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Biasing Experiments with a Ti Electrode in the Tohoku University Heliac

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Abstract

Improvement of plasma confinement was observed in the Tohoku University Heliac (TU-Heliac) when the Titanium (Ti) electrode was biased positively. In addition, the electron density and the line intensity of H_α increased by about 10-fold as compared with those before biasing when the Ti electrode was biased negatively. The latter phenomenon, which was not observed by negative biasing with a stainless steel electrode, suggested that the Ti electrode emits electrons/neutral particles into the plasma when biased negatively.

1. Introduction

Since its discovery in the ASDEX tokamak in 1981 [1], the H mode has been observed in many devices [2–5]. In the Tohoku University Heliac (TU-Heliac), the influence of a radial electric field on the improved modes has been investigated by electrode-biasing experiments. In both positive and negative biasing experiments with a stainless steel (SUS) electrode (cold-electron or ion collection), the improvement of plasma confinement was clearly observed when the radial electric field was formed [6]. Furthermore, by negative biasing with a hot cathode (electron-emission), the radial electric fields can be actively controlled as a consequence of control of the electrode current, I_E [7–9].

Here, we report the first experimental results using a Titanium (Ti) electrode. Using an electrode made of a hydrogen storage metal, such as Titanium (Ti) or Vanadium (V), the following can be expected: (1) ions accelerated from the positive-biased electrode allow simulation of the orbit loss of high-energy particles, and (2) the electrons/neutral particles injected from the negative-biased electrode provide production of high-density plasma if hydrogen is successfully stored in the electrode.

2. Experimental setup

The TU-Heliac is a small standard heliac device of $n = 4$ [10, 11]. The heliac configurations are produced by three sets of coils: toroidal field coils, a centre conductor coil, and vertical field coils. Various magnetic configurations can be formed easily by selecting ratios of coil currents, and Fourier components can be varied over a wide range. The target plasma was produced by ohmic heating with an 18.8 kHz alternating current in additional radio frequency coils. The vacuum vessel was filled with a fuel gas (He or Ar) before discharges.

Plasma parameters were measured with a Langmuir probe (triple probe) at toroidal angle

$\phi = 0°$ and a 6-mm microwave interferometer at $\phi = 90°$. The line intensity of H_α, $I_{H\alpha}$, was measured with a 25-cm monochromator coupled with a CCD and a photo multiplier tube at $\phi = 159°$.

The position of the Ti electrode is shown in Fig. 1 together with the computed cross-section of the magnetic flux surfaces in the vacuum at $\phi = 0°$. The Ti electrode was inserted into the plasma, vertically from the top at $\phi = 0°$. It was biased positively or negatively against the vacuum vessel through a field-effect transistor (FET). The Ti electrode measuring 10 mm in diameter and 7 mm in length was fixed at the end of the copper shaft housed in a glass tube as an insulating sheath. The Ti electrode was conditioned in the upper chamber separated by a gate-valve. The temperature of the Ti head could be controlled by heating a Tungsten wire 0.15 mm in diameter and was measured with a thermocouple.

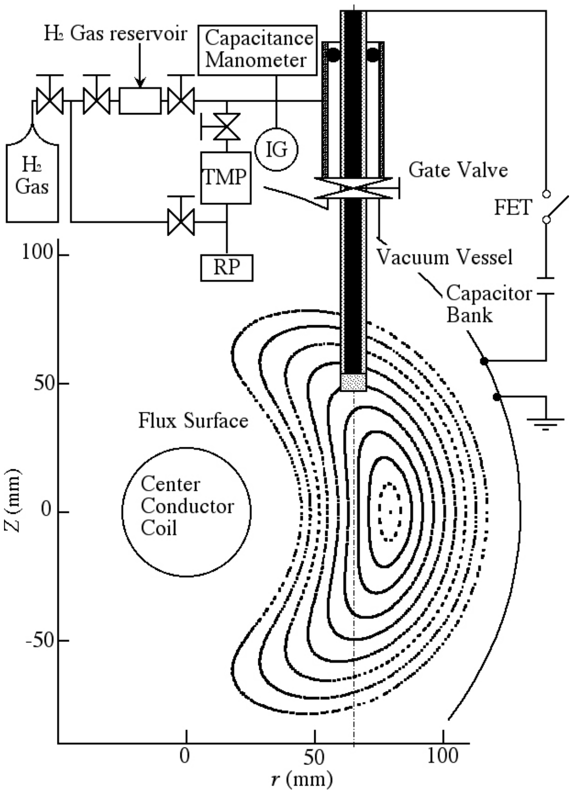

Fig. 1 The position of the Ti electrode and the computed cross-section of the magnetic flux surfaces in the vacuum at $\phi = 0°$. The Ti electrode was conditioned in the upper chamber separated by a gate-valve, and was inserted into the plasma, vertically from the low magnetic field side. The electrode was biased positively or negatively against the vacuum vessel.

