Development of an Energetic He^0 Beam for Alpha Particle Diagnostics on ITER

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Abstract

Confined alpha particles can be measurement in ITER by injecting energetic He^0 (ground state) beam to neutralize alphas in the plasma. It was experimentally confirmed that auto-detachment of a He^- beam produces a ground state He^0 beam through the Time Of Flight (TOF) neuralization. A full size strong-focusing He^+ ion source was developed, and a beam current higher than 2A was achieved with the minimum beam radius of 11.3 mm, at the beam energy of 20 – 25 keV, which is suitable to be converted to He^- in an alkali vapour.

1. Introduction

The self-heating of a DT plasma by fusion-produced alpha particles is the key to realize self-sustaining ignition of a thermonuclear plasma for fusion reactors. Measurement of the spatial and energy distributions of alpha particles in an ITER DT plasma is essential to understand the energy tranport, plasma pressure and pressure gradient properties of a burning plasma, and to obtain an insight for achieving the self-standing burning in a fusion reactor[1].

A beam neutralization system for the confined alpha particle measurement has been proposed for ITER [2]. Because the cross section of two electron capture process

$$He^{++} + He^0 \rightarrow He^0 + He^{++}$$

decreases rapidly at the relative energy higher than 200 keV, a forward angle detection arrangement and a neutral beam injection of atoms heavier than helium in MeV region are required[3]. In general, a neutral beam is produced from a negative ion beam in this region, but a substantial fraction of He^- would be neutralized into a meta-stable atom, which would be easily ionized in the edge plasma, and would not penetrate into the plasma core .

A time of flight (TOF) neutralization using the 10 and 300 μs life times of He^- was proposed to produced a ground state He^0 [2-3]. If the initial He^- beam current is 10 mA and is injected into a 500MW ITER DT plasma after TOF neutralization, it is predicted that the signal count rate is 10^3 – 10^6/s at the detector of 1 cm^2, and the signal to noise ratio is greater than 1 at the reduced radius ρ<0.4, even without beam modulation [4]. Usage of a lock-in technique at the frequency of Radio Frequency Quadrapole (RFQ) accelerator will make measurement at the outer region possible. The concept is summarized in Fig.1.

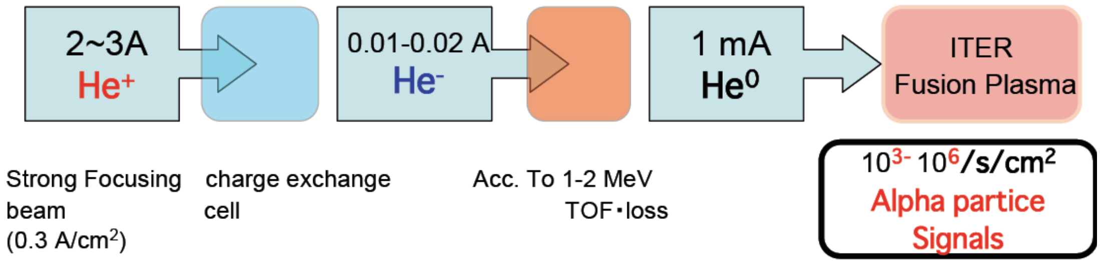
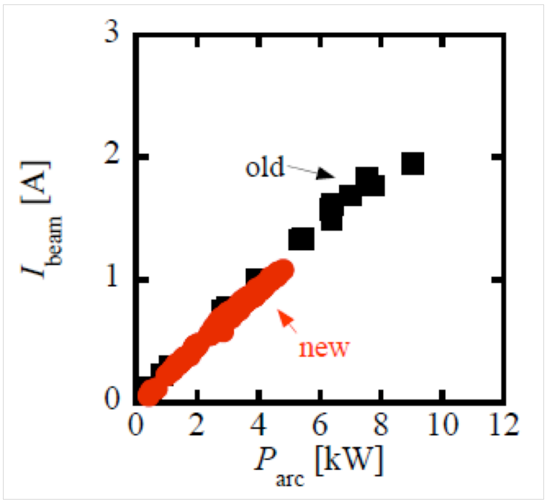


Fig. 1. The concept of an energetic He^0 (ground state) beam probe system

2. Full-size He^+ ion source

Considering the low conversion efficiency (<2%) from He^+ to He^- and the optimum conversion energy of 10–20 keV, an ampere-size He^+ ion source was designed for ITER application[5]. The ion source consists of a plasma chamber 300 mm in diameter and 280 mm in length surrounded by a set of permanent magnets that form a cusp magnet field, 4 or 8 filaments and three concave multi-aperture electrodes. From the centre area of 100 mm in diameter, more than 300 beamlets are extracted through apertures 4 mm in diameter. Concave electrodes were chosen so that the extracted beam focuses into an acceptable size of an alkali vapour cell without using electrostatic lenses which diminish the space charge neutralization effect. The source was installed on the NBI test stand at National Institute for Fusion Science with a vacuum chamber of 1 x 1 x 1 m^3 for diagnostics. In this chamber, a Rogowski coil and a movable carbon beam dump target (100 x 100 x t2 mm^3) were installed. The beam dump temperature was observed from the backside of the target with an infrared camera installed outside the chamber to obtain the 2D beam current density distribution [6]. The extracted beam current was directly measured using a 811-turn Rogowski coil of 88 mm in major diameter, as shown in Fig. 2(a).



