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Production of Helium-Hydrogen Positive Ion Beams for the Alpha Particle Measurement in ITER

H. Sakakita[1], S. Kiyama[1], Y. Hirano[1], H. Koguchi[1], Y. Yagi[1], K.Yambe[1], M. Sasao[2]

[1]*National Institute of Advanced Industrial Science and Technology (AIST), Tsukuba, Japan*
[2]*Tohoku University, Sendai, Japan*

1. Introduction

It is very important to measure the behavior of alpha particles, which contribute for the continuous plasma burning in nuclear fusion plant of deuterium-tritium reaction in ITER. In order to measure the spatial profiles and the velocity distributions of alpha particles, the injection of permeable helium neutral beam of ~1 MeV to the burning plasma has been considered [1]. The helium neutral (He^0) beam exchanges charges with helium ions (alpha particles), and the produced high-energy helium neutral particles are measured by the energy analyzer. To produce diagnostic He^0 beam, following two methods are being considered.

(1) A helium ion (He^+) beam of ~20 keV and ~100 mA/cm^2, used as a primary beam, is converted to negative helium ion (He^-) through the alkali gas cell (conversion rate ~1 %) [2,3], and accelerated to ~1 MeV, then He^- of ~1 MeV spontaneously becomes He^0 (~0.2 mA/cm^2) by passing through a reasonable length (neutralization efficiency ~20 %). In this system, it is important to produce focused high-current-density ion beam in order to pass through small apertures of alkali gas cell with an enough signal level.

(2) Another method which can give a simple way to realize the 1 MeV He^0 beam is to use the helium-hydrogen ion (HeH^+) beam of ~20 keV and ~2 mA/cm^2 as a primary beam. This beam can be accelerated to ~1 MeV, and neutralized through the gas cell with sufficient probability (neutralization efficiency ~10 %) [2,4]. In this method, the strong focusing characteristics may not be so important, though the divergence of the beam should be as small as possible. This method may have considerable advantage to the former one. However, the conditions of producing high current and high current density HeH^+ beam has not yet been investigated in the suitable system.

We had already developed a high current and high-current-density neutral hydrogen beam system, with strong focusing characteristics in order to inject the beam through a narrow port in the vacuum vessel [5]. The considerable amount of ion beams of various kinds of the elements (hydrogen, deuterium, helium and nitrogen) can be also extracted in this system, which has the multi-aperture concave-type electrodes and the bucket type ion source. This type of the beam source not only has the capability of producing the strongly focused beam of high current and of high current density, but also has the characteristics of relatively long life, high reliability and excellent beam control property. The optimization of this type of the machine for the diagnostic application in ITER will give a suitable performance there.

In this paper, we will report the results on the optimized conditions for obtaining sufficient HeH^+ beam intensity, including with the characteristics of He^+ beam, in this beam system.

2. Experimental Setups

In our ion beam system, three multi-aperture concave-type electrodes, that is, acceleration, deceleration and grounded electrodes are used. The diameter of each extraction aperture on the concave acceleration electrode structure is 4.0 mm at the ion-source side [6]. The transparency of each electrode is ~50 %. The distance between the acceleration and deceleration electrodes is 5.5 mm, and that between the deceleration and grounded electrodes is 2.0 mm. The thickness of all electrodes is 2.0 mm. This aperture configuration may be rather simple and ordinary, but it allows the wide range of the operation for the current density, the acceleration voltage and the species of the gases.

The plasma is produced using a bucket type ion source whose inside surface is covered by a copper sheet of 2.0 mm thick to prevent accidental arc erosion. Narrow hairpin tungsten filaments of 2 mm in diameter are adopted as cathodes [7], and inserted a few mm inside the plasma region. The cusped magnetic field is larger than 0.15 T at the inside surface of the chamber, and the residual magnetic field in the plasma region is smaller than 0.5 mT. The magnetic field measured by a gauss meter shows a fairly good agreement with the designed value. This optimized configuration of the arc chamber gives high performance of the ion source, and the arc efficiency (= beam current /arc power) of more than 1 A /1.5 kW is attained for He^+ beam extraction. The most severe problem for the concave-type electrode in operation is that the acceleration (plasma) electrode is heated by the radiation from the filaments and the ion flow to it, and the temperature rise causes the elongation of the electrode and then the considerable reduction of the focal length. To reduce the problem, the electrode is supported by the flexible copper cylinder so that it may expand freely. To raise the arc efficiency is also very helpful to reduce the problem.

