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Development of a miniature time-of-flight mass/charge spectrometer for ion beam source analyzing

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A B S T R A C T

To diagnose the vacuum arc discharge process, a miniature time-of-flight mass spectrometer (TOF MS) with compact structure was developed for cathodic vacuum arc discharge ion source. An orthogonal acceleration region and an angle reflector were employed for the miniature TOF MS instrument. Especially, a small extraction hole in the acceleration region was set for getting relative high mass resolution, an ion detector with a large rectangular effective area were designed for getting wide ion kinetic energy distribution measurement capability. The compact size of the TOF MS is 413 mm × 250 mm × 414 mm, the mass resolution is 600 (FWHM) and the detection range of ion kinetic energy is two orders of magnitude. A copper cathodic vacuum arc discharge ion source was tested and the charge states of Cu ions from 1+ to 3+ were detected. The miniature TOF MS was successfully developed with relative high mass resolution and wide ion kinetic energy distribution measurement capability which could be used to diagnose the cathodic vacuum arc discharge plasma.

1. Introduction

The cathodic vacuum arc discharge ion sources are capable of generating ion beams of almost all the metal elements of the periodic table [1,2], and it makes this kind of ion source an excellent experimental tool for studying implantation of different ions and thin film preparation by producing high density ion beams [3–5]. It is well known that the cathodic vacuum arc plasmas contain multiple ion charge states and the velocities of ions in the plasmas are supersonic with respect to the ion sound velocities, of order 10^4 m/s [6,7,1]. An important issue in this case is the uniformity of plasma density at the emission surface, where ion beam is formed. There are numerous studies of ion kinetic energies of vacuum arc plasmas because these energies are surprisingly high (up to 200 eV) and of great technological relevance for the synthesis of dense coatings [6,8–10,1,11].

In the last decade, magnetic spectrometry [12] was used for measuring the mass-to-charge (m/z) composition of such ion beams usually. This method has high resolution and reasonable sensitivity, which is based on the deflection of ions in a transverse magnetic field. In this analytical approach, the beam is not sampled but is continuously analyzed. And it is expensive, consuming significant energy, rather elaborate, and the beam cannot be used for its primary purpose while the analysis is taking place [13]. While for many situations these constraints are acceptable and magnetic m/z analysis is the preferred approach, for other situations an alternative method may be more suitable [12,13]. Time-of-flight mass spectrometry (TOF MS), with a reasonably high resolving power and a rather high sensitivity, was introduced to directly determine the charge state of plasma and charge-resolved ion velocities [1,14–17]. The usual way to obtain the ion charge state distribution of the cathodic vacuum arc plasmas is measuring the time-resolved data after arc triggering with a TOF MS. These investigations are of great interest to make a better understanding of the fundamental processes occurring in the cathode spots. Furthermore it could be concluded that the researches are focused on the study of the metal cathodic vacuum arc plasmas by using TOF MS.

In this paper, we present a home-made miniature TOF MS used in the application of diagnostic of a copper cathodic vacuum arc

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plasma, getting clear spectrums of ion beams. Performances of the miniature TOF MS, such as mass resolution and detection range of ion kinetic energy are also represented.

2. Instrumentation

The schematic diagram of the TOF MS with vacuum arc ion source is shown in Fig. 1. The entire instrument measures 413 mm × 250 mm × 414 mm, weights about 25 kg which makes it easily moveable. The TOF MS mainly consists of vacuum system, an orthogonal acceleration TOF analyzer, data acquisition system, and power supply system. The design of the TOF MS took a full consideration of the characteristics of this kind of ion source, such as dense ion beam density, wildly distribution of kinetic ion energies and so on. Unlike previous TOF MS developed by our team [18–22], a small extraction hole was set in the orthogonal acceleration region, and an ion detector with a large rectangular effective area was set for the TOF MS, cooperating with dual anodes.

The TOF MS combined with the vacuum arc ion source by an annular flange. The dense ions in the plasma are generated from the cathode initially, expand through the anode, across the free expansion region and then arrive in the acceleration region of TOF analyzer. Here, they are distinguished by the flight time, and the ion signals of different ions are recorded by an oscilloscope. The vacuum arc is powered by a LC line which provides an arc current of up to about 200 A. To measure the time-resolved charge state distribution and other characteristic of ions, a pulse generator (MODEL DG535) with two output channels is used to trigger the ion source (trigger 1) and the TOF MS (trigger 2) separately, as shown in Fig. 1. The trigger time interval between two output channels can be adjusted from 0.5 μs to 30 μs with increment about 0.5 μs or 1 μs. The method for measuring ion beam is based on the micro-channel plate (MCP) signal response of the ions extracted from the plasmas on the arc current pulse, which is shown in Fig. 2.

