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医療用負イオン源における水素負イオン生成量の解析

Numerical modeling of the Negative Hydrogen Ion Production in the Ion Source for Cyclotrons

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Multi cusp DC arc-discharge H^- ion sources have been developed for medical applications, Such as Boron Neutron Capture Therapy [1]. It is highly required to get the high extracted beam current from the source in order to shorten the treatment time.

In H^- ion sources, H^- is obtained by the Cs-free volume production [2] and the Cs-seeded surface production [3]. While the surface production is more efficiently to obtain the large amount of H^- production, the long pulse and stable operation is generally more difficult than the pure hydrogen operation. Therefore, in this study, we focus on the Cs-free volume production.

In the volume production, H^- is produced by following reactions,

(a) $\mathrm{H_2}(v) + e_{\mathrm{fast}} \rightarrow \mathrm{H_2}(v') + e,$ (EV)

(b) $\mathrm{H_2}(v') + e_{\mathrm{slow}} \rightarrow \mathrm{H^-} + \mathrm{H}.$ (DA)

The first reaction (a) is the vibrational excitation (EV) by the impact of high energy electrons (>10 eV) on the hydrogen molecules. The second reaction (b) is called dissociative attachment (DA), which produces H^- by the low energy electrons (~1 eV) with vibrationally excited molecules H_2(v).

It is very important to control the Electron Energy Distribution Function (EEDF), because the cross section of the EV and the DA reactions strongly depend on the EEDF. In order to control the EEDF, the magnetic filter concept was proposed. The magnetic filter divides the plasma into the high energy electron region (Driver Region) for the EV reaction, and the low energy electron region (Extraction Region) for the DA reaction. To optimize the H^- production, it is important to analyze the effect of the filter field on the EEDF.

In this presentation, the effect of the filter magnetic field on the H^- volume production in the Sumitomo Heavy Industries, Ltd. DC arc-discharge H^- ion source[1] will be reported. The analysis is conducted by the KEIO-MARC code (**K**inetic modeling of **E**lectrons in the **IO**n source plasmas by the **M**ulti-cusp **ARC**-discharge) [4] and rate equations for H_2(v) and H^-. The KEIO-MARC code solves Boltzmann-equation. In the KEIO-MARC code, collisions between electrons and hydrogen species are calculated by 'null collision method' [5], and Coulomb collisions between electrons and ions are calculated by 'binary collision method' [6]. From the result of KEIO-MARC code, the H^- production is calculated by the zero-dimensional rate equations, which contains all the H_2(v) states.

The strength of the magnetic filter field is controlled by the length of the permanent magnets. Figure 1 shows the results of the numerical simulations performed in two filter cases, the 18 mm and 25 mm filter magnets. It is shown that the H^- production decreases in the condition of the strong magnetic filter, since the electron density and the high energy component of the EEDF in the extraction region decrease.

Furthermore, the numerical results in other filter strength cases will be reported.

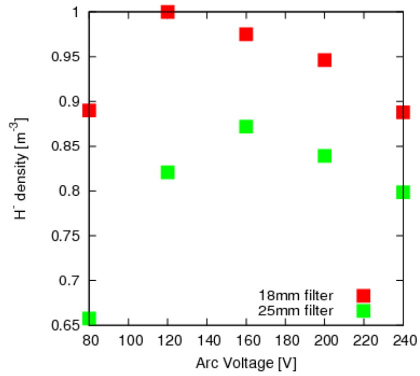

Fig. 1 H^- production vs. Arc Voltage

[1] H. Etoh *et al.*, Plasma and Fusion Res. **11**, 2406063 (2016)
[2] M. Bacal, *et al.,* J. Appl. Phys. **52**, 1247 (1981).
[3] Yu. Belchenki, Rev. Sci. Instrum. **64** 1385 (1993).
[4] T. Shibata, *et al.,* J. Appl. Phys. **114**, 143301 (2013).
[5] K. Nanbu et al., Proc. Soviet Union-Japan Symp. Comput. Fluid Dynamics, (Computing Center of the USSR Academy of Sciences, 1989), Vol.2, pp.126-132.
[6] T. Takizuka and H. Abe, J. Comput, Phys. 25, 205 (1977).