Proceedings of the Korean Nuclear Society Autumn Meeting
Seoul, Korea, October 2001

# Discharge Characteristics of an MFTF-B Short Pulse Ion Source

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## Abstract

The discharge characteristics of an MFTF-B (A Tandem Mirror Fusion Test Facility) short pulse (0.5 sec) NBI (Neutral Beam Injection) ion source was investigated with low arc power (<10 kW) and filament heating power (<75 kW). The ion source will be used for the preliminary experiment of beam extraction prior to a prototype LPIS (Long Pulse Ion Source) of the KSTAR (Korea Superconducting Tokamak Advanced Research), afterwards. Optimum operating pressure in the ion source was 1 $20 \times 10^{-3}$ torr with hydrogen gas, and the plasma density was 1 $11 \times 10^{10}$ $cm^{-3}$ during the discharge. The electron temperature measured by using a cylindrical Langmuir probe shown two temperature plasma by non-Maxwellian electron effect, which was originated from primary electrons emitted from the hot filament cathode. The deduced values of electron temperature with plasma potential and floating potential were close to the low electron temperature as the increase of the arc power and the plasma density.

## 1. Introduction

A neutral beam injection (NBI) system is essential in the next step fusion experimental devices, such as ITER, for an auxiliary plasma heating, because long pulse or continuous burning experiments are proposed. These devices are required to be operated continuously and without maintenance for a long period since the accessibility to the device is extremely restricted due to its radio activity. The NBI auxiliary heating system is also being developed for the Korea Superconducting Tokamak Advanced Research (KSTAR) tokamak [1]. The prototype long pulse ion source (LPIS) [2], which was developed originally by the Lawrence Berkeley National Laboratory (LBL) [3] and used for the Tokamak Fusion Test Reactor (TFTR), has been designed and is in constructed for the KSTAR tokamak.

Prior to the experiments of beam extraction with a prototype LPIS for the KSTAR tokamak, a MFTF-B (A Tandem Mirror Fusion Test Facility, Lawrence Livermore National Laboratory, USA) short pulse NBI ion source [4-7] will be installed on the KSTAR NBI Test Facility for the preliminary experiments of beam extraction, afterwards. The ion source was designed for 80 kV, 80 A, and 0.5 second operation and discharged with arc and filament power supplies for the KSTAR prototype ion source. The discharge characteristics of an MFTF-B short pulse ion source was investigated with low arc power (<10 kW) and filament heating power (<75 kW). Using the ion source, the low power discharge was not avoidable, because the specifications of two discharge power supplies were not satisfied those for the short pulse ion source.

To prove the discharge characteristics of ion source, the relationships between discharge voltage and current as the operating pressure and the plasma parameters as the arc power were obtained. The plasma parameters, such as plasma density, electron temperature, plasma potential, and floating potential, were measured by using one of two cylindrical Langmuir probes installed near two small side-walls in a discharge chamber. The ion source was discharged in the region of emission-limited mode, because the hot filament was not fully heated to emit the saturated primary electrons, as the applied heating power. Optimum operating pressure was found as the arc power, and the low plasma density was measured with these discharge powers. The electron temperatures measured by using a cylindrical Langmuir probe shown two temperature plasma by non-Maxwellian electron effect, which was originated from primary electrons emitted from the hot filament cathode. In some experimental results with the low plasma density by hot filament discharge [8] and LaB6 cathode discharge [9], which simulates the edge region of a tokamak device, the thermalization of high energy electrons becomes poor and the electron distribution function displays a non-thermal high energy component. For these analysis of Langmuir probe characteristics, non-thermal electron distribution functions can be accurately described by a two temperature distribution model. In this work, the two temperature distribution was compared with plasma potential and floating potential, thus it was found that the deduced values of electron temperature with plasma potential and floating potential were close to the low electron temperature as the increase of the arc power and the plasma density, even though the values were close to the high electron temperature in the very low arc power and plasma density.

