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ECR discharge cleaning and followed He GDC on HT-7 tokamak

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ABSTRACT

A study of ECR discharge cleaning is conducted on HT-7. Radio frequency (RF) waves of 2.45 GHz were used under toroidal field of 0.088–0.066 T. Toroidally symmetric ECR plasmas were obtained, and the resonance layers were scanned by toroidal field. RF powers, neutral pressures and working gas species were investigated as parameters of cleaning. And ECR was compared with ICR discharge cleaning. After the cleaning, the enhancement of wall recycling and the increase of carbon and oxygen impurities were observed in the followed shots. Another ECR discharge cleaning was followed by He GDC, it was shown that the intensity of H_α radiation was much lower than that before cleaning. This indicates that D_2 ECR discharge cleaning followed by He GDC is effective for wall conditioning.

1. Introduction

It has long been recognized that impurities and wall recycling play a critical role on tokamaks. Impurities mainly cause the radiation loss of power and the dilution of the hydrogenic species, furthermore impact plasma stability and global energy confinement [1]. ECR discharge cleaning is one of the effective ways for impurities removal, and it has been performed on many fusion devices under very broad parameters as shown in Fig. 1, see also [2–9]. It was reported that ECR discharge cleaning has as good as or even better cleaning effect than GDC and TDC [2,3], it is effective for both ohmic heated and lower hybrid current drive (LHCD) plasmas on TRIAM-1 M [4]. Furthermore, it was found that the ECR in D_2 was effective to desorb tritium from the graphite first wall on JT-60U [8]. ECR discharge cleaning is one of the candidates of wall conditioning for ITER. However, the disadvantage and weak point of ECR discharge cleaning for the recovery of plasma discharges were studied by only a few papers. The enhancement of recycling caused by ECR is a crucial problem for plasma breakdown and density control. In JT-60U, the initiation of ohmic discharge was difficult because of the enhancement of outgas from the first wall after D_2 ECR discharge cleaning, while GDC in He was useful to reduce the recycling rate and to obtain low recycling ohmic discharges [8].

Recently, two cases of ECR discharge cleaning and recycling control were studied experimentally in detail on HT-7 superconducting tokamak [10], one was ECR discharge cleaning in D_2 only, and the other was immediately followed by He GDC. The impact of ECR discharge cleaning in this paper is emphasized on the changes of impurities and recycling, by studying loop voltages, intensities of CIII, OII emissions and H_α radiation at the plasma breakdown.

2. Experimental setup

The material of HT-7 superconducting tokamak first wall is stainless steel, and 18% of the wall is covered by graphite tiles [11]. Fig. 2 shows schematic experimental setup for ECR discharge cleaning on HT-7 tokamak. A piezoelectric valve was induced in the gas puffing system to control the flux of gas injection, one molecular pump with pumping speed of 600 l/s was taken into use. The microwave power at the frequency of 2.45 GHz was supplied by Lower Hybrid Radio Frequency (LHRF) system with the maximum power output of 1.2 MW [12], which is composed by 12 klystrons, while only the area in highlight frame as shown in Fig. 3 were employed in this experiment without any change, and RF powers used in discharge cleaning were 3, 5 and 9 kW. Toroidal magnetic field at the radial center was set at ~0.088 T. A vertically movable triple Langmuir probe was installed to measure the electron temperature of the plasma, along with a visible camera to observe the position of the ECR plasma from a top port. A vacuum ionization gauge, a Residual Gas Analyzer (RGA) and a differentially pumped system with another RGA were equipped at the outlet of vacuum chamber, to monitor partial pressures of different gas ingredients pumped out of the chamber.

The ECR discharge cleaning was carried out with the power of 3–9 kW under the D_2 of $(0.78–8.3) \times 10^{-2}$ Pa, for totally 36 min discharge, the influence of different parameters on removal rates were investigated. Another ECR discharge cleaning employed RF power of 8–10 kW under 7.2×10^{-2} Pa for 20 min, followed by He GDC of 275 min using only one electrode with the voltage of

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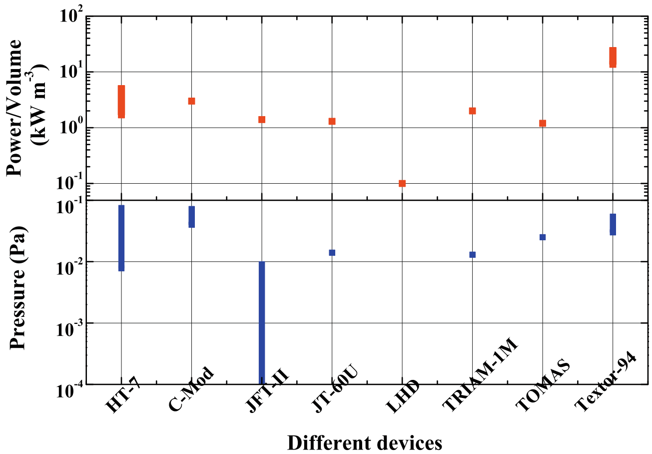

Fig. 1. Power densities and total pressures used in ECR discharge cleaning by different devices.

