J. Plasma Fusion Res. SERIES, Vol. 4 (2001) 391–394

Radial Electric Field Control with a Biased Hot Cathode in the Tohoku University Heliac

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(Received: 5 December 2000 / Accepted: 5 October 2001)

Abstract

The influence of a negative biased electrode on the plasma parameters in the Tohoku University Heliac (TU-Heliac) with an emissive hot cathode made of LaB_6 is investigated. It is found that this negative biased hot cathode, which works as an electron source, induces the strong negative radial electric field, the increase in line density and the increase in energy confinement time. The formation of the negative radial electric field depends on the power input through the hot cathode.

Keywords:

plasma, helical axis stellarator, heliac, electrode, biasing, hot cathode, radial electric field, H mode

1. Introduction

The high confinement mode can be triggered by a biased electrode inserted in the Tokamak plasma [1-3]. Radial electric field control in a helical axis stellarator is also one of very important research subjects for understanding the mechanism of the H mode. Furthermore in a heliac configuration a center conductor coil is surrounded with a helical plasma, thus it is possible to substitute a center conductor coil can for a biased electrode in order to control the radial electric field if this coil can is set inside a vacuum vessel and insulated electrically from the vacuum vessel.

We have investigated the influence of biasing electrode on the plasma parameters in the TU-Heliac with a small spherical electrode made of a stainless steel ball [4]. We have observed the substantial plasma parameter changes after the electrode biasing: the increase in line density, the steeping of electron density profile, the fluctuation suppression and the formation of a strong *positive* radial electric field and large plasma rotation. However, we have never observed any significant effects by *negative* biasing with this small electrode in TU-Heliac. This is because this cold electrode can not collect a sufficient radial current in negative biased cases. Furthermore, we can not clarify the dependence of a stored energy on the input power through the electrode because of the difficulty in the power control of the cold electrode. For above reasons we changed the electrode into a hot cathode made of LaB_6. It is convenient to control the emission current and the bias voltage, namely the input power through the hot cathode.

In this paper the experimental results of radial electric field control with a hot cathode and the influence on the plasma parameters in TU-Heliac are presented. We also studied the dependence of a stored energy on the input power through the hot cathode.

2. Experimental Results

TU-Heliac is a small heliac without an inner helical winding (number of field period is 4, major radius is 48

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cm, average radius of the last closed flux surface is ~7 cm) [5]. In this experiment the plasma was produced with low frequency ($\omega < \omega_{ci}$, ω_{ci}: ion cyclotron frequency) ohmic heating. The low frequency ohmic heating power (f = 18.7 kHz, P_{max} = 35 kW) is supplied to RF coils which are wound outside toroidal field coils like vertical field coils [6].

The experimental set-up is shown in Fig. 1. The electrode is a cylindrical hot cathode made of LaB_6, 10 mm in diameter and 17 mm in length. The *leg* of the hot cathode for electrical connection is 10 mm in length and the total length of the hot cathode is 27 mm. The maximum emission current I_e is about 8 A. The hot cathode is inserted horizontally from the low field side and located at a toroidal angle ϕ = 270° and negative bias voltage V_e is applied against to the vacuum vessel, which works as an electron source. The target plasma is sustained only by low frequency ohmic heating. The following results are obtained in the target plasma at $n_e = 0.6 \times 10^{12}$ cm^{-3} (Helium), $T_e \sim 25$ eV and the magnetic field on axis is 0.31 T. The line density is measured along a vertical chord passing through a magnetic axis with a 6 mm microwave interferometer which is placed at a toroidal angle ϕ = 90°.

Typical temporal behavior of the heliac plasma parameters is shown in Fig. 2, which clearly shows that the plasma parameters change substantially after the electrode biasing. The hot cathode is biased up to V_e = –350 V at t = 3.75 ms and a hot cathode current I_e flows up to 5 A (Fig. 2 (a)). The top position of the hot cathode is at r = 87 mm. Figure 2(b) shows the line density and the density at r = 130 mm, where r is the minor radius which is the distance from the axis of the center conductor coil. The line density increases by factor of 3 without gas feed. In contrast, the density at r = 130 mm, where is about 10 mm outside the last closed flux surface (LCFS), remains constant during the biasing. This indicates that the electron density profile becomes steep. On the other hand, the electron temperature decreases to about half (Fig. 2 (c)). In Fig. 2 (d), the difference among the floating potential signals measured at three different radial points shows that the strong negative radial electric field is formed by the hot cathode biasing and the polarity of this radial electric field changes from positive to negative at t = 3.75 ms, although the absolute value of the electric field is small. Figure 2 also shows that the radial electric field is formed more rapidly than the growth of the electron density, which indicates that the radial electric field is the cause of the increase in the electron density. This delay time in the density and the potential may be associate with the particle confinement time.

