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ECR DISCHARGE CLEANING ON JT-60U

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Yoshitaka IKEDA, Kenkichi USHIGUSA, Masami SEKI,
Kazuaki SUGANUMA and Noboru TOYOSHIMA

日本原子力研究所
Japan Atomic Energy Research Institute

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ECR Discharge Cleaning on JT-60U

Yoshitaka IKEDA, Kenkichi USHIGUSA[+1], Masami SEKI,
Kazuaki SUGANUMA[+2] and Noboru TOYOSHIMA[+1]

Department of Fusion Facility
Naka Fusion Research Establishment
Japan Atomic Energy Research Institute
Naka-machi, Naka-gun, Ibaraki-ken

JAERI, Toka

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Electron Cyclotron Resonance Discharge Cleaning (ECR-DC) was studied on JT-60U whose first wall was composed of graphite tiles. The radio frequency of 2 GHz band, which was the original Lower Hybrid Range of Frequency (LHRF) heating system, was applied to the ECR-DC at the toroidal magnetic field of around 0.06T. A high power ECR-DC up to ~125kW was performed for quasi steady state operation. Though ECR-DC caused the increase in the recycling rate on the graphite first wall, a remarkable desorption of water vapor (mass number of m/e=20) was observed by the ECR in Deuterium gas. Moreover, it was found that the ECR in D_2 was effective to desorb Tritium from the graphite first wall.

Keywords: Electron Cyclotron Resonance Discharge Cleaning, ECR-DC, Lower Hybrid Range of Frequency, LHRF, Desorption, Tritium

[+1] Department of Fusion Plasma Research

[+2] Advanced Photon Research Center

ＪＴ－60Ｕにおける電子サイクロトロン共鳴放電洗浄

日本原子力研究所那珂研究所核融合装置試験部
池田　佳隆　・牛草　健吉[+1]・関　　正美
菅沼　和明[+2]・豊島　　昇[+1]

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グラファイトタイルから成る第一壁を有するＪＴ－60Ｕにおいて、電子サイクロトロン共鳴放電洗浄（ＥＣＲ－ＤＣ）を調べた。低域混成波帯加熱装置の２GHz帯を用いて、トロイダル磁場約0.06Ｔにおいて ＥＣＲ－ＤＣを実施し、最大入射電力125kWまでの準定常運転を行った。グラファイトタイルに対してＥＣＲ－ＤＣはリサイクリング率を増加させるものの、重水素ＥＣＲ－ＤＣは重水脱離には非常に効果的であった。さらに、グラファイトからのトリチウム除去に対して重水素ＥＣＲ－ＤＣが有効であることを明らかにした。

那珂研究所：〒311－01　茨城県那珂郡那珂町向山801－１
+1　炉心プラズマ研究部
+2　光量子科学センター

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1. Introduction

It is well recognized that Taylor Discharge Cleaning (TDC) and Glow Discharge Cleaning (GDC) are effective to clean the first wall of the tokamak devices, so they are standard methods of wall conditioning on the tokamak devices [1-4]. In future steady state fusion devices with superconducting coils, such as ITER, TDC and GDC will be hard to employed, because the high-repetition rate of TDC reduces the life-time of the superconducting coils and GDC can not be performed under the operation of the high toroidal magnetic field of superconducting coils. Electron Cyclotron Resonance Discharge Cleaning (ECR-DC) is the another effective way to clean the wall of the magnetic fusion device [5-8]. Indeed, ECR DC is the candidate of the wall conditioning method in ITER [9], because it will work under the operation of the superconducting coils. ECR-DC has been performed on the many small and medium size tokamak devices. Most of the results were obtained on the metallic wall and showed the desorption of Oxygen from the metallic wall by chemical reaction. On large tokamak devices, the graphite tiles have been employed for the first wall to reduce the effective charge of plasma Z_{eff} under high heat flux in the high power heating experiments. Therefore, it is necessary to study the effect of ECR-DC on large tokamak devices with graphite first wall.

This paper shows the results of ECR-DC on JT-60U using graphite first wall. The injection power was up to ~125kW by using Lower Hybrid Range of Frequency (LHRF) heating system. The experimental set-up is shown in Section. The experimental results and discussion are given in Section 3 and 4, respectively. Finally, summary is given in Section 5.

2. Experimental setup

The cross sectional view of the JT-60U vacuum vessel is shown in Fig. 1 [10]. The machine parameters of JT-60U are the major radius of 3.4 m and the minor radius of 1x1.5 m. The volume of the D-shaped Inconel steel vacuum vessel are around 95m^3 and its inner surface are around 160m^2 covered by graphite tiles. The divertor tiles are made of Carbon Fiber Composite. The normal magnetic field is 1 to 4 T with the plasma current of 0.5 to 5MA. The normal pulse length is 15 sec. The wall conditioning is usually operated by the TDC and GDC before plasma experiments and after a large plasma disruption [11]. The vacuum vessel is baked at 280° during operation.

In order to perform the ECH-DC, the 2GHz band LHRF heating system were used at the continuous toroidal field of ~0.06T. Since the magnetic field was very low

compared to the normal control operation, the magnetic field of the toroidal coil could not be adjust the ECR resonance at the center of the vacuum vessel. The microwave was generated by optimizing the operational condition of the LHRF heating system. The original specification of the heating system was designed to 8MW with 8 klystrons for the pulse length of 10 second with duty of 1/60 [12]. The pulse duration of all components including klystron and power supply was limited by their thermal condition. To operate quasi steady stately, the beam current of the klystron was set low as much as the thermal capacity of the power supply. The position of turner of the klystrons was also optimized for high power generation at this beam voltage. Then the total maximum output power up to around 250kW was obtained for quasi steady state operation at the frequency of 1.74 GHz.

