MEVVA II Ion Source Test Stand

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Abstract – Investigations of metal ion beams extracted from vacuum arc plasmas are interesting for both basic and applied physics. For example, it is important for physic of vacuum arc discharges or for injection of metal ions into heavy ion accelerators, as well as for implantation of metal ions at surface of semiconductor or non-semiconductor materials.

A new test stand including ion source MEVVA II, ion beam line drift chamber, and ion time-of-flight spectrometer has been designed and developed. The MEVVA II source has the following parameters: the accelerating voltage is up to 20 kV, ion beam current is about 100 mA, pulse length 400 µs, and pulse repetition rate up to 5 pps. This test stand is a simple, reliable and useful experimental tool for research both vacuum arc phenomena and ion beam physics.

1. Introduction

Ion beams based on the vacuum arc discharge find wide applications for ion implantation, mainly into non-semiconductor materials [1, 2]. Surfacing of solid body by ion beams allows changing its properties, such as surface hardness, friction coefficient, wear and corrosion resistances and some others. For this reason development of ion sources – devices for production of such beams important for introduction of high technologies in industry. Necessity of efficient production supporting of such technologies dictates use of wide-aperture ion beams.

For gaseous beams generation the best method of plasma formation (environment from which wide-aperture ion beam extract) is the use of gaseous discharge [3]. For metal ion beams generation the best method is the use of vacuum arc discharge [4, 5]. On the basis of such kind of the discharge it is possible to form in microsecond pulse range ion beams by cross-section in tens sq. cm. with a pulse ion current up to 1 A and level accelerating voltage of 100 kV [6]. On the other hand, engineering of technologies and training of the experts, working in this area, demand creation of relatively simple and, thus, inexpensive ion source. Such sources will find the application both in educational process, and for fundamental physics experiments.

One of the major parameter of an ion source is mass/charge composition of the ion beam. There are various methods of its measurement. The magnetic spectrometers have good resolution and high sensitivity, however is complicate enough and has high cost. For this reason it is not always accessible to use.

Time-of-flight spectrometer has satisfactory resolution capability (more than 10), a wide range of ion mass/charge ratio measurement and rather high sensitivity. Its essential advantages are: possibility of simultaneous measurement of shares of all beam components and direct measurement of ion beam structure taken from discharge plasma. It is necessary to notice, that this method imposes certain restrictions on pressure in the spectrometer vacuum chamber as ion beam spread on atoms of tail gas and energy loss should be insignificant at beam transportation on distance of meter. However, the given restriction is not essential to sources based on the vacuum arc discharge, functioning at the lowered gas pressure.

In the present work, we report design and parameters concerning simple and inexpensive vacuum arc MEVVA II [7] ion source test stand which is an equipment system including metal ions source with power supply, time-of-flight spectrometer for measurement of mass-charge ion beam structure and the vacuum chamber with exhausting by turbo-molecular pump.

2. Ion source

The MEVVA II ion source test stand (Fig. 1) consists of ion source itself and time-of-flight mass/charge spectrometer.

The ion source includes the cathode *1* and the anode *3*, and system of ion beam formation *5*. For increase of plasma stream *4* reached area of ion beam extraction the magnetic coil *2* in serial connection with the vacuum arc discharge circuit is used.

Working principle of an ion source is the following. The vacuum arc discharge is triggered by flashover via dielectric (ceramic) surface when a short high voltage trigger pulse is applied between the cathode *1* and trigger electrode surrounding it on a ceramic face dividing these electrodes. The vacuum arc discharge between the cathode *1* and the anode *2* has current of 100 A and duration of 400 µs. Metal plasmas of the vacuum arc is produced by cathode spots and ions of a cathode material.

Vacuum arc plasma *4* expands from the cathode *1* to the anode *3* and thus emission surface at the anode bottom is forming. Ions are extracted by accelerating voltage of 20. The multi-grid accelerating system *5* is used. It is obvious, that use of ion special design of ion optical system provides the best characteristics

