ELSEVIER

Journal of Nuclear Materials 266–269 (1999) 538–541

journal of nuclear materials

Helium retention of plasma facing materials

T. Hino *, Y. Yamauchi, Y. Hirohata

Department of Nuclear Engineering, Hokkaido University, Kita-13, Nishi-8, Kita-ku, Sapporo 0608628, Japan

Abstract

The helium retention properties such as retained amount, desorption temperature and activation energy of desorption were examined for graphite, B_4C, SiC and tungsten. After the helium ion irradiation with a helium energy of 5 keV in an ECR ion source, these data were obtained by using a technique of thermal desorption spectroscopy. The amount of retained helium saturated at the fluence higher than $(0.5–3) \times 10^{22}$ He/m^2 for every material. The maximum retained amount was $(1–5) \times 10^{21}$ He/m^2. The maximum helium concentration in the implanted depth was compared with that of hydrogen similarly obtained. The atomic ratio, He/H, was 0.3 for graphite, 0.15 for B_4C, 0.3 for SiC and 0.3 for tungsten. It was seen that a considerable large amount of helium was trapped in the plasma facing materials. The desorption temperatures were 570 K for graphite, 570 and 1200 K for B_4C, 570 and 1140 K for SiC and 770 K for tungsten. The helium retention can be reduced by baking with a temperature of 600 K or 800 K for graphite or tungsten, respectively. However, such reduction becomes difficult for SiC or B_4C, since the desorption temperature is very high. Thus, the effective shielding of the scrape-off layer in a diverted plasma has to work sufficiently to avoid the back flow of helium into the core plasma, when the helium emits during discharges.

Keywords: Helium; Retention; Plasma facing material; Graphite; Boron carbide; Silicon carbide; Tungsten

1. Introduction

The reduction of helium ash in the core plasma is one of the most important issues in sustaining a burning plasma for a long period [1]. If the effective confinement time of helium is reduced, the helium ash concentration can be reduced. For this purpose, the confinement time of helium has been measured in tokamaks [2]. For the reduction of the confinement time, the recycling flow of helium from a divertor or first walls to a core plasma has to be low [3,4]. The emission of the helium retained in the walls also has to be suppressed [5].

In the case of a burning plasma, the plasma facing materials are exposed to the helium ash produced by fusion reactions, and also to the helium ion during the helium discharge cleaning. Thus, the plasma facing walls may retain the helium. The helium ash concentration in the core plasma increases when the helium is emitted by an ion impact or thermal desorption and the shielding by the scrape-off layer in diverted configuration is not effective.

In order to evaluate the helium emission from the walls, the helium retention properties of the plasma facing materials have to be investigated, before suitable handling of the retained helium can be considered. Although the erosion of plasma facing material by helium ion has been studied [6], there may not be sufficient data on helium retention.

2. Experimental

The helium ion irradiation was carried out in an ECR ion irradiation apparatus as shown in Fig. 1. The energy and the flux of helium ion were 5 keV and 1×10^{18} He/m^2 s, respectively. The pressure during the irradiation was 4×10^{-4} Pa. The sample temperature was kept room temperature (RT) during the irradiation.

As the samples, isotropic graphite (PD-330S), B_4C converted graphite with a B_4C thickness of 100 μm, SiC

* Corresponding author. Tel.: +81 11 706 7195; fax: +81 11 709 6413; e-mail: tomhino@apollo.ge.eng.hokudai.ac.jp

0022-3115/99/$ – see front matter
PII: S0022-3115(98)00587-X

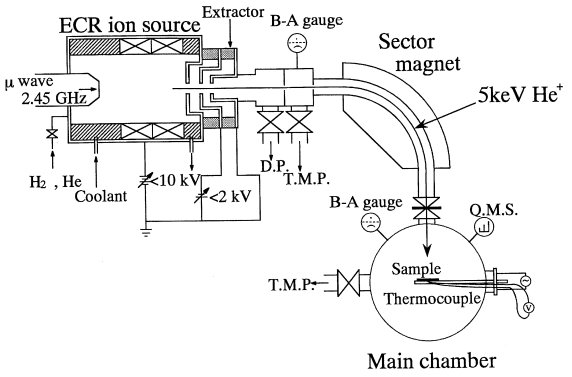

Fig. 1. Schematic of ECR ion irradiation apparatus.

converted graphite with a SiC thickness of 500 μm and polycrystalline tungsten with a purity of 99.99% were used. These samples and coatings were exposed to the helium ions.

