

Deuterium Retention of Tungsten with Surface Nanostructures

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Tungsten specimens with nano-morphology (Nano-W) were prepared by exposure to helium plasma in the divertor plasma simulator NAGDIS-II. For comparison, tungsten specimens with smooth surface (Polished-W) were also prepared. Surface area of Nano-W was measured by using BET method. Deuterium retention of Nano-W and Polished-W was investigated by thermal desorption spectroscopy (TDS) after exposure to D₂ gas. It was found that surface area of Nano-W was significantly larger than that of Polished-W. Deuterium retention was also greatly increased due to nanostructure formation.

1. Introduction

It is widely accepted that tungsten is one of the most promising candidates of plasma-facing materials in fusion reactors because of its excellent properties, such as high melting point, low erosion yield and hydrogen isotope solubility etc. However, tungsten surface is strongly modified by exposure to He plasma/ions. Blistering occurs at temperature below 1000K [1], while holes/bubbles [2] and nanostructures [3] form at higher temperatures. Incident ion energy and surface temperature were found to be key parameters for the formations of the nanostructures [4].

Influence of such drastic change in surface structure on hydrogen isotope retention is necessary to be investigated. From these viewpoints, the deuterium (D) retention by nanostructured tungsten was examined in the present study.

2. Specimen preparation

Tungsten specimens with nano-morphology (Nano-W) were prepared by exposing pure tungsten sheets to He plasma in the divertor plasma simulator NAGDIS-II. Two batches of Nano-W (indicated as #1 and #2 Nano-W) were prepared under slightly different irradiation conditions given in Table I. As reference, specimens with smooth surface (Polished-W) were also prepared by polishing tungsten sheets with diamond powder and colloidal silica suspension.

Table I. Helium plasma irradiation conditions

	#1 Nano-W	#2 Nano-W
Ion energy (eV)	57	59
He Ion flux (m ⁻² s ⁻¹)	3.33×10 ²²	9.1×10 ²¹
He Ion fluence (m ⁻²)	4.20×10 ²⁵	1.09×10 ²⁵
Temperature (K)	1180	1260

3. Surface area measurement

Surface area of Nano-W was measured by BET method. Namely, after heating in vacuum at 873K, adsorption of Kr gas on the Nano-W was measured at 77 K as function of pressure. The adsorption isotherm thus obtained is shown in Fig. 1(a). This isotherm was replotted according to the BET equation:

$$\frac{1}{V[(P/P_0) - 1]} = \frac{1}{V_m C} + \frac{(C - 1) P}{V_m C P_0},$$

where, P is pressure of Kr gas, P_0 is saturation vapour pressure of Kr at 77 K, V is the volume of Kr gas adsorbed at given P/P_0 , V_m is the volume of Kr gas to give monolayer coverage and C a constant related to the heat of adsorption. A linear relationship was observed between $1/V [(P/P_0)-1]$ and P/P_0 as shown in Fig. 1(b). Hence, V_m was determined from the slope and intercept, and surface area was calculated by assuming that the area occupied by single Kr adatom is 18.5 Å² [5].

Surface areas of #1 and #2 Nano-W were thus evaluated to be 24 and 12 cm², respectively. As reported by Baldwin et al. [6], thickness of nanostructured lays depends on He ion fluence. The larger surface area of #1 Nano-W was ascribed to larger fluence of He ions.

Macroscopic surface areas of these specimens were 2 cm². Thus, surface area of #1 and #2 Nano-W were increased by 12 and 6 times, respectively, due to nanostructure development.

4. Deuterium retention

Both Polished-W and Nano-W were exposed to D₂ gas at 573 K and 1.2 kPa for 5 hours. The amount of D₂ retained in Polished/Nano-W was

then measured by thermal desorption spectroscopy (TDS) at ramp rate of 0.5K s^{-1} .