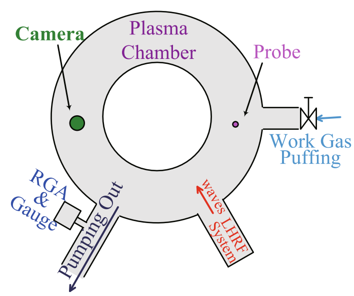

Fig. 2. Schematic experimental setup of ECR discharge cleaning on HT-7.

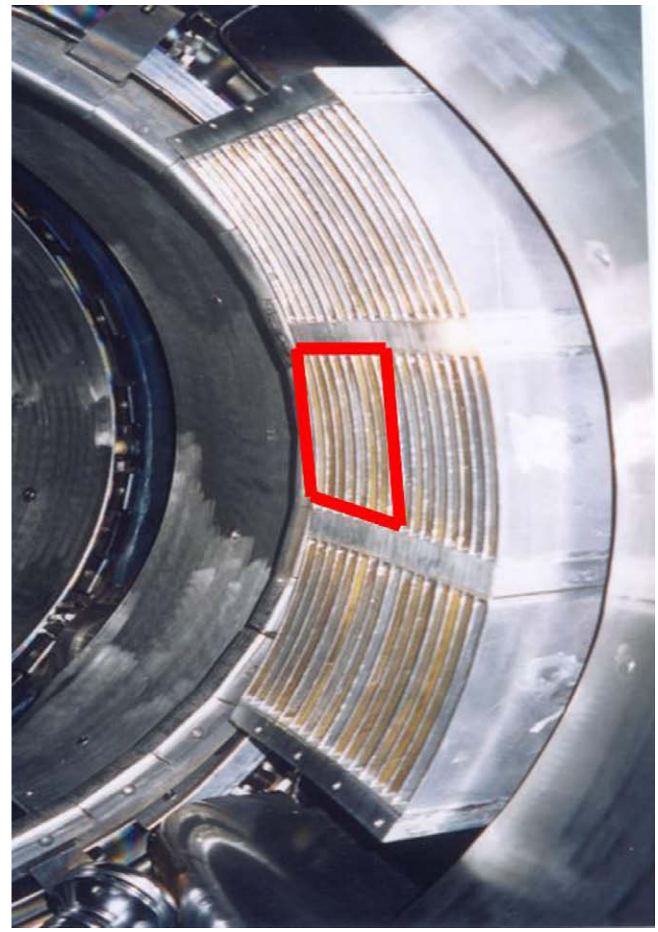

Fig. 3. The antenna of LHRF system on HT-7, the area in highlight frame was employed in the experiment.

220 V and current of 2 A under He 5×10^{-3} Pa. The two cases discharge cleanings were compared experimentally in detail in view of the performance of plasmas.

3. Results

ECR plasmas of ~3 eV and 1–5 $\times 10^{16}$ m^{-3} were obtained with RF power of 5 kW at D_2 pressure of 2.7×10^{-2} Pa. The ECR plasmas were observed from the camera at the top port, it shows that they seemed toroidally symmetric and mainly concentrated on the resonance layer in radial direction. Plasma region was observed to be moving to higher field side (HFS) until disappear along with descending scanning of the toroidal field from 0.088 T to 0.066 T, which was well coincident with the fundamental resonance of electron. Different parameters of RF powers, neutral pressures and working gas species were studied via the variation of partial pressures. The RF powers of 3, 5 ad 9 kW used in ECR discharge cleaning made little difference on cleaning, while neutral pressure of working gas played a important role on the impurities removal, it was observed that higher pressure induced better removal in view of partial pressures of $m/e = 2$, 18, 28, 32, 44 in the D_2 pressures of 7.8×10^{-3}, 2.7×10^{-2} and 8.3×10^{-2} Pa. Moreover, it was shown that working gas D_2 had higher removal rates than He under the similar parameters as shown in Fig. 4. ECR was also simply compared with ICR discharge cleaning [11] in the respect of removal rates of H atoms. It shows that ECR discharge cleaning was 5–10 times lower than that of ICR.

