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Difference in oxygen impurity behavior between repetitive short discharges and one long discharge on TRIAM-1M

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Abstract

Oxygen impurity behaviors of one long duration discharge and repetition of short duration discharges have been investigated in TRIAM-1M. In the former case, the OII line intensity divided by the line averaged electron density, which is considered as a monitor of oxygen concentration on the plasma facing surface (PFS), decreased with the time constant, τ_d, of 30–50 s during the discharge due to the hydrogen flux to PFS. In the latter case, τ_d is in the range of 70–600 s. There exists a big difference of global behavior of oxygen impurity between both cases. The difference seems to result from the absence or presence of the interval time between the discharges. The oxygen concentration on PFS increases during the interval time due to adsorption of H_2O. The time constant of the increase in the oxygen concentration is evaluated to be about 5500 s from Langmuir adsorption isotherms analysis.

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1. Introduction

It is important to study the plasma–wall interaction (PWI) during a long duration discharge in order to achieve the steady state operation (SSO), which is one of the critical requirements for the future fusion device [1]. In TRIAM-1M, PWI phenomena such as hydrogen recycling during the long duration discharge have been studied [2–5]. It is found that wall surface condition continues to change during the discharge. For example, the co-deposition of hydrogen with the atom sputtered from the plasma facing components continues to occur on the wall surface during the discharge. It should be noted that the wall surface condition changes not only during the discharge but also during the interval time between discharges. It is necessary to take into account the change in the wall surface property during the interval time to understand PWI phenomena in SSO. The above issue

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has been studied focusing on the difference in the oxygen impurity behavior between one long duration discharge and the repetition of short duration discharges in TRIAM-1M.

2. Experimental result

TRIAM-1M ($R_0 = 0.84$ m, $a = 0.11$ m, $B_T < 8$ T) is a superconducting tokamak with capability to produce a long duration discharge. The main chamber is made of stainless steel and the limiters and divertor plates are Mo. The whole machine is put in the outer vacuum vessel for thermal isolation of the superconducting coils. The main chamber is connected to the outer vacuum vessel through many extension pipes of which whole surface area is larger than that of the main chamber. The plasma is initially produced by ohmic heating and afterwards sustained by the lower hybrid current drive (LHCD). The experiments which are described in this paper are carried out with a limiter configuration.

Fig. 1 shows the discharge evolution of plasma with a duration of 150 s. The LHCD power is ~12 kW and the plasma current, I_p, is ~22 kA. The line averaged electron density, $\bar{n}_e$, is $\sim 1.3 \times 10^{18}$ m^{-3}. The OII line intensity, I_{OII} ($\lambda \sim 465$ nm), decreased with time and finally it became half of the initial value. In order to compensate the effect of the density on I_{OII}, the OII line intensity is divided by the line averaged electron density, $I_{OII}/\bar{n}_e$. The value of $I_{OII}/\bar{n}_e$ is considered as a monitor of oxygen concentration on the wall surface. Fig. 2(a) shows the time evolution of $I_{OII}/\bar{n}_e$ in the discharge of Fig. 1. The broken line is drawn by using the following equation:

$$f(t) = A + B\exp(-t/\tau_d). \quad (1)$$

The time constant, τ_d, of the decrease in $I_{OII}/\bar{n}_e$ is 48 s.

Fig. 2(b) shows the time evolution of $I_{OII}/\bar{n}_e$ in the case of the repetition of discharges. The horizontal axis means cumulative plasma duration. The data of $I_{OII}/\bar{n}_e$ of eight discharges are connected in the order of the discharge number from #84512 to #84519. The signal has a large spike at the beginning (i.e., ohmic heating phase) of each discharge that is indicated by the arrow in Fig. 2(b). The discharge durations of the first seven discharges are in the range of 30–60 s and the last one is 420 s. The interval time between the discharges is in the range of 6–13 min. I_p is 28 kA and $\bar{n}_e$ is $\sim 1.4 \times 10^{18}$ m^{-3}

