§11. Development of Cesium-free Hydrogen Negative-ion Source Based on Plasma-assisted Catalytic Ionization

Oohara, W., Kobayashi, K., Hibino, T., Matsushima, Y. (Yamaguchi Univ.),
Fukumasa, O. (Ube National Col. Technol.),
Ando, A., Tanaka, N., Funaoi, T., Oikawa, S., Saito, Y. (Tohoku Univ.),
Hatayama, A. (Keio Univ.),
Takeiri, Y., Tsumori, K., Ikeda, K., Kisaki, M.,
Nakano, H.

A plasma-assisted catalytic ionization method for the production of positive and negative hydrogen ions using catalyst has been proposed for generating a hydrogen pair-ion plasma and developing a highly efficient hydrogen negative-ion source without a Cs admixture.[1)] The production mechanism of negative ions is discussed referring to the results of ion extraction property and ion energy analysis at the catalyst surface.[2)]

A hydrogen plasma is generated by a dc arc discharge between filament cathodes and a wall anode in a cuboidal chamber with a cross section of 25 cm×25 cm, i.e., a bucket plasma source. Positive ions in the plasma are irradiated onto a porous plate or a grid made of nickel as catalyst under controlled irradiation current density and energy. The porous plate is a commercially available with a pore size of 0.45 mm, a thickness of 1.4 mm, a specific surface area of 5800 m^2/m^3, and a porosity of 96.6%. The grid has 100 meshes, a wire diameter of 0.1 mm, and an aperture ratio of 36.8%. The catalyst is 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 a schematic view of the experimental setup.

Typical extraction current density (J_{ex})–voltage (V_{ex}) characteristics in the cases of using the porous plate and the grid are measured at V_{pc} = –400 V and J_{ir} = 10 mA/cm^2, respectively. The J_{ex}–V_{ex} characteristics are focused around −70 V < V_{ex} < +20 V. The differentiated profiles calculated from the J_{ex}–V_{ex} characteristics correspond to the kinetic-energy distributions of ions at the catalyst surface, as shown in Fig. 2(a). J_{ex} exponentially decreases when −15 V < V_{ex} < +2 V in the case of the porous plate. The peak component near V_{ex} = 0 V in the differentiated profile is the primary component of passing positive ions. The broad component within −15 V < V_{ex} < 0 V is an energy-scattered component corresponding to passing positive ions reacting with the catalyst surface, because the energy is slightly lower than the irradiation energy. Two obvious peak components at V_{ex} ~ –20 V and 0 V and a broad component, on the other hand, exist within the differentiated profile in the case of the grid. The peak component at V_{ex} ~ –20 V is unobservable in the case of the porous plate.

The dependence of the energy distribution on J_{ir} is shown in Fig. 2(b), where the catalyst potential is constant at V_{pc} = –400 V. The two peak components at V_{ex} ~ –20 V and 0 V that exist in the energy distributions of Fig. 2(a) are comparable to those at e(V_{ex} − V_{pc}) ~ 380 eV and 400 eV and J_{ir} = 10 mA/cm^2 in Fig. 2(b). The energy of the latter component is nearly equal to the irradiation energy e(ϕ_s − V_{pc}) and is almost constant and independent of J_{ir}. Therefore, the latter component is the primary component of passing positive ions. On the other hand, the energy of the former component, indicated by arrows, increases with decreasing J_{ir} and becomes equal to the energy of the primary component at J_{ir} = 4–5 mA/cm^2. The former component corresponds to not positive ions but negative ions, because it is unlikely that the irradiated positive ions have two different energies. When passing positive ions are decelerated in the applied electric field and slowed to about 20 eV at J_{ir} = 10 mA/cm^2, a passing positive ion will receive two electrons from the catalyst metal by a resonant electron transition and be negatively ionized.

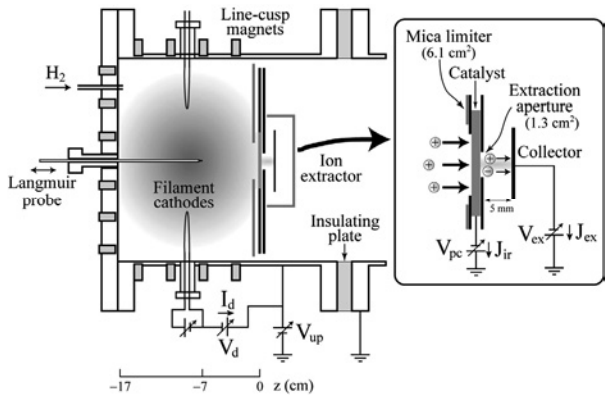

Fig. 1. Experimental setup. Positive and negative ions are produced by plasma-assisted catalytic ionization.

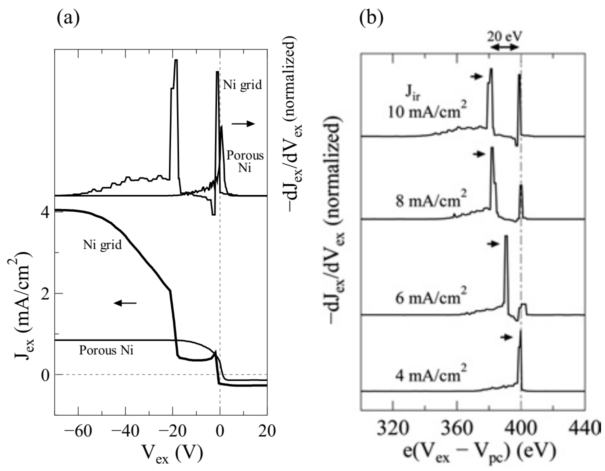

Fig. 2. (a) Extraction current density J_{ex} – voltage V_{ex} characteristics and ion energy distributions calculated from the characteristics, (b) Dependence the energy distributions on irradiation current density of positive ions.

1) Oohara, W., Maeda, T. and Higuchi, T. : Rev. Sci. Instrum. **82** (2011) 093503.
2) Oohara, W., Hibino, T., Higuchi, T. and Ohta, T. : Rev. Sci. Instrum. **83** (2012) 083509.