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# Investigation of Production Mechanism of Negative Hydrogen Ions using Metal Grids
# 金属グリッドを用いた水素負イオン生成機構の解明


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Negative hydrogen ions are produced by the plasma-assisted catalytic ionization using metal grids. When positive ions passing through the grid are decelerated by an electric field, the extraction current density of passing positive ions is sharply reduced. When fast positive ions with hundreds eV are irradiated onto the grid, secondary electrons cannot be ignored. Slow positive ions decelerated by the electric field, on the other hand, appear to be decreased by neutralization and negative ionization.


## 1. Introduction

The production mechanism of negative hydrogen ions can be classified in terms of the electron source. In surface production, an electron at the Fermi level in the conduction band of a metal shifts by tunneling to an electron affinity level of a hydrogen atom approaching the metal surface. The probability of an electron shift is increased as the effective work function of the metal surface decreases. Such an electron shift occurs in particle reflection and sputtering phenomena. We have proposed a plasma-assisted catalytic ionization method for the production of negative hydrogen ions [1,2]. When positive ions produced by discharge are irradiated onto a metal grid, negative ions are produced from the back of the irradiation plane. The production mechanism of negative hydrogen ions is still unknown.

## 2. Experimental Apparatus

A hydrogen plasma is generated by a dc arc discharge between filament cathodes and a chamber-wall anode in a cuboidal chamber with a cross section of 25 cm×25 cm. Figure 1 shows a schematic view of the experimental setup. The cathodes are four U-shaped tungsten filaments of 0.7 mm diameter and 15 cm length (height of 6 cm and width of 2 cm) biased at a dc discharge voltage of $V_d = -70$ V with respect to the grounded wall anode. Positive ions are produced by collisions of the fast electrons with neutral gas molecules. The plasma generated in a field-free region is surrounded by azimuthal line-cusp magnetic fields near the chamber wall. The hydrogen pressure in the discharge section during operation is about 0.1 Pa. Plasma parameters in the discharge section are measured using a Langmuir probe at $z = -7$ cm. The electron density, the electron temperature, and the plasma potential at the plasma core are typically $2\times10^{11}$ cm$^{-3}$, 5 eV, and +10 V, respectively. Plain-weave grids made of copper, nickel, aluminum, titanium, and iron are used for negative-ion production. The grid of 100 mesh, located at $z = 0$ cm, is negatively biased at a dc voltage of $V_{pc}$ and then irradiated with positive ions. Positive ions are accelerated to $e(\phi_s - V_{pc})$ (eV) in the sheath formed in front of the grid, where $\phi_s$ is the plasma core potential. An electrode made of copper is located at a distance of 3 mm from the grid, and doubles as an ion extractor and a collector. All charged particles are extracted or reflected by an electric field applied between the grid and the electrode biased at a dc voltage of $V_{ex}$. Total current of charged particles extracted from the back of the irradiation plane is measured, as the extraction current density $J_{ex}$.

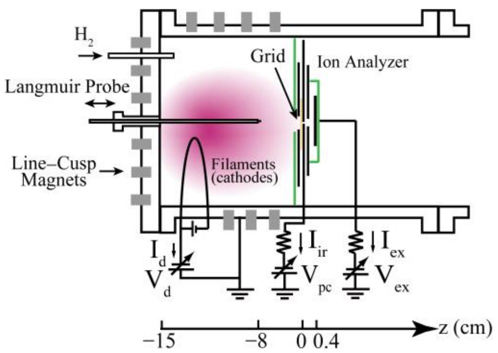


Fig. 1. Schematic view of experimental setup.

## 3. Results

The extraction current density $J_{ex}$ as a function of the extraction voltage $V_{ex}$ is measured using the

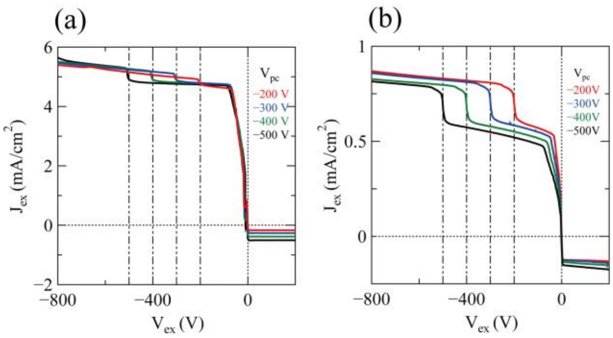


Fig. 2. $J_{ex}$ – $V_{ex}$ characteristics depending on $V_{pc}$ with irradiation of (a) hydrogen and (b) helium ions.

