ELSEVIER

Journal of Nuclear Materials 258–263 (1998) 607–611

journal of nuclear materials

Section 5. Plasma facing materials and high heat flux materials. 1. Plasma facing materials

The dependence on ion energy and temperature of helium trapping in nickel

H. Yanagihara *, Y. Hirohata, T. Hino

Department of Nuclear Engineering, Hokkaido University, Kita-13, Nishi-8, Kita-ku, Sapporo 060, Japan

Abstract

The reduction of helium concentration in the core of the plasma is a major issue to control the fusion reaction. Nickel has been proposed to be used in the vicinity of the divertor as a helium selective pumping material. In this study, the amount of trapped helium in nickel after helium plasma irradiation was measured by thermal desorption spectroscopy (TDS). The incident energy of helium ion was adjusted by the negative bias voltage. The dependence of the trapped amount of helium on the helium incident energies was studied using different irradiation temperature. Besides a peak at low temperature, desorption peaks of helium appeared in the high temperature region when the energy of the helium ion is relatively high. For irradiation temperatures below 400°C, the amount of trapped helium increased linearly with the energy of the helium ion. For irradiation temperatures higher than 500°C, the trapping of helium needed of relatively high incident ion energies. The dependence of the amount of trapped helium on the irradiation fluence was also investigated.

1. Introduction

In a fusion reactor, it is important to reduce the helium ash concentration in a core plasma for sustaining the ignition condition. If the pumping efficiency of helium by divertor or limiter is not sufficient, additional pumping is necessary. Helium selective pumping materials in the vicinity of the divertor or limiter have been suggested [1–3]. It is reported that metals, such as nickel and molybdenum, trap more helium than hydrogen, i.e. these metals have the property to pump helium selectively [4–6]. If such materials are placed near the divertor, the helium recycling flow from the divertor to the core plasma is suppressed, and then the helium concentration in the plasma largely reduced [3]. It is known that nickel has a large capability of helium trapping [6]. In the limiter of TEXTOR, nickel was used as a helium pumping material, and a reduction of the helium concentration in the plasma was observed [7–9]. Although results for several metals exist [2,4,10,11], the helium trapping properties of nickel in an extended range of temperatures and ion energies have not been sufficiently investigated. It may be required to obtain such date, in order to consider the application for ITER [12]. In this study, in order to obtain these date, helium plasma irradiation experiments were carried out for nickel by changing the helium energy at various irradiation temperatures.

2. Experimental

Polycrystalline plates of nickel (purity: 99.9%) were used as samples. All the samples were polished mechanically and cleaned in an ultrasonic bath with ethanol. Fig. 1 shows the schematic diagram of the ECR plasma irradiation apparatus [4–6] used for helium plasma irradiation. It has two chambers, the ECR plasma chamber and the irradiation chamber. The helium plasma was produced in the ECR chamber. The discharge pressure was 5 Pa. The nickel sample was placed on the sample holder. Before helium plasma irradiation, the sample was degassed at 800°C for 2 h. After this treatment, the sample was irradiated by helium plasma. A negative bias voltage was controlled in order to adjust the energy of the helium ion. The experimental variables were the negative bias voltage (V_B) and the irradiation temperatures (T_{irrad}). For each irradiation, the V_B was

* Corresponding author.

