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Angular resolved energy distributions of low energy light ions reflected from a polycrystalline Mo surface

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Abstract

We have developed an experimental system to study systematically the interaction of low energy beams with materials. The angular distributions and energy spectra of positive and negative ions reflected from a polycrystalline Mo surface bombarded by a beam of low energy (1–3 keV) ions and neutrals of H, H_2, H_3, He, and O have been measured with this system. The experimental results show that the charge state of outgoing particles yields a pronounced difference in the reflection coefficient and some weaker effect upon the energy distribution. The reflected beams usually showed maximum intensities at around the angle of mirror reflection of the incident beams. A carbon coated Mo sample prepared in a separate plasma chamber was also tested.

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1. Introduction

High-*Z* metals such as Mo and W are being considered as candidate materials for use of divertors and/or limiters in magnetically confined fusion devices. The divertor has two important roles as it evacuate alpha ash produced during fusion together with other impurity ions, and it controls hydrogen recycling. Precise data on particle reflections at the surfaces facing the plasma are necessary to understand the heat deposition mechanism due to plasma irradiation and the edge plasma cooling associated with the hydrogen recycling. In practice the particles in plasma such as positive, negative and neutral hydrogen atoms and molecules interact with material surface. The properties of high-*Z* materials have been studied under plasma and beam irradiation, but there is not enough systematic experimental data (especially for polycrystalline materials) to simulate accurately the phenomena in the plasma boundary, and therefore to design a divertor system for the future fusion device. Recently, we have developed an experimental system to study fundamental processes of surface negative ion production for negative ion beam based plasma diagnostic system [1–3]. The angular resolved energy distributions of reflected ions from a target sample can be measured

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with the system, and the results for a polycrystalline Mo surface bombarded by low energy (1–3 keV) ions and neutrals of H, H_2, H_3, He, and O are reported in this paper.

2. Experimental setup

Fig. 1 shows a schematic diagram of the experimental setup with the definition of the incident and reflection angles [3]. The ion source produces not only positive ions but also negative ions by adding removable filter magnets in the extraction region. A manipulator can rotate the target angle from 0° to 360°, while a water-cooled 90°, bending magnet used as a momentum analyzer is installed on a rotational table. Thus we can change the target and analyzer angles independently, avoiding any contamination in the incident beam from particles of different mass. This is the major difference and advantage of the present system when compared with past apparata. In this system we can also measure both reflected positive and negative ions together with the emitted electrons by changing the polarity of the analyzer magnet current during a single scan. The energy of the reflected particles is identified from the value of current applied to the bending magnet, since it has been carefully calibrated by injecting weak intensity positive and negative ion beams directly from the ion source to the analyzer. The analyzer energy resolution is theoretically estimated to be about $E/\delta E = 45$ in a few keV energy range, where E and δE are the energy and energy spread, respectively. The accuracies of the incident and reflection angles are about ±3° and ±2°, respectively. The analyzer chamber is evacuated to better than 2×10^{-6} Pa. The target can be moved to a chamber separated from the analyzer chamber, where we have a small ion source to clean the target surface. A polycrystalline Mo target is bombarded by He or Ar ion beam to clean the surface before measurements. We also prepared, in a separate system, a target of carbon deposited on Mo surface by a glow discharge of Ar plasma for 2 h. The incident beam intensity is from a few to a few tens nA. We repeat the scan of the magnetic analyzer several times and the data are averaged.

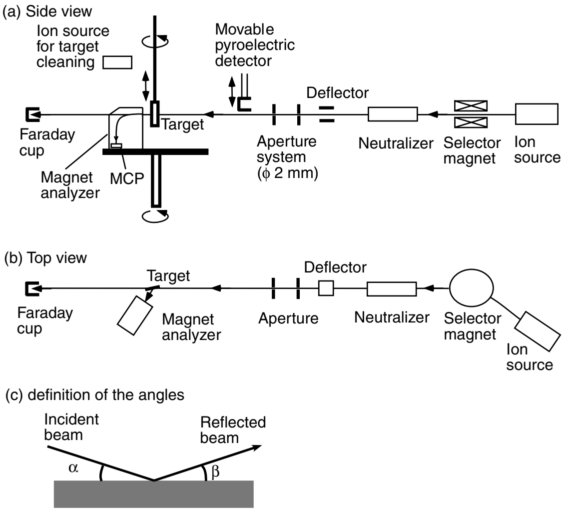


Fig. 1. Schematic diagram of the experimental setup with the definition of incident and reflection angles.