3. Experimental results

3.1. Positive biasing

After treatment for hydrogen storage ($p_{H2} = 2.7\times10^5$ Pa, 12 hours), the Ti electrode was positively biased. Figure 2 shows the typical time evolutions of (a) the electrode bias voltage, V_E, and the electrode current, I_E, (b) the electron density at $r = 90$ mm, (c) the plasma potential, V_s, at $r = 90$, 105 and 115 mm and (d) the line intensity of H_α, $I_{H\alpha}$. The Ti electrode was positively biased from 4 ms to 10 ms. This electrode biasing resulted in increases in the plasma potential, and the line intensity of H_α and the electron density increased by about 2-fold as compared with those before biasing. Figure 3 shows the differences in the profiles of

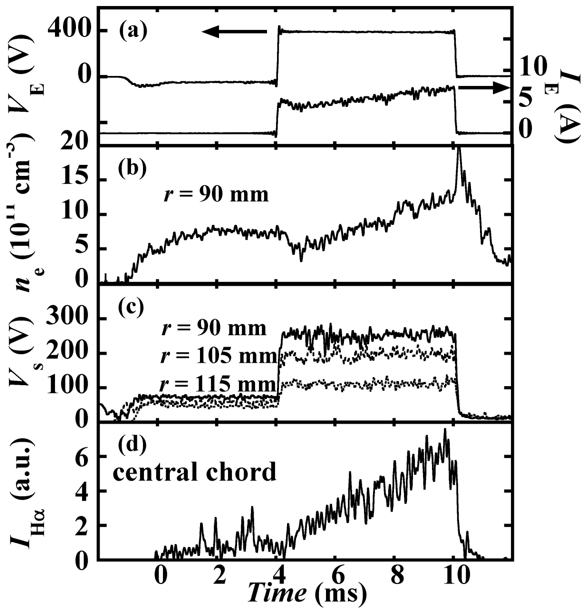

Fig. 2 Typical time history of (a) the electrode bias voltage, V_E, and the electrode current, I_E, (b) the electron density at $r = 90$ mm, (c) the plasma potential, V_s, at $r = 90$, 105 and 115 mm (d) and the line intensity of H_α, $I_{H\alpha}$, on positive biasing.

(a, e) the electron density, n_e, (b, f) the electron temperature, T_e, (c, g) the plasma potential, V_s, and (d, h) the radial electric field, E_r, measured with the triple probe, between the SUS electrode (left side) and the Ti electrode (right side) biasing experiments, both before biasing (solid circles) and during biasing (open triangles). In the case of Ti electrode biasing, the radial distribution of the electron density sloped steeply at r = 60 ~ 90 mm (e) and a strong positive radial electric field was formed at r = 100 ~ 120 mm (h), indicating improvement of plasma confinement. In positive biasing, an electrode is collecting electrons. In biasing of both the SUS electrode and the Ti electrode, the electrode currents were almost the same. This current level was too high to induce the improved mode for SUS electrode biasing. On the other hand, in the plasma biased by the Ti electrode, the electron density increased inside the electrode position. This suggested that the hydrogen storage electrode made of Titanium injected hydrogen ions.