The dimension of the hot cathode is somewhat too large for the small size plasma in TU-Heliac. Therefore, we carefully covered feeders of the cathode with insulator in order to isolate the cathode feeders from

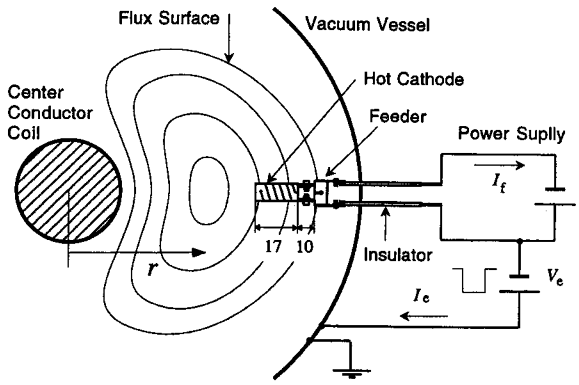

Fig. 1 Experimental set-up of the hot cathode, which is made of LaB_6, 10 mm in diameter and 17 mm in length. The *leg* of the hot cathode for electrical connection is 10 mm in length and the total length of the hot cathode is 27 mm. The feeders of the cathode are covered with insulator. The hot cathode is inserted horizontally from the low field side and negative bias voltage V_e is applied against to the vacuum vessel.

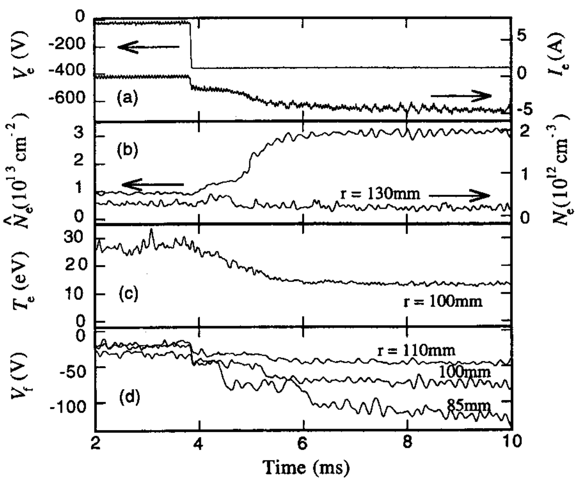

Fig. 2 Time evolutions of (a) hot cathode bias voltage V_e and emission current I_e, (b) line density and density at r = 130 mm, (c) electron temperature at r = 100 mm and (d) floating potential V_f at r = 85, 100 and 110 mm. The top position of the hot cathode is at r = 87 mm.

plasma electrically. The behavior of biased plasma depends on the hot cathode position. Figure 3 shows (a) the dependence of the plasma space potential on *top position* of the hot cathode, (b) the line density and (c) the emission current of the hot cathode. In this case the hot cathode bias voltage V_e is –350 V and the filament current I_f for heating is 23 A. The plasma space potential is measured at r = 100 mm. The total hot cathode length is 27 mm and the LCFS is at r = 117 mm. In Fig. 3 the plasma potential drops and the line density increases at r = 90 mm and this point corresponds to the position where the end part of the cathode is exactly inside of the last closed flux surface. Namely, the plasma space potential begins to drop at the position where the whole part of the cathode is immersed inside of the plasma.

Figure 4 shows typical radial profiles of (a) the electron temperature, (b) the electron density, (c) the plasma space potential and (d) the normalized fluctuation level of the ion saturation current. These are measured with a triple probe placed at a toroidal angle ϕ = 0°. Before biasing, the plasma potential is slightly positive which indicate that the weak positive E_r (< 20 V/cm) exists. On the other hand, after biasing plasma potential clearly changes to negative which indicates that the strong negative E_r (> – 40 V/cm) is produced. The electron density increases by a factor of 5 near the magnetic axis, though the electron temperature decrease to ~12 eV and has an almost flat radial profile, which suggests that the stored energy increases by a factor of 2. Furthermore, the normalized fluctuation level is suppressed after biasing. From these results it seems some improvement of plasma confinement occurs, but we need to survey the dependence of the stored energy on the power input through the hot cathode in order to discuss an improvement of plasma confinement.

Figure 5 shows that the dependence of the product of the electron temperature and the line density on the power input through the hot cathode. We can regard this product of the electron temperature which is measured

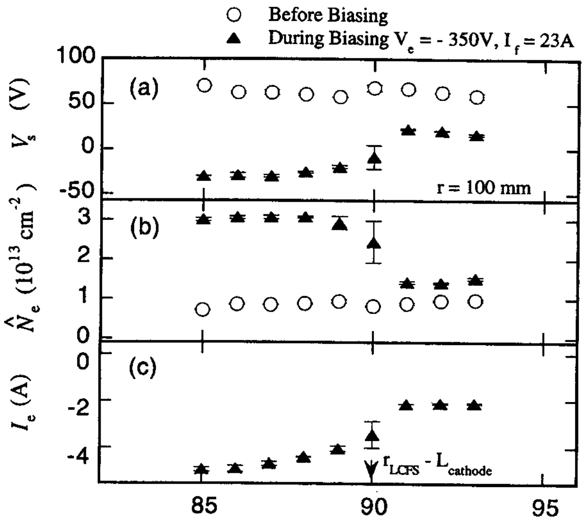

Fig. 3 (a) The dependence of the plasma space potential on top position of the hot cathode, (b) the line density and (c) the emission current of the hot cathode. The plasma space potential is measured at r = 100 mm. The total hot cathode length $L_{cathode}$ is 27 mm and the last closed flux surface (LCFS) is at r_{LCFS} = 117 mm.