The microwave was injected by the antenna, which was originally designed for the LHRF. The antenna, so called Multi-junction launcher, was optimized to excite the LH waves to drive plasma current efficiently [13]. Though the coupling efficiency to excite ECR wave was not good due to the antenna design, the high power up to 125kW could be injected by the LHRF system.

A quadrupole mass analyzer (QMA) was located in the LHRF antenna with differentially pumped system. It measured the mass peaks m/e of 2, 4, 20, 44, simultaneously during ECR-DC. A desorption of tritium was measured at the outlet of the pumping system of the JT-60U. The electron density and temperature during ECR-DC were measured by double probes located at the antenna mouth. A visible CCD camera was placed on a viewing port to detect the plasma production of ECR DC near the LHRF antenna.

3. Experimental results

At first, the power dependence of the ECR plasma production was studied at the frequency of 1.74GHz in Deuterium gas. The filling pressure was around 1.75×10^{-2} Pa. The coupling coefficient of the antenna to ECR plasma was around 50%, so the maximum injected power was limited less than around 125kW. An ECR plasma was produced when the injection power is more than 25kW as shown in Fig. 2. A large amount of pressure drop was observed during ECR-DC. The open and closed circles show the pressure of the vacuum vessel of JT-60U before/ during ECR-DC, respectively. The drop of the pressure increased with the injected power. Figures 3 (a), (b), (c) and (d) show the field view of the CCD camera and the ECR plasma near the antenna at P_{in}=25, 50 and 125kW, respectively. The CCD camera showed that the plasma became larger in

proportion to the injected power. The electron density and temperature at the antenna mouth were detectable when the plasma production was observed near the antenna mouth. The electron density and temperature at the antenna mouth were $2x10^{16}$ m^{-3}, 4.4eV for Pin=50kW and $3.2x10^{16}$ m^{-3}, 6.5eV for Pin=125kW, respectively.

Figure 4 shows the typical time history of partial pressure in ECR-DC in D_2. The pulse duration of ECR-DC was 10 - 60 second with duty ~1/3 at the filling pressure of $1.4x10^{-2}$ Pa, Pin=~50kW in this experiment. The partial pressure, especially m/e=2 (D), 20 (D_2O), increased just after the microwave was turnned off. This result indicates that a strong desorption of water vapor was obtained by ECR-DC. It was found that a short pulse ECR-DC of 10 second duration is enough to desorb the water vapor from the graphite first wall. The partial pressure of m/e=20 during TDC in D_2, which are carried out at plasma current of ~20kA for ~30ms pulse duration with duty 1/200 - 1/300 at filling pressure 10^{-2}- 10^{-3}Pa, was around $7x10^{-7}$ in the same scale of Fig.4. So the effect of desorption of water vapor by ECR-DC in D_2 seems to be higher than that of TDC in D_2. The power dependence of the desorption is shown in Fig. 5. The desorpion values are defined as the peaked pressure just after ECR-DC of the pulse duration of 10 s. It is found that ECR-CD at low power is more effective to desorb the water vapor.

The desorption of tritium was observed by ECR-DC in D_2. Figure 6 shows the time history of the count of tritium β-ray at the outlet of the vacuum pumping system after GDC in He and ECR-DC in D_2. The time delay of the detector system was around 20 - 30 minute due to the pumping conductance. Before ECR-DC in D_2, GDC in He was carried out at the condition of the discharge current 10A, voltage 100V and filling pressure $1.7x10^{-1}$ Pa, respectively (Fig. 6(a)). ECR-DC in D_2 was steady stately carried out at Pin=25~50kW for ~50 minute. A strong desorption of the tritium was observed after ECR-DC in D_2. The desorption level by ECR-DC in D_2 was much higher than that of the GDC in He.

After the ECR-DC in D_2 of several 10 minute duration, Ohmic plasma was not easy to start up due to degradation of the recycling rate. GDC in He was required to reduce the recycling rate. It seemed a large desorption by ECR-DC and/or the absorption of D_2 gas in the graphite tiles resulted in the degradation of the recycling rate. The reduction of Z_{eff} was not clear because the base Z_{eff} was enough low (~2 in Ohmic plasma) in JT-60U using the graphite tile [14]. To reduce the recycling rate, the optimization of the ECR DC condition should be studied in future campaign.

The ECR-DC in He gas was also studied. Figure 7 shows the condition of the ECR plasma in He. The ECR plasma was not produced below the pressure of $0.4x10^{-2}$ Pa. The typical electron density and temperature at the antenna mouth were $1.1x10^{16}$ m^{-3} and 7.8

eV, respectively at Pin=50kW and 3.8×10^{-3} Pa. At the high power and high pressure condition, the breakdown at the antenna mouth was observed. The most different point between the ECR-DC in He and in D_2 is the partial pressure behavior. The pressure did not change during/after ECR-DC as shown in Fig. 8. ECR-DC was carried out at Pin=~15kW and ~2×10^{-2} Pa. ECR-DC in He was few effect to remove the water vapor. The recycling rate of the wall was increased after the ECR-DC in He. Figure 9 shows the line averaged plasma density at the plasma current of 1MA without gas puffing before/after ECR-DC. Before ECR, the reduction of the plasma density was observed when the divertor configuration was produced from around t=2s. No reduction of the density was observed after ECR-DC in He of several 10 minute duration. The desorption of the tritium was not observed by ECR-DC in He. Therefore, ECR-DC in He was no effective for the wall conditioning.

