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DEVELOPMENT OF DIAGNOSTIC HELIUM BEAMS FOR HIGH ENERGY PARTICLE MEASUREMENT IN MAGNETICALLY CONFINED PLASMA

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Abstract

An intense He+ beam of more than 50 mA/cm2 at 16 keV has been developed and beam characteristic parameters are measured. The optimum beam condition for He- production though a charge exchange cell has been studied The feasibility of an He^0 beam produced directly from this He+ source , as a tool to diagnose high energy helium ions in a high temperature plasma has also been investigated by comparing the injected He^0 density with the calculated residual He^0 density in a LHD plasma.

Introduction

Measurement of energetic helium ions in magnetically confined plasma is of great importance for the study of ICRF minority heating scenario, and that of alpha particle confinement[1]. An intense He^0 beam combined with a neutral particle analyzer is considered to be one of the most promising tools to diagnose the behaviors of these particles in a high temperature fusion plasma. Considering the velocity matching between a probing neutral particle and a high energy ion to be measured, the former should be accelerated up to 200 keV - 2 MeV. Among various methods to produce an He^0 beam, production from He^+ is effective for the beam energy lower than 400 keV, while production from He^- is effective for the beam energy higher than 1 MeV[2]. An He^- ion can only be produced effectively from He^+ via a two- step electron capture process in an alkali metal gas cell, such as Li, Na, Mg, K, Rb, or Cs in the energy range of 6 - 20 keV[2], while the beam expansion due to the space charge force and the finite emittance are severe problem for the extraction and transport of a beam in this velocity range. An intense He^+ beam of more than 50 mA/cm2 at 16 keV has been developed and the beam parameters are measured . These beam characteristics are discussed from view points of (a) the effective charge exchange scenario for He^- production, and (b) the feasibility of a He^0 beam directly converted from He^+ as a probing beam for the measurement of ^3He high energy tail in a LHD plasma in this paper.

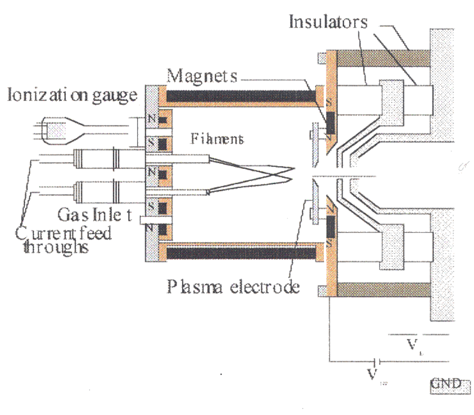

Fig. 1 a schematic diagram of the multi-cusp He+ ion source ion source

Beam characteristics of He+ beam

In Fig. 1 is shown the schematic diagram of the multi-cusp He+ ion source[3]. An helium plasma is generated by two hair-pin type of tungsten filaments (0.4 mm-diameter) in an 8.5 cm-diameter and 10 cm-long compact multicusp source, which can be operated either in a pulsed mode or in a DC mode with discharge current up to 20 A. An He+ beam is extracted from a set of three electrodes of 6 mm-diameter. The ion source itself is biased at acceleration voltage, V_{acc}, and the second electrode is negatively biased ($-V_L$). He+ ions are extracted with $V_{acc} + V_L$, but the final beam energy is eVacc. The total beam current from the source was measured at 18 cm down stream by a large Faraday cup. The emittance was measured at the same position by a multi-slit-and-movable-Faraday cup type gauge and by a pepper-pot type gauge [3,4].

Fig. 2 shows the beam energy (eV_{acc}) dependence of (a) the He+ current measured by the large Faraday cup and (b) the normalized beam emittance (90%) for various discharge current.

