§1. Development of Cesium-Free Negative Hydrogen Ion Source Based on Plasma-Assisted Catalytic Ionization

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A plasma-assisted catalytic ionization method for the production of positive and negative hydrogen ions has been proposed for generating hydrogen pair-ion plasma and developing a highly efficient negative ion source without any Cs admixture. The production mechanism of negative ions is discussed referring to the results of ion extraction property at the catalyst surface.[1] Hydrogen plasma is generated by a dc arc discharge between filament cathodes and wall anode in a cuboidal chamber with a cross section of 25 cm×25 cm, i.e., so-called bucket plasma source. Positive ions in the plasma are irradiated onto a nickel grid or a plasma grid under controlled irradiation current density and energy. The nickel grid has 100 meshes and an aperture ratio of 36.8%. The plasma grid has a single aperture of 13 mm-diameter, which is made of aluminum (Al-PG). The grid and the Al-PG are negatively biased at a dc voltage of V_{pc} and the irradiation energy is controlled by V_{pc} and the plasma potential ϕ_s. The irradiation current density J_{ir} is controlled by the discharge power. Figure 1 shows the Al-PG, an extraction electrode with deflecting magnetic field for electron removal, and an ion collector.

Typical extraction current density (J_{ex})–voltage (V_{ex}) characteristics in the cases of irradiation of positive hydrogen and helium ions are compared at J_{ir} = 10 mA/cm^2, as shown in Fig. 2. Negative current is superimposed at $V_{ex} \sim V_{pc}$ in the J_{ex}–V_{ex} characteristics in the both ion irradiation. Since a helium atom is not negatively ionized in this situation, the negative current superimposed consists of secondary electrons in the helium-ion irradiation. When positive hydrogen ions are irradiated onto a Cu grid, the negative current is found to be superimposed at $V_{ex} \sim V_{pc}$ as the same in the nickel grid. It can be said that negative ions are not produced by desorption ionization owing to fast ion collision, because hydrogen molecules are not dissociated and adsorbed onto the Cu surface. Therefore, the dominant component of negative current in the hydrogen ion irradiation with 200 eV or more appears to be secondary electrons from the nickel surface. It is clear that the energy of positive ions for negative-ion production is in the range of low energy of 200 eV or less.

The ion extraction characteristics are measured using the Al-PG. Negative and positive ions can reach the ion collector biased at V_c = +150 V and –350 V, and the current densities of J_{c-} and J_{c+} are measured, respectively. Their current densities as a function of V_{ex}, depending on the irradiation energy e(ϕ_s – V_{pc}) of positive ions, are shown in Fig. 3, where the irradiation current density is constant at J_{ir} = 10 mA/cm^2. A maximum J_{c-} of 1.3 mA/cm^2 was obtained, when the energy of positive ions passing through the aperture of Al-PG is about 20 eV (V_{ex} ~ –10 V), but V_{ex} at the peak of J_{c+} is positively shifted. Negative ions are produced on the inner surface of the aperture through the processes of neutralization and negative ionization of positive ions. An incident angle of positive ions to the metal surface is considered to be a key parameter for efficient production of negative ions.

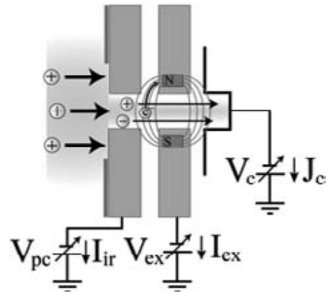

Fig. 1. Schematic view of plasma grid, extraction electrode, and ion collector.

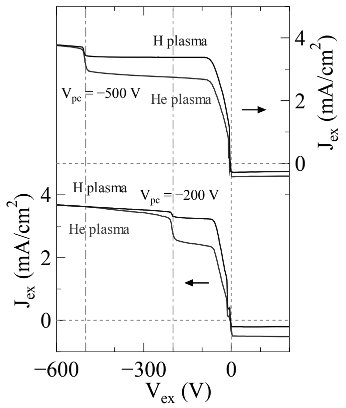

Fig. 2. Extraction current density – voltage characteristics in irradiation of positive hydrogen and helium ions.

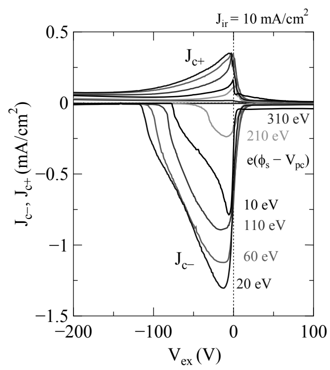

Fig. 3. Current density of negative and positive ions as a function of V_{ex}, depending on irradiation energy of positive hydrogen ions.

1) Oohara, W., Kawata, K. and Hibino, T.: Phys. Plasmas **20** (2013) 063506.