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Conditionings for Boron-Carbon Plasma Facing Wall

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Abstract

For plasma facing material with components of boron and carbon, the method of conditionings due to He discharge cleaning and baking is considered. The conditioning time required to suppress the hydrogen recycling is discussed. It is shown that the hydrogen trapped by the boron can be relatively easily removed only by the baking at 300°C or only by He discharge cleaning with current density of 0.1 mA/cm^2. It is not easy to remove the hydrogen trapped by the carbon by the baking since the temperature required becomes 500°C. The current density required also becomes high, 1 mA/cm^2, for the reduction of the hydrogen trapped by the carbon.

1. Introduction

Recently, it has been observed that the energy confinement characteristic of plasma was largely improved by applying the boronization for the graphite wall in tokamaks such as JT-60U$^{1)}$ and DIIID$^{2),3)}$. The surface composition of the boronized wall consists of the boron and/or the carbon. It is known that the boron well reduces the oxygen impurity level of plasma due to the gettering action. In DIIID, VH mode with the energy confinement time several times larger than that of H mode was obtained$^{2)}$, and the reduction of impurity penetration is believed as the reason for the enhancement of the energy confinement time. The reduction of the hydrogen recycling$^{4)}$ by the boronized wall is regarded as the possible reason for the confinement improvement in JT-60U$^{1)}$. The hydrogen recycling properties of the boronized wall, however, has not been clarified yet. The hydrogen recycling causes the deterioration of the energy confinement time, and thus for the suppression of the recycling the retained hydrogen concentration of the plasma facing wall has to be well reduced by the conditionings before the main discharge shots.

In this note, we consider suitable wall conditionings due to baking and He discharge cleanings for the plasma facing wall with components of boron and carbon. Namely, the baking temperature and the He ion flux required to remove the trapped hydrogen are suggested.

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2. Model for Hydrogen Desorption due to He Discharge Cleaning and Baking

In the present large devices, the fuel hydrogens, and the impurities such as oxygen and carbon, trapped in the graphite wall, are partly removed by the baking with temperature less than about 300°C and discharge cleanings. For the reduction of the impurities, the use of hydrogen discharge cleanings is effective. In order to remove the trapped hydrogen, the helium discharge cleaning is employed.

In the boron-carbon material, the hydrogen ions may be trapped in forms of B-H and C-H bongings[4]. The activation energies of thermal desorption for B-H and C-H bondings were estimated as 1.8 eV and 2.4 eV, respectively[4]. Since the bond energy, and the collision probability of He ion depends on the bonding state, the cross section of He ion impact desorption also depends on the bonding state. For the trapped hydrogen density of i-bonding state, n_i(cm^3), the balance equation can be written as

$$\frac{dn_i}{dt} = -\nu_i n_i - \sigma_i^{He} J_{He} n_i, \qquad (1)$$

where $\nu_i = \nu_i^0 \exp(-E_i/kT)$ is the thermal desorption rate(/s), E_i the activation energy of thermal desorption(eV), ν_i^0 the frequency factor(/s), σ_i^{He} the cross section of He ion impact desorption(cm^2), J_{He} the He ion flux(/cm^2·s), T the baking temperature(K), k the Boltzmann constant (8.62×10^{-5} eV/K), and i=1 and 2 represent C-H and B-H bondings, respectively. Figure 1 shows the desorptions due to baking and He discharge cleaning.

For the initial hydrogen density, n_i^0, the decay of the density is expressed as

$$n_i = n_i^0 e^{-\frac{t}{\tau_i}}, \qquad (2)$$

where $\tau_i = (\nu_i^0 exp(-E_i/kT) + \sigma_i^{He} J_{He})^{-1}$ is the decay time constant. The conditioning time required is given by

