19PA-018

Surface Morphology Change and Sputtering of F82H Reduced Activation Ferritic/Martensitic Steel and Fe by Low-Energy, High-Flux Deuterium Plasma

低エネルギー・高フラックス重水素プラズマによるF82H低放射化フェライト鋼および純Feの表面形態変化とスパッタリング

Yuji Hatano[1], Vladimir Kh. Alimov[1], Naoaki Yoshida[2], Hideo Watanabe[2], Makoto Oyaidzu[3] and Takumi Hayashi[3]

波多野雄治[1], アリモフ ウラジミール[1], 吉田直亮[2], 渡辺英雄[2], 小柳津誠[3], 林巧[3]

[1]*Hydrogen Isotope Research Center, University of Toyama*
Gofuku 3190, Toyama 930-8555, Japan
富山大学水素同位体科学研究センター 〒930-8555 富山市五福3190

[2]*Research Institute for Applied Mechanics, Kyushu University*
Fukuoka 816-8580, Japan
九州大学応用力学研究所 〒816-8580 福岡県春日市春日公園6-1

[3]*Japan Atomic Energy Agency*
2-166 Omotedate, Rokkasho-mura, Kamikita-gun, Aomori 039-3212, Japan
日本原子力研究開発機構 〒039-3212 青森県上北郡六ヶ所村大字尾駮字表舘2番166

Plates of F82H steel and pure Fe was exposed to low-energy (140–200 eV), high-flux (~10^{22} $m^{-2}s^{-1}$) D plasma and He plasma at temperatures from 350 to 773 K to examine the sputtering rates and the change in surface morphology. The specimens of F82H steel showed lower sputtering rates than Fe specimens due to enrichment of W at the surface. Clear temperature dependence was observed for the sputtering rates of F82H steel and Fe under exposure to both D plasma and He plasma.

1. Introduction

Reduced activation ferritic/martensitic (RAFM) steels such as F82H and Eurfer97 steels are potential candidates for structural materials of tritium breeding blankets of fusion reactors [1]. Those steels may be used also as the first wall materials in selected areas in the reactor core with moderate particle and heat loads. To understand the interactions of the steel surfaces with hydrogen isotope plasma, the authors examined the change in surface compositions and morphology of F82H steel after exposure to low-energy, high-flux D plasma at various temperatures [2]. Significant enrichment of heavy alloying elements, i.e. W, was observed due to the preferential sputtering of Fe [2]. In addition, the surface morphology was sensitively dependent on temperature; a column-like structure was formed at around 460 K and a fiber-like nanostructure was developed at around 773 K [2].

In this study, the temperature dependence of sputtering rates of F82H steel and pure Fe was examined under exposure to low-energy, high-flux D plasma; the comparison between F82H steel and Fe was to investigate the effects of alloying elements on sputtering rates. The exposure of Fe specimens to He plasma was also performed under similar conditions for comparison. The surface morphology of plasma-exposed specimens were also examined.

2. Experimental

Specimens used were plates (10×10×0.5 mm) of F82H steel and Fe. Major alloying elements of F82H steel are Cr (8%), W (2%), V (0.2%) and Ta (0.02%) [3]. The specimens were exposed to low-energy (140–200 eV), high-flux (~10^{22} $m^{-2}s^{-1}$) D plasma at temperatures from 350 to 773 K in a linear plasma generator [4] in the Japan Atomic Energy Agency (JAEA). The sputtering rate was evaluated from mass loss. The plasma consists of D^+ ions (~30%) and D_2^+ ions (~70%). Only the sputtering by D^+ ions was considered in the sputtering rate evaluation because the kinetic energy per D nucleus in D_2^+ ions was a half of that in D ions. The surface morphology of plasma-exposed specimens was examined with a field emission scanning electron microscope (FE-SEM). The exposure to He plasma was performed at ion energy of 200 eV, flux of ~1.6×10^{21} $m^{-2}s^{-1}$ and temperatures up to 773 K.

3. Results and Discussion

Fig. 1 (a) shows the temperature dependence of sputtering rates of F82H steel and Fe under exposure to D plasma. The sputtering rate for F82H steel was clearly smaller than that of Fe. The difference between the steel and Fe can be ascribed to the enrichment of W on the surface caused by the preferential sputtering of Fe; the concentration of W on the surface was about 30 at.% in the maximum case [2]. The sputtering rates of F82H steel and Fe monotonously increased with increase in exposure temperature T_{exp}. The constants for proportionality of F82H steel and Fe were comparable with each other, and 2.6×10^{-5} and 2.8×10^{-5}, respectively.

