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Generation of High Power Neutral Beam in Hydrogen Negative Ion Source for NBI
NBI用水素負イオン源での大電力ビーム生成

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In this article we describe on the large scaled negative ion sources for one of LHD-NBIs. The beam accelerator consists of multi-slot grounded grid (MSGG) to break through the limit of injection power in conventional multi-hole grounded grids (MHGG). Using the new accelerator in the 2002 fiscal year, the maximum beam power and energy attained to 4.4 MW and 180 keV, which is the design energy value. To obtain the other design value, injection power, on LHD-NBI, tuning for H^- production rate was applied by adjusting the temperature of H^- conversion surface. After this adjustment, extracted H- current increased, and the maximum injection power reached 5.7 MW at the energy of 186 keV. The power is exceeded the LHD-NBI design value of 5 MW.

1. Introduction

Neutral beam injectors based on hydrogen negative ion (H^-) sources has been equipped for large scaled plasma confinement devices [2,3] and are planed to build for ITER. The advantage of accelerating H^- to proton beams is the higher neutralization efficiency of H^- ions in the energy range of more than 100 keV. In H^- ion sources for NBI, the very important issues to enhance the injection power are 1) high acceptance of beam electrodes to accelerate intense beam, and 2) enhancement of H^- production rate and its uniformity over wide area of H^- production region. Accelerated H^- ions accommodate electrons due to the neutralization process by the collision of the ion and residual neutral hydrogen molecular. The electrons carries its energies onto electrodes and are considered to cause voltage breakdowns between electrodes. To enhance the production rate of H^-, cesium (Cs) vapor is introduced into arc-discharge chamber of the ion source. Although the decisive mechanism for the H^- production is not clear, the most plausible one is believed double charge exchange process on Cs adsorbed metal surface (Cs-M) as follows:

$$H_n^+ + e\,(\text{Cs-M}) \rightarrow nH \quad (\text{neutralization})$$
$$H + e\,(\text{Cs-M}) \rightarrow H^- \quad (\text{negative ionization})$$

The notation of H_n^+(n=1-3) indicates hydrogenous positive ion. The workfunction of the H^- production surface decreases by applying Cs inside the chamber, and transition probability from metal surface to H atom increases. Controlling the coverage of Cs, therefore, has a strong influence to the H^- production rate. Here we describe the beam injection results from point of views both of beam acceleration and of H^- production control.

2. Large Scaled H^- ion Source with MSGG

Figure 1 shows cross-sectional view of the H^- ion source developed and adopted for one of the beam line in LHD. The source divided into two parts, i.e. the arc chamber and the beam accelerator. Arc plasmas are generated by filament discharge with addition of Cs vapor via back-plate side. The corners of the chamber on that side are cut to improve the stability of arc discharge.

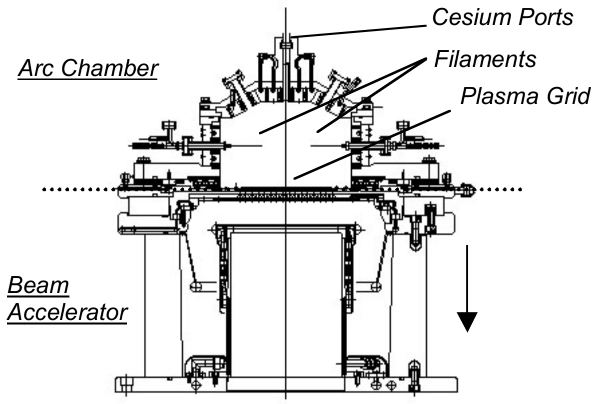

Fig. 1. Cross-sectional view on the short side of a negative ion source for one of LHD-NBIs. The arrow indicates beam direction

A partial cut view of accelerator electrodes, which are called grids, is illustrated in Fig. 2. The accelerator consists of four electrodes, which are a plasma grid (PG), extraction grid (EG), steering grid (SG) and multi-slot grounded grids (MSGG). As shown in Fig. 2, MSGG has a long width slot instead of circler hole apertures. Potential difference between SG and MSGG is the largest and heat load carried by beams larger than the other grids.

