

STRONGLY FOCUSED HE⁺ BEAM SOURCE FOR ALPHA PARTICLE MEASUREMENT AT ITER

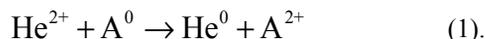
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Abstract

A He⁺ beam source for a high energy He⁰ beam probe system to diagnose fusion produced alphas in thermonuclear fusion plasma has been assembled on a test stand for beam parameter measurements. The ion source is equipped with a beam extraction system made of three concaved electrodes. Across the 100 mm diameter extraction area 300 beamlets are formed through 4 mm apertures. Converging beamlets directed to an alkali metal charge exchange cell of the 35 mm entrance opening intersect at the position 750 mm down stream of the extraction electrodes. The test stand has several beam diagnostic apparatuses. The total beam current, the beam profile and the beam emittance are being measured to design a proper alkali metal vapour cell for a He⁻ beam production by a double-charge-exchange process, and a beam transport line for the post beam acceleration system up to MeV energy region.

INTRODUCTION

Confinement of alpha particles produced by D-T nuclear fusion reaction in a plasma is one of the top-priority research issues for future experimental devices such as International Thermonuclear Experimental Reactor (ITER). Several methods to measure the spatial and velocity distributions of the alpha particles in the core plasma have been proposed. One of the most promising methods is based upon the double-charge-exchange reaction of a fusion produced alpha particle in the core plasma. Fusion produced alphas capturing two electrons escape from the plasma. These alphas can be detected by an energy analyzer installed outside the confinement magnetic field. Post *et al.*[1] proposed an active beam probe method to neutralize the alpha particles inside the plasma by injecting an energetic neutral helium (He⁰) or lithium (Li⁰) beam into the core plasma;



The injected energetic neutrals must be in the ground electronic state to penetrate deep into a high density plasma. Sasao and Sato showed the possibility of producing energetic He⁰ beam by spontaneous electron detachment from negative helium ions (He⁻) to diminish the metastable excited component.[2]

Recently, Sasao *et al.* has estimated the signal-to-noise ratio of He⁰ obtained by double-charge-exchange reaction

of alphas through injecting He⁰ beam into ITER.[3] As the result, it is found that a He⁻ beam of 10 mA intensity and 1-1.5 MeV energy is required to obtain enough signal of neutralized alphas against noise induced by fusion produced neutrons. This beam intensity requirement has been adopted by the concept design of the energetic He⁰ beam system for fusion produced alpha diagnostics presented in a previous paper.[4]

A He⁺ beam source with the current as large as 3 A is required to produce 10 mA He⁻ beam as the conversion efficiency of double-charge-exchange process from He⁺ ions is known to be less than several percent. Besides, a small beam size is required to match the demand from the downstream beam optics. Thus, a strongly converging He⁺ beam is directed to the charge-exchange cell and the produced He⁻ beam is transported by beam focusing components to match beam optics. In this paper, the status of development of a strongly focused He⁺ beam source which has been recently assembled on a test stand is reported.

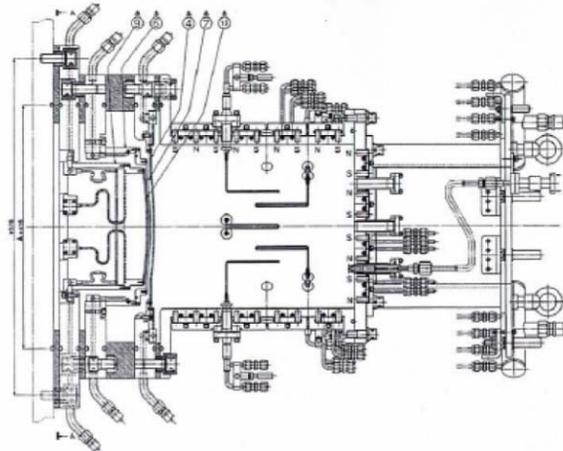


Figure 1: Illustration of a strong focused He⁺ beam source.

FOCUSED HE⁺ BEAM SOURCE

A strongly focused He⁺ beam source can deliver large current into the alkali metal vapour cell through a small aperture to produce a high intensity He⁻ beam. An ion source with three concaved multi-aperture electrodes to focus the extracted beam to a narrow spot has been developed at National Institute for Advanced Industrial Science and Technology (AIST) in Japan.[5] A concept drawing of the He⁻ beam production system based on the

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focusing He⁺ beamlets is shown in Fig. 1. The beamlets extracted from the source converge at the centre of the cell to form the He⁻ beam emitted from a narrow region in the cell.