As previously reported [2], the fiber-like nanostructure was developed for F82H steel at 773 K. However, the development of the nanostructure was not observed for Fe. The comparable constants for proportionality for the steel and Fe indicates that the temperature dependence of sputtering rate is insensitive to surface morphology.

The temperature dependence of sputtering rate of Fe under He plasma exposure is shown in Fig. 2. The rate of sputtering by He ions was larger than that by D ions due to larger mass of He. Interestingly, the sputtering rate under exposure of He plasma also showed clear temperature dependence, and it monotonously increased with increase in temperature, as observed for D plasma.

Roth et al. [5] has examined the sputtering of graphite by H and He ions. They reported that the sputtering rate by H ions showed clear temperature dependence due to the chemical sputtering, while no significant temperature dependence was observed for the physical sputtering by He ions [5]. In the present study, the sputtering rate of Fe by He ions showed significant temperature dependence, as described above. In other words, the temperature dependence of physical sputtering was clearly observed at the kinetic energy of ~200 eV and flux of $\sim10^{22}$ $m^{-2}s^{-1}$. The mechanisms underlying the temperature dependence of physical sputtering has not been fully understood. The systematic study with metals having different physical properties is currently under preparation.

Although the sputtering rate of F82H steel by D ions was clearly lower than that of Fe, the difference is not very big; a factor of 1.5 or less. Further investigation is required for more pronounced reduction of sputtering rate.

4. Summary

The sputtering rate of F82H steel by D ions was clearly lower than that of Fe due to the enrichment of W at the surface. However, the difference was still not very big; a factor of 1.5 or less. The sputtering rate of F82H steel and Fe under exposure to D plasma and He plasma showed clear temperature dependence, and it increased with increase in temperature.

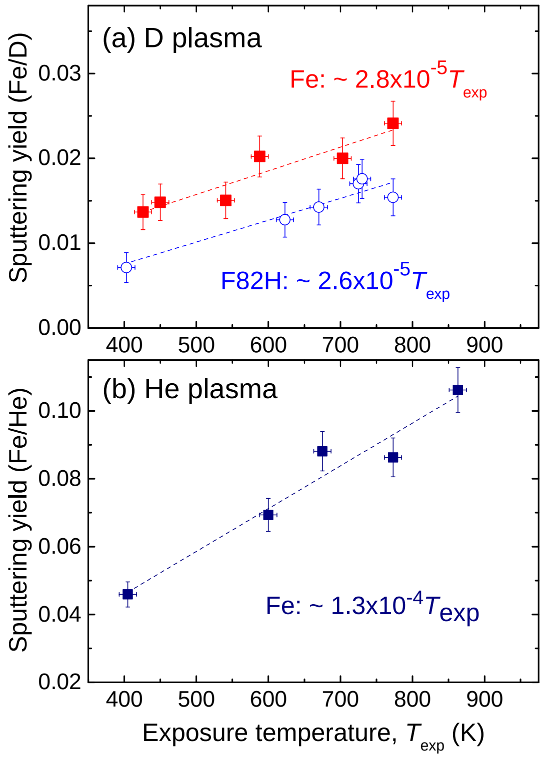

Fig. 1.Temperature dependence of sputtering rates of H82H steel and Fe under exposure to (a) D plasma and (b) He plasma.

Acknowledgments

This study was supported by JAEA under the Joint Work contract #26K266, as a part of Broader Approach activities, and Joint Research program of the Research Institute for Applied Mechanics, Kyushu University. The authors would like to thank Dr. H. Tanigawa, JAEA, for F82H steel specimens.

References

[1] Q. Huang, N. Baluc, Y. Dai, S. Jitsukawa, A. Kimura et al.: J. Nucl. Mater. **442** (2013) S2.

[2] V. Kh. Alimov, Y. Hatano, K. Sugiyama, M. Balden, T. Höschen, M. Oyaidzu, J. Roth, J. Dorner, M. Fußeder and T. Yamanishi: Phys. Scr. **T159** (2014) 014049.

[3] H. Hayakawa, A. Yoshitake, M. Tamura, S. Natsume, A. Gotoh and A. Hishinuma: J. Nucl. Mater. **179–181** (1991) 693.

[4] G.-N. Luo, W. M. Shu, H. Nakamura, S. O'Hira and M. Nishi: Rev. Sci. Instrum. **75** (2004) 4374.

[5] J. Roth, J. Bohdansky, W. Poschenrieder, M. K. Sinha: J. Nucl. Mater. 63 (1976)