Samples with size of $5 \times 10 \times 1$ mm^3 were degassed by the annealing with a temperature of 1273 K for 1 h in the irradiation chamber, followed by helium ion irradiation. After the irradiation, the samples were resistively heated from RT to 1273 K at a heating rate of 50 K/min. During the heating, the helium desorption rate was measured by a quadrupole mass spectrometer (QMS). The amount of the retained helium was obtained by integrating the desorption rate with the heating time. The helium ion fluence was changed in the range from 1×10^{21} to 5×10^{22} He/m^2, and the similar sequence was repeated for different samples.

3. Results

The helium desorption spectra of graphite, B_4C, SiC and tungsten are shown in Figs. 2–5, respectively. Since the peak temperature shifts by the heating rate, the horizontal axis in these figures is expressed as the heating time. The fluence dependence of the helium retention for graphite, B_4C, SiC and tungsten are shown in Fig. 6.

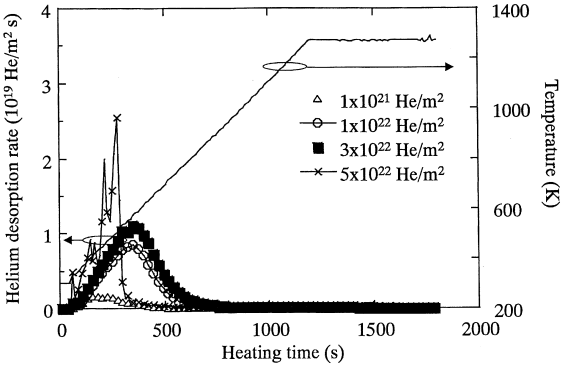

Fig. 2. Helium desorption spectra of graphite after the helium ion irradiation.

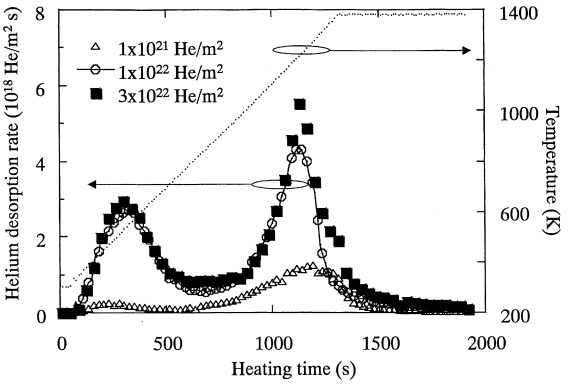

Fig. 3. Helium desorption spectra of B_4C after the helium ion irradiation.

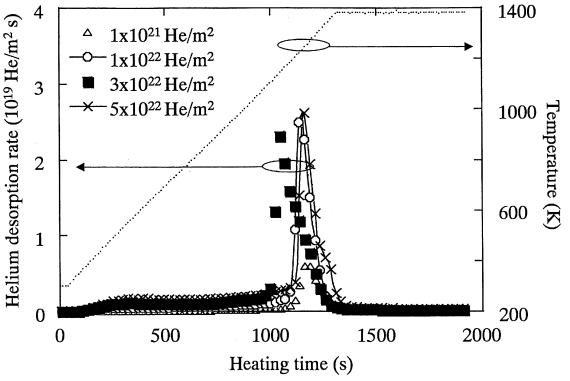

Fig. 4. Helium desorption spectra of SiC after the helium ion irradiation.

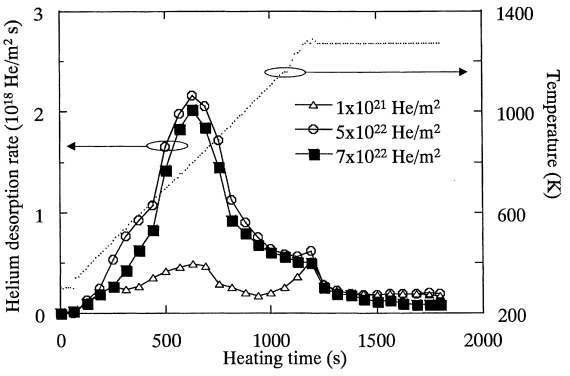

Fig. 5. Helium desorption spectra of tungsten after the helium ion irradiation.