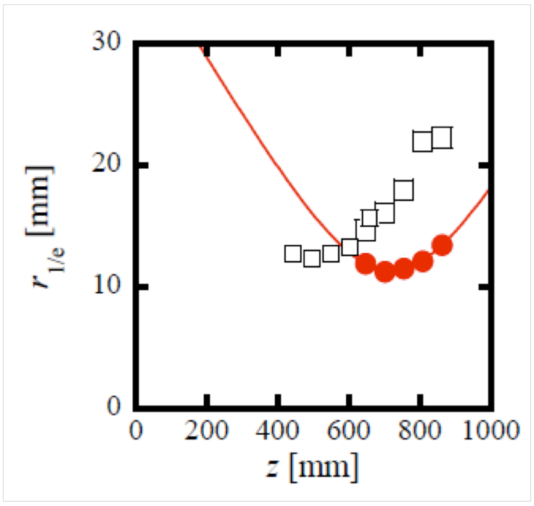


Fig. 2 The H^+ beam current extracted from a strong focusing source(a), and the beam radius along the distance from the ground electrode (b). The old extraction electrodes were deformed during a high power operation of 60 kW, but the required beam current was obtained by operation at a power less than 10 kW.

The e-folding radius of the beam at the optimum perveance was measured and is shown in Fig 2(b). The focal length, the beam divergence and the minimum beam radius were about 720 mm, ~15 mrad and 11.3 mm, respectively, while their designed values were 750 mm, <16 mrad and <12.5 mm, respectively [7].

3. He^0 production by Auto-detachment

A test stand device named Advanced Beam Source 103 (ABS103) has been constructed to study the beam transport related to the double charge exchange He^- production, and to provide experimental confirmation on the production of a ground state through auto-electron detachment[8-10]. It has a compact bucket-type He^+ ion source, a set of einzel lens, alkali vapour gas cell (Li cell), a double focus bending magnet, an accelerator column and a free flight tube with an ion separator and a pyro-electric detector[10].

In the present experiment, 1 μA He^- beam was accelerated to 142 keV, chopped by 1 Hz, and introduced to a 10 m flight tube. By activating the charge separator in front of the pyro-electric detector on and off, the He^0 beam and the sum of He^0 + He^- beam flux were measured separately at 2.5 m and 7.5 m flight distance. Here the pyro-electric detector measured the polarization voltage change due to the beam power deposited on the surface.

Figure 3 shows the ratio of He^0 beam flux to the initial He^- beam flux as a function of flight length. The straight line shows the theoretical prediction from the life times of 10 μsec (50%) and 300 μsec (50%). This ratio is consistent with the measurement, showing the TOF

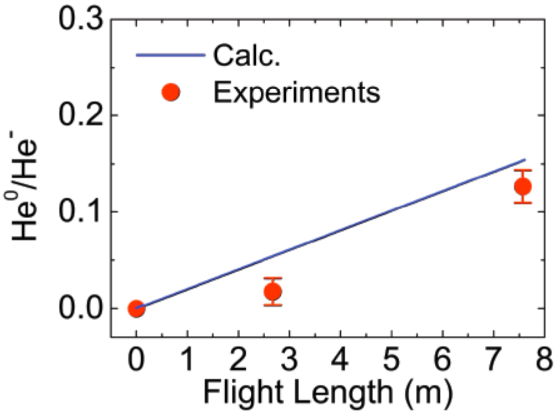


Fig. 3 The ratio of He^0 beam flux to the initial He^- flux as a function of flight length. He^0 was increased linearly against the flight length, as predicted from the He^- life times[10].

neutralization to a ground state He^0 beam.

4. Summary

A proof-of-principle experiment of TOF production of ground state He^0 beam from He^- beam shows that the beam neutralization system is applicable to the confined alpha particle measurement by a double charge exchange beam neutralization system on ITER. A 2A strong-focusing He^+ beam source was developed, and the beam size was small enough to be accepted by an alkali vapour cell for He^- beam production. Now, RFQ accelerator design work and further rigid ITER arrangement work are to be started.

Acknowledgment

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