However, after cleaning the discharge could not be recovered, and most discharges were disruptive. The loop voltage at the plasma breakdown was increased dramatically as shown in Fig. 5(a), which indicates much worse condition of the first wall than that

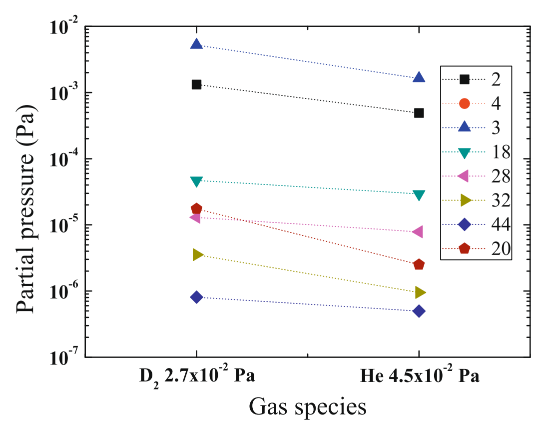

Fig. 4. Partial pressures during ECR discharge cleaning in deuterium and helium.

before. The intensities of H_α emission normalized by electron density were increased too as shown in Fig. 5(b), which suggests the enhancement of the wall recycling. The increased wall recycling may be due to the absorption of D_2 into the wall associated by ECR plasma, which enhanced the outgassing of D_2 at the plasma initiation [9]. Moreover, the intensities of CIII and OII radiation were also enhanced as shown in Fig. 5(c) and (d), respectively.

After the two cases of ECR discharge cleanings, both the base pressures were decreased, from 2.5×10^{-5} to 1.5×10^{-5} Pa at the first time of ECR, and from 1.2×10^{-5} to 8.4×10^{-6} Pa at the

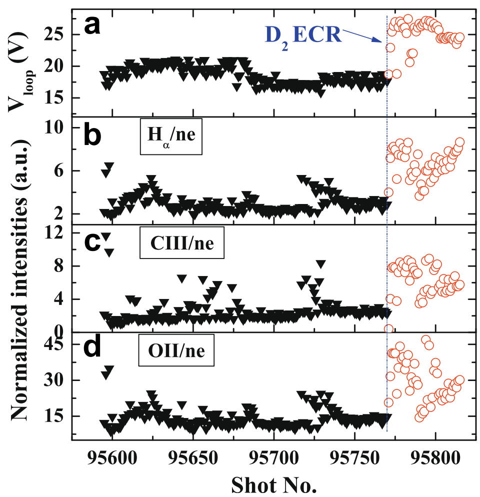

Fig. 5. Influence of D_2 ECR discharge cleaning on plasmas: (a) is loop voltages; (b), (c) and (d) are intensities of CIII, OII and H_α normalized by electron density at the plasma breakdown respectively, Solid down triangles are before cleaning, and open circles are after cleaning, broken line represents ECR discharge cleaning.

second. It indicates that good removal of impurities was obtained. Most partial pressures of ingredients were also decreased greatly, but the partial pressures of $m/e = 18$, 19 and 20 were increased obviously as shown in Fig. 6. They were considered mainly as the oxides and carbides of hydrogen and its isotopes (H_2O, HDO, D_2O, CD_4, etc.), which were formed during the ECR discharge cleanings. However, much of them were probably redeposited on the wall instead of being pumped out. Therefore after ECR discharge cleaning the outgassing of the first wall was increased, impurity radiations were enhanced, and the performance of tokamak plasmas was depressed.

After ECR discharge cleaning, it was suggested that GDC in He was useful to reduce the recycling rate and to obtain low recycling ohmic discharges in JT-60U [8]. In HT-7 tokamak, another ECR discharge cleaning followed by He GDC was also studied. After the ECR + GDC cleaning, the discharge was recovered immediately, and the plasma performance (shot 91307) was improved notably as shown in Fig. 7. Moreover, it was observed that the intensity

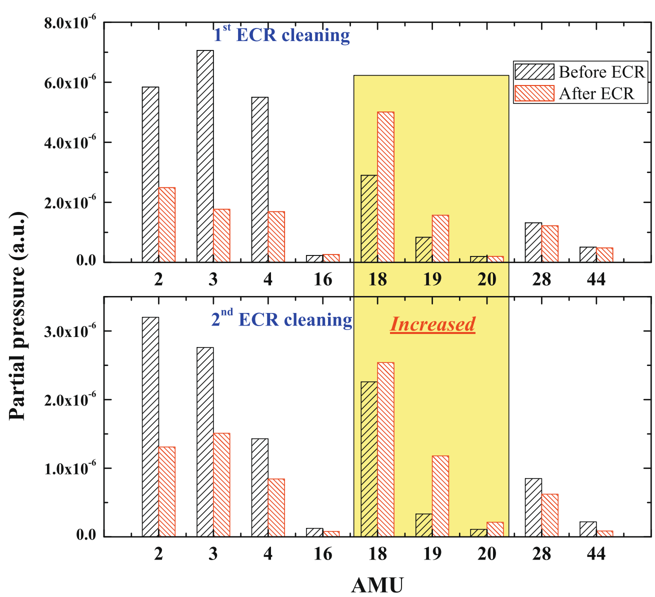

Fig. 6. Partial pressures of different ingredients before and after ECR cleanings.

