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Numerical Analysis of Spatial Non-Uniformity in Negative Ion Source with Tent-Shaped Magnetic Filter

テント型磁場配位を用いた水素負イオン源プラズマの
空間的非一様性形成機構に関する数値シミュレーション

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Atomic production rate has been calculated in the driver region and the extraction region in the JT-60 SA negative ion source by the H_2 collisional radiative (CR) model with the electron energy distribution function (EEDF) obtained from the KEIO-MARC code. Also surface H^- production rate has been estimated with simple assumptions from the H^0 production in each region. The spatial distribution of the H^0 production in the driver region has strong correlation with the spatial profile of the H^- production because of the high production rate and the long mean free path of the H^0 atoms. The results suggest that controlling of the EEDF and the resultant H^0 production in the driver region may lead to uniform H^- beam extraction.

1. Introduction

In the neutral beam injection (NBI) for fusion plasmas, it is one of the serious issues that the spatial non-uniformity of H^- ions in negative ion sources causes local degradation of beam divergence [1]. In order to improve the uniformity of H^- ions, the magnetic filter in JT-60 SA negative ion source was modified from the Plasma Grid (PG) filter to the tent-shaped filter [2]. However, even with the tent-shaped filter, the H^- current density profile becomes non-uniform in the end part of the extraction area in the longitudinal direction. Namely, the H^- current density in the end part is lower than that in the center region by a factor of 0.6. In order to understand the non-uniformity, the electron density and the electron temperature in the extraction region have been measured by Langmuir probe [2]. The longitudinal distributions of the electron density and the electron temperature do not have strong correlation with the H^- current density profile. From the previous study [3], it has been shown that the first-flight H^0 atom flux (FFAF) from the driver region greatly affects the production of H^- ions.

In order to understand the correlation of the electron parameters with the H^- current density profile in the experiments, we have first calculated the EEDF in the driver region and the extraction region by the KEIO-MARC code [4]. Based on the EEDF, the H^0 production rate by the H_2 dissociation processes has been calculated by the H_2 collisional radiative (CR) model for electronically excited states [5]. Finally, based on the H^0 production rate, FFAF on the PG surface is calculated to obtain H^- surface production rate.

2. Simulation Model

In the present study, the KEIO-MARC code is applied to calculate the EEDF in the JT-60 SA negative ion source. The experimental setup of the ion source is briefly explained in Ref. [2]. The brief summary of the numerical code is mentioned in Ref. [4]. In the calculation, the source chamber is divided into small cells with volume $1\,\mathrm{cm} \times 1\,\mathrm{cm} \times 1\,\mathrm{cm}$. The H_2 CR model is also applied to calculate the local H^0 production rate with the EEDF obtained from the KEIO-MARC code in each cell.

The spatial distributions of H^- production rate due to the H^0 atoms from the driver region and the extraction region are estimated by a simple model of H^0 transport. The main assumptions in the model are shown as follows. The produced H^0 atoms have isotropic velocity distribution with Franck-Condon energy (2.15 eV). The collisions between H^0 atoms and other particles are neglected, because the mean free path (MFP) of the H^0 atoms is larger than the size of the source chamber as mentioned later. The H^0 atoms are assumed to be removed at the wall. The probability of the H^- production due to the surface production is calculated from the equation of Rasser as in Ref. [6].

3. Results and Discussion

Figure 1 shows the spatial distribution of the H^0 production rate and the electron density. The horizontal axis Z is the distance from the PG surface. The vertical axis is the H^0 production rate and the electron density averaged in the XY plane. The H^0 production in the driver region ($Z = 340$ mm) is higher than that in the extraction region by an order of magnitude. The MFP of H^0 atoms is roughly estimated to be $1/n_i\sigma$, where n_i and σ are H^+ density and cross section of charge exchange process between ground state H^0 atoms and H^+ ions, respectively, because the dominant collision process for the first-flight H^0 atoms is considered to be charge exchange. The cross section σ can be fixed as 4.0×10^{-19} m^2 for H^+ temperature 1 eV. The H^+ density is assumed to be equal to the electron density due to the quasi-neutrality. For the calculation of MFP, the highest electron density in Fig. 1 (1.2×10^{18} m^{-3}) at $Z = 340$ mm is applied to obtain the minimum MFP. The MFP is calculated to be 2.1 m, which is larger than the size of the source chamber < 1 m.