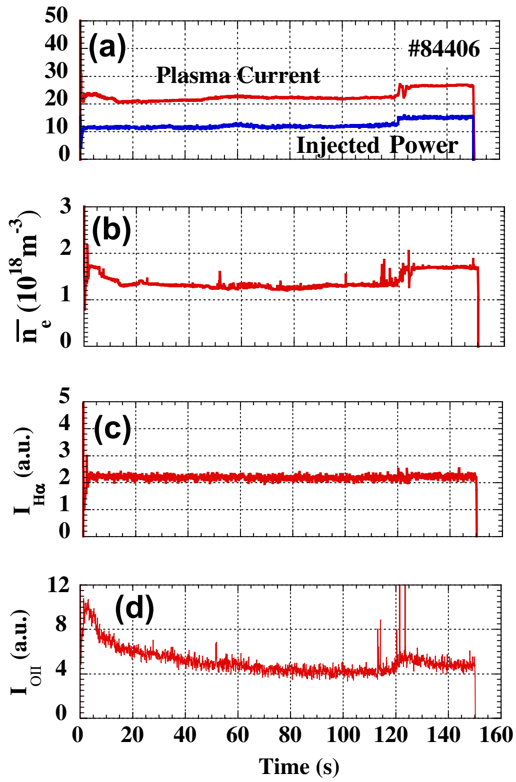

Fig. 1. Time evolution of (a) plasma current and RF power, (b) line averaged electron density, (c) Hα line intensity and (d) OII line intensity in the typical long duration discharge.

in each discharge. It is noticed that 4500 s was spent from the first discharge to the last one. The broken line in Fig. 2(b) is also drawn by using Eq. (1). The time constant of decrease in I_{OII}/n_e is 141 s, which is about three times longer than that of the one long duration discharge shown in Fig. 2(a). The final value of $I_{OII}/\bar{n}_e$ in the case of the repetition of the discharges is almost the same as that of the one long duration discharge. The thick solid line in Fig. 2(b) indicates a result of a model analysis, which is explained in Section 3.

Dependence of τ_d on the initial value of $I_{OII}/\bar{n}_e$ is shown in Fig. 3. The value of $I_{OII}/\bar{n}_e$ at 3 s after the initiation of the discharge is used as the initial value in order to avoid the spike signal at the ohmic heating phase. The closed circle and closed square indicate τ_d for the one long duration discharge and the repetition of discharges, respectively. In each discharge, I_p is in the range of 20–30 kA and $\bar{n}_e$ is $(1.2–2.0) \times 10^{18}$ m^{-3}. In the case of the one long duration discharge, τ_d is in the range of 30–50 s and it does not depend on the initial value of

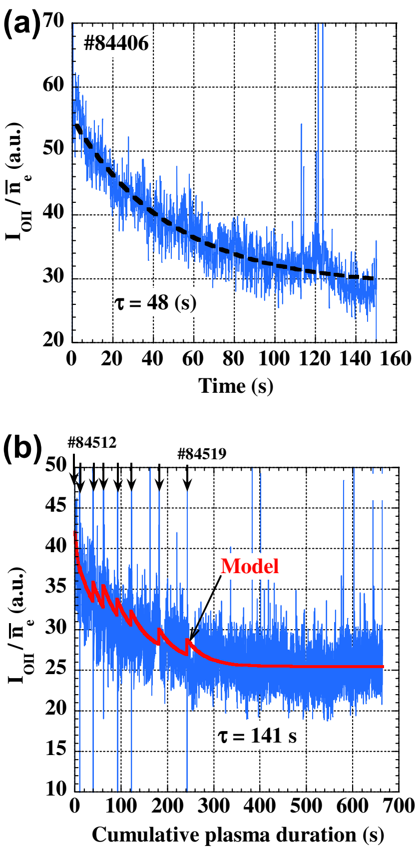

Fig. 2. Time evolution of OII line intensity divided by the line averaged electron density in (a) one long duration discharge and (b) repetition of discharges. The broken line is drawn by exponential fitting. The arrow in (b) indicates the beginning of each discharge. The thick solid line indicates a result of the model analysis.