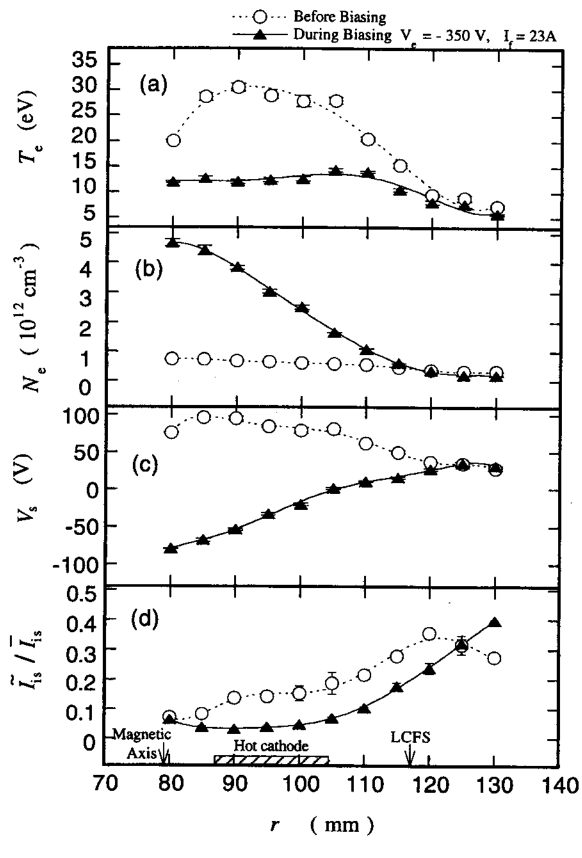

Fig. 4 Radial profiles of (a) the electron temperature T_e, (b) the electron density n_e, (c) the plasma space potential V_s and (d) the normalized fluctuation level of the ion saturation current both before (2.5 ms; open circles) and during (9.5 ms; solid triangles) the biasing of the hot cathode. The magnetic axis is at r = 79 mm, the top position of the hot cathode is at r = 87 mm and the LCFS is at r = 117 mm.

at r = 100 mm and the line density as the stored energy by reason that the electron temperature has an almost flat radial profile. We neglected the low frequency ohmic heating power because no significant changes exist in a plasma current, a loop voltage and phase shift between the plasma current and the loop voltage after biasing. In Fig. 5 it is clear that there are two groups in data, low and high stored energy groups, and the stored energy jumps to the high energy group at a critical input power (~700 W). The negative potential transition and the negative radial electric field appear in this high stored energy group. It is also clear that the gradient for the power dependence in the high stored energy group is about 2 times as large as that for the low stored energy group. This indicates that the increase in an energy confinement time occurs by radial electric field control with the hot cathode. The energy confinement time is about 70 μsec which is roughly estimated from the gradient in the high stored energy group.

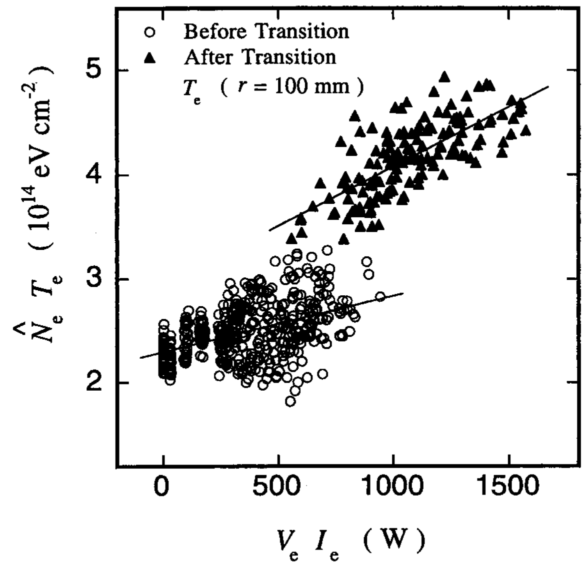

Fig. 5 The dependence of the product of the electron temperature T_e at r = 100 mm and the line density on the input power $V_e I_e$ through the hot cathode. The open circles and solid triangles indicate the data before and after potential transition. The top position of the hot cathode is at r = 87 mm.

3. Summary

The negative biased hot cathode induces the strong negative radial electric field and the increase in line density. The plasma space potential begins to drop at the position where the whole part of the cathode is immersed inside of the plasma. The energy confinement time after the potential transition is about 2 times as large as the time before the transition.

Acknowledgment

We are grateful to Shigeru Inagaki for his useful discussions. Thanks are also due to Satoru Itoh and Kazutoshi Kitago for assistance with the experiments.

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