Figure 2 shows the longitudinal distribution of H^- surface production rate. The blue line and the red line are the H^- production rate due to the H^0 atoms from the driver region ($Z = 340$ mm) and the extraction region ($Z = 20$ mm), respectively. The horizontal axis is the H^- production rate averaged in transverse direction (X direction). The vertical axis Y is the longitudinal position on extraction area. The H^- production rate due to the H^0 atoms from the driver region is higher than that in the extraction region by a factor of $4 - 11$. Hence, the spatial profile of the H^- production is mainly determined by that of the H^0 production in the driver region. The longitudinal profile of the H^- production shows the similar spatial distribution as the H^- current density from the measurement shown in Ref. [2].

4. Conclusion

The spatial profile of the H^0 production rate in the JT-60 SA negative ion source has been calculated by the KEIO-MARC code and the H_2 CR model. The H^- production is mainly due to the H^0 production not in the extraction region but in the driver region ($Z = 340$ mm) because of the high production rate and the long MFP of the H^0 atoms. Therefore, the EEDF and the resultant H^0 production in the driver region are strongly correlated with the H^- production. Moreover, the longitudinal profile of the H^- production shows similar spatial distribution as the H^- current density from the measurement shown in Ref. [2]. The controlling of the EEDF and the resultant H^0 production in the driver region is very important for the uniform H^- production. However, many critical assumptions are applied for the H^0 transport. The detailed study, which takes into account precise H^0 transport process, is reported in the future.

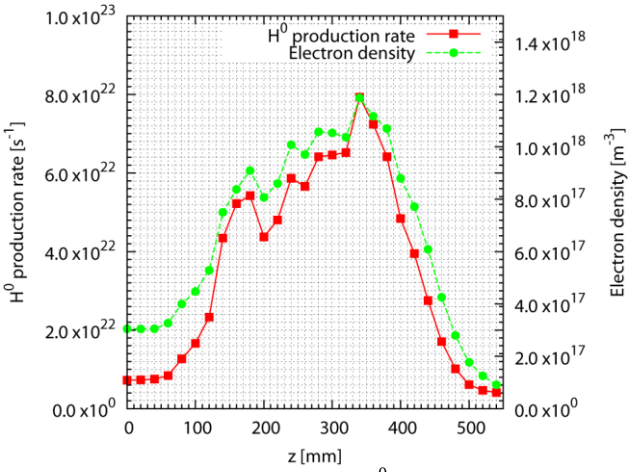

Fig. 1 Spatial distributions of the H^0 production rate and the electron density.

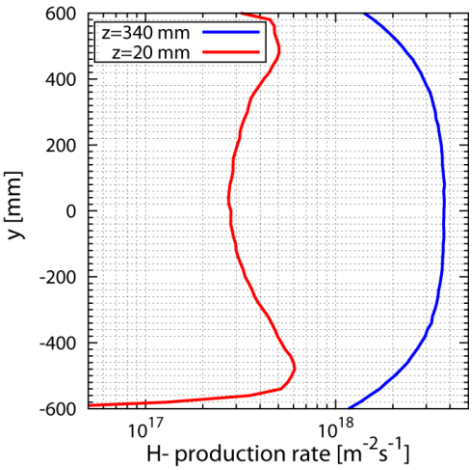

Fig. 2 Spatial distributions of the H^- production rate due to the H^0 atoms from the driver region and the extraction region.

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