irradiated temperatures. Yield stress (YS) increased significantly by irradiation and saturated above about 10 dpa. The irradiation embrittlement effects are significant in the specimens because the strain to necking (STN) reduced sharply to less than 1% after 7.1 dpa irradiation, as shown in Figs. 1～3. For comparison, the tensile properties of SA316LN, JPCA, SS316F, EC316LN stainless steels irradiated in SINQ are plotted in Figs. 2 and 3 for test temperatures of RT and elevated temperatures, respectively. Irradiation-induced hardening and decrease in the work hardening capacity are similar in these austenitic steels.

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3 - 9 Thermal Desorption and Surface Modification of Tungsten Implanted by 100 keV He-ions

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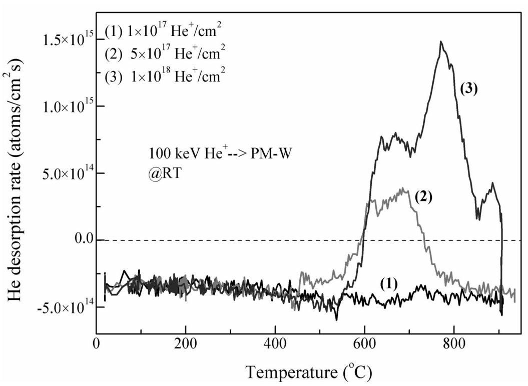

Fig. 1 THDS of the specimens implanted with 100 keV He^+ at RT to different doses.

Tungsten is a candidate material for divertor in fusion reactors due to its high melting point and good thermal performance[1]. Helium introduced by burning plasma and neutron irradiation in tungsten will possibly re-emit into the core plasma and affect the safety. Thermal desorption behavior of helium in tungsten needs to be understood to estimate the amount of helium re-emission. In this work, the dose dependence of helium desorption behavior in tungsten was investigated.

The tungsten specimens with high purity of 99.99% were irradiated with 100 keV He^+ at room temperature (RT). The mean flux was about 4.7×10^{13} ions/(cm^2 s). The doses were low 1.0×10^{17}, middle 5.0×10^{17} and high 1.0×10^{18} ions/cm^2. After irradiation, He desorption behavior was investigated by Thermal He Desorption Spectroscopy (THDS) and SEM was used after THDS to identify the surface morphology.

Thermal helium desorption spectra for the case of 100 keV He^+ irradiation at RT is shown in Figs. 1. It should be illustrated that the He desorption rates below zero are considered as background, i.e. zero, and only those data above zero will be discussed.

The He desorption spectra indicated that when the temperature was not above 900 ℃ the desorption behavior suddenly changed at the middle dose of 5.0×10^{17} ions/cm^2 with several peaks. Therefore the threshold dose of He desorption is between 1.0×10^{17} and 5.0×10^{17} ions/cm^2, which is almost the same as the case of 8 keV in Ref. [1]. The temperature range of He desorption, the temperature and desorption rate at the peak as well as the total desorption for the two specimens are listed in Table 1. In the case of 5.0×10^{17} ions/cm^2, He atoms releasing started at about 585 ℃ and stopped after about 730 ℃ with two peaks between them. When the dose increased to 1.0×10^{18} ions/cm^2, He desorption started at about 598 ℃ and four peaks appeared below 900 ℃. The helium desorption rates at the two lower peaks were more than twice the rates of the specimen with 5.0×10^{17} ions/cm^2. The total He desorption was also much higher in the case of the high dose. The total desorption did not show the saturation of the total desorption and did not reach the saturation value of 1.0×10^{17} ions/cm^2 as reported in other studies[1-2] probably because the maximum annealing temperature was lower in our work.

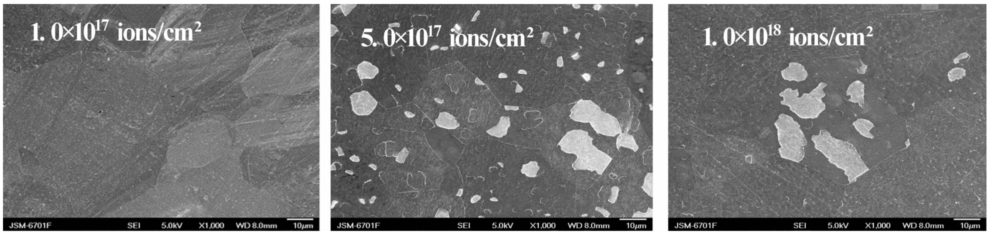

Fig. 2 Surface modification of specimens irradiated with 100 keV He^+ at RT to different doses after THDS.

SEM observation of the specimens after THDS indicated that exfoliation and holes occurred at the dose of 5.0×10^{17} ions/cm^2, as shown in Fig. 2. The exfoliation zones were irregular in shape with several micrometers in size and dense round granules or their clusters appeared at the bottom. Outside the exfoliation zones, small holes appeared. The density of the surface holes and granules or their clusters for the specimen with middle dose was higher than that for the specimen with high dose and the average size was lower. It was believed that some micro-paths formed along the inter-bubble cracks when the blisters appeared.

Based on the He desorption mechanism discussed by Zelenskij[3] and the surface modification shown in Fig. 2, we believe that the pore formation is largely related to the helium bubbles near the surface and the exfoliation attributes mainly to helium bubbles near the helium concentration peak. Helium bubbles grow larger with annealing temperature and burst to release helium atoms which the two lower peaks for both specimens are associated with. The two higher peaks for the specimen with high dose attribute to the dissociation and release of the small single He-V complexes by break-through the miro-paths among the blisters[1] or through holes[1,3]

Table 1 He desorption data of the specimens irradiated with 100 keV He^+ at RT

Dose (ions/cm^2)	Temperature range of He desorption (℃)	Temperature at the peak (℃)	Desorption rate at the peak (atoms/(cm^2 s))	Total desorption (atoms/cm^2)
5×10^{17}	585～730	～ 614	～ 2.99×10^{14}	～1.14×10^{16}
		～ 685	～ 3.90×10^{14}	
1×10^{18}	598～900	～ 637	～ 7.74×10^{14}	～6.88×10^{16}
		～ 669	～ 8.03×10^{14}	
		～ 770	～ 1.48×10^{15}	
		～ 886	～ 4.28×10^{14}	

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