## 2. Experimental Setup

An MFTF-B short pulse ion source was designed with the beam extraction area of 10×40 $cm^2$ and 4-slit type accelerating electrodes. Schematic drawing of the short pulse ion source is shown in Fig. 1. The main design parameters of short pulse ion source are as the following: The beam voltage and current are 80 kV and 80 A; The beam species are $D^+$ with the transparency of 0.6 and the perveance of 3.5 μpervs; The pulse length is 0.5 second; The operating duty cycle is 1.0 %; The grid type is a slit-type with Molybdenum shaping rods; The atomic ratios are 67 % of $D^+$, 20 % of $D^{2+}$, and 13 % of $D^{3+}$; The arc chamber type is a magnetic field-free chamber; The beam divergences ($\perp$, $\parallel$) are 1.5° and 0.5°; The electrode insulator is molded ceramic leads and plates; The filaments are arranged as 226 hairpin types with the diameter of 0.5 mm and  20 A per filament; The filament operating power is 9.5  11.5 V and 5.5 kA during the pulse width of 3.5 second; The arc operating power is 21  60 V and 4 kA (35  130 kW); The optimum gas injection rate is $10^{-3}$  $10^{-2}$ torr (20  40 t·ℓ/sec). The ion source was cooled by a passive water-flowing system and pumped a hydrogen gas by one TMP (520 ℓ/sec) and one mechanical rotary pump (380 ℓ

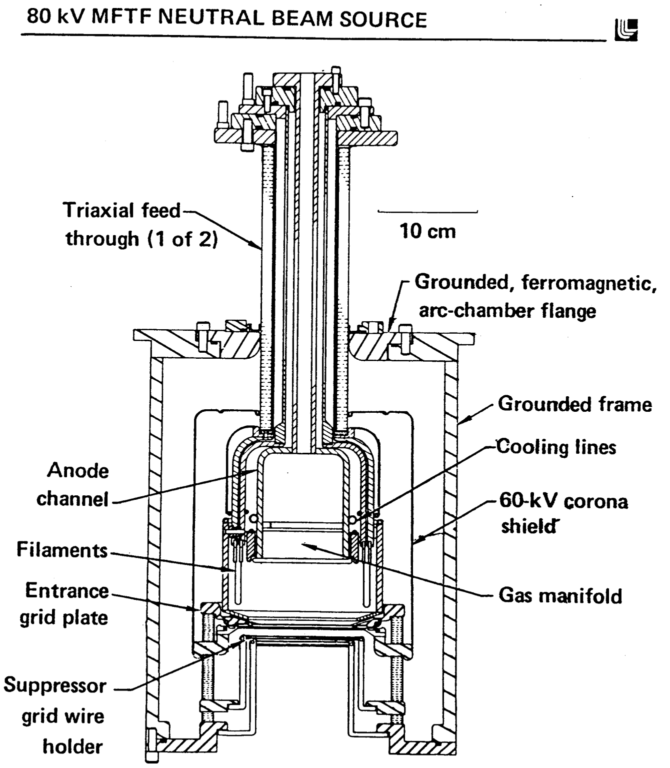

Fig. 1. The schematic drawing of an MFTF-B short pulse ion source.

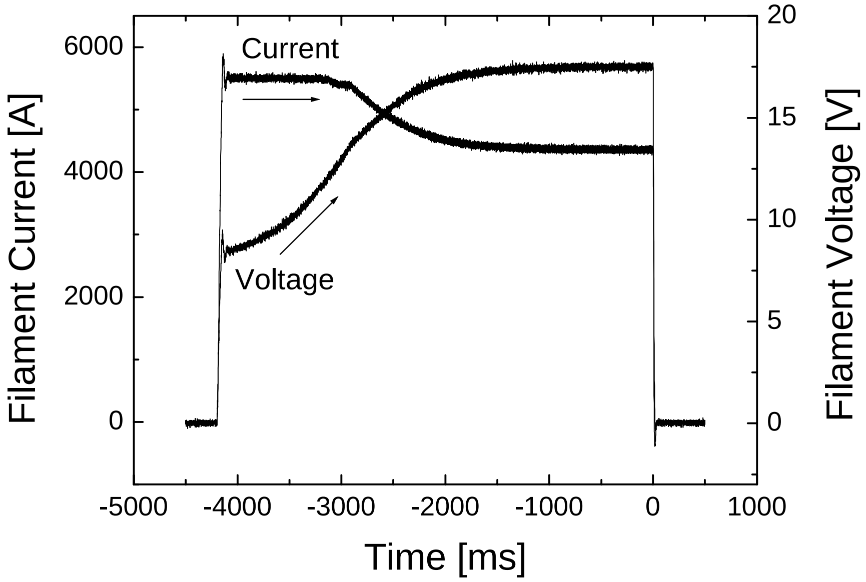

Fig. 2. A time history of filament heating power by constant current (CC) mode operation during about 4 seconds.