4. Discussion

The mechanism of the ECR-DC is to produce the active neutral atom which chemically reacts and removes the Oxygen from the wall. The microwave power to produce the ECR plasma in D_2 is roughly estimated from the production of deuterium molecular and the confinement of the ECR plasma as following [5,15];

$$P = \left\{ \frac{n_e(T_e + T_i)}{\tau_p} + \frac{\frac{1}{2} n_D E_f}{\tau_0} \right\} \bullet V_p \qquad (1)$$

where ne, Te, Ti, n_D, E_f, τ_p, τ_0 and Vp are electron density, electron temperature, ion temperature, atomic deuterium density, Franck-Condon excitation energy (11.5eV), plasma confinement time, atomic deuterium life time and plasma volume, respectively. The plasma confinement time and the life time of atomic deuterium are given by the drift velocity of the electron and the velocity of the Franck-Condon neutral atom, respectively. The deuterium atom density was given by the reaction of deuterium molecular and electron as following;

$$\frac{n_D}{\tau_0} = 2 n_{D2} n_e \langle \sigma v_e \rangle \qquad (2)$$

where n_{D2}, $\langle\sigma v_e\rangle$ are deuterium molecular density and the reaction rate coefficient (~3×10^{15} m^3s^{-1}). On assuming that the average density and temperature are given by the edge values measured by the antenna probe, the microwave power to produce ECR is estimated 48kW for the experimental injection power of 50kW, f=1.74GHz, $n_{D2}=4.6\times10^{18}$ m^{-3} (filling pressure: 1.75×10^{-2} Pa) and Vp=95 m^3. The experimental power agrees well with the theoretical power. The neutral atom flux density onto the

first wall is given by

$$\phi_D = \frac{n_D}{\tau_0} \bullet \frac{V_p}{A_W} \tag{3}$$

where A_w is the surface of the first wall (~160m^2). Then the flux of atomic deuterium is around 3.3x10^{20} m^{-2}s^{-1}. This flux is much higher than that of the previous small tokamak experiments (~10^{19} m^{-2}s^{-1}) because the flux is in proportion to the plasma minor radius ($\propto$ volume/surface) at the same $n_{D2}n_e<\sigma v_e>$. Therefore, ECR-DC is seemed to be more effective to desorp water vapor and tritium on large tokamak devices.

In the case of ECR-DC in He, there is no chemical reaction between plasma and wall, so there is no effectiveness of desorption of Oxygen. The physical sputtering of the He atom and ion is only reaction between the plasma and wall. The energy of the He atom and ion are in the order of the plasma temperature of several eV in ECR-DC, so the sputtering effect is much weaker than that of GDC (energy of He ion: several 100eV). It seems that few interaction between He atom and wall does not change the pressure.

The key of the graphite tile for the first wall is to reduce the recycling rate. Baking and GDC in He has been recognized effective methods to reduce the recycling of the graphite. Though this study showed ECR-DC causes degradation of the recycling of the graphite first wall, short pulse ECR-DC with high repetition may efficiently desorb water vapor and tritium with low recycling rate. A surface baking by the microwaves seems to be another methods to degas the graphite tile [16]. To reduce the recycling, more detailed study should be required in future campaign.

5. Summary

High power ECR-DC was performed by using LHRF heating system on JT-60U. ECR plasma was produced by injecting the microwave of 2GHz -band at the power up to ~125 kW. The ECR DC in D_2 was effective to desorp the water vapor from the graphite tile. It was noticeable that ECR-DC in D_2 is also effective to remove the tritium from the first wall. The required microwave power was well explained by the theory of production of neutral atom. ECR in He showed few effects on the wall conditioning on the graphite first wall. The remained issue of ECR-DC is to reduce the recycling rate of the graphite tile. These experiments have shown that LHRF system can be well applied to ECR-DC on tokamak devices.

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References

[1] T. Arai et al., J. Nuclear Materials 145-147 (1987) 686-690.
[2] G.L. Jackson et al., J. Nuclear Materials 162-164 (1989) 489-495.
[3] JET team, Proc. of 11th Int. Conf. on Plasma Physics and Controlled Nuclear Fusion Research 1986, IAEA-CN-47/A-I-2.
[4] K.W. Hill et al., Proc. of 11th Int. Conf. on Plasma Physics and Controlled Nuclear Fusion Research, 1986, IAEA-CN-47/A-IV-2.
[5] Y. Sakamoto et al., J. Nuclear Materials 93-94 (1980) 333-337.
[6] Y. Matsuzaki et al., J. Nuclear Materials 145-147 (1987) 704-708.
[7] Y. Sakamoto et al., J. Nuclear Materials 111-112 (1987) 485-488.
[8] E. Jotaki et al., FURKU Report 97-03(44). Research Institute for Applied Mechanics, Kyushu University. Feb. 1997.
[9] Tec. Basis for the ITER Detail Design Report, 1996, IAEA.
[10] H. Ninomiya et al., Plsam Devices and Operations, 1 (1990) 43.
[11] T. Arai et al., J. Nuclear Materials 162-164 (1989) 743-747.
[12] T. Nagashima et al., Nuclear Eng. Des./ Fusion 5 (1987) 101.
[13] M. Seki et al., Proc. of 16th Symp. on Fusion Technology, London, UK, 1060-1064 (1990).
[14] T. Sugie et al., Proc. of 13th Int. Conf. on Plasma Physics and Controlled Nuclear Fusion Research, 1990, IAEA-CN-53/A-V-4.
[15] H. Oyama et al., J. Plsam and Fusion Research 54 (1985) 79-94 (in Japanese).
[16] S. Hiroki et al., J . Vacuum Soc. Japan, 28 (1984) 300-303 (in Japanese).