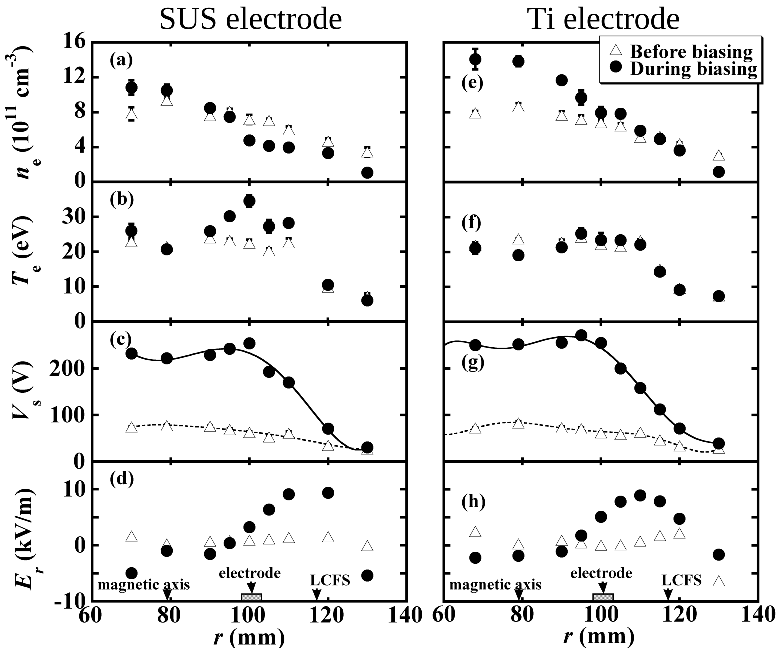

Fig. 3 Comparison of the SUS electrode (left side) biasing experiment with the Ti electrode (right side) biasing experiment profiles of (a) the electron density, n_e, (b) the electron temperature, T_e, (c) the plasma potential, V_s, and (d) the radial electric field, E_r, measured with the triple probe, both before biasing (solid circles) and during biasing (open triangles).

3.2. Negative biasing

In some Ar discharges biased *negatively* with the Ti electrode after treatment, the electron density and the line intensity of H_α increased by about 10-fold as compared with those before biasing. Typical time histories of plasma parameters are shown in Fig. 4. When the Ti electrode was negatively biased from 4 ms to 10 ms, (a) the electrode current, I_E, (b) the line electron density, $n_e l$, (c) the electron density at r = 90 mm, (e) the plasma potential, V_s, at r = 90 mm and (f) the line intensity of H_α, $I_{H\alpha}$, increased rapidly, and (d) the electron temperature, T_e, decreased. This phenomenon has not been observed by negative biasing with the SUS electrode. Such high-density plasma production was observed only 1 ~ 3 times in the treatment for hydrogen storage. There was a threshold in the electrode bias voltage. This result suggested that the mechanism of high-density plasma production was the injection of electrons/neutral hydrogen from the Ti electrode into the plasma, caused by sputtering of Ar ions and hydrogen ions. Using a Vanadium (V) electrode, production of the high-density plasma, which was the same as that produced in the Ti electrode experiments, was observed.

4. Summary

In the TU-Heliac, in the case of the Ti electrode biased *positively* after treatment for hydrogen storage, the improvement of plasma confinement was observed in He plasma, which was the same as the experimental results with the SUS electrode. However, in the electron density profiles inside the electrode position there were differences between the plasma biased by the Ti electrode and that biased by the SUS electrode.

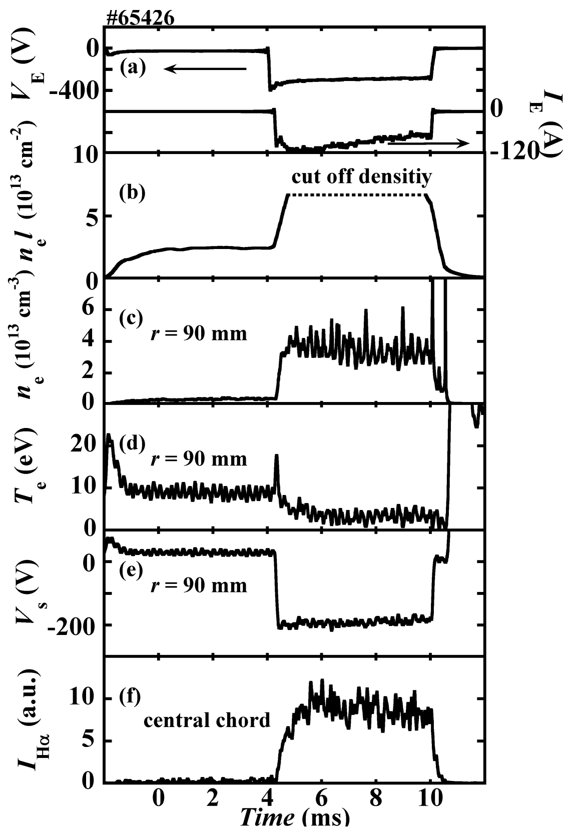

Fig. 4 Time evolution of (a) the electrode bias voltage, V_E, and the electrode current, I_E, (b) the line electron density, $n_e l$, (c) the electron density at r = 90 mm, (d) the electron temperature, T_e, (e) the plasma potential, V_s, at r = 90 mm and (f) the line intensity of H_α, $I_{H\alpha}$, using the Ti electrode with negative biasing.

In some Ar discharges biased *negatively* with the Ti electrode after treatment, the electron density and the line intensity of H_α increased by about 10-fold as compared with those before biasing. This phenomenon was not observed in Ar plasma biased by the SUS electrode, suggesting that the Ti electrode injects electrons/neutral hydrogen into the plasma.

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