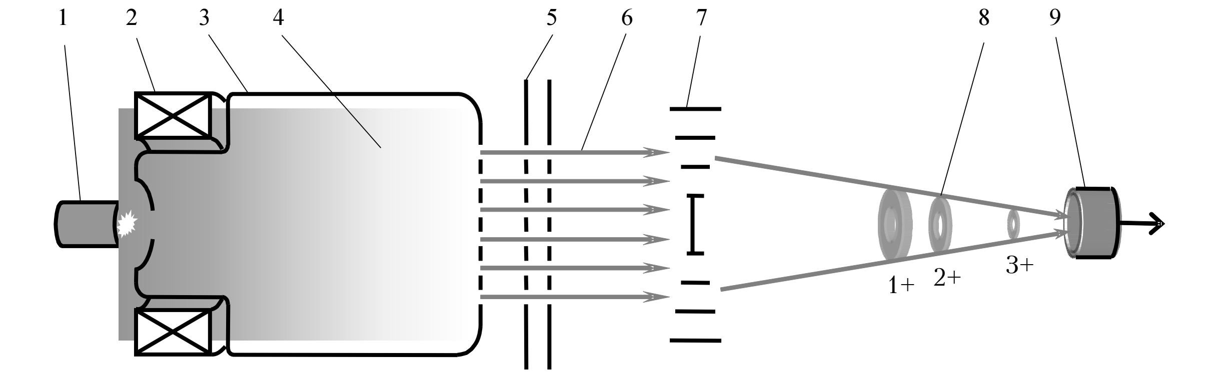

Fig. 1. The electrode scheme of experimental assembly. Ion source: *1* – the cathode; *2* – the magnet coil; *3* – the anode; *4* – a plasma stream of a vacuum arc; *5* – an accelerating electrode; *6* – an ion beam. Time of flight spectrometer: *7* – gate; *8* – ion beam composition; *9* – Faraday cup

of an ion beam concerning its divergence and a minor current of the return electron caused secondary ion-impact emission from the first accelerating grid. However, rather low accelerating voltage used in the device allows using multi-grid system which is simpler in manufacturing and operation.

Ion beam 6 consists of cathode materials ions with different charge states can be used, for example, for ion implantation. The ion beam mass/charge composition is analyzed by time-of-flight spectrometer. The basic parts of a spectrometer are gate *7*, Faraday cup *9* and drift tube (distance between electrodes *7* and *9* which makes time-of-flight spectrometer ion flying base). In more details, the spectrometer design is described in following section.

3. Time-of-flight spectrometer

For measurement of the ion beam, mass/charge composition the vacuum arc ion source a time-of-flight method was introduced. The scheme of experimental assembly is presented in Fig. 2. Time-of-flight spectrometer consists of a gate *6*, placed on axes of an ion beam, and Faraday cup *8* with magnetic suppression of secondary electrons. This method is based on time separation for different ion beam mass/charge fractions after passing gate, which provides minor deflection of ion beam toward accepted hole of the Faraday cup. The length of beam drift line (between electrodes *6* and *8* on Fig. 2) was 1.03 m that provides sufficient time separation from various mass/charge components of the ion beam. The vacuum chamber 7 is pumped out by the turbo-molecular pump to re-sidual pressure as low as $5 \cdot 10^{-6}$ Torr.

The beam-deflection system of the gate consists of several couple of metal rings. A short (100 ns) high voltage (5 kV) pulse is applied between each couple of rings to deflect ions. Central metal disk prevents entry of ions to the Faraday cup in the absence of deflecting voltage. The disk serves also as the emitter of secondary electrons appeared from ion beam bombardment. These electrons are necessary for ion beam charge compensation. Presence of secondary electrons results not only in beam compensation in the area between an ion source and beam-deflection system, but also in the drift tube. That is expressed in increase in the peak current and reduction of the minimum ion beam energy at which measurements are still possible.

Proceeding from known proportion for kinetic energy and for the energy picked up in the acceleration gap, it is possible to receive the equation connecting frequency of ion charge rate z with time delay t between the deflecting pulse and a maximum of the current peak of Faraday cup:

$$(z/A) = 5.34 \cdot 10^{-9}/(U_{acc}\, t^{2}), \qquad (1)$$

where A is ion mass; U_{acc} is accelerating voltage, V.

Transverse and longitudinal ions speed ratio leaving the deflecting gap of time-of-flight spectrometer, can be written down as

$$(v_{+}/v_{=}) = (U_{defl}/2U_{acc})\,(l/d), \qquad (2)$$

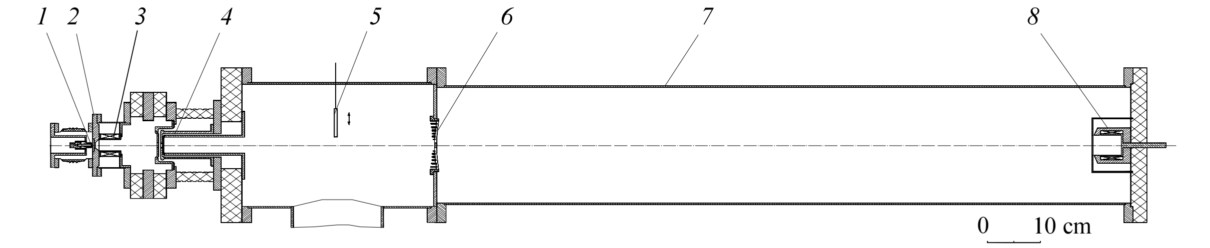

Fig. 2. Assembly design: *1* – vacuum arc cathode; *2* – the anode; *3* – magnet coil; *4* – accelerating system; *5* – beam monitor; *6* – gate; *7* – drift tube; *8* – Faraday cup

where U_{defl} is deflecting pulse amplitude; U_{acc} is accelerating voltage; l is rings width forming deflecting gap; d is distance between rings. From (2) follows, that the ions divergence angle from a deflecting gap does not depend on ion charge and mass, so ions from different cross section of beam are turned on nearly the same angle. Composition of ion beam is estimated by analysis of ratios between Faraday cup current peaks for each ion mass/charge fraction.