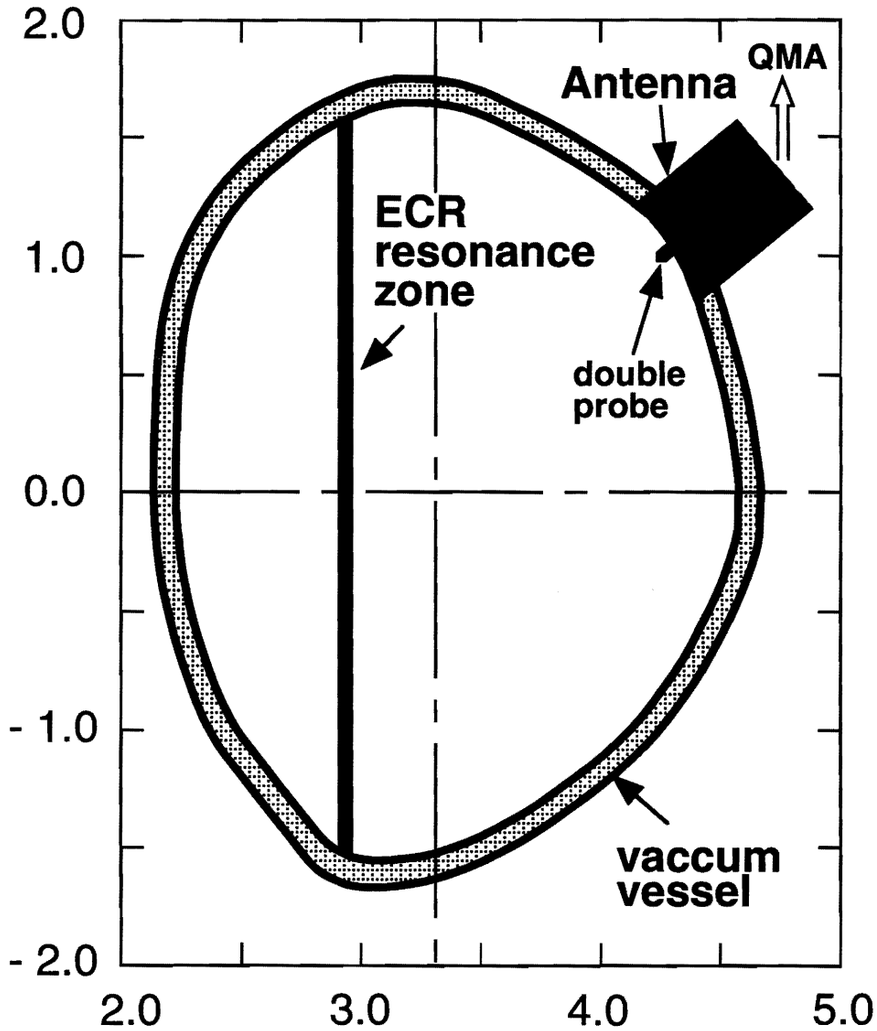

Fig. 1 Cross sectional view of the vacuum vessel of JT-60U.
ECR resonance region is at R=2.9 m for f=1.74GHz. Double probe is located at the antenna mouth. Quadrupole mass analyzer (QMS) is equipped in the antenna system.

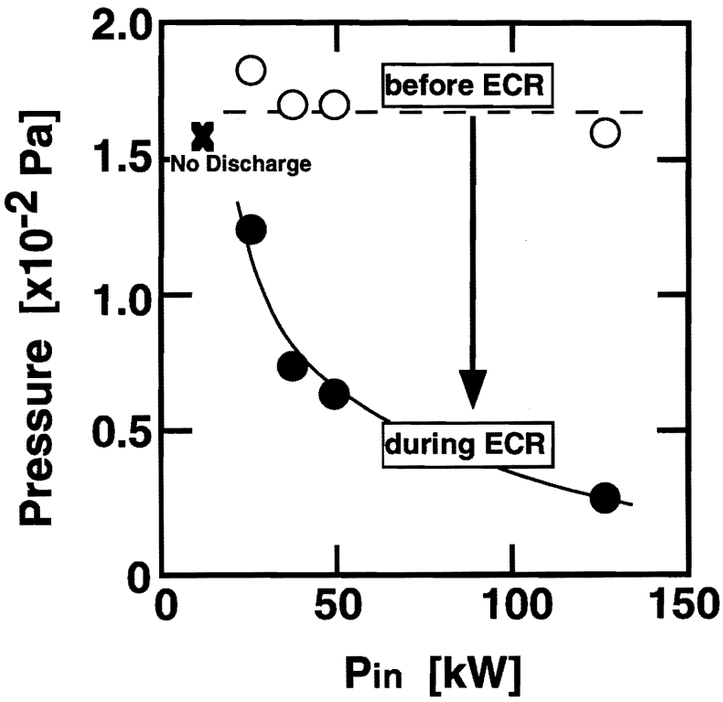

Fig. 2 Pressure drop during ECR-DC in D2. ○:filling pressure before ECR-DC, ●:pressure during ECR-DC, ×: no discharge.