A power supply (PS) system with capacitor banks is adopted. The specifications of PSs are 30 kV and 50 A with the voltage ripples less than 5% for the acceleration PS, -5 kV and 6 A for the deceleration PS, and 300 V and 1 kA for the arc PS. The filament PS of DC operation (30 sec) has the specifications of 20 V and 2700 A (= 180 A x 15 sets of filaments), and the programmed constant-voltage control property with the setting accuracy of 0.1%. The designed beam duration is 30 ms.

In order to measure the beam characteristics of each species, a mass spectrometer with an energy analyzer (Balzers Instruments, PPM422), whose energy range is less than 500 eV, is used. Therefore, in the case of mass and energy analysis, DC power supply system of 300 V and 20 A is used as an acceleration PS (here, the voltage of –4.5 kV is applied to the deceleration electrode for the efficient beam extraction).

3.Experimental result

In order to produce HeH^+ component in the ion source, helium and hydrogen gases are mixed in the gas reservoir tank at a fixed rate of $P_{He\text{-}ratio}$ which is the He gas pressure ratio to total gas pressure of the mixture gas (hydrogen and helium). Figure 1 shows time evolutions

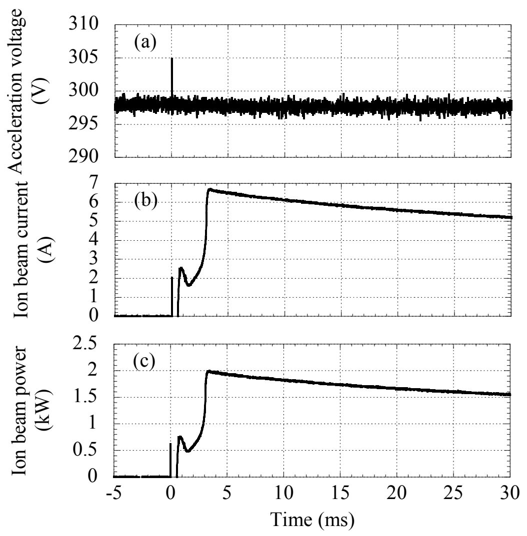

Fig. 1. Time evolutions of (a) acceleration voltage, (b) extracted ion beam current and (c) ion beam power.

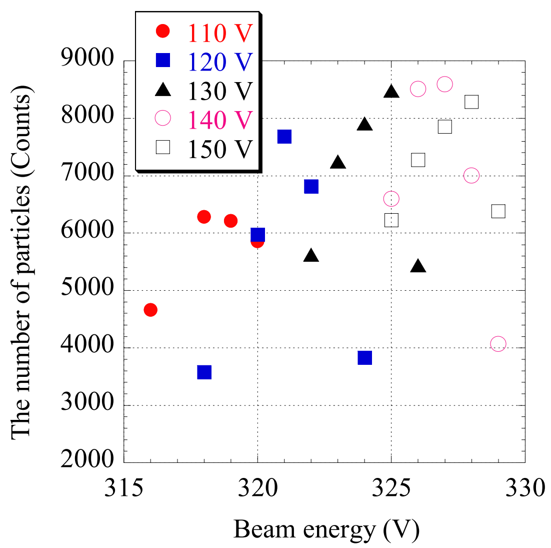

Fig. 2. The energy spectrum of HeH^+ particles measured by the mass spectrometer with energy analyzer for several arc voltages.

