§19. Negative Ion Formation from Molecular Hydrogen Beam Injection onto a Complex Surface

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[Introduction] Negative hydrogen isotope ion sources have been used in injection systems of proton beam accelerators and in heating sources in nuclear fusion experiments[1]. It is known that most of negative ions are produced from vibrationally exited molecules, and/or on low work-function surface of metal electrodes, but details of production mechanism have not been clarified yet. Upon these backgrounds, we focus on (1) the measurement of negative ion production yield on a metal and a complex low-work-function surfaces, and (2) theoretical understanding underlying its formation and interaction, starting from the first principle investigation.

[Measurement of H^- yield in reflection] The beam-surface interaction apparatus [2] at National Institute for Fusion Science was used for measurement of the angle-resolved energy distribution function of positive/negative ions produced from Mo and Mo-alkali-complex surfaces. The hysteresis effect of the analyzer magnet was studied for both positive/negative ions.

The Mo-alkali-complex surface was fabricated by spreading NaOH and KOH solutions each with a concentration of 1 to 1 in weight on a clean Mo sample. Active drying and application of alkali solutions were repeated several times, and then the sample was baked in vaccum. The work function of Mo-alkali-complex surface prepared with this process was measured on a separate experiment using a 325.0nm He-Cd laser and several diode lasers of 405 nm, 460 nm, 532 nm and 643.8 nm. It was found that the work function changes in 2.3 ~ 3.0 eV range, depending upon the baking temperature, duration, and number of repetition[3]. The work function used in the present experiment might possibly be around 3 eV.

A proton beam of 0.3, 0.5 and 1 keV was injected on the target with an angle of 10°, 20°, 30°, 40°, 50° from the surface. For each setting of the target angle, the energy analyzer for the measurement of reflected ions was moved from 4° - 50°, 4° - 46°, 4° - 40°, 4° - 36°, 4° - 26°, respectively. The magnetic field of the analyzer was scanned from -4 keV to +4 keV continuously, and only H^- and H^+ peaks at energy of 60 – 100 % of injection energy were observed[4].

Fig. 1 shows the reflection angle dependence of H^- intensity to that of H^+ from the Mo surface (a) and the Mo-alkali-complex surface (b). The ratio of the complex surface is generally higher than that of clean Mo surface, and they are increasing as the reflection angle decreases. A numerical simulation calculation, Atomic Collision in Amorphous Target (ACAT), has been carried out to get the angular distribution of total reflection particle flux ($H^0 + H^+ + H^-$), as shown in Fig. 2. The experimental observation of H^- has maximum at a larger angle, showing that the negative ion refection probability has maximum at the outgoing perpendicular velocity of 0.04 atomic unit.

[Theoretical investigation] We have reported the theoretical analysis of the electronic structure changes and work function variation in alkali metal—metal surface systems [5]. In 2015, Newns-Anderson Model study of hydrogen atoms moving towards and outgoing from the surface has started [6]. A graphene surface was studied as an *ab-initio* based calculation. It was found that delocalization of 1s hydrogen occurred with respect to Fermi level of graphene, and that charge neutralization/ionization rates are increased due to interaction potential energy.

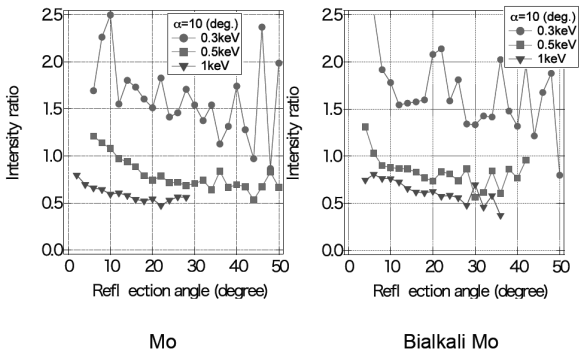

Fig. 1. H^-/H^+ intensity ratio of reflected flux from Mo (a) and Mo-alkali-complex (b) surfaces

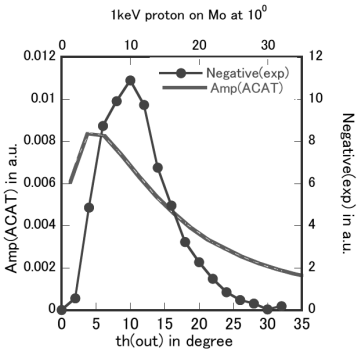

Fig. 2. Comparison of the measured H^- reflection distribution with the total reflection flux distribution calculated by ACAT.

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[2] H. Yamaoka, et al., Review of Scientific Instruments 77, 03C301 (2006).
[3] K. Tanemura et al., presented at the JPS Anuual meeting, 19pCB-5. (March 2016, Sendai)
[4] T. Kanazawa et al., presented at the JPS Anuual meeting, 19pCB-5. (March 2016, Sendai)
[5] A.A. B. Padama, K. Oka, W.A. Diño, H. Kasai, Journal of the Vacuum Society of Japan 57(:01) (2014) 27-31.
[6] W. Thammada and W. A. Diño, et al., private communication.