3. Results and discussion

In the following, intensities of the reflected particle beams are normalized by the target current. To avoid the change in the trajectory reaching the analyzer, we do not apply any potential to suppress the secondary electrons from the target. Therefore we cannot directly compare the intensities of the reflected particles between the different charge states of the incident beams. But actual incident beam intensity will be able to be measured by a pyroelectric detector just before the target in the future. During the measurements the beam current onto the target was kept constant.

Fig. 2 shows examples of the energy and angular resolved intensity profiles of H^+ and H^- ions reflected from a Mo surface at the incident angle of 20° for H^+ and H^- beam injection with the contour intensity plots. We see a pronounced difference in the reflection coefficient depending upon the charge states of the outgoing particles; the intensity of the reflected positive ions is usually higher than that of the negative ions in the case of hydrogen and oxygen beam injections in this energy range. Meanwhile those intensities are in the same order of magnitude for both positive and negative hydrogen ions. Thus the negative ion fraction near the plasma first wall boundary cannot be neglected. The energy distribution of the reflected particles shows some difference depending upon the charge states. Energies at which the energy distributions are maxima usually larger for hydrogen positive ions than for negative ions. Similar results had been reported by Verbeek and others [4–6]. These phenomena cannot be explained when we consider only one elastic scattering from the Mo surface [7] because in a single binary collision the elastically scattered particle energy is only slightly difference from the incident beam energy in our experimental conditions. The elastic scattering from light atoms such as H, H_2, H_3, He and C adsorbed on the Mo surface also does not explain this effect, because the reflected energy should exhibit a strong dependence upon reflection angle, while the experimental results show a weak dependence upon the reflection angle.

At larger incident angles the spread of the angular distribution of reflected beam becomes larger. The

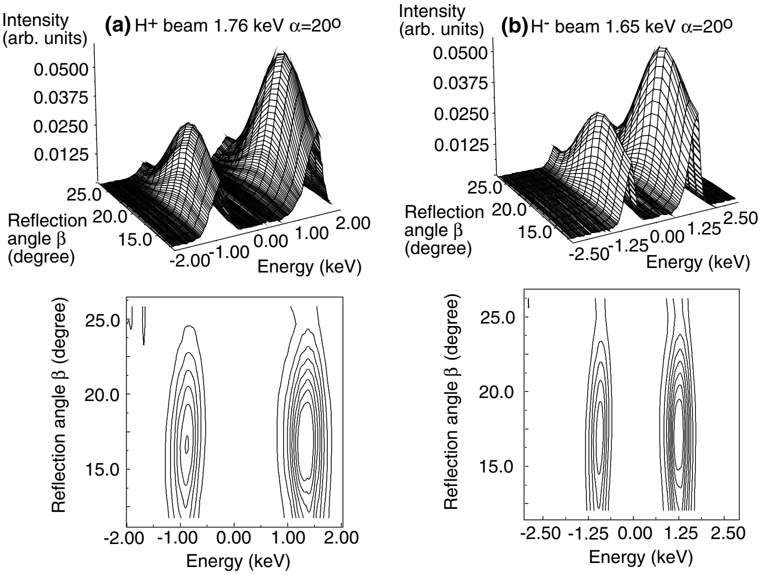


Fig. 2. Examples of energy and angular resolved intensity profiles of H^+ and H^- ions reflected from Mo surface at the incident angle of 20° for (a) H^+ and (b) H^- beam injection with the contour intensity plots.

reflectivity in the case of negative ion injection is higher than that of positive ion injection. The peak energy of the reflected beam increases gradually as the reflection angle increased. A similar behavior for the shift in the peak energy is observed for all reflected beams. Regardless of the charge polarity, reflected beams usually show maximum intensities at around the angle of mirror reflection of the incident beams. This can be seen in Fig. 3, where the horizontal axis corresponds to the intensity multiplied by $\cos\beta$. In Fig. 3, the change in the reflection angle is observed from higher value than the expected mirror angle at $\alpha = 10°$ to lower value at $\alpha = 20°$ and 30°. But they are almost within the accuracy of the incident angle of ±3°.