collector as shown in Fig. 1. The $J_{ex}$ – $V_{ex}$ characteristics in the case of using the Ni grid with irradiation of positive hydrogen ions, which depend on the grid potential $V_{pc}$, are shown in Fig. 2(a), where the irradiation current density is constant at $J_{ir}$ = 10 mA/cm$^2$.The diminution of $J_{ex}$ at $V_{ex}$ ~ $V_{pc}$ and $V_{ex}$ = –30 ~ –10 V, that is, a negative current is superimposed on $J_{ex}$. When a fast positive ion accelerated in the sheath collides with a hydrogen atom adsorbed onto the grid surface at $V_{ex}$ ~ $V_{pc}$, a negative ion seems to be produced by desorption ionization. Since the kinetic energy of irradiated positive ions is of the order of $10^2$ eV, there is a possibility of secondary emission from the surface, where the abundance ratio of negative ions and electrons is unknown.

Positive helium ions, which are not negatively ionized, are irradiated onto the Ni gird, secondary emission and neutralization of positive ions are focused. The $J_{ex}$ – $V_{ex}$ characteristics depending on $V_{pc}$ with irradiation of positive helium ions are shown in Fig. 2(b), where the irradiation condition except for ion species is the same as Fig. 2(a). The negative current is superimposed on $J_{ex}$ at $V_{ex}$ ~ $V_{pc}$, the same as in the positive hydrogen-ion irradiation. Therefore the negative current consists of secondary electrons, and the secondary electron current cannot be ignored in the positive hydrogen-ion irradiation, too.

Typical $J_{ex}$ – $V_{ex}$ characteristics in the cases of using the Ni and Cu grids and the positive hydrogen-ion irradiation are shown in Fig. 3, where the grid potential and irradiation current density are

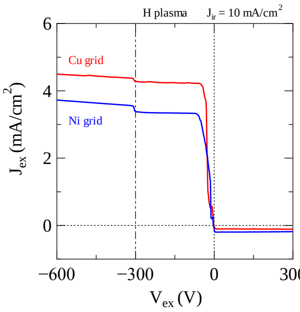


Fig. 3. Typical $J_{ex}$ – $V_{ex}$ characteristics at $V_{pc}$ = –300V.

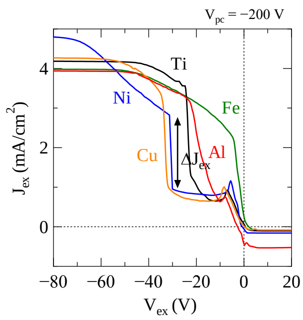


Fig. 4. $J_{ex}$ – $V_{ex}$ characteristics enlarged at $V_{pc}$ = –200V in Ti, Al, Fe, Ni, and Cu grids.

$V_{pc}$ = –300 V and $J_{ir}$ = 10 mA/cm$^2$, respectively. The diminution of $J_{ex}$ at $V_{ex}$ ~ $V_{pc}$ in the Cu grid, that is, the negative current superimposed is smaller than that in the Ni grid. Since there is no hydrogen atoms adsorbed on Cu surface, desorption ionization is not caused and the negative current seems to consist of secondary electrons in the Cu grid. Therefore negative ions may be produced at $V_{ex}$ ~ $V_{pc}$ in irradiation of positive hydrogen ions on the Ni grid, but the dominant negatively-charged particles are considered as secondary electrons.

Typical $J_{ex}$ – $V_{ex}$ characteristics focused around $V_{ex}$ = –80 ~ +20 V in the Ti, Al, Fe, Ni, and Cu grids are shown in Fig. 4, where the grid potential and irradiation current density are $V_{pc}$ = –200 V and $J_{ir}$ = 10 mA/cm$^2$, respectively. The positive current of $J_{ex}$ in the Fe grid exponentially decreases when $V_{ex}$ approaches to the plasma potential. The point of interest is not the exponential decrease but the drastic decline in the current density of passing positive ions. The negative currents, on the other hand, seem to be superimposed at $V_{ex}$ = –30 ~ –10 V in the other grids. $J_{ex}$ is sharply reduced at $V_{ex}$ ~ –30 V in the Ni and Cu grids. The diminution on $J_{ex}$ is defined as $\Delta J_{ex}$, which depends on the metallic material as shown in Fig. 4. $\Delta J_{ex}$ in the Al and Ti grids are larger than $\Delta J_{ex}$ in the Ni and Cu grids, it has possibilities that more negative ions are produced. It is found that $\Delta J_{ex}$ does not depend explicitly on the work function of the materials from the correlation between $\Delta J_{ex}$ and the work function. It is not known at present what parameters of physical metallurgy essentially affects $\Delta J_{ex}$.

**References**

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

[2] W. Oohara, H. Yokoyama, Toshiaki Takeda, Y. Maetani, Takashi Takeda, and K. Kawata, Phys. Plasmas, **21**, 063514 (2014).