A strongly focused He⁺ beam source with an extraction system consisting of three concaved electrodes has been designed and constructed based upon technical data obtained at AIST. The specifications of the assembled He⁺ beam source are summarized in Table 1. As the production efficiency of the He⁻ beam is largely determined from the double-charge-exchange efficiency while the efficiency is strongly affected by the He⁺ beam energy,[6] the incident beam energy realizing the brightest He⁻ beam is experimentally investigated.

Table 1: Specifications of the strongly focused He⁺ beam source. (Design parameters)

Arc Power	~ 40 kW
Pulse Duration	< 10 s
Pulse Reputation	< 0.01 Hz (> 120 s)
Beam Energy	< 30 keV
Beam Current	~ 3 A
Extraction Region	φ100 mm, Concaved
Extraction Apertures	φ4 mm x 300 apertures
Beam Divergence	< 0.7 deg.
Focal Length	750 mm

R&D items of the He⁺ beam source for the alpha particle measurement system are;

- He⁺ beam energy and beam current,
- He⁺ beam emittance and energy distribution, and
- Beam size and profile at the focal point.

Because the concaved electrodes made of molybdenum are exposed to a high radiant heat from the plasma, their deformation should affect the beam optics. Electrodes are water cooled to mitigate overheating only at their peripheries for achieving high transparency. Thus the time dependent change of the beam optics arising from electrode deformation is investigated theoretically and experimentally.

The ideal beam envelope extracted from the strongly focused He⁺ ion source has been estimated based on a simple theoretical model. The result neglecting the collision in the gas cell is shown in Fig. 2. At the focal point, the beam size is estimated to be about 20 mm in diameter. If the longitudinal size of the alkali metal vapour cell is 200 mm, the aperture sizes of the entrance and exit of the cell can be less than 35 mm in diameter. Because the beam diverges strongly due to collisions in the cell, the optics toward the down stream transport to

the post-accelerator will be simulated by inserting a gas cell with the present setup.

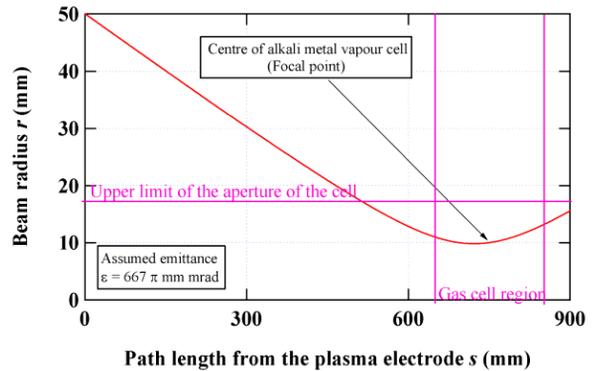


Figure 2: Envelope of the He⁺ beam extracted from the strongly focused He⁺ ion source.

STATUS OF SOURCE DEVELOPMENT

The He⁺ beam source is assembled on a vacuum chamber of the test stand containing beam diagnostics tools. The test chamber has been installed at Neutral Beam Injection (NBI) test stand at National Institute for Fusion Science (NIFS). A photograph of the test stand is shown in Fig. 3. He⁺ beam has not been extracted yet because of the polarity of the high voltage power supplies of the NBI test stand. The construction for changing the polarity will be done in the summer of fiscal year 2006, and the He⁺ beam test will be started from this autumn. Therefore, the plasma production characteristics of the ion source are mainly investigated for the present time.