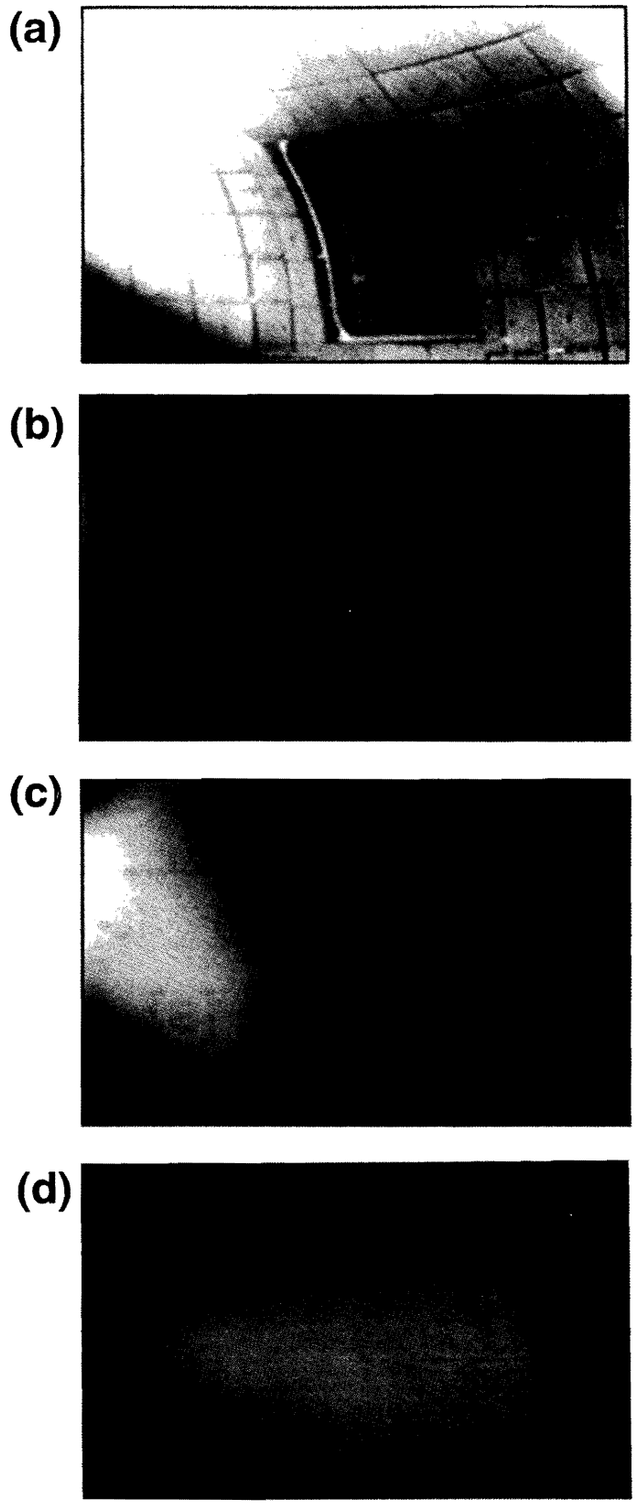

Fig. 3 ECR plasma near the LHRF antenna measured by CCD camera.
(a) field view of CCD camera, (b) ECR plasma at Pin=25kW
(c) ECR plasma at Pin=50kW (d) ECR plasma at Pin=125kW