of each parameter in the case of $V_{acceleration}$ = 300 V, $V_{deceleration}$= -4.5 kV, V_{arc}= 110 V, $V_{filament}$= 10.5 V and $P_{He\text{-}ratio}$ of 75 %. Ion beam of ~6 A, which includes H^+, H_2^+, H_3^+, He^+ and HeH^+ components, is extracted. Figure 2 shows the energy spectrum of HeH^+ particles measured by the mass spectrometer with energy analyzer for the various arc voltages (100V-150V), in the same condition as in Figure 1, except for the arc voltage. The maximum number of each particle component may be found in these energy spectra. As the arc voltage increases, the number of HeH^+ particles increases, but saturates around 130-140 V, which almost corresponds to electron energy at which the ionization cross section to He^+ becomes maximum. Figure 2 also shows that the peaks of the energy spectrum shift to higher energy with increase of the arc voltage. Higher arc voltages may cause the higher space potential in the ion source, which may be favorable for the extraction and the convergence of the beam. Figure 3 shows the number of HeH^+, He^+ and H^+ particles as a function of $P_{He\text{-}ratio}$, in the same case as in Figure 1. It is clear that the production rate of HeH^+ component increases sharply with increase of $P_{He\text{-}ratio}$ up to ~75 %, and then keep nearly constant up to 90%, whereas that of H^+ and He^+ components are nearly constant in this range of $P_{He\text{-}ratio}$ (50-90%). It may suggest the mechanism of the production in the ion source chamber and the extraction through the electrodes for each component. In the case of $P_{He\text{-}ratio}$= 90 %, the number of HeH^+ particles corresponds to 15 %, or even more (as the analyzer sensitivity for H^+ may be considerably larger than that for HeH^+), of the total counts for H^+, He^+ and HeH^+ particles.

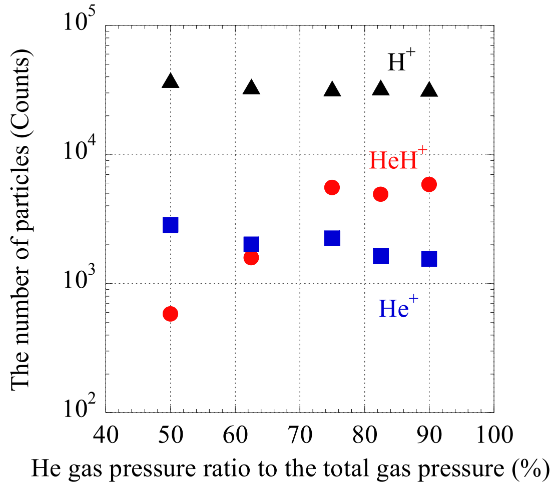

Fig. 3. The number of HeH^+ (circle), He^+ (square) and H^+ (triangle) particles as a function of He gas pressure ratio to total gas pressure.

In order to study the performance of high-energy beam of ~25 keV, the complex beam of H^+, H_2^+, H_3^+, He^+ and HeH^+ components is extracted. Figure 4 shows time evolutions of each parameter in the case of $V_{acceleration}$ = 25 kV, $V_{deceleration}$= -1.2 kV, V_{arc}= 250 V, $V_{filament}$= 13.9 V and $P_{He\text{-}ratio}$= 75 %. The ion beam of ~40 A is extracted. If 15 % of the total current is assumed to be HeH^+ component, the current density of HeH^+ is estimated as ~13mA/cm^2(=40×0.15/(πr^2×0.5)), whose value is much larger than necessary value (~2 mA/cm^2) in ITER. However, in order to verify the estimation, we must directly measure the beam current of the high energy HeH^+ component, separated among the other components (H^+, H_2^+, H_3^+, He^+) by using the magnetic field system.