/min). Two cylindrical Langmuir probes (diameter = 0.65 mm, length = 4 mm) inserted into the ceramic holder were installed near two small side-walls in a discharge chamber. The plasma parameters were measured by using one of two cylindrical Langmuir probes. To monitor the plasma density variation from the ion saturation current, two Langmuir probes were biased constantly with -50 V relative to the filament electrode during the discharge. The ion source was discharged with low arc power (<10 kW) and filament heating power (<75 kW), because the specifications of two discharge power supplies for the KSTAR prototype NBI ion source were not matched with those for the short pulse ion source. An arc power supply is capable of 0 160 V (DC) and 1200 A (CW), and a filament power supply is also capable of 0 15 V (DC) and 3.2 kA (CW)/5.5 kA (10 sec). The arc and filament power supplies are controlled in a pre-programmed mode on the various operating conditions. A time history of filament heating power by constant current (CC) mode operation during about 4 seconds is shown in Fig. 2. The time of arc discharge during 0.5 second was ended with the one of filament heating at same time. The base pressure in the arc discharge chamber was 3 $4\times10^{-6}$ torr, and a hydrogen gas is injected into the upper side of arc chamber through a mass flow controller (MFC).

## 3. Analyses and Results

Figure 3 shows the variation of arc current as the filament current by constant voltage (CV, 100 V) mode operation of arc power. This result implies that the ion source was discharged in the region of emission-limited mode, because the filament cathode was not fully heated to emit the saturated primary electrons as the applied heating power. Figure 4 shows an example of discharge result with two ion saturation currents from two Langmuir probes by constant current (CC) mode operation of arc power. It was supposed that the large difference of two ion saturation currents was caused by the coating or the breaking of one ceramic probe holder, so the effective area of one probe was larger than the other probe. In further experiments, the difference of two ion saturation currents was more larger than before. This problem can be avoided by more careful fabrication of Langmuir probe in centering the tip into the ceramic holder. The optimum operating pressure as the arc discharge voltage was obtained from the CC (100 A) mode operation of arc power, as shown in Fig. 5. The optimum region of operating pressure was 1 $20\times10^{-3}$ torr. An example of raw logarithmic data for the electron current ($I_e$) from I-V characteristic curve of a Langmuir probe is shown in Fig. 6, showing obviously two electron temperatures.

From the typical I-V characteristic curve by a Langmuir probe, the electron temperature ($T_e$) can be deduced by the difference between plasma potential ($V_p$) and floating potential ($V_f$) [10]: i.e. $V_p$-$V_f$(3.34+0.5lnμ)$T_e$/e. μ is the ion mass ratio normalized to hydrogen, and thus μ=1 for the hydrogen gas. The measured electron temperatures and a deduced electron temperature are shown in Fig. 7, as the arc voltage with constant current (CC) mode operation of filament heating power. The deduced electron temperatures are close to the high electron temperature in the low arc power. Otherwise, as the increase of the arc power, the deduced values are close to the low electron temperature. The increase of arc power implies the increase of plasma density, and theses results as the arc current are shown in Fig. 8, which were obtained from the same experimental shots in the result of Fig. 7.

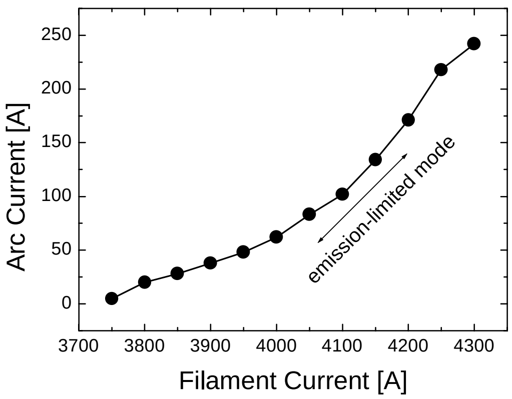

Fig. 3. The variation of arc current as the filament current by constant voltage (CV, 100 V) mode operation of arc power.