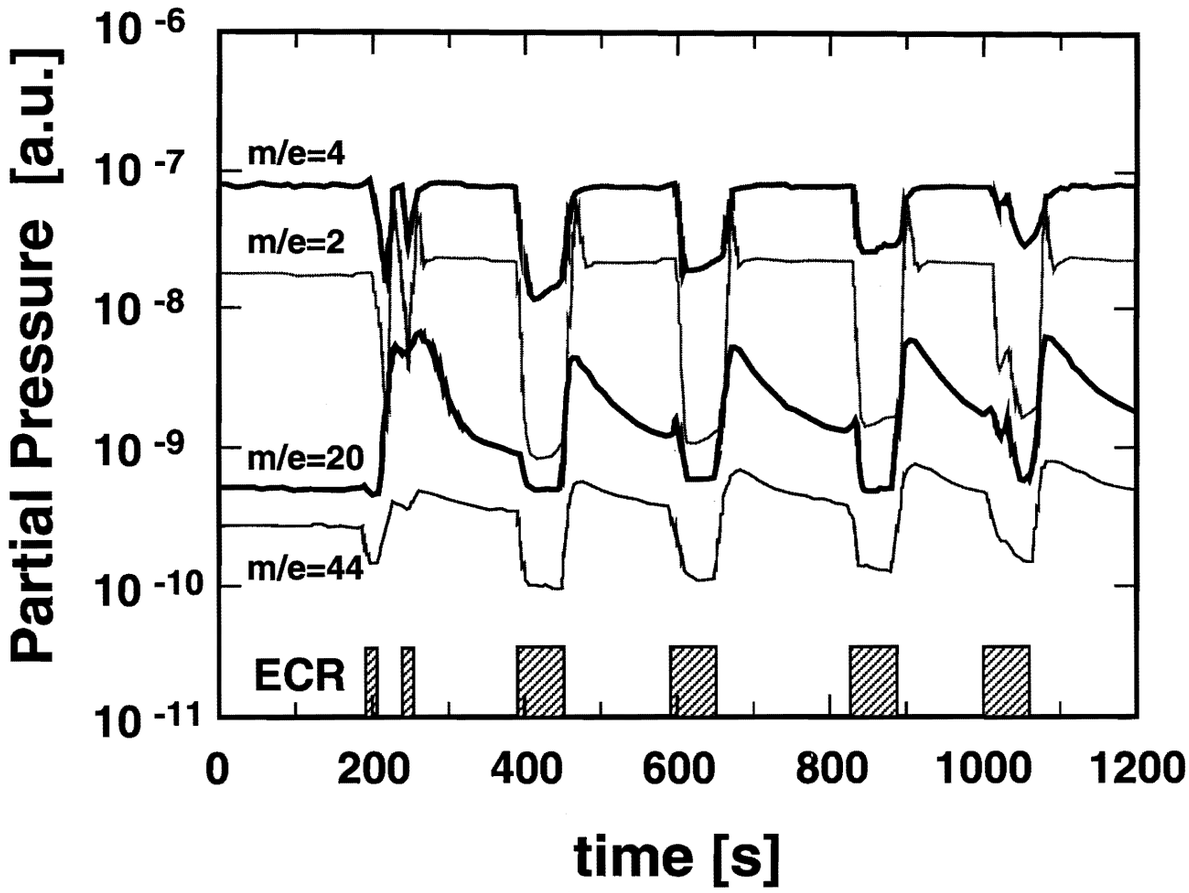

Fig. 4 Time history of partial pressure during ECR-DC in D_2.
Filling pressure and injected power are ~1.4×10^{-2} Pa, ~50 kW, respectively.

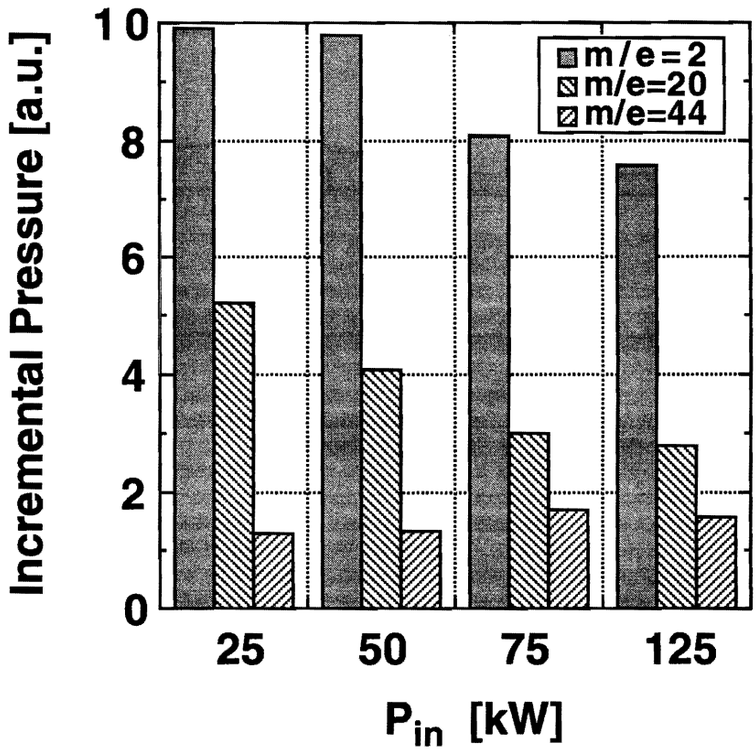

Fig. 5 Power dependence of desorption.
These values are defined as the peaked pressure just after ECR-DC turns off.