2.1. Vacuum system

The whole instrument must work in vacuum condition. As shown in Fig. 1, the vacuum system mainly consist several pumps and valves. The TOF MS chamber is pumped by a turbo-molecular pump with pumping speed 260 L/s (HiPace300, Pfeiffer, Germany) and a diaphragm pump with pumping speed 4.3 m^3/h (MD 4 NT, VACUUBRAND, Germany) as backing pump, to achieve the pressure of 1×10^{-4} Pa, measured by a cold cathode gauge (IKR 270, Pfeiffer, Germany). The whole vacuum system is powered by 24 V DC power source and controlled by the electrical system.

A gate valve (valve 1 in Fig. 1), two angle valves (valves 2 and 3 in Fig. 1) and a vent valve are used for the vacuum system. Due to this structure, it can realize to replace metal samples within minutes by controlling state of the valves without shutting down the vacuum system.

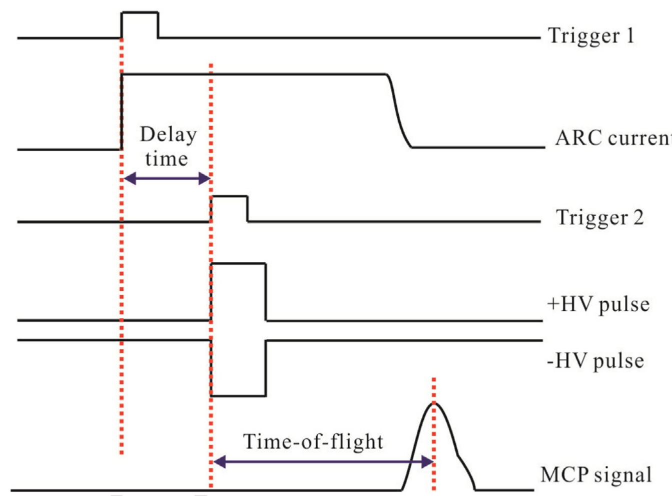

Fig. 2. Example of the oscillograms of pulses.

2.2. Interface for ion source

The copper cathodic vacuum arc ion source was used for combining with the miniature TOF MS. The vacuum arc plasma was produced at nonstationary cathode spots—micro-size, nonstationary locations of very high current density and plasma density. So a collimating aperture structure (two stainless steel sheet with 2 mm center holes were set along the ion diffusion direction) is set in order to reduce the amount of ions and ensure that the parallel ion beams with low initial spatial distribution go into the orthogonal acceleration region. In this case the resolution of the miniature TOF MS can be improved.

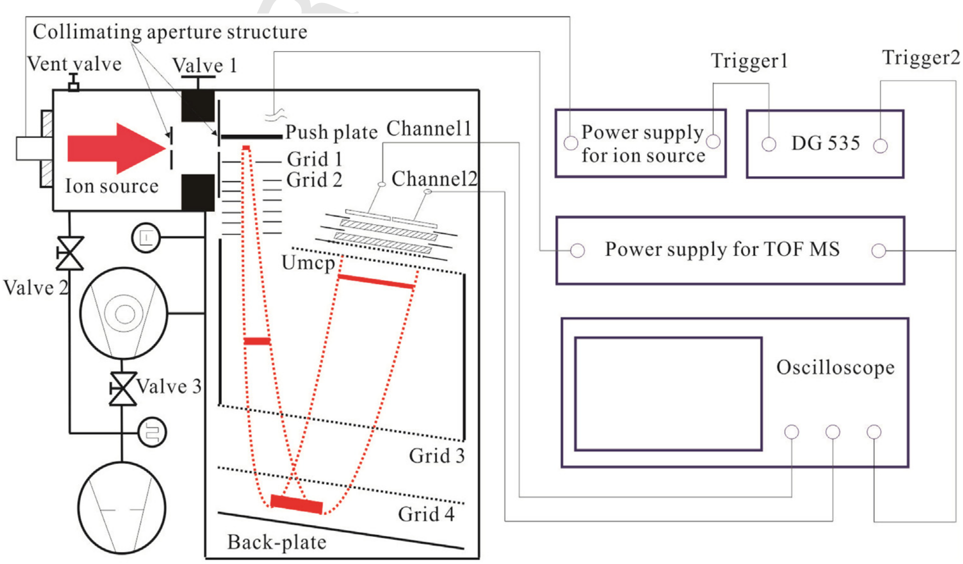

Fig. 1. Schematic of the instrument.