0022-3115/98/$19.00
PII: S0022-3115(98)00110-X

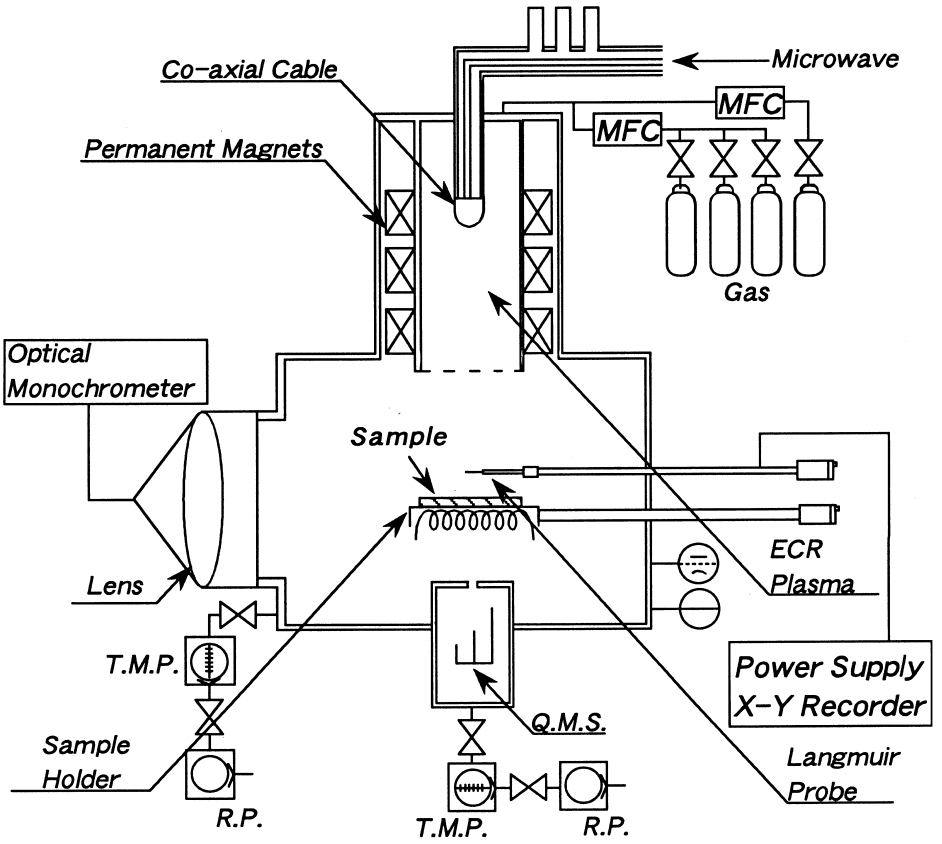

Fig. 1. ECR plasma irradiation apparatus.

changed from 0 to −1 kV and T_{irrad} from room temperature (RT) to 600°C. The current to the sample was measured in order to estimate the flux of helium ions. Reference values of helium fluences were $\sim 2.0 \times 10^{18}$/cm^2.

After the irradiation, the sample was taken out from the irradiation chamber and moved to the thermal desorption spectroscopy (TDS) apparatus [13,14], for measuring the amount of trapped helium. The sample was linearly heated from RT to 1000°C, and kept at 1000°C for 30 min. The heating rate was 10°C/min. During the heating process, the amount of desorbed helium was continuously monitored by a quadruple mass spectrometer (QMS).

3. Results

3.1. Helium desorption spectra

Fig. 2(a) and (b) show the TDS spectra for helium obtained from samples irradiated at 200°C and 600°C respectively. The bias voltage was changed in the range from −0.1 to −1 kV. For $T_{irrad} = 200$°C, only one desorption peak appeared in the temperature range 300–400°C when the voltage was below −400 V. Two or more desorption peaks appeared for temperatures above 600°C and negative bias voltage larger than −500 V. The apparition of the peaks at the higher temperature region may result from the trapping of helium at different trapping states. For $T_{irrad} = 600$°C, no desorption peak was observed when the negative bias voltage was below −700 V.

The activation energy for the helium desorption was evaluated on the basis that the thermal release limits, at first order, the desorption process. The activation energy of helium desorption was estimated by using the following equation [15,16]:

$$E_d/kT_p = \ln\left(vT_p/\beta\right) - 3.64, \quad (1)$$

where E_d is the activation energy in J/mol, k the Boltzmann constant, T_p the peak temperature in K, v the frequency factor ($= 10^{13}$/s) and β the heating rate in K/s. In the TDS spectra, there were two major desorption peaks at the high temperature side (Peak-H) and the low temperature side (Peak-L). Fig. 3 shows the activation