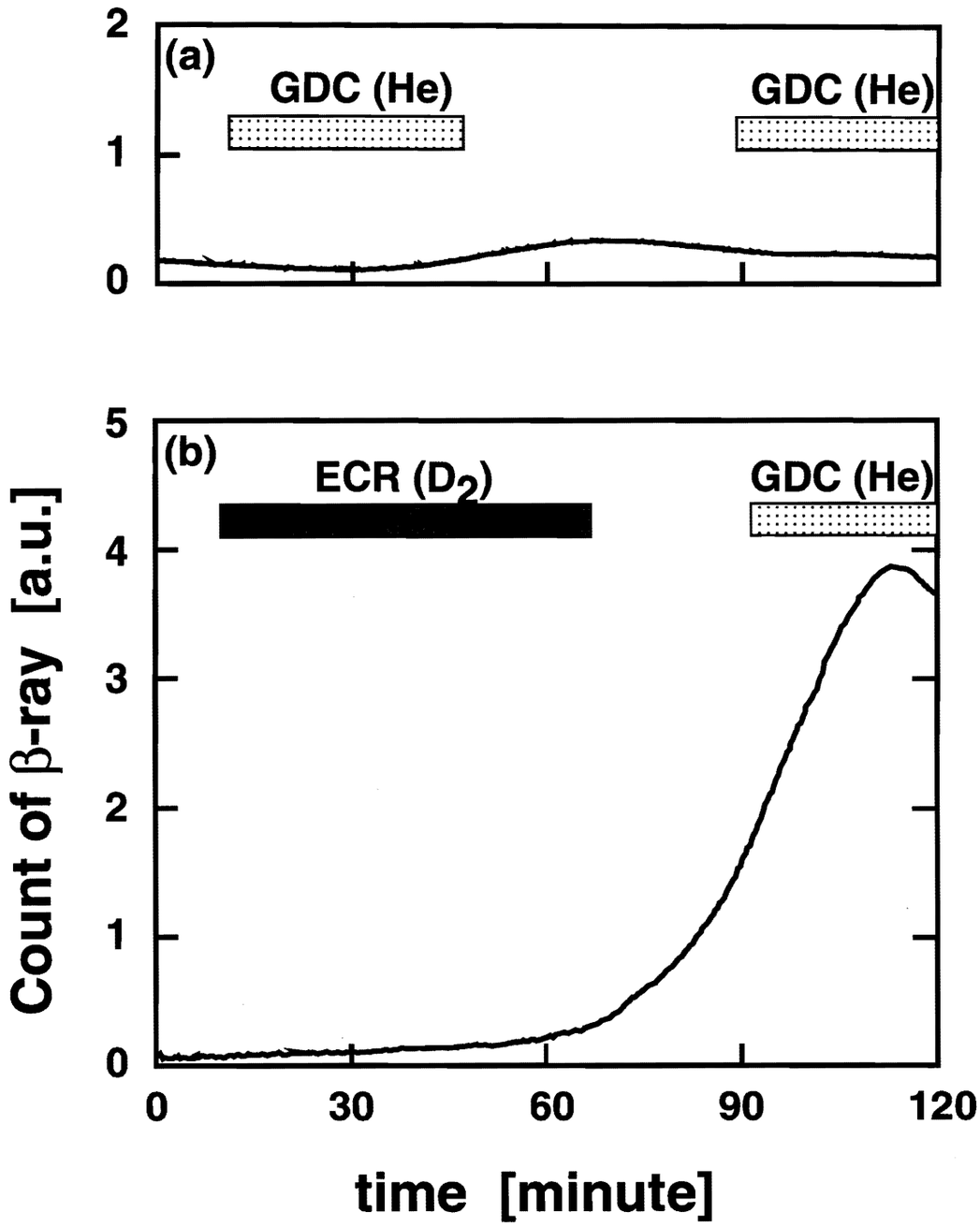

Fig. 6 Time history of desorption of tritium during/after GDC in He and ECR-DC in D_2.

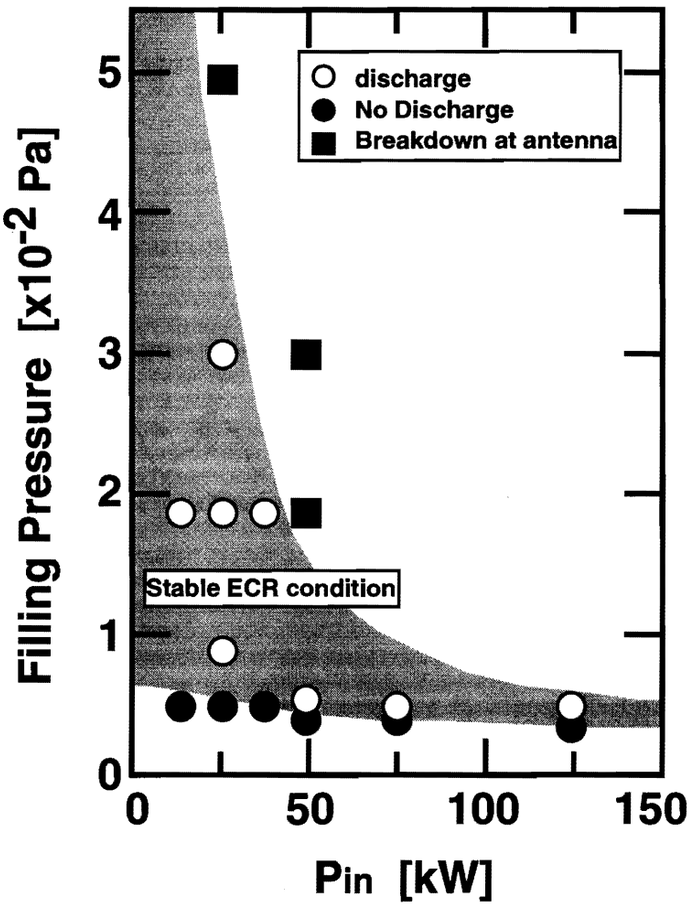

Fig. 7 Condition of ECR-DC in He.
○:stable ECR plasma, ●: No discharge, ■: breakdown at the antenna mouth.
Dark region shows the stable ECR-DC condition.