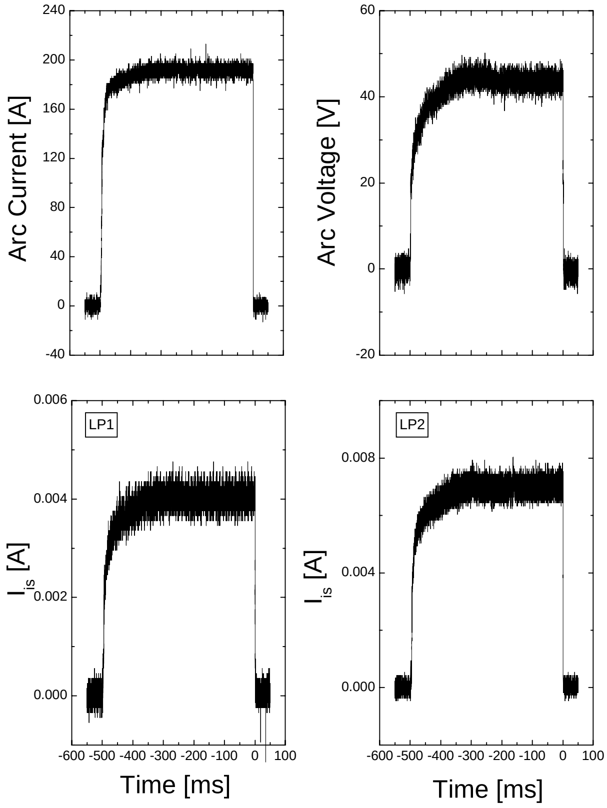

Fig. 4. An example of discharge result with two ion saturation currents ($I_{is}$) from two Langmuir probes (LP1 and LP2) by constant current (CC) mode operation of arc power.

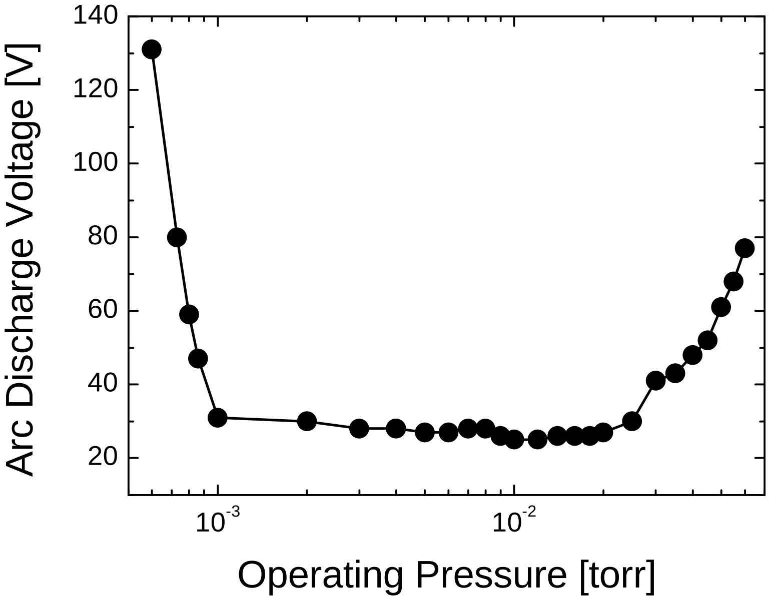

Fig. 5. The operating pressure as the arc discharge voltage from CC (100 A) mode operation of arc power.

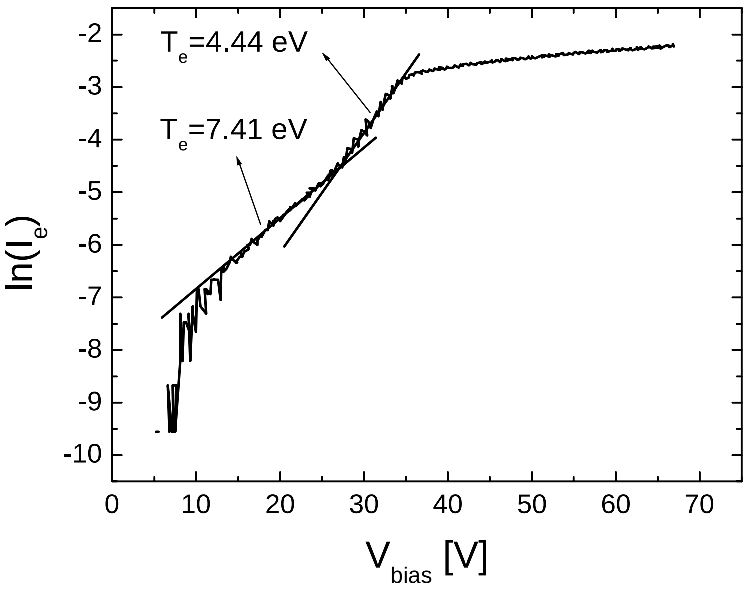

Fig. 6. An example of raw logarithmic data for the electron current ($I_e$) as the sweeping bias voltage ($V_{bias}$) from I-V characteristic curve of a Langmuir probe.