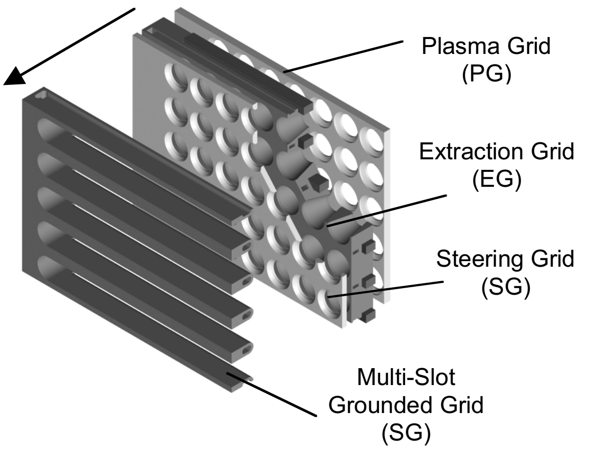

Fig. 2. Partial cut view of the accelerator with MSGG. The arrow indicates beam direction.

3. Beam Injection Using Accelerator with MSGG

Using the ion source with MSGG, beam injection into LHD has been done. The injection power is shown in Fig. 3 as a function of beam energy. In this figure, the powers before and after tuning of H^- production rate are denoted as open squares and solid circles. The line A is proportional to a 5/2-power of the beam energy, which follows the Child-Langmuir's low. In the energy range of more 160 keV, the plot indicating not tuning the H^- production falls out form the line A and starts to follow the line B, which is linear to beam energy. This suggests the H^- current is not sufficient to the condition of space charge limit.

There exist two methods to increase the H^- current. One is enhancement of the concentration of H_n^+(n=1-3) ions, which are the seeds of H^- ions. The other is increase the production rate of H^- ions by reducing the workfunction of plasma grid, whose surface is considered conversion area for H^- ion production. The former is achieved by increasing the input power for arc discharge, and only very slight change was observed in this case. In the latter case, the workfunction changes by the coverage of Cs on PG surface. The coverage is represented by a combination of vapor pressure of Cs inside arc chamber and temperature of PG in practical operation. Change of the vapor pressure was not effective to increase the H^- current, then we focused the tuning of the PG temperature. The PG temperature adjusted by irradiation from the plasmas during arc discharges and heat carried by hot particles form the plasmas. The averaged PG temperature was 210 °C before tuning of H^- yield, and the optimal temperature was 240-250 °C. The averaged temperature is risen up by insulating the heat transfer form PG to cooling parts. After the temperature tuning, the injection power increased form 4.4 MW to 5.7 MW at the energy of 186 keV.

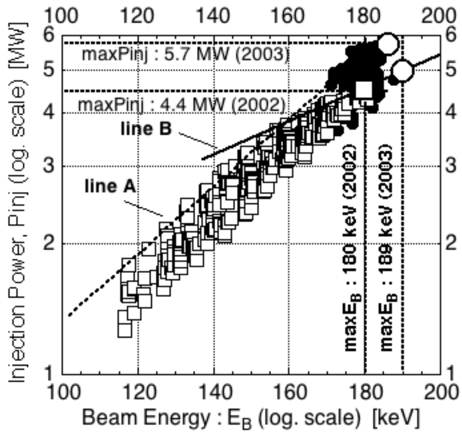

Fig. 3. Injection power as a function of beam energy. The data obtained using the ion source with MSGG. The open squares, data of FY2002, and solid circles, data of FY2003, indicate the powers before and after tuning for H^- production, respectively.

4. Summary

The beam accelerator with multi-slot grounded grid, whose beam transparency is twice higher than that of convention multi-hole grounded grid, was developed and adopted for large scaled H- ion source for LHD-NBI. The plasma-grid temperature tuned to optimize for H^- production. The former and latter correspond to improvement of beam energy and increase of H^- current. By combining those improvements injection power attained up to 5.7 MW, consequently.

References

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