Journal of Nuclear Materials 463 (2015) 351–354

Contents lists available at ScienceDirect

Journal of Nuclear Materials

journal homepage: www.elsevier.com/locate/jnucmat

Angle-resolved intensity and energy distributions of positive and negative hydrogen ions released from tungsten surface by molecular hydrogen ion impact

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ARTICLE INFO

Article history:
Available online 17 December 2014

ABSTRACT

Hydrogen ion reflection properties have been investigated following the injection of H^+, H_2^+ and H_3^+ ions onto a polycrystalline W surface. Angle- and energy-resolved intensity distributions of both scattered H^+ and H^- ions are measured by a magnetic momentum analyzer. We have detected atomic hydrogen ions reflected from the surface, while molecular hydrogen ions are unobserved within our detection limit. The reflected hydrogen ion energy is approximately less than one-third of the incident beam energy for H_3^+ ion injection and less than a half of that for H_2^+ ion injection. Other reflection properties are very similar to those of monoatomic H^+ ion injection. Experimental results are compared to the classical trajectory simulations using the ACAT code based on the binary collision approximation.

1. Introduction

Particle recycling on plasma facing materials of a fusion reactor plays a critical role in determining overall device performance [1]. In recent fusion reactors, one of key issues is design of the divertor with the proper selection of the tile material, which is robust against high particle and heat flux, but retains less amount of tritium. The divertor surface is continuously bombarded by deuterium or tritium ions, their molecular ions, helium and impurity ions, as well as their neutrals, of wide energy ranges from MeV region down to below 1 eV. Therefore, the sustainment of plasma detachment is strongly demanded. Both understanding of particle recycling characteristics of these particles on divertor tile surface and modeling of divertor plasmas are important. Recently it is reported that the ITER will be equipped with a full-tungsten divertor from the beginning [2]. Tungsten has an advantage of a lower rate of erosion and low tritium retention. While an intensive effort has been made on the study of erosion and nanostructure formation [3], the database of particle reflection properties are insufficient. Especially, data for molecular ions which plays an important role for detachment through molecular assisted recombination [4] are indispensable.

We have studied the fundamental processes of beam-surface interactions by measuring the charge states and energy distributions of hydrogen ions scattered from solid surfaces following low-energy (< a few keV) atomic hydrogen ion beam injection [5–9]. Both positive and negative ions from Mo [5], W [6], vanadium alloy [7], and carbon nano wall [10] surfaces were observed. Surface roughness also appears to affect the reflection properties of hydrogen ions [11].

In this paper we report results of molecular hydrogen ion interaction with tungsten surface at room temperature. Reaction processes related to molecular hydrogen ions should play an important role in diverter plasma physics, while some interesting anomaly due to break-up interaction is expected [12]. Ions of H_2^+ and H_3^+ as well as H^+ and He^+ are injected onto a polycrystalline W surface. Angle- and energy-resolved intensity distributions of both scattered H^+ and H^- ions are measured by a magnetic momentum analyzer. Classical trajectory simulations of angular and energy distribution for reflected hydrogen using the ACAT (Atomic Collision in Amorphous Target) code [13] are performed to understand general features of a low-energy solid-particle interaction.

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http://dx.doi.org/10.1016/j.jnucmat.2014.12.026

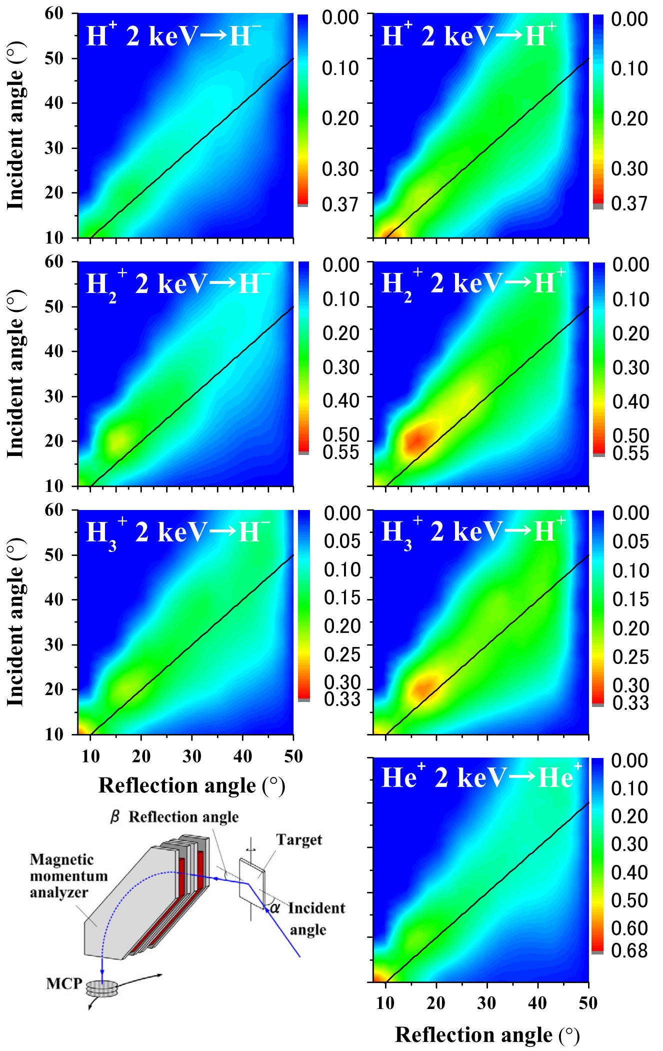

Fig. 1. Two dimensional (2-D) contour intensity plots of the incident and reflection angle dependence of the H^+ and H^- ion intensity from W surface for H^+, H_2^+, and H_3^+ beam injections. The 2-D plot for He^+ ions for He^+ ion injection is also shown. The incident beam energy is 2.0 keV. Solid lines correspond to the specular reflection. Definition of the incident (α) and scattered (β) angles is also shown. We used a microchannel plate (MCP) to detect reflected ions.