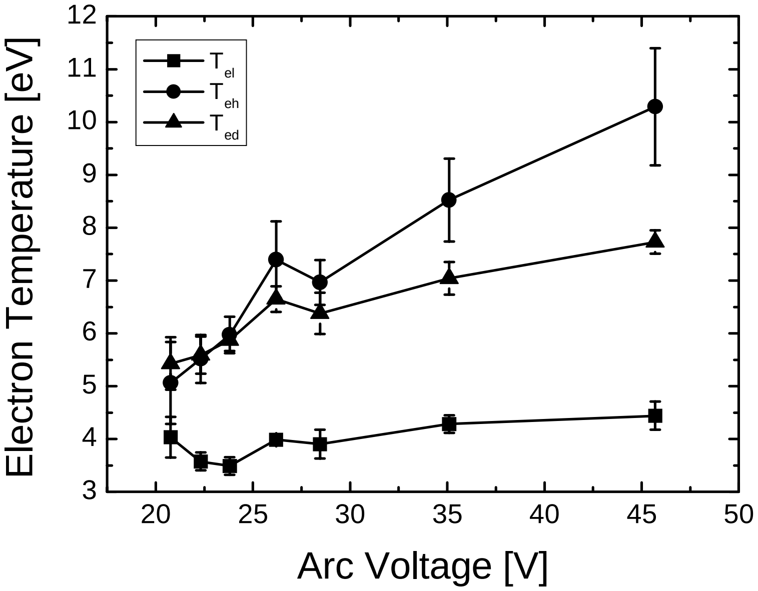

Fig. 7. The measured electron temperatures and a deduced electron temperature ($T_{ed}$) as the arc voltage with constant current (CC) mode operation of filament heating power. $T_{el}$ indicates the low electron temperature, $T_{eh}$ is the high electron temperature.

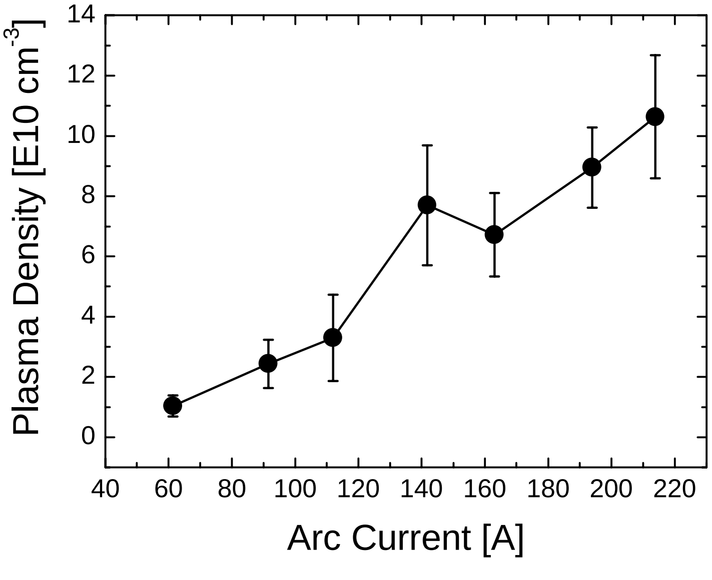

Fig. 8. The plasma density as the arc current.

## 4. Discussions

The discharge characteristics of an MFTF-B short pulse NBI ion source was investigated with low arc power (<10 kW) and filament heating power (<75 kW). The ion source was discharged in the region of emission-limited mode, because the filament was not fully heated to emit the saturated primary electrons as the applied heating power. The optimum region of operating pressure was 1  $20 \times 10^{-3}$ torr with a hydrogen gas. Two electron temperatures are obtained generally by the raw logarithmic data for the electron current ($I_e$) from I-V characteristic curve of a Langmuir probe. The electron temperature was deduced by the difference between plasma potential ($V_p$) and floating potential ($V_f$). The deduced electron temperatures are close to the high electron temperature in the low arc power. Otherwise, as the increase of the arc power, the deduced values are close to the low electron temperature. The increase of arc power implies the increase of plasma density in low discharge power. The electron temperature in the ion source measured by using a cylindrical Langmuir probe shown two temperature plasma by non-Maxwellian electron effect, which was originated from primary electrons emitted from the hot filament cathode. In this kind of low density plasma, the thermalization of high energy electrons becomes generally poor and the electron distribution function displays a non-thermal high energy component. For these analysis of Langmuir probe characteristics in the ion source with low plasma density, a two temperature distribution model should be needed to describe accurately the non-thermal electron distribution functions. Furthermore, it is expected that the deduced electron temperature of ion source will be approached finally to the low electron temperature of a bulk plasma when the arc power and the plasma density are increased to some extent. To avoid the damage of Langmuir probes in a ion source with the high density plasma, more careful fabrication in centering the probe tip into the ceramic holder is indispensable.

## Acknowledgement

This work has been supported by the KSTAR Project. The authors thank the staffs of Nuclear Fusion Laboratory, Nuclear Physico-Engineering Team in Korea Atomic Energy Research Institute (KAERI), for their comments and technical supports.

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