Fig. 3 shows desorption spectrum of D from Polished-W. The amount of D released from Polished-W (Q_p) was calculated to be $6.6 \times 10^{17} \text{ D m}^{-2}$. The D desorption spectra from Nano-W are shown in Fig. 4. The amounts of D from #1 Nano-W (Q_{N1}) and #2 Nano-W (Q_{N2}) were $1.5 \times 10^{19} \text{ D m}^{-2}$ and $8.2 \times 10^{18} \text{ D m}^{-2}$, respectively.

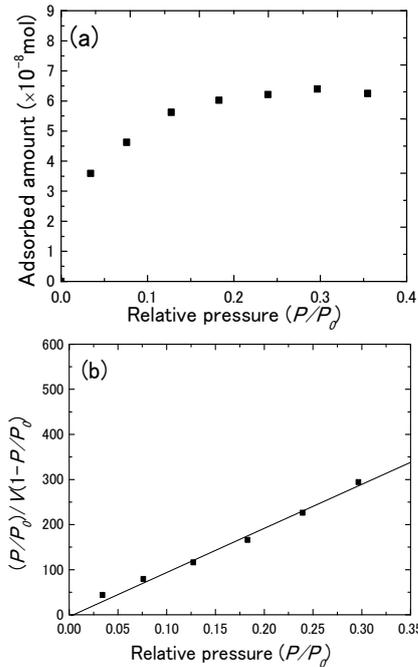


Fig. 1 BET measurement results of surface area of #1 Nano-W, (a) Kr adsorption isotherm at 77K, and (b) Plot of $1/V [(P/P_0)-1]$ against P/P_0 .

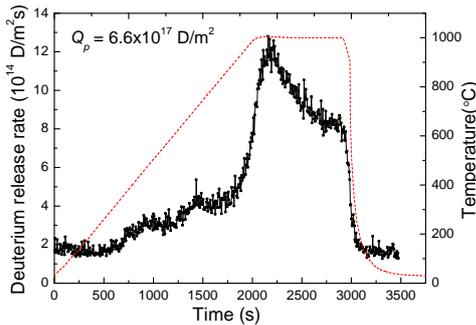


Fig. 2 D desorption spectrum of Polished-W

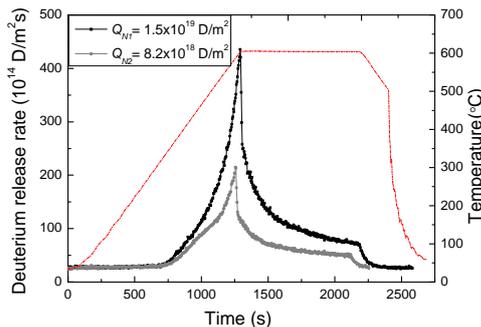


Fig. 3 D desorption spectra of Nano-W

The correlation between surface area and D retention is shown in Fig. 4. The amount of retained D increased almost linearly with surface area. Thus, the larger D retention by Nano-W was attributed to the increase in surface area due to nanostructure development.

Nano-size He bubbles inside nano-fibers were identified by TEM observation [7]. These pre-existed helium bubbles can act as trapping sites of D. Further investigation is necessary to clarify the roles of He bubbles in D retention.

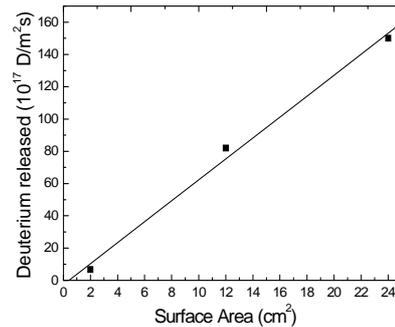


Fig. 4 Correlation between D retention and surface area.

5. Summary

Nanostructures formed on tungsten surface inevitably resulted in huge increase in surface area comparing with tungsten having smooth surface. The surface area of nanostructured tungsten was increased with fluence of He ions. Deuterium retention by tungsten under exposure to D_2 gas significantly increased with the development of nanostructure. The linear correlation was observed between D retention and surface area.

References

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