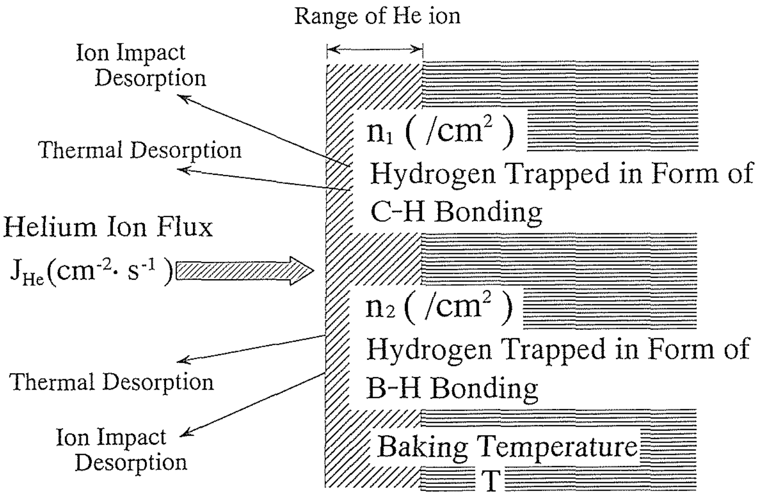

Fig. 1 Hydrogen desorptions due to baking and He discharge cleaning.

$$t = \frac{ln(\frac{n_i^0}{n_i})}{\nu_i^0 e^{-\frac{E_i}{RT}} + \sigma_i^{He} J_{He}}. \tag{3}$$

Since $\nu_1^0 \simeq \nu_2^0 \simeq 10^{13}/s$, $E_1 = 2.4\,eV$, $E_2 = 1.8\,eV$, $J_{He} = 10^{14-16}/cm^2 \cdot s$ and $\sigma_i^{He} \lesssim 10^{-17} cm^2$, the first term of denominator in Eq.(3) is ignored when the temperature is low. In this case, the cross section of He ion impact desorption is approximated as

$$\sigma_i^{He} \simeq \frac{1}{J_{He} t} ln(\frac{n_i^0}{n_i}). \tag{4}$$

The value of σ_i^{He} has not been obtained yet up to now. If the He ion fluence, $J_{He} \cdot$ t, and the reduction factor, n_i^0/n_i, are known, σ_i^{He} can be determined from Eq.(4).

3. Required Conditioning Time

For the boron-carbon material, B_4C converted graphite, the reduction ratio of trapped hydrogen due to He ion bombardment after the implantation of hydrogen ions was measured by using a technique of thermal desorption spectroscopy[5]. Figure 2 shows the desorption rate versus temperature before and after the He ion irradiation. Before the He ion irradiation (solid curve), there were two desorption peaks at 350°C and 700°C. The desorptions of B-H bonding and C-H bonding correspond to the peaks at 350°C and 700°C, respectively. After the irradiation with the fluence of $J_{He} \cdot t = 5 \times 10^{18}/cm^2$, the trapped hydrogen densities of B-H bonding and C-H bonding were about 1.7 and 20 times reduced. From Eq.(4), we can have the cross sections of He ion impact desorption as follows

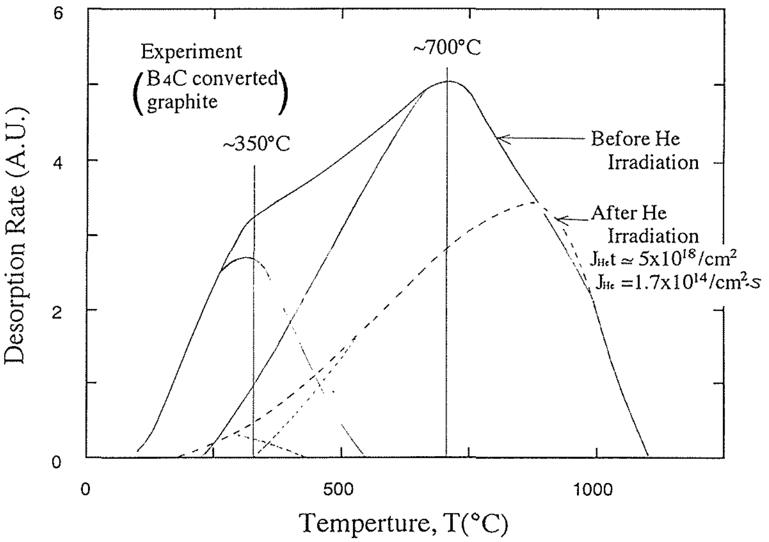

Fig. 2 Thermal desorption spectra of boron-carbon material, B_4C converted graphite, before and after He ion irradiation.

$$\sigma_1^{He} = 1\times10^{-19}\,cm^2,$$
$$\sigma_2^{He} = 6\times10^{-19}\,cm^2.$$

This result indicates that the desorption rate for hydrogen in form of B-H bonding due to the He discharge cleaning is a few times larger than that for hydrogen in form of C-H bonding.