$I_{OII}/\bar{n}_e$. On the other hand, in the case of the repetition of discharges, τ_d increases from 70–600 s with the initial value of $I_{OII}/\bar{n}_e$. It is found that there exists a big difference in the oxygen impurity behavior between one long duration discharge and the repetition of short ones.

3. Discussion

In order to investigate the cause of the difference of the oxygen behaviors between the single long duration discharge and the repetition of short ones, we should take into account the interval time between discharges, since the wall surface condition would change during the interval time. Actually, $\Delta I_{OII}/\bar{n}_e$ increases with increase in the interval time as shown in Fig. 4. It is defined as a difference between the initial value of $I_{OII}/\bar{n}_e$ in the discharge and the final one in the previous discharge. The result in Fig. 4 seems to mean that the oxygen concentration on the plasma facing wall surface increases during the interval time. Candidates for the mechanism of the increase in the surface concentration of oxygen are as follows: diffusion of oxygen from the bulk of the wall to the surface and adsorption of O_2 or H_2O or both. The former mechanism may not contribute so much, because the oxygen atom which is co-deposited with Mo is stably trapped as MoO_2 or MoO_3 in the wall [6]. In order to investigate the latter mechanism, we use the following equation that is derived from Langmuir adsorption isotherms [7].

$$\frac{\mathrm{d}\theta}{\mathrm{d}t} = \frac{s(1-\theta)}{\sigma_m}\left(\frac{v}{4}\right)n - \frac{\theta}{\tau_a}, \tag{2}$$

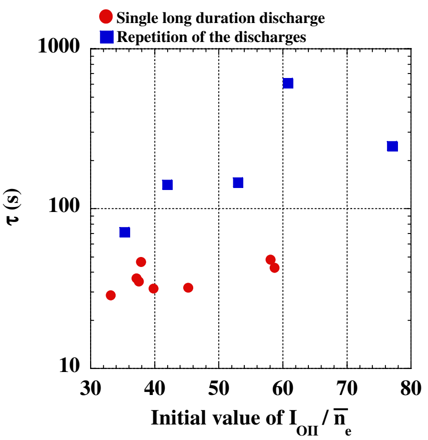

Fig. 3. Dependence of the time constant of the decrease in I_{OII}/n_e on the initial value of $I_{OII}/\bar{n}_e$.

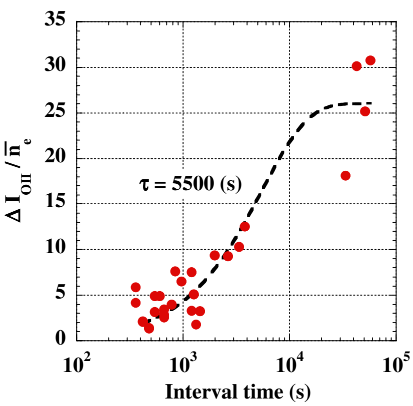

Fig. 4. The initial value of $I_{OII}/\bar{n}_e$ in the discharge as a function of the interval time between the discharge and the previous discharge. The broken line is drawn by using Eq. (3).

where θ is H_2O coverage on the wall, s is the sticking probability of H_2O, σ_m is the number of molecules per unit area of the wall on which one monolayer is adsorbed, v is the thermal velocity of H_2O, n is the density of H_2O in the main chamber and τ_a is the mean adsorption time for H_2O. The contribution of O_2 can be omitted, since the partial pressure of O_2 in the main chamber is negligible small (<few %) compare to that of H_2O. Provided that $\frac{s}{\sigma_m}\frac{v}{4}n \gg \frac{1}{\tau_a}$, Eq. (3) gives a solution as follows:

$$\Delta\theta = (1-\theta_0)\{1-\exp(-t/\tau_i)\}, \tag{3}$$

where θ_0 is the initial value of θ , $\Delta\theta$ is the increment of θ (i.e., $\Delta\theta = \theta - \theta_0$). τ_i is the time constant of the increase in θ and it is $\frac{4\sigma_m}{svn}$. $\Delta\theta$ can be considered as increase in oxygen concentration on the plasma facing wall during the interval time between discharges and it corresponds to $\Delta I_{OII}/\bar{n}_e$. The data in Fig. 4 is well fitted by using Eq. (3) as shown by the broken line and τ_i is $\sim$5500 s, which corresponds to the value of $\frac{4\sigma_m}{svn}$ at $s \sim 1$. The source of H_2O seems to be surface area which does not face the plasma, e.g., the extension pipes. The H_2O molecules which have desorbed from the surface of the extension pipes are considered to adsorb on the plasma facing surface of which H_2O coverage has been reduced due to the plasma discharge.

To reproduce the experimental observation shown in Fig. 2(b), the following model has been performed. The value of $I_{OII}/\bar{n}_e$ decreases with τ_d during the discharge and the initial value of $I_{OII}/\bar{n}_e$ of the discharge is given by using Eq. (3), the interval time between the discharges and the final value of $I_{OII}/\bar{n}_e$ of the previous discharge. As shown by the thick solid line in Fig. 2(b), the time evolution of $I_{OII}/\bar{n}_e$ in the repetition of discharges can well be reproduced when 40.7 s and 5500 s are given for τ_d and τ_i, respectively. The value of τ_d is within the range of the time constant of the one long duration discharge (i.e., 30–50 s). The modeling result means that the interval time during the repetition of discharges plays an important role in the global behavior of the oxygen impurity. Fig. 5 shows the time constant of the decrease in $I_{OII}/\bar{n}_e$ as a function of the cumulative interval time during the repetition of discharges. The data is the same as that of Fig. 3. The number in the parenthesis in Fig. 5 indicates the number of repetition of discharges. It is found that τ_d in the case of repetition of discharges has good correlation with the cumulative interval time. The dependence of τ_d of the repetition of discharges on the initial value of $I_{OII}/\bar{n}_e$, which is shown in Fig. 3, seems to be attributed to the relation between τ_d and the cumulative interval time. The above results mean that the difference of global oxygen behaviors between one long duration discharge and repetitive short ones results from the absence or presence of the interval time between discharges during which the oxygen concentration on the plasma facing wall surface increases.

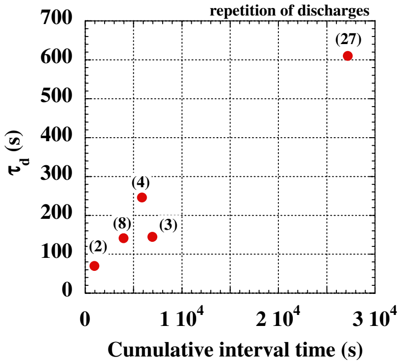

Fig. 5. The time constant of the decrease in $I_{OII}/\bar{n}_e$ as a function of the cumulative interval time during the repetition of discharges. The number in the parenthesis indicates the number of repetition of discharges.

4. Summary

In TRIAM-1M, PWI issues for the steady state operation have been studied. One of the important issues is the difference of PWI phenomena between one long duration discharge and the repetition of short duration discharges of which cumulative discharge duration corresponds to one long discharge duration. In this paper, we focus on the difference of the oxygen impurity behaviors between the both cases. The OII line intensity decreases during the discharge due to the cleaning effect of the plasma on the plasma facing surface. There exists a big difference of the time constant of decrease in $I_{OII}/\bar{n}_e$, which is considered as a monitor of the oxygen concentration on the plasma facing wall surface, between the both cases as follows: 30–50 s for the one long duration discharge and 70–600 s for the repetition of discharges. The difference seems to results from the absence or presence of the interval time between discharges. It was indirectly observed that the oxygen concentration of the plasma facing surface increased during the interval time. The time constant of the increase in the oxygen concentration is about 5500 s. This increase may result from the adsorption of H_2O on the plasma facing surface during the interval time. The interval time between discharges plays an important role in the global oxygen behavior.

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