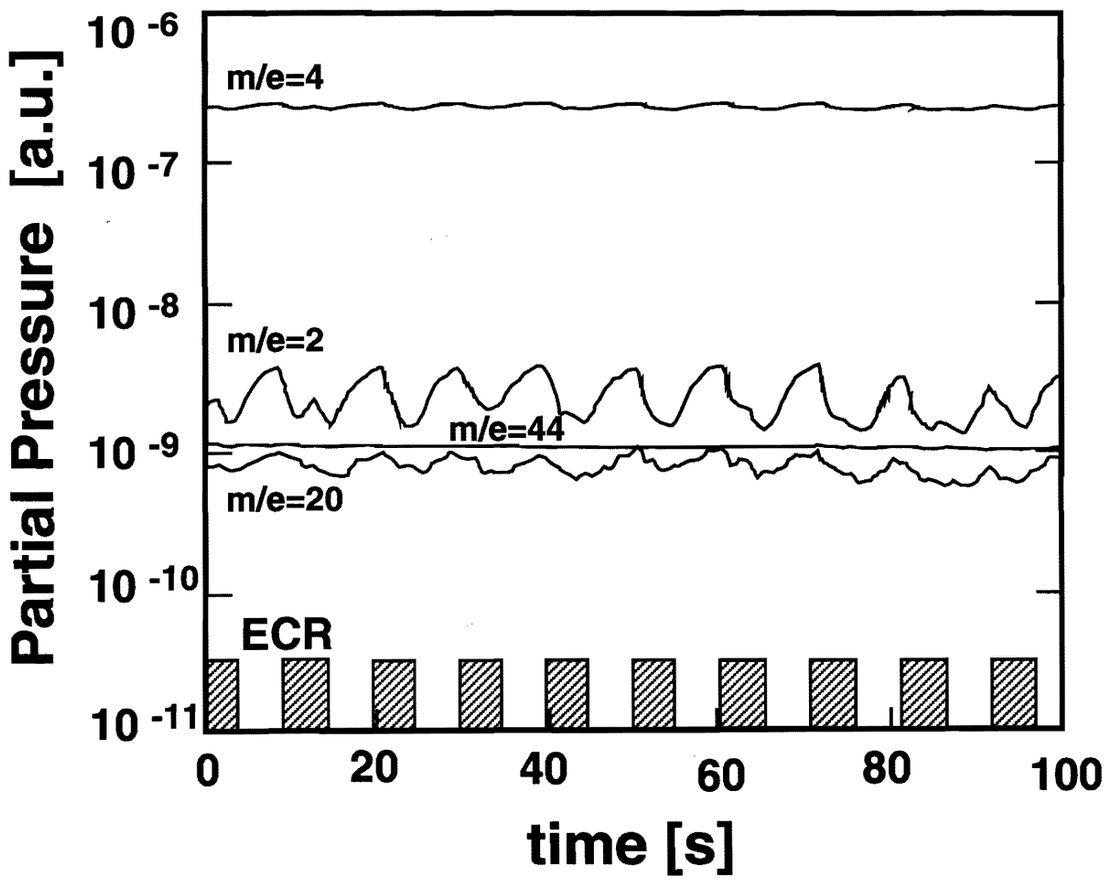

Fig. 8 Partial pressure during ECR-DC in He.
Filling pressure and injected power are ~2×10^{-2} Pa, ~15 kW, respectively.

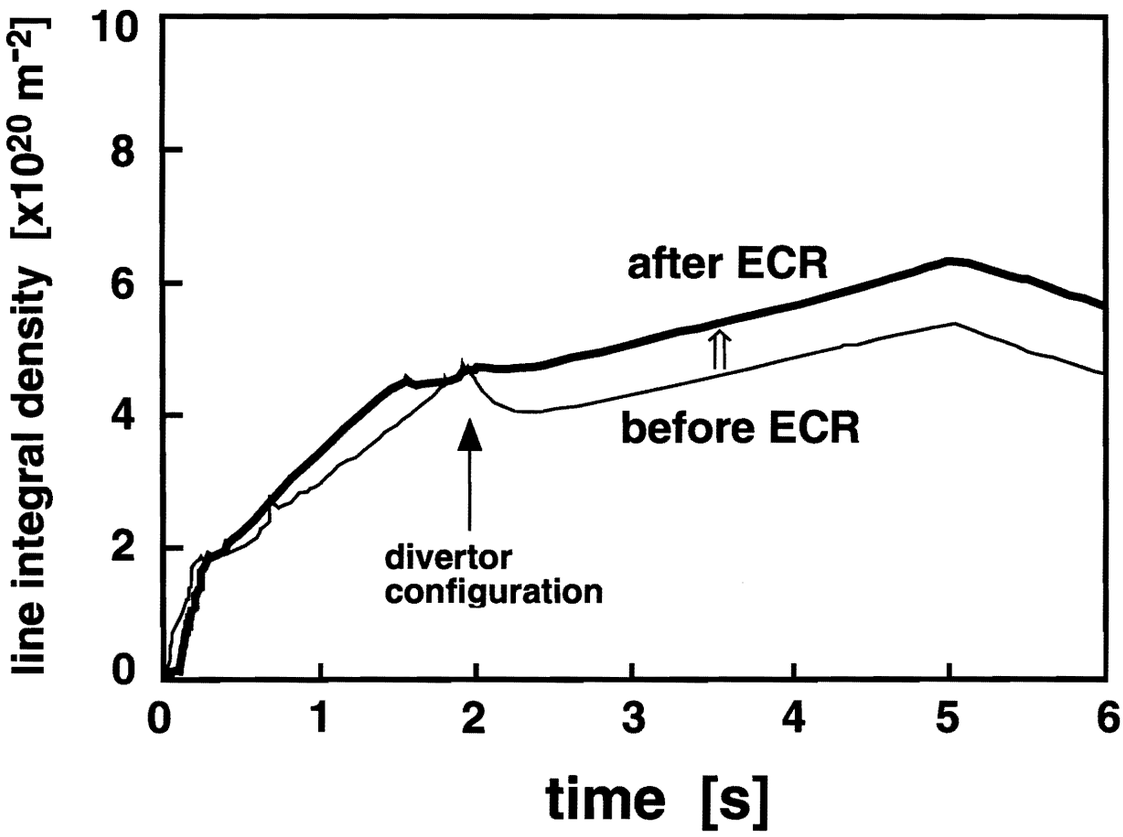

Fig. 9 Line average density at plasma current of 1MA before/after ECR-DC in He. Plasma was started up without gas puffing. Divertor configuration was produced at t=2 s.