Impact of helium irradiation and damage introduction on hydrogen isotope retention behaviors in tungsten

* Sun Fei[1], Togari Akihiro[1], Nakata Moeko[1], Zhao Mingzhong[1],
Kondo Sosuke[2], Hinoki Tatsuya[3], Oya Yasuhisa[1]
[1]Shizuoka Univ., [2]Tohoku Univ., [3]Kyoto Univ.

Abstract

Impact of helium irradiation and damage introduction on hydrogen isotope retention behaviors was studied using simultaneous He^+ and Fe^{3+} irradiation. The additional D_2^+ implantation was performed, and D retention was evaluated by TDS. Based on these experimental results, the model of hydrogen isotope diffusion and trapping across helium bubble layer in tungsten was established. Good agreement can be achieved by comparing simulations based on the established model to the experimental results, indicating that D desorption behavior can be reasonably explained.

Keywords: Helium, hydrogen isotope, irradiation damages, simulation, tungsten, fusion

1. Introduction

During the operation of fusion reactors, hydrogen isotope implantation and diffusion into plasma facing materials will enhance its inventory, leading to the impact on fuel recovery efficiency and fusion safety. However, recent findings show a reduction of hydrogen isotope retention by helium implantation due to reduction of hydrogen isotope diffusion toward bulk by the formation of helium bubbles. In actual fusion condition, helium will be implanted not only from plasma but also alpha-decay by neutron irradiation in bulk. In addition, neutron irradiation will also introduce various irradiation damages. Therefore, it is quite important to study both of irradiation damages and helium effect in bulk W to evaluate the reactor design.

2. Experiments

The annealed mirror finished disk-type tungsten samples were installed into Dual-Beam Facility for Energy Science and Technology (DuET) facility at Kyoto University. A 1.7 MV tandem accelerator and 1 MV single end accelerator were used to introduce 6.4 MeV Fe^{3+} and, 201, 467, 737 and 1000 keV He^+ simultaneously at room temperature. The ratio of helium to damage concentration was set to be 100 appm He / dpa on average. Thereafter, 1 keV D_2^+ implantation was performed at room temperature at Shizuoka University. The following thermal desorption spectroscopy (TDS) was applied from room temperature up to 1173 K to evaluate the D desorption behavior using a high-resolution mass spectrometer.

3. Results and discussions

It can be found that the diffusion of deuterium was largely suppressed by He^+ and Fe^{3+} simultaneously irradiation compared with only damage introduction. All the desorption peaks were shifted towards lower temperature side. In the meanwhile, the desorption rate decreased, especially at high TDS temperature. Based on the experimental results, the mechanical model of hydrogen isotope diffusion and trapping across bulk helium and damages introduced tungsten was established using HIDT simulation code. It was found that the bulk helium would act as a strong diffusion barrier to prevent deuterium diffusing toward the bulk. In addition, trapping energies would be decreased with the existence of bulk helium, which is related to the amount of helium along the depth. What’s more, helium would introduce some trapping sites, which can change hydrogen isotope inventory near surface. In the presentation, more details would be introduced.

References

[1] Y. Oya, S. Sakurada, K. Azuma, et al., Nucl. Mater. Energy, 16 (2018) 217-220

[2] M.J. Baldwin, R.P. Doerner, Nucl. Fusion, 57 (2017) 076031