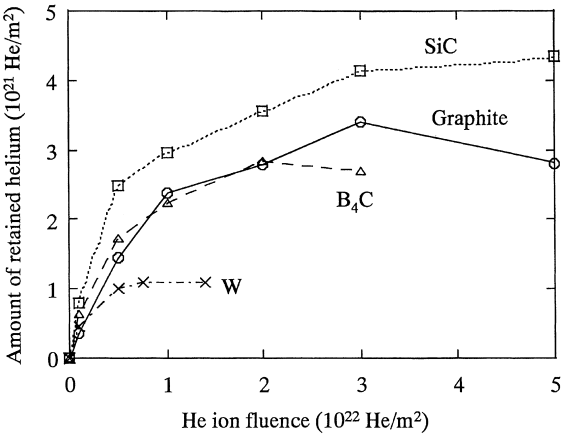

Fig. 6. Helium retention amounts of graphite, B_4C, SiC and tungsten vs helium ion fluence.

In the helium desorption spectra of graphite, the peak temperature of the desorption was about 560 K (Fig. 2). This peak temperature decreased with an increase of the helium fluence. The amount of the helium retention saturated at the fluence of 3.4×10^{21} He/m^2 (Fig. 6). Based on the assumption that the desorption is of first order, the activation energy of the helium desorption was calculated as 1.6 eV. This energy is close to the value, 1.3–1.8 eV, calculated from the data obtained by the other authors [7,8]. It is believed that the helium is trapped in the void or the dislocation loop in the graphite [8]. When the fluence was higher than 5×10^{22} He/m^2, the desorption rate changed with the heating time. This behavior may be caused by the destruction of such defects containing the helium.

The ratio of trapped helium to target atom was estimated by the assumption that the helium was uniformly distributed in the implanted depth [9]. Implanted depths of 5 keV helium ion in graphite, B_4C, SiC and tungsten are 45, 45, 67, and 14 nm, respectively. In the present ECR ion irradiation apparatus, the hydrogen ion irradiation was similarly conducted for graphite, B_4C, SiC and tungsten samples [10,11]. The helium concentration was compared with the hydrogen concentration. Then, the ratio of helium concentration to hydrogen concentration was obtained. This He/H ratio was 0.28 for graphite. The corresponding H/C ratio was about 0.4.

In the case of B_4C, two desorption peaks were observed at temperatures of about 570 and 1200 K (Fig. 3). The peak height at the lower temperature was smaller than that at the higher temperature. The activation energies for the lower and the higher temperature desorptions were 1.6 and 3.5 eV, respectively. The desorption at the lower temperature corresponds to the helium trapped in the graphite content. The desorption at the higher temperature may be due to the helium trapped in the other defect or the decrease of the diffusion speed. The amount of the helium retention saturated at the fluence of 2×10^{22} He/m^2 (Fig. 6), and the value was as high as 2.7×10^{21} He/m^2, approximately 4/5 of that of graphite. The amount desorbed at the lower temperature regime was 35% of the total amount. The ratio, He/H, was 0.15, and the H/B_4C ratio was about 0.5.

The desorption peaks appeared at about 570 and 1140 K, in the case of SiC (Fig. 4). The higher temperature peak was very sharp, although the lower temperature peak was very broad. The activation energies for the lower and the higher temperature peaks were 1.6 and 3.3 eV, respectively. The amount of the helium retention was as high as 4.2×10^{21} He/m^2 (Fig. 6), 1.2 times of the retention in graphite. The amount desorbed at the lower temperature regime was 20% of the total amount. The ratio, He/H, was 0.28, and the H/SiC ratio was 0.5.

In the polycrystalline tungsten, the major peak appeared at around 770 K (Fig. 5). The activation energy was 2.2 eV. The helium retention was as high as 1×10^{21} He/m^2, approximately 1/3 of the retention in graphite. The ratio, He/H, was 0.3, and the H/W was about 0.1.

