A radial position-sensitive 127.3° electrostatic coaxial cylindrical spectrometer for sputtering ion measurements

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Abstract

A 127° electrostatic coaxial cylindrical energy spectrometer with a radial position sensitive MCP detector is designed and constructed. Beyond the traditional step-by-step voltage scanning method, this spectrometer is able to measure a segment of energy spectra at a working voltage. Therefore, the experiment efficiency is notably enhanced and it is suitable for measuring the energy spectra of sputtering ions. The first test was done by measuring an energy spectrum of the sputtering ions in 800keV Ar8+ bombarding on beryllium target.

Keyword: electrostatic coaxial cylinder spectrometer, radial position sensitive, sputtering ions energy spectrum

1. Introduction

Since 1929, Hughes and Rojansky pointed out that by electrostatic means could analyze electronic velocities almost as well as by magnetic ones [1], various electrostatic spectrometers, such as the 180° spherical capacitor, the parallel plate mirror, the concentric cylindrical mirror, and especially the 127.3° coaxial cylindrical energy spectrometer have been developed and widely studied [2-9]. In recent years, the study of potential energy dissipation in highly charged ion (HCl) with surface collisions was received great attention, and the main interests were focused on the sputtering yield, the energy spectrum of x-rays and electrons, and secondary-ion emission [10, 11]. However, although few scattering and recoiling spectra were studied by time-of-flight method with pulsed beam technique [12-14] and by the 127.3° electrostatic coaxial cylindrical spectrometer [9], and a few energy distribution of sputtered atoms [11] were investigated, the energy spectrum of sputtering ion in energetic HCl-surface collisions, as far as we know, has not been reported. Due to the small solid angle to collimate the sputtering ions, the measurement efficiency will be too low if one scanning the voltage step-by-step to obtain a full energy spectrum of sputtering ions. In this paper, we describe a cylindrical energy spectrometer which can measure a energy spectra at one working voltage point. It was tested by measuring a segment of energy spectrum of the sputtering ions induced by 800keV Ar8+ bombard on a beryllium target.

Fig.1 Trajectories of ions entering the entrance split. The deflection angle between 0° and 127.3° is shown.

2. Design of the spectrometer

It is well known that monoenergetic ions starting off from a same point (the source point) but with different incidence angles will be first-order focused on the image point at 127.3° (π/√2) with the same radius if the working voltage is fit [1, 7]. In present work, the ion trajectories in a coaxial cylindrical electrostatic field of different energies, different source positions (due to the finite size of the skimmer) and different incidence angles were calculated, as shown in Fig.1. Close attention was paid to the...
focus characteristic of beam though a finite size skimmer. Our numerical calculation shows that, 1) ions with different energy over charge ratio \((E/q)\) will be focused again at 127.3°, but on image points at different radials; 2) considering a monoenergetic beam of energy \(E\) though an entrance slit with a size \(\Delta x\) on the radius, if the center trajectory energy is \(E_c\), its image size \(\Delta x'\) at 127.3° is \(\Delta x' = (E/E_c)\Delta x\). Therefore, it offers us an opportunity to obtain a segment of energy spectrum with one working voltage, if a position-sensitive detector (e.g., an MCP detector) is placed on the radial plane at 127.3°. In addition, the energy resolution is mainly restricted by the size of the entrance aperture and by the position resolution of the detector.

\[
E_c/E_e = [1 + 0.0159(r - r_c) - 4.17 \times 10^{-5}(r - r_c)^2] \quad (3)
\]

Here, \(r\) and \(r_c\) are in the unit of mm. According to above equation, if the size of the entrance aperture is \(\Phi 0.5\) mm and the position resolution of the detector is 0.5 mm, the energy resolution of the present design is about 1.2%.

![Fig.2. The schematic view of the 127° electrostatic coaxial cylindrical energy spectrometer. In present case, the radius of the inner electrode is 50 mm, and the radius of the outer electrode is 76 mm.](image)

According to the above calculation, an energy spectrometer was designed by combining a 127.3° cylindrical electrostatic analyzer and an MCP detector. The schematic view is illustrated in Fig.2. The inner cylindrical electrode radius is \(r_i = 50\) mm, and the outer cylindrical electrode radius is \(r_o = 76\) mm. Therefore, the center trajectory has a radius of \(r_c = 63\) mm. The electrodes are made of stainless steel, and both have heights of 60 mm and thicknesses of 3 mm. If the working voltage between the two electrodes is \(\Delta U\), it is well known that the center trajectory energy \(E_c\) over the charge state \(q\) is:

\[
E_c/q = \Delta U/r_c \ln(r_i/r_o) \quad (1)
\]

In present design, it is reduced to:

\[
E_c (eV) = 1.194 q \Delta U (V) \quad (2)
\]

Furthermore, according to our numerical calculation, the energy \(E_r\) over the charge state \(q\) of the ions which hit the detector at radius \(r\) satisfy:

\[
Fig. 3 Skimmer tube, it has a length of 115 mm, and an inside diameter of \(\Phi 3\) mm; skimmer A and skimmer B are dismountable. The aperture can be changed with \(\Phi 0.2\) mm, \(\Phi 0.5\) mm, \(\Phi 1\) mm or \(\Phi 3\) mm.