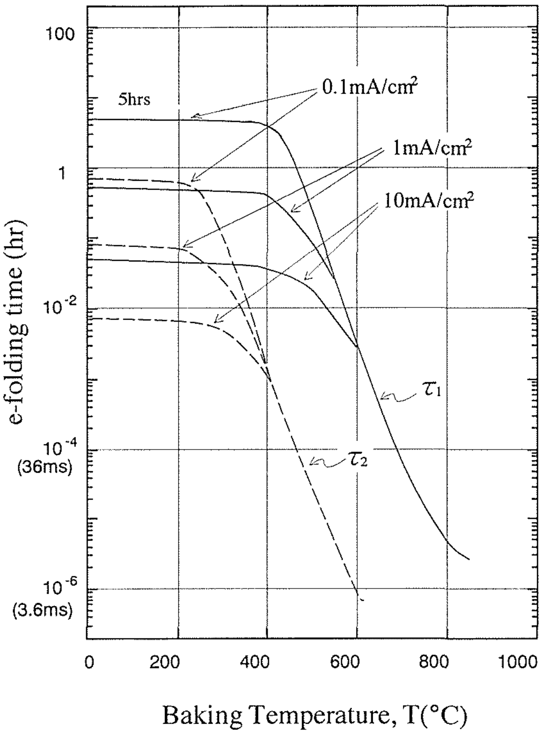

Fig. 3 The e-folding times of hydrogen densities trapped by carbon (τ_1) and boron (τ_2) versus baking temperature, for several values of He ion current densities.

Since all parameters are now known, we can calculate the e-folding times both for the desorptions of C-H bonding and B-H bonding. Figuer 3 shows the e-folding time versus baking temperature for several values of He ion flux or current density. For the desorption of C-H bonding, only the He discharge cleaning is useful when the baking temperature is lower than 400°C. If the current density is 0.1 mA/cm^2, the required conditining time exceeds a few hours. So the current density of 1 mA/cm^2 is needed to shorten the conditioning time less than 1 hour. For the desorption of B-H bonding, the He discharge cleaning is quite effective even when the baking temperature is lower than 200°C. The conditioning time required becomes less than 1 hour when the current density is 0.1 mA/cm^2 in this case.

When the He discharge cleaning is not applied, e.g. only the baking is used, the baking temperatures required for the e-folding time to be less than 1 hour, become 300°C and 500°C for the desorptions of B-H and C-H bondings, respectively. For the reduction of trapped hydrogen in form of B-H bonding, it is accepted to use only the baking if the temperature is kept 300°C. The desorption of C-H bonding may occur, when the wall is largely heated in such case of disruption. For example, at 1000°C, the time constant of C-H desorption becomes approximately 10 ms.

4. Discussion and Summary

The model for hydrogen desorptions of C-H and B-H bondings is described, in which both the He ion impact desorption and the thermal desorption are taken into account. Based on the experimental data for the boron-carbon material, the cross sections of He ion impact desorptions for C-H and B-H bondings are determined. The decay time constant of the trapped hydrogen is discussed.

For the desorption of hydrogen trapped in form of B-H bonding, the suitable temperature is about 300°C, which is well accepted as the baking temperature. Without the baking, the hydrogen of B-H bonding is also desorbed largely by the He discharge cleaning with relatively low current density, 0.1 mA/cm^2. For the desorption of C-H bonding, the baking temperature required is considerably high, 500°C. The current density required to desorb the hydrogen of C-H bonding becomes one order of magnitude higher, 1 mA/cm^2.

Above results suggest that the removal of hydrogen trapped by the boron is relatively easier, compared with the case of carbon. If the graphite surface is entirely covered by the boron, the conditionings for the suppression of recycling may work well. In JT-60U, the confinement characteristic was significantly improved after the boronization1). Since the hydrogen concentration of the boron is easily reduced by the conditionings, the hydrogen emission during the discharge shot might be suppressed. This may be a possible explanation for the suppression of the recycling in JT-60U.

Acknowledgement

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