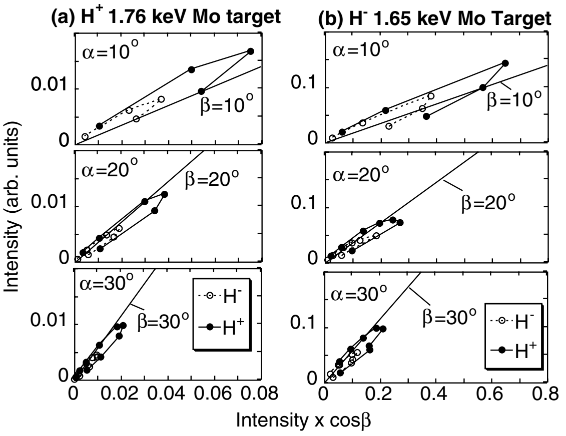
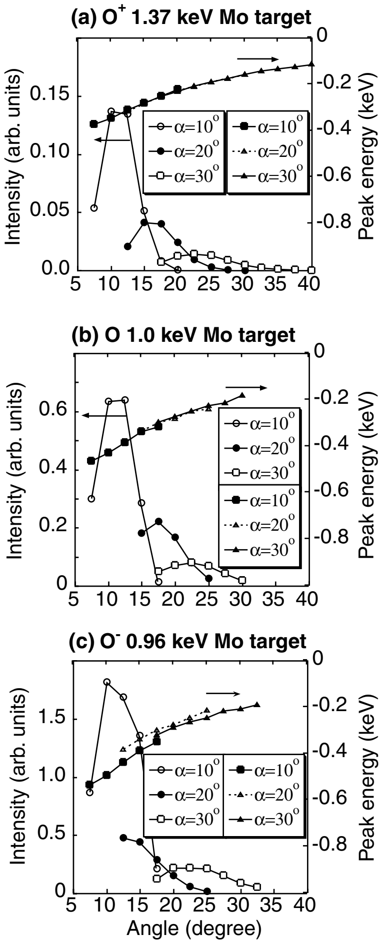


Fig. 3. Angular distribution of the intensity of reflected H^+ and H^- ions for (a) H^+ beam of 1.76keV and (b) H^- beam of 1.65keV.

In the case of molecular neutral and ion beam injection, such as H_2 and H_3, only atomic positive and negative ions are reflected and there are no molecular ions in the reflected particles. For molecular ion beams of hydrogen, the angular- and energy-distribution are the same with those of proton beam of the same velocity. Similar results were shown in the past experiments [9]. The reflectivity of molecular hydrogen ions is smaller than that of atomic ions. But it is noted that molecular hydrogen ions can survive at lower incident energies [9].

Oxygen negative ions dominate the particle emission from Mo surface and there are almost no positive oxygen ions. This result coincides with a large electron affinity (1.46eV) of oxygen. When hydrogen beams were injected, they were reflected with both positive and negative charge states from the surface. Fig. 4 shows the dependences of reflected negative oxygen ion intensity and peak energy position upon the incident beam angle. Similar results were obtained in hydrogen ion reflection from carbon [10]. As the incident angle increases, the reflected beam intensity decreases more rapidly than in the cases of hydrogen or helium beam injection. In the case of oxygen beam injection, we confirm the reproducibility after the long-term beam injection to check the effect of oxidation.

Effects due to co-deposition were also studied with the present experimental setup [3]. When a carbon coated Mo sample prepared in a separate plasma chamber was tested, the yield ratio of positive ions to negative


(a) O^+ 1.37 keV Mo target

(b) O 1.0 keV Mo target

(c) O^- 0.96 keV Mo target

Fig. 4. Reflection angle and energy dependence of O^- ions at given incident angle for (a) O^+ beam of 1.37 keV, (b) neutral O° beam of 1.0 keV and O^- beam of 0.96 keV.

ions was found to be larger at the beginning. As the integral of incident ion flux was increased with time and the layer of surface carbon deposition was removed, the ratio recovered its original value. This result indicates that the reflection of particles from high-*Z* plasma facing material depends on the condition of impurity coverage in the actual fusion devices. The reflected beam energies of positive and negative ions were apparently much smaller than those from polycrystalline Mo surface.

4. Summary

We have studied low energy beam interaction with materials systematically. The experimental results show some interesting physical phenomena, such as single charge state reflection of oxygen, and the peak energy shift of the reflected beam as a function of the reflection angle. Unlike the case of single crystalline sample [8], these physical processes have not been properly explained yet, and they should be investigated in the near future. We will improve the system further to study the precise mechanisms related to particle surface interaction and compile the data for future fusion device design.

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