A grounded skimmer tube was employed to collimate and to guide the ions into the electrostatic field, shown in Fig.3. The inner diameter and the length are \(\Phi 3\) mm and 115 mm, respectively. At both ends of the tube there are two changeable skimmers, which aperture can be changed with \(\Phi 0.2\) mm, \(\Phi 0.5\) mm, \(\Phi 1\) mm and \(\Phi 3\) mm, respectively. As mentioned before, the energy resolution of the spectrometer is mainly restricted by the size of the entrance aperture, not by the incidence angle, the skimmer near to the target (Skimmer A) is usually bigger than the one which is located inside the electrostatic field (Skimmer B) for higher count rates.

![Fig.3](image)

![Fig.4. The detector is composed of a couple of disk MCPs in \(\Phi 3\) mm>0.5 mm and the detector anode. A double-deck electrostatic field was constructed to post-accelerate the ions and to repel the secondary electrons from the MCP surface.](image)

To minimize the field distortion induced by the grounded skimmer tube, the inner and the outer electrodes were biased with inverse polarities, i.e., to ensure the center trajectory is on the ground potential:

\[
U_i = -\frac{\ln(r_i/r_o)}{\ln(r_i/r_o)} \Delta U \approx -0.552 \Delta U \quad (4)
\]

\[
U_o = \frac{\ln(r_o/r_i)}{\ln(r_o/r_i)} \Delta U \approx 0.448 \Delta U \quad (5)
\]

All the materials of the spectrometer are nonmagnetic to avoid unexpected deflection. The whole spectrometer is covered
by a grounded shield which made of stainless steel to restrain the background.

![Diagram of Detector Anode](image)

Fig. 5 Schematic View of Detector anode, made up of 80 gilt copper fingers (0.18mm×8mm), and the distance between two adjoining ones is 0.12mm.

An MCP detector is placed at 127.3° and employed to distinguish the radius position. It is mainly composed of two parts: a couple of disk MCPs in φ33mm×0.5mm and the detector anode, as shown in Fig. 4. To post-accelerate the ions and to repel the secondary electrons from the MCP surface, a double-deck electrostatic field was constructed by using Net I and II, with a square windows of 26mm×8mm, mounted above the front of the MCP. Gilt tungsten filaments of Φ25μm are crossed the windows of Net I and Net II spaced every 1 mm. Three gilt copper rings I, II and III, with the thicknesses of 50μm, 200μm and 200μm, respectively, are used as the electrodes of MCPs. To increase the detecting efficiency, the Net I and electrode I are biased to -3000V to post-accelerate the ions, while the Net II (inserted between Net I and electrode I) and electrode I are biased to 400V to build a reverse electric field to repel the secondary electrons. The detector anode is made up of 80 separated gilt copper fingers, with the width and length of 0.18mm and 8mm for each finger, and the distance between two neighbor fingers is 0.12mm, as shown in Fig. 5. Between every neighbor fingers a 10kΩ resistor was inserted, and two additional 150kΩ resistors were connected to both marginal fingers, respectively, to distinguish the signals originated from marginal sticks and others. Therefore, the total resistance of detector anode is 1090kΩ. The circuit elements were integrated on the backside of detector anode to restrain interference.

The position signals output from both ends of the anode. A pair of ORTEC model 142A preamplifiers and two ORTEC model 572 amplifiers were used to amplify and shape the signals, and then were picked up by using the classical charge-division method. An ORTEC model 533 dual sum and invert amplifier and an ORTEC model 464 divider were used. The acquisition system was consists of a WIENER CAMAC crate controller CC32 and a PHILLIPS 7164 CAMAC ADC.

3. Test Experiment

The energy spectrum of the sputtering ions induced by a 170nA 800keV Ar⁺ beam bombard on a beryllium target was obtained. In order to make the angles between the ion beam and the target surface (θ), the angles between the sputtering ion and the target surface (β) adjustable, both the spectrometer and the target were set on a table in the vacuum chamber. In present work, θ = β = 45° was arranged. The aperture of skimmer A and B are φA = 1mm and φB = 0.5mm, respectively. In the first test, a lengthways grid was prefixed in front of the detector, for ensuring the absolute positions of the ions hitting on detector. The lengthways grid is in 0.1mm thickness. The slits were 0.2mm width and with a period of 2mm. As shown in Fig. 6, the spectrum was combined by 7 segments, while the working voltage ΔU = 81V, 110V, 150V, 200V, 270V, 370V and 500V, respectively.

![Energy Spectrum Graph](image)

Fig. 6. The energy spectrum of the sputtering ions induced by a 170nA 800keV Ar⁺ beam bombard on a beryllium target. It was combined by 7 segments, while the working voltage ΔU = 81V, 110V, 150V, 200V, 270V, 370V and 500V, respectively.

4. Summaries and Conclusions

A radial position resolving 127° electrostatic coaxial cylindrical energy spectrometer as well as an additional compact MCP detector is described. Numerical calculation shows that the energy resolution is mainly restricted by the size of the entrance aperture but not the incidence angle. To minimize the field distortion induced by the grounded skimmer tube, the inner and the outer electrodes were biased with inverse polarities and specific ratio. In contrast with the traditional step-by-step voltage scanning measurement, it is able to obtain a segment of energy spectrum region between 0.85E₀ and 1.15E₀ (E₀ represents the center trajectory energy) at one working voltage, which notably improved the measurement efficiency. In principle, by changing a few voltage points, the full range energy spectra can be obtained. The spectrometer was tested by measuring a segment of energy spectrum of the sputtering ions induced by a 170nA 800keV Ar⁺ beam bombard on a beryllium target at the working voltage ΔU = 110V. It is feasible to measure continuous energy spectra of low energy sputtering ions.

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