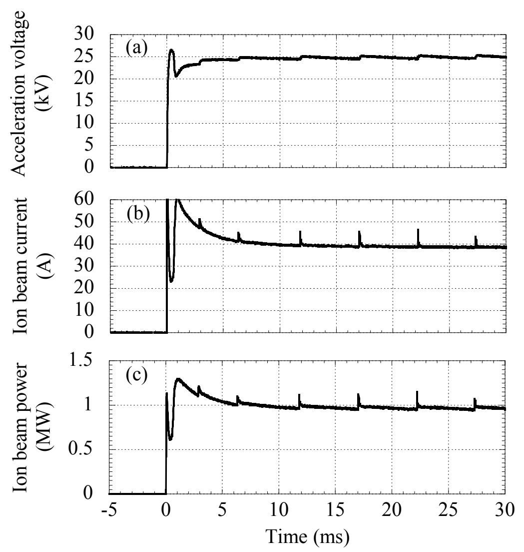

Fig. 4. Time evolutions of (a) acceleration voltage, (b) extracted ion beam current and (c) ion beam power.

In order to examine beam shape, focal point and beam divergence angle, the high energy beam of ~25 keV is irradiated to the stainless steel target plates which are installed in the target chamber. The melted patterns on the plate are taken at several positions of the distance X= 1530, 1735, 1835 and 1920 mm from the electrodes. As an example, the beam trace of the target plate at X= 1530 mm is shown in Fig. 5. From these melted traces, it is estimated that the focal length is ~1400 mm and the divergence angle is about ±0.8 deg, which is almost same as for the hydrogen beam.

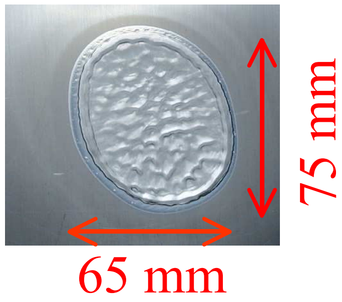

Fig. 5. The beam trace of the stainless steel target plate at X= 1530 mm.

4. Summary

The characteristics of HeH^+ beams, which convert into He^0 beam used for the alpha particle diagnostics, are described. In order to extract HeH^+ beams as a primary beam, the strongly focused high current density hydrogen neutral beam system, which has the multi aperture concave type electrodes and the bucket type ion source, is used [5]. It has been shown that the neutral hydrogen beam is strongly focused into a diameter of ~36 mm at the focal point, with the divergence angle of about ±0.8 deg, which is almost the same as for HeH^+ beam.

In the case of low energy beam of about 300 eV, it is measured by the mass spectrometer with energy analyzer that the number of HeH^+ particles corresponds to more than ~15 % of the total counts for H^+, He^+ and HeH^+ particles in the case of $P_{He\text{-}ratio}$= 90 %.

In the case of 25 kV acceleration, if 15 % of the total current (which includes H^+, H_2^+, H_3^+, He^+ and HeH^+ components) is assumed to be HeH^+ component, the current density of HeH^+ is estimated as ~13 mA/cm^2, which value is much larger than necessary value (~2 mA/cm^2) in ITER. However, to confirm it, we must directly measure the beam current of the high energy HeH^+ component, separated among the other components (H^+, H_2^+, H_3^+, He^+) by using the magnetic field system. This procedure will be performed in near future.

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References

[1] M.Sasao, Proc. 9th IAEA Technical Meeting on Energetic Particles in the magnetic confinement systems, Takayama, OT11 (2005).
[2] M.Sasao, et al., Proc. Int. Workshop on Diagnostics for ITER, Varenna (2005) 51.
[3] K.Shinto, et al., Proc. 9th IAEA Technical Meeting on Energetic Particles in the magnetic confinement systems, Takayama, P21 (2005).
[4] J.Warren, et al., Phys. Rev. A 4 (1971) 1960.
[5] H.Sakakita, et al., Proc. 32nd Eur. Phys. Conf. on Control. Fusion and Plasma Phys., Tarragona, P4-109 (2005).
[6] J.R.Coupland, et al., Rev. Sci. Instrum. **44** (1973) 1258.
[7] M.Kuriyama, et al., JAERI Reports, JAERI-M87 (1987) 169 [in Japanese].