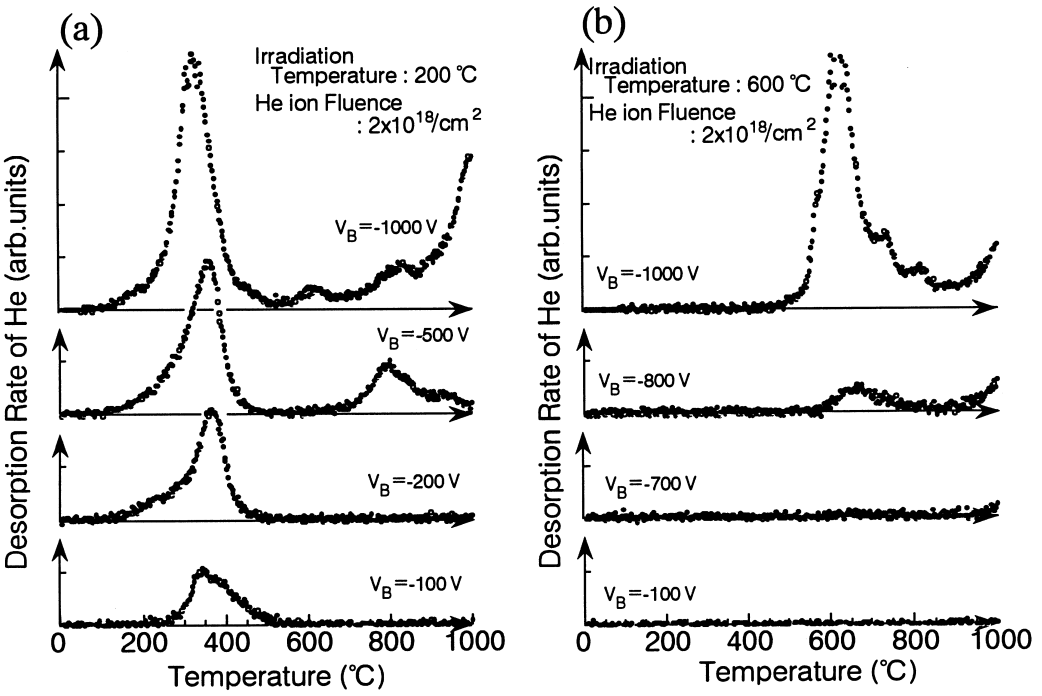

Fig. 2. (a) Thermal desorption spectra of helium for nickel after irradiations with various bias voltages at $T_{irrad} = 200°C$. (b) Thermal desorption spectra of helium for nickel after the irradiations with various bias voltages at $T_{irrad} = 600°C$.

energies for such major desorption peaks versus the irradiation temperature when the bias voltage was −1kV. The activation energy of desorption for the Peak-L increased with increasing irradiation temperature. On the contrary, the activation energy of the Peak-H was almost constant (~3.2 eV) and independent from the irradiation temperature. This value agrees with the energy for nickel self-diffusion [17,18]. So, the Peak-H is regarded to be due to the self-diffusion of nickel.

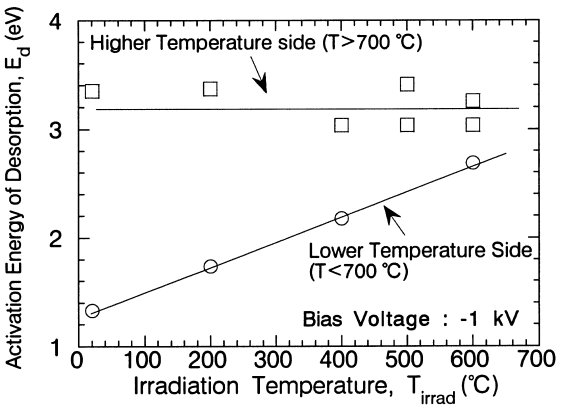

Fig. 3. Activation energy of helium desorption for various irradiation temperatures (bias voltage: −1 kV, helium ion fluence: 2×10^{18} He/cm^2).

3.2. Amount of trapped helium

Fig. 4 shows, at different temperatures, the dependence on energy of the amount of trapped helium. For temperatures lower than 400°C, the amount of trapped helium increased with increasing negative bias voltage. However, for the irradiation temperatures above 500°C, there was almost no possible to see trapping when the bias voltage was below −(600–700) V. This behavior may result from the quick detrapping of helium before the diffusion into the bulk.

Fig. 5 shows the dependence on irradiation temperatures of the trapped helium for different bias voltage. Irrespective of bias voltage, the amount of trapped helium showed a maximum value at about $T_{irrad} = 200°C$. With $V_B = -1$ kV, and even at the higher irradiation temperature the amount of trapped helium was also large.