Since the helium concentration was considerably high, the reduction of the helium retention by annealing was investigated. The annealing temperature dependence of the retained helium is shown in Fig. 7. In this figure, the retention at RT is normalized unity. For the cases of graphite and tungsten, the baking temperature required for the reduction is low, at 600 and 800 K, respectively. However, for the cases of B_4C and SiC, the baking temperature required is high, at 1200 K. In this case, the retained helium may emit by ion impact or thermal desorption during discharges. If the back flow of helium from these plasma facing materials to a core plasma takes place, the shielding effectiveness of the

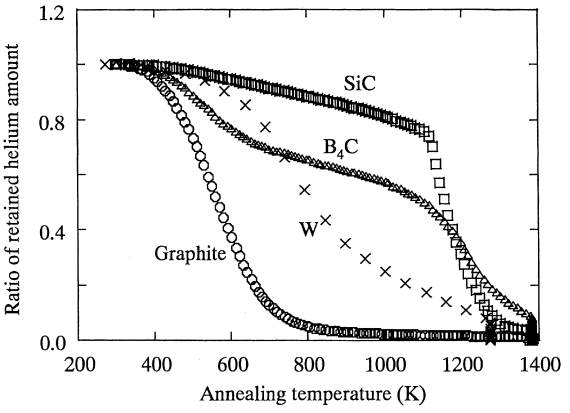

Fig. 7. Annealing temperature dependence of helium retention for graphite, B_4C, SiC and tungsten.

scrape-off layer has to be high in a diverted plasma, e.g. the helium has to be ionized and to be pushed back to the wall by friction force of the diverted plasma.

4. Summary

Since the back flow of retained helium of plasma facing materials may increase the helium ash concentration in a core plasma, it is required to evaluate the helium retention properties of these materials. For graphite, B_4C, SiC and tungsten, the helium implantation with a helium ion energy of 5 keV and at RT was carried out, and the helium retention properties were then investigated.

The maximum retained amounts were 3.4×10^{21} He/m^2 for graphite, 2.7×10^{21} He/m^2 for B_4C, 4.2×10^{21} He/m^2 for SiC and 1×10^{21} He/m^2 for tungsten. The helium concentration in the material was also compared with the hydrogen concentration. The ratio, He/H, was 0.28 for graphite, 0.15 for B_4C, 0.28 for SiC and 0.3 for tungsten. At a corresponding H/material ratio of 0.1–0.5, the helium retention can be high.

In the case of graphite or tungsten, a single desorption peak was observed at temperature of 560 or 770 K, respectively. Thus, the helium retention in graphite or tungsten can be reduced by baking with a temperature of about 600 or 800 K, respectively. In the cases of B_4C and SiC, the desorption peak at the higher temperature region appeared in addition to the peak at 570 K. In these cases, the reduction of the helium retention only by an usual baking can be difficult. Therefore, the shielding effectiveness of the scrape-off layer for the back flow of desorbed helium has to be high to maintain the performance of the core plasma.

References

[1] IAEA, ITER Documentation Series No. 7, Technical Basis for the ITER Interim Design Report, Cost Review and Safety Analysis, International Atomic Energy Agency, Vienna, 1996.
[2] A. Sakasai, H. Takenaga, N. Hosogane, S. Sakurai, H. Ohara, H. Kubo, S. Higashijima, H. Tamai, N. Asakura, K. Itami, K. Shimizu, these Proceedings.
[3] T. Hino, H. Yanagihara, T. Yamashina, Fusion Eng. Design 24 (1994) 437.
[4] T. Hino, Fusion Eng. Design 30 (1995) 299.
[5] K. Nakamura, Y. Okumura, R. Jimbou, V. Bandourko, M. Akiba, presented at 12th Int. Conf. on Plasma–Surface Interactions, San Diego, CA, May 1998.
[6] T. Hino, Y. Yamauchi, Y. Hirohata, K. Mori, Fusion Technol. 1 (1997) 255.
[7] H. Atsumi, S. Tokura, T. Yamauchi, S. Yamanaka, M. Miyake, J. Nucl. Mater. 141–143 (1986) 258.
[8] W. Moller, B.M.U. Sherzer, J. Ehrenberg, J. Nucl. Mater. 111 and 112 (1982) 669.
[9] H.H. Anderson, J.F. Zieger, Stopping Powers and Ranges in All Elements, Pergamon, New York, 1977.
[10] Y. Yamauchi, T. Hino, Y. Hirohata, Vacuum 47 (1996) 973.
[11] T. Hino, Y. Yamauchi, Y. Hirohata, Fusion Eng. Design 39&40 (1998) 227.