2. Experiment

We prepared a polycrystalline tungsten metal as a target. The detail of the experimental system has already been reported elsewhere [7,8]. Incident ions of H^+, H_2^+, H_3^+, and He^+ are extracted from a multi-cusp ion source. A 60°-bending magnet was used to select the beam species. The ion beam was transported through the two deflector systems and two einzel lens systems. The target was heated before the measurement up to more than 100 °C for about one hour. The analyzer and target angles were calibrated against the incident beam. We measure the scattered ions from the target by using a movable magnetic momentum analyzer (MMA) installed in the vacuum. Our MMA system has an advantage that the positive and negative ions scattered from the target were measured by a single sweep of the analyzer magnetic field. In most of other experiments the measurement has been performed under the limitation of $\alpha + \beta =$ const. so far, where α and β are incident and reflection angles with respect to the target plane. Whereas, our system is capable of rotating the target and analyzer angles independently in the range of 0–360° and ±80°, respectively. The incident beam energy was 2 keV and the intensity varied from a few to a few tens nA. The analyzer energy resolution is theoretically designed to be about

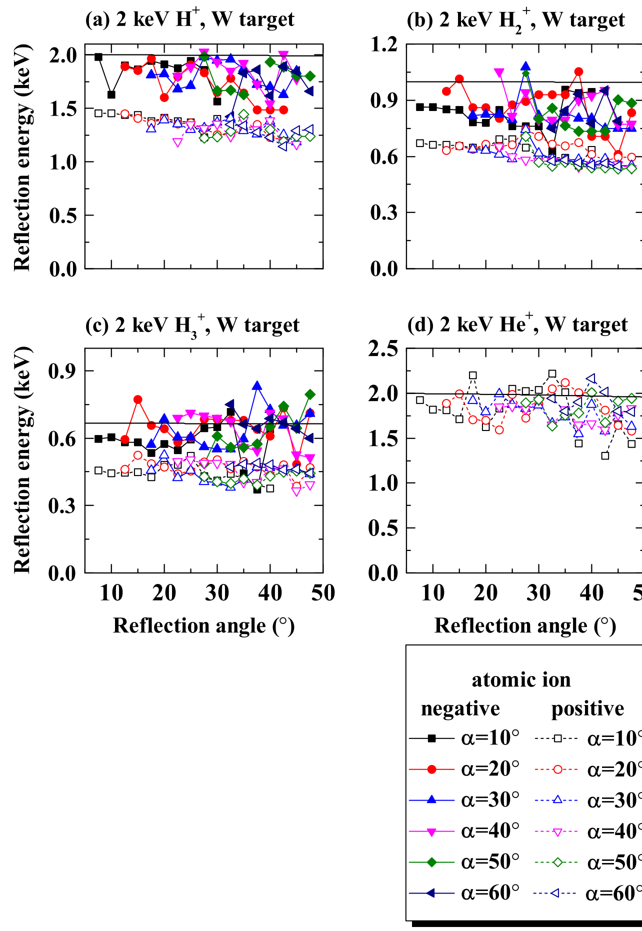

Fig. 2. Reflection angle dependence of the scattered atomic ion energies. Open and closed symbols correspond to the negative and positive atomic ions, respectively. Solid lines are calculated results based on the classical binary collisions [15].

$E/\delta E = 45$ in a few keV energy range, where E and δE are the energy and energy spread. Actually δE is now 10–20% for the reflection energy. Angles of α and β have errors of ±2° and ±1°, respectively.

3. Results and discussion

Fig. 1 shows two-dimensional (2-D) contour intensity plot of the reflected positive and negative atomic ions scattered from the W surface as a function of the incident angle (α) and reflected angle (β) following H^+, H_2^+, H_3^+, and He^+ ion beam injections. Solid lines correspond to the specular reflection, $\alpha = \beta$. Note that we cannot detect He^- ions because of very low production rate owing to the very small electron affinity of 0.077 eV [14]. The system detects particle signal of only reflected atomic hydrogen ions emitted from the surface, which are dissociated from incident molecular hydrogen ions, within the detection limit. The intensities of reflected positive hydrogen ions are usually higher than those of negative hydrogen ions in the incident energy range less than 3 keV. At a low incident angle the intensity of the reflected ions takes the maximum around the mirror angle for particle reflection. However, the angle at which the reflected particle takes the maximum deviates from the mirror reflection angle for a larger incident angle of incoming hydrogen ions.

In Fig. 2 we show the reflection angle dependence of the scattered particle energy. The order of the reflected hydrogen ion energy is approximately less than one-third of the incident beam energy for H_3^+ ion injection and less than a half of that for H_2^+ ion injection. This indicates that dissociation takes place for most