The beam-deflection system is made according to (2), width of the rings forming deflecting gap, and dwell time of deflecting electric field increase in process of increase rings radius for supporting of ion beam deflection periphery on bigger angle.

Besides, the centre of external ring gaps is displaced relating to the centre of internal in a direction to Faraday cup so that the length of ions trajectory between beam-deflection system and Faraday cup was identical to each of three gaps.

The typical current oscillogram in Faraday cup circuit (Fig. 3) allows distinguishing components of ion beam. Using expression (1), it is easy to recognize mass/charge ion fraction correlated to each measured peak.

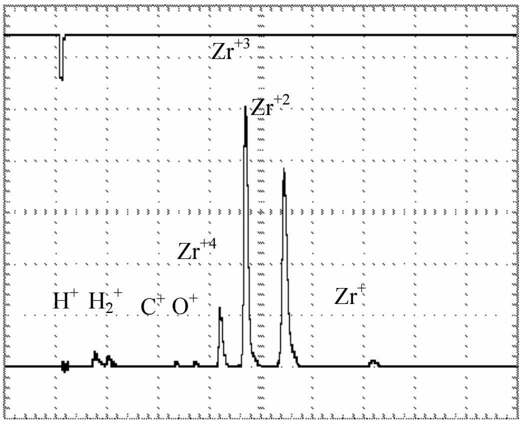

Fig. 3. Current oscillogram of Faraday cup time-of-flight spectrometer (down), deflecting pulse (up). 1 μs/dev. Vacuum arc current – 200 A. Cathode – zirconium

4. Conclusion

View of the MEVVA II ion source test stand is show in Fig. 4. Parameters of an ion source are the following:

– accelerating voltage is up to 20 kV;
– ion beam current during 400 μs pulse is 100 mA;
– pulse repetition rate is up to 5 pps.

This test stand is a simple, reliable and useful experimental tool for research both vacuum arc phenomena and ion beam physics.

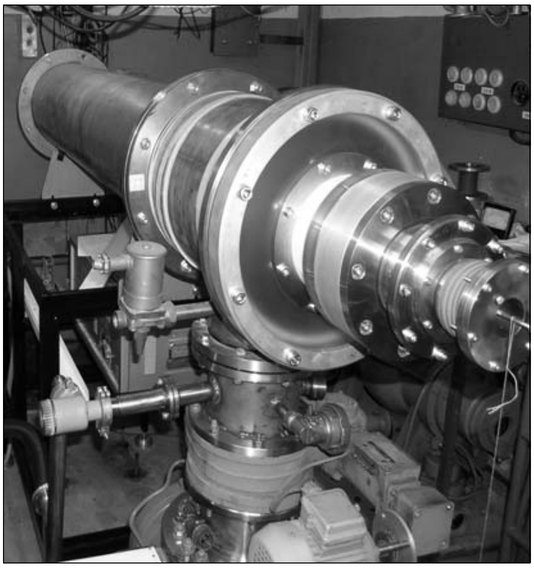

Fig. 4. View of the MEVVA II ion source test stand

References

[1] *Conferences on Modification of Materials with Particle Beams and Plasma Flow*, Tomsk, Russia, 2000; 2002; 2004; 2006.
[2] Yu.A. Bykovskiy, V.N. Nevolin, and V.Yu. Fominskiy, *Ion and laser implantation of metal materials*, Moscow, Energoatomizdat, 1991.
[3] *Handbook of ion sources* / Ed. by B.H. Wolf. Boca Raton, FL, CRS Press, 1995.
[4] *The physics and technology of ion sources* / Ed. by I.G. Brown. N.Y., John Wiley, 1989.
[5] G.A. Mesyats, *Ectons in vacuum discharge: breakdown, the spark, and the arc*, Moscow, Nauka, 2000, 424 pp.
[6] I.G. Brown and E.M. Oks, IEEE Trans. on Plasma Sci. **25**, No. 6, 1222–1228 (1997).
[7] E.M. Oks, Rev. Sci. Instrum. **69**, No. 2, 776–781 (1998).