In Fig. 6, comparison of our results with other existing [8] results are done. Our results were in good agreement with those reported in [8] for $T_{irrad} = RT$ and with the low bias voltage. In the experiment of TEXTOR [8,9], the amount of trapped helium was observed to be small when compared with results obtained at RT. In

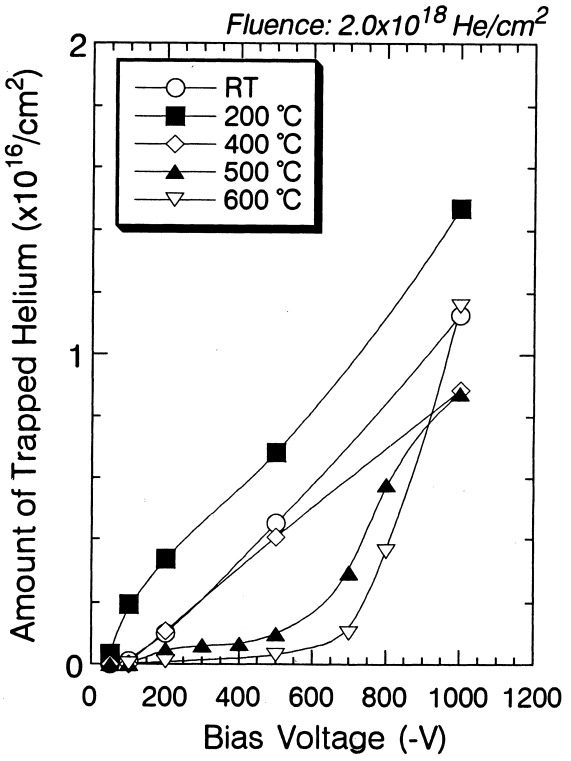

Fig. 4. Helium energy dependences for trapped helium amounts in nickel at various irradiation temperatures.

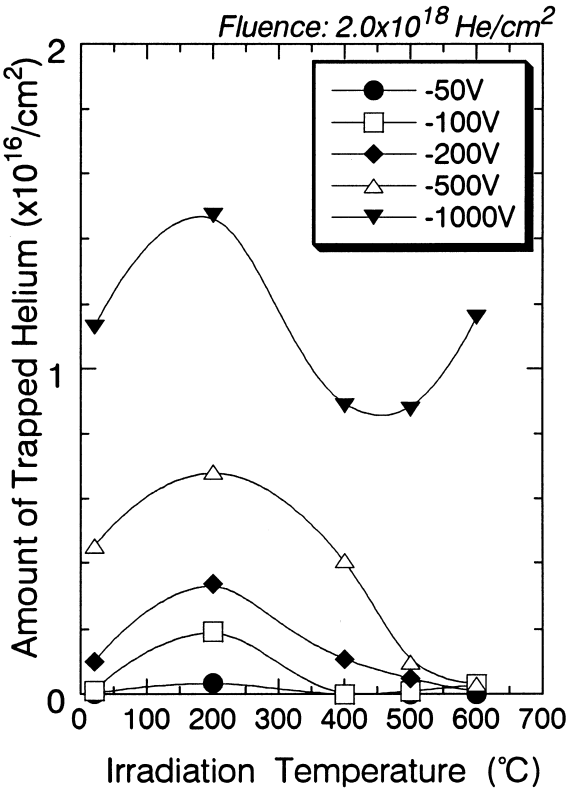

Fig. 5. Irradiation temperature dependences for trapped helium amounts in nickel at various bias voltages.

TEXTOR, it was reported that the nickel temperature was about 450°C and helium energy was about 150–200 eV. The trapping amount in TEXTOR was almost comparable with our results at $T_{irrad} = 400$°C and $V_B = -0.2$ kV.

4. Summary

The amount of trapped helium and thermal desorption behavior of helium has been studied in nickel after irradiation with helium ion under various irradiation temperatures and negative bias voltages. The main results of the present study are summarized as follows.