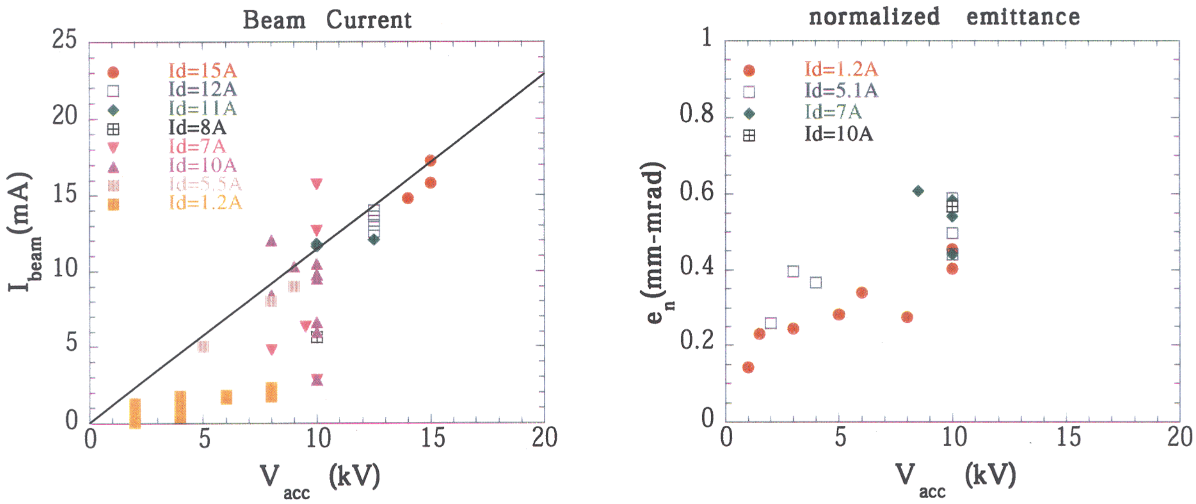

Fig. 2 (a) The He+ current extracted from the 6-mm diam electrodes. (b) the normalized beam emittance (90%)

In Fig. 2(a) the data points of the beam current scatter even when V_{acc} is fixed, because the discharge current and V_L is not optimized. However, the envelope is linearly increasing as V_{acc} is raised and an empirical scaling of I_{Beam}(mA) ~ 1.1 x V_{acc} (kV) can be obtained for optimized lens and discharge conditions. The correlation between the normalized emittance of this type of source and plasma parameters near the extraction has been investigated and characterized[3]. As is shown in Fig. 2b, it increases gradually as the V_{acc} increases, because the optimum discharge current, hence the electron temperature of the ion source plasma is increased.

Beam transport systems, such as an electro static quadrupole system (ESQ), have been developed and it was examined these low velocity beams can be transported without significant change of emittance, and can be focused at a distance several tens cm away, where the main acceleration starts[5].

He- Production

The He- fraction (F-) obtained through a various alkali metal gas, such as Li, Na, Mg, K, Rb, or Cs via a two step process is shown in Fig. 3.[6,7]. The maximum value of 1.7% is obtained through collisions with a Rb target, at an He+ ion incident energy of 6-9 keV[6]. As is shown in Fig. 2a, the extracted current (I+) also depends on the beam energy. If the most of the extracted current is transported into the charge exchange cell, then the outgoing negative ion current is expected to be proportional to $F^- \times I^+$, which are also shown in Fig. 3. A Na vapor is suitable as a charge exchange gas for the He+ beam around 15 keV.

The beam envelope will expand as

$$\frac{d^2 r_b}{dz^2} = \frac{K}{r_b} + \frac{\varepsilon^2}{\beta^2 r_b^{\,3}} + \mathrm{C(collision)} \qquad (1)$$

Here, the first term expresses the space charge effect, which is practically neutralized because of the opposite charge flow in this scheme. Then the beam radius of the outgoing beam will be effected mostly by collisions in the cell and the finite emittance. Both effects become larger when the beam energy is high[8], but the beam energy dependence of the emittance shown in Fig. 2b is not strong. The effect of multiple collisions in the cell should be separately estimated.

Diagnostic Beam System

The feasibility of an He^0 beam produced from He^+ with the beam characteristics shown in Fig.2, as a tool to diagnose high energy helium ions is examined. Here a high temperature plasma , such as a plasma of the Large Helical Device (LHD), which is a superconducting heliotron type device with the plasma major/minor radii of 3.6-3.9 m and 0.6-0.65m, respectively, is considered. During the third campaign of LHD experiment(1999), ICRF heating power up to 1.3 MW was successfully injected into plasm and the energy confinement time close to that of tangential NBI heated plasma was obtained[9]. Perpendicularly accelerated high energy minority particles are passively measured by natural diamond detectors[10]. The results show a good confinement property of helically trapped particles. For the profile measurement of those particles, especially that of high energy ^3He minority ions, a medium energy (200 - 400 keV) He^0 diagnostic beam will become a promising tool. In this case, ^3He ions are neutralized actively into $^3He^0$ through the charge exchange reaction of

$$^3He^{++}(\text{confined}) + {}^4He^0\ (\text{beam}) \text{ ----> } {}^3He^0\ (\text{detected}) + {}^4He^{++}.$$

Previous estimation [11]showed that the attenuation due to ionization of beam particles and that of neutralized particles is negligibly small and the count rate of 10^4/sec/cm^2 will be obtained for the minority density of 10^{10}/cm^3 by a probing beam of 1mA/cm^2 with a depth of 10 cm. The beam current in Fig. 2a exceeds this estimation.

