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医療用負イオン源プラズマ中における高エネルギー電子が負イオン生成へ及ぼす影響の解析

Effect of High Energy Electrons on H^- production in a High Current DC Negative Ion Source for Cyclotron

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In cyclotrons used for the medical application, negative hydrogens (H^-) are injected and accelerated to obtain higher extraction efficiently [1]. In such a medical application of H^- ions, it is highly required to enhance the H^- production in H^- ion sources and to obtain the high H^- beam current. Among various types of H^- ion sources, in this study, we focus on the multi-cusp DC arc-discharge source [2]. A systematic study of the EEDF (Electron Energy Distribution Function) in the arc-discharge plasma has been conducted. Especially, the effect of the EEDF on the efficient H- production has been studied by the KEIO-MARC code (Kinetic modeling of Electrons in the IOn source plasmas by the Multi-cusp ARC-discharge) [3].

In Cs-free negative ion sources, H^- ions are mainly produced by the volume production. In the volume production, the following two reactions take place subsequently. The first reaction is H_2 molecules' vibrational excitation (EV reaction), which is caused by the impact of the high-energy electron (several tens of eV) on the H_2 molecule. In the second reaction, the H^- ion is generated via the dissociative attachment (DA reaction) of the low energy electron (~1eV) to the vibrationally excited molecule $H_2(v)$ [4]. In our previous analyses with the KEIO-MARC code, it is shown that Electron Energy Distribution Function (EEDF) in JAEA 10A arc-discharge source has a high energy tail [3]. The high energy tail, i.e., the non-equilibrium part of the EEDF, possibly plays a key role for the efficient H^- volume production, because high energy electrons promote the EV reactions, which lead to the increase in the H2(v) density and resultant H^- production. On the other hand, however, high-energy electrons also enhance H^- destructions through the electron detachment from the H^- ion (ED reaction). Therefore, it is important to study the EEDF, especially the high-energy part of the EEDF.

On the basis of the above discussion, the EEDF in the DC arc-discharge plasma has been analyzed by the KEIO-MARC code. The KEIO-MARC code solves Boltzmann-equation. In the KEIO-MARC code, collisions between electron and hydrogen are taken into account by "null collision method" [5], while Coulomb collisions between electrons by "binary collision method" [6]. By using the results of the EEDF from the KEIO-MARC code, H^- production rate/destruction rate is calculated by a system of zero-dimensional (0D) rate equations, which include all the $H_2(v)$ states. Effects of the arc-discharge voltage/current on the EEDF and on the resultant H^- production/destruction have been studied systematically. The results of the analysis explain the experimental result of H^- extraction current reasonably. In the experiment, the saturation of the extracted H^- beam current is observed at the high arc voltage region [7]. As shown in Fig. 1, the saturation of H^- is also observed in our analysis.

Furthermore, some improvements of the KEIO-MARC code regarding neutral reactions and transport have been conducted. These improvements of the code will be also reported.

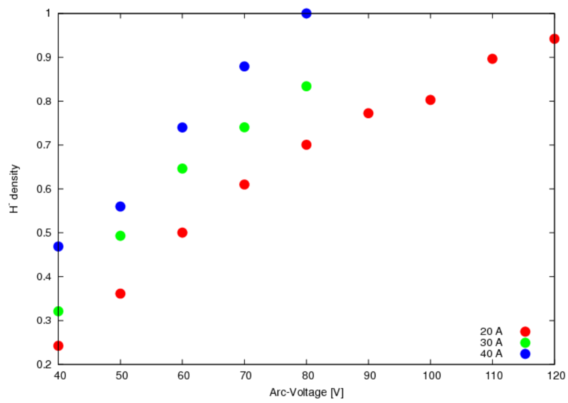

Fig. 1 H^- density vs. Arc-Voltage (calculated)

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