1. Desorption peaks of helium appeared in the temperature region higher than 600°C when the negative bias voltage was higher than −500 V, in addition to the peak in the low temperature range of 300–400°C for $T_{irrad} = 200$°C. For $T_{irrad} = 600$°C, there was no desorption peak when the bias voltage was below −(600–700) V.
2. Activation energy of helium desorbed at the higher temperature region was about 3.2 eV, which may be due to self-diffusion of nickel.
3. For $T_{irrad} < 400$°C, the amount of trapped helium almost linearly increased with the negative bias voltage. On the contrary, in case of the irradiation temperature higher than 500°C, the helium was not trapped

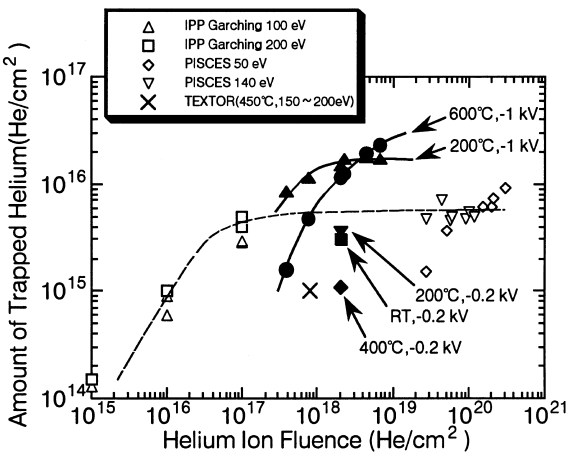

Fig. 6. Comparison of the amount of trapped helium among low energy helium irradiations [8].

when the negative bias voltage remained below the threshold voltage of −(600–700) V.

Acknowledgements

This work was supported by JSPS Research Fellowship of the Japan Society for the Promotion of Science for Young Scientists.

References

[1] J.N. Brooks, R.F. Mattas, J. Nucl. Mater. 121 (1984) 392.
[2] A.E. Pontau, W. Bauer, R.W. Conn, J. Nucl. Mater. 93/94 (1980) 564.
[3] T. Hino, H. Yanagihara, T. Yamashina, Fusion Eng. and Design 24 (1994) 438.
[4] H. Yanagihara, I. Fujita, T. Hino, T. Yamashina, J. Nucl. Mater. 220–222 (1995) 856.
[5] H. Yanagihara, T. Hino, Y. Hirohata, M. Uesaka, T. Yamashina, Vacuum 47 (1996) 661.
[6] H. Yanagihara, Y. Yamauchi, T. Hino, Y. Hirohata, T. Yamashina, J. Nucl. Mater. 241–243 (1997) 1098.
[7] J.N. Brooks, R.E. Nygren, K.H. Dipple, B.L. Doyle, K.H. Finken, Y. Hirooka, A. Krauss, R.F. Mattas, R.T. McGrath, D.L. Smith, D. Walsh, J. Nucl. Mater. 176/177 (1990) 635.
[8] R.E. Nygren, B.L. Doyle, D.S. Walsh, W. Ottenberger, J.N. Brooks, A. Krauss, J. Nucl. Mater. 196–198 (1992) 558.
[9] J.N. Brooks, A. Krauss, R.E. Nygren, B.L. Doyle, K.H. Dippel, K.H. Finken, J. Nucl. Mater. 196–198 (1992) 664.
[10] A.E. Pontau, C.B. Layne, W. Bauer, J. Nucl. Mater. 103/104 (1981) 535.
[11] C.A. Outten, J.C. Barbour, B.L. Doyle, D.S. Walsh, He self-pumping by Tokamak pump limiter materials Al, V, Ni, alloys, in: Proceedings of US–Japan Workshop Q-142 on High Heat Flux Components and Plasma–Surface Interactions for Next Devices, SAND92-0222, 1992, pp. 2–96.
[12] K. Tomabechi, J.R. Gilleland, Yu.A. Sokolov, R. Toshi and the ITER Team, Nucl. Fusion 31 (1991) 1135.
[13] T. Yamashina, T. Hino, J. Nucl. Mater. 48/49 (1991) 483.
[14] Y. Hirohata, J. Vac. Soc. Jpn. 33 (1990) 448.
[15] P.A. Redhead, Vacuum 12 (1962) 203.
[16] R.O. Rantanen, A.E. Moen, E.E. Donaldson, J. Vacuum Sci. Technol. 7 (1970) 18.
[17] N.L. Peterson, J. Nucl. Mater. 69/70 (1978) 3.
[18] T. Yamauchi, S. Yamanaka, M. Miyake, J. Nucl. Mater. 179–181 (1991) 308.