However, the residual He^0 will generate background counts when the minority He atoms are injected into a plasma. Recently a code for neutral distribution using a simplified model has been developed to calculate both H^0 and He^0 distribution in a cylindrical geometry. The H^0 distributions obtained by this code almost agree with those from Princeton code [Ref.12: AURORA code]. Calculated results for a LHD-sized plasma with the He ion density and the electron density of 1×10^{13}/cm^3 and $T_e(0) = 2$ keV for various He^0 initial speeds are shown in Fig. 4. The He^0 penetration depends on its initial speed. The current density shown in Fig. 2b will decrease by a factor of 2-20 due to the neutralization efficiency and the beam expansion during transportation, but still it is about same order as the values in Fig. 4. Considering that the minority ratio is about 10%, and neutral penetration is much less when the plasma density is higher, we have a margin more than 10 times.

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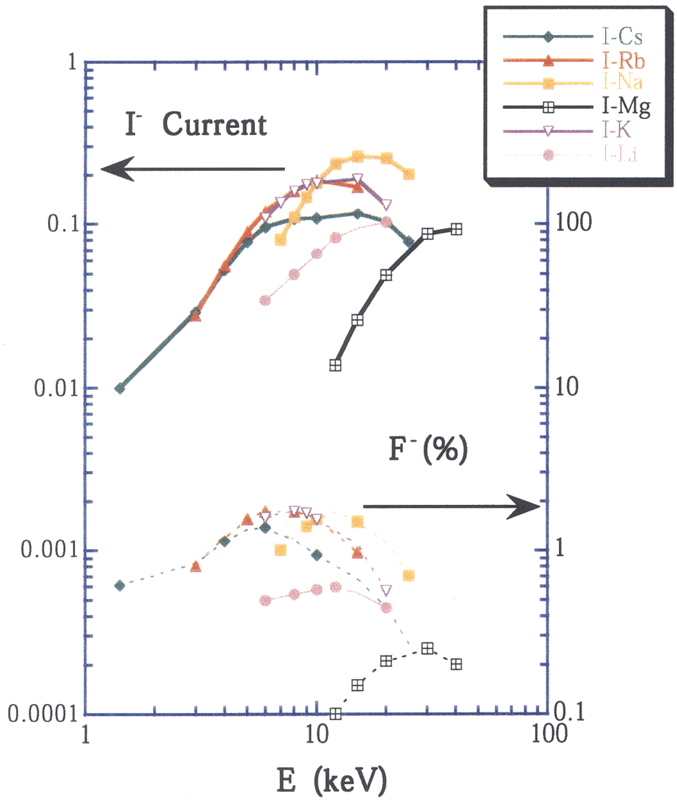

Fig. 3 Energy dependence of conversion efficiency of He+ beam to He- (dashed lines) and prospected He- current (solid lines).

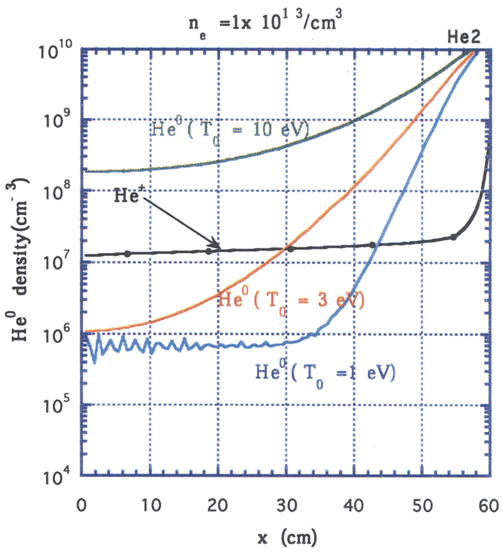

Fig. 4 He0 and He+ density profiles calculated for a LHD-sized plasma at $n_e=n_i=1 \times 10^{13}$/cm3 and $T_e(0)$ = 2 keV for various He0 initial speeds.