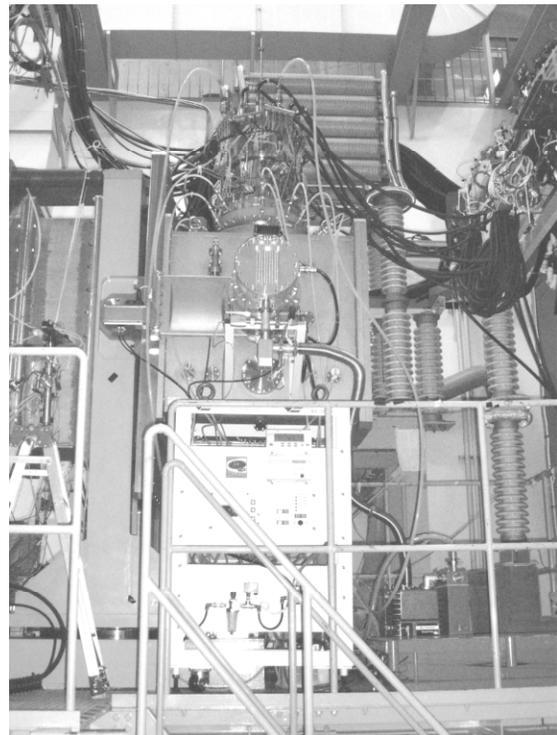


Figure 3: A photograph of the strong focused He⁺ beam source on a vacuum chamber installed at NBI test stand in NIFS.

An experimental result of the arc power of the He⁺ ion source is plotted as a function of the arc voltage in Fig. 4. He plasmas with the arc power exceeding 60 kW, 1.5 times the rated power, has been stably maintained for the 4 s pulse duration. However, present cathode structure requires higher arc voltage for lower flow rate, and is being modified to realize lower arc voltage operation.

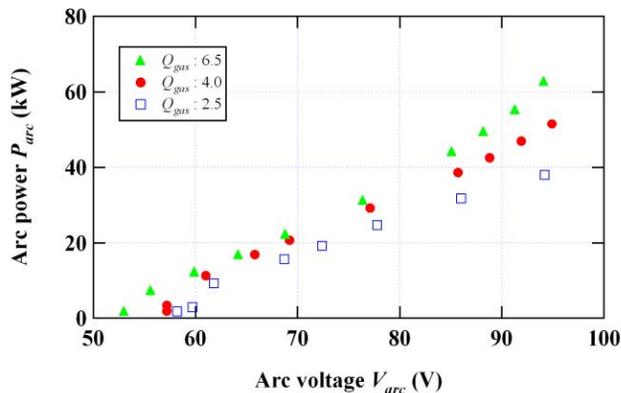


Figure 4: Arc power of He⁺ beam source plotted as a function of arc voltage.

Plasma parameters of He plasma are being investigated with a Langmuir probe. The result shows electron temperature as high as 6 eV indicating good confinement of the primary electrons. Ion saturation current density as high as 200 mA/cm² can be obtained with 20- 30 kW arc power by properly maintaining the discharge.

BEAM DIAGNOSTIC APPARATUSES

Because of the high power density of the extracted He⁺ beam, particularly at the focal point (~300 MW/m²), beam current monitors that absorbs the beam power should be used with enough carefulness. To measure the He⁺ beam current correctly to distinguish the particle flux neutralized by the residual gas, a current transformer type beam monitor is under construction. A nanocrystalline soft magnetic material called *FINEMET* developed by Hitachi Metals[7] is employed as a magnetic core of the current transformer. The magnetic characteristics of the *FINEMET* have been measured and it is known to have high permeability at high frequencies. The beam pulse duration can be less than 1 s in the test stand operation depending upon the beam condition. The design of the beam current monitor system will guarantee enough time response for aperture as long as 50 cm.

To measure the precise spatial distribution of the beam power at high power density operation, a set of a tungsten-brush-type beam dump, optical components and

a far infrared radiation (Far-IR) camera is designed to be employed as a beam power profile monitor. The beam dump is designed applying the result obtained from tungsten brush armour tiles proposed for use in ITER plasma facing components.[8] As the spatial resolution of infrared radiation due to heating by energetic particle flux density is enhanced at the surface of honeycomb structure of tungsten rods, the heat flux distribution can be monitored by a far-IR camera installed outside of the vacuum chamber. Phase space distribution of the beam will be also measured by scanning the beam profile monitor longitudinally.

SUMMARY AND FUTURE PLAN

A strongly focused He⁺ beam source has been put into operation, and the plasma performance is now being optimized. Appreciable warp of three concave electrodes has not been observed yet with the plasma operation. After changing the polarity of the power supply system, effects due to ion beamlets striking extraction electrodes upon electrode warp will be investigated starting this summer. Diagnostics of extracted beams from the source begins from this autumn. Construction of the total beam current monitor system, the beam profile measurement system and the beam emittance measurement system is now underway.

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