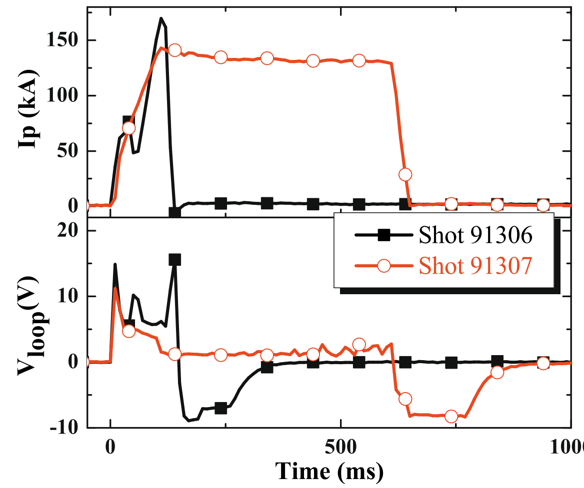

Fig. 7. Plasma currents and loop voltages before (91306) and after (91307) ECR + GDC.

of H_α was much lower than that before cleaning as shown in Fig. 8(b), and loop voltages were decreased greatly in Fig. 8(a). It indicates that good control of He GDC after ECR discharge cleaning

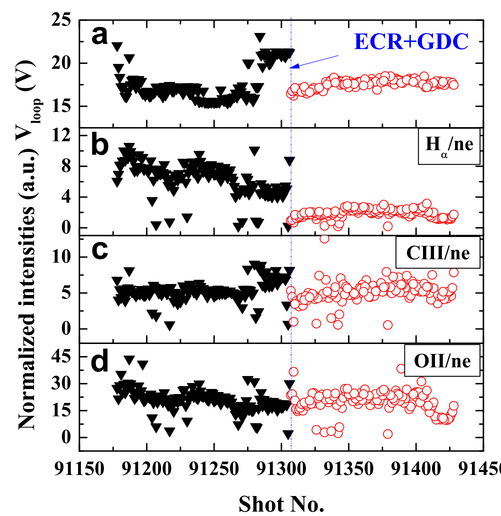

Fig. 8. Influence of ECR + GDC on plasmas: (a) is loop voltages; (b), (c) and (d) are intensities of H_α, CIII and OII normalized by electron density at the plasma breakdown, respectively.

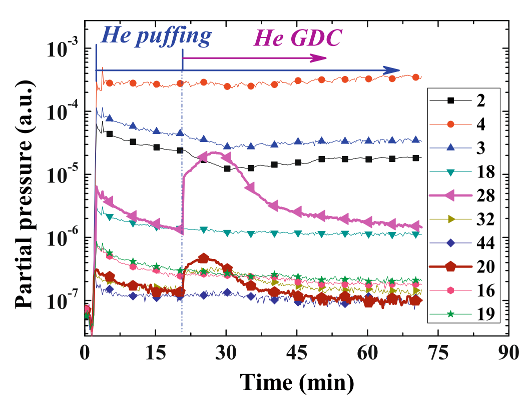

Fig. 9. Time evolutions of partial pressures during He GDC after ECR discharge cleaning.

on hydrogen recycling was achieved. During the He glow discharge after ECR discharge cleaning, besides the replacement of deuterium with helium, it was observed that CO and hydrocarbon impurities were removed from the carbon surfaces as shown in Fig. 9, which may be the reason why the intensity of CIII was lower than before cleaning as shown in Fig. 8(c).

4. Conclusions

ECR discharge cleaning of 2.45 GHz and followed He GDC were carried out on HT-7 superconducting tokamak. Toroidally symmetric ECR plasmas were obtained, and the resonance layers were scanned by toroidal field. RF powers of 3, 5 and 9 kW were tested on HT-7 tokamak. It was observed that RF powers made little difference, and higher neutral pressure resulted in higher cleaning efficiency, and working gas D_2 had higher removal rates than that of He. Removal rate of hydrogen in ECR discharge cleaning was 5–10 times lower than that in ICR. However, after the ECR discharge cleaning, the enhancement of hydrogen recycling and the increase of carbon and oxygen impurities were observed in the followed shots. Another ECR discharge cleaning was followed by He GDC, it was shown that the intensity of H_α radiation was much lower than that before cleaning. This result confirms that deuterium ECR discharge cleaning enhanced the recycling rate, and followed GDC in He was useful to reduce wall recycling. This indicates that D_2 ECR discharge cleaning followed by He GDC is effective for wall conditioning.

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