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Effects of low energy helium plasma irradiation on potassium doped tungsten

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ABSTRACT

Effects of helium plasma irradiation on spark plasma sintering (SPS) W-K, pure W and traditionally sintered commercial W-K have been studied, concerning the density, grain size and potassium content as the influence factors. Pinholes are formed under 120 eV He ions at 600 °C and 1×10^{23} m^{-2} fluence on the surface of all samples. It is found that SPS-sintered W-K shows the best irradiation resistance among the present samples, and SPS-sintered pure W exhibits higher irradiation tolerance than commercial W-K. Different He-plasma tolerance was observed among the SPS-sintered W-K samples due to varied potassium content and grain size. In addition, the microstructure evolution under helium irradiation, the growth-migration of helium bubbles and their interactions of potassium bubbles have also been discussed.

1. Introduction

Tungsten-based materials have been regarded as one of the most promising candidates for plasma facing material (PFM), due to their excellent thermo-mechanical properties, low sputtering yield, and low hydrogen isotope retention, etc. [1–3]. Contrast to these superiorities, pure W shows inferior ductility and fracture toughness. These shortages would be strongly aggravated under helium ion incident (regarding energy from eVs to KeVs, temperature from 300 to 3000 K and fluence range from 1×10^{19} to 1×10^{27} He$^+$ m^{-2} [4]). Moreover, the implanted helium would not be released until high temperature due to its strong interaction with lattice defects [5], which can drastically modify the surface morphology and macroscopic properties, such as volume expansion, irradiation hardening, recrystallization, amorphization, increasing of ductile-to-brittle transition temperature (DBTT), etc. Especially, this damage could be deteriorated under a fusion condition for the high working temperatures [6].

This problem has spawned a very strong interest and long-term research concerning tungsten-based materials [7]. D. Nishijima and his co-workers investigated the bubble formation on tungsten surfaces with low-energy and high-flux helium plasma irradiation, and thought that the vacancy concentration, helium concentration and the mobility of point defects in tungsten are three important factors [8]. S.Wurster proposed that the primary step towards optimizing radiation tolerance of materials is to offer solid-vapor or solid–solid interfaces and to provide short diffusion paths toward grain boundary to extinguish these defects [6]. This method has been confirmed by kinds of newly immerged W alloys, including dispersing strengthened tungsten alloys and their nano-crystallization [9,10].

The previous studies have greatly enhanced our understanding on the helium plasma irradiation damage to tungsten alloys, especially under high energy helium irradiation [11]. However, it is still an open question to explore the irradiation mechanism for tungsten-based PFMs, and to improve their irradiation tolerance under these severe working conditions [12,13]. For this purpose, numerous candidate tungsten alloys have been studied. Among these systems, traditional W-K material, so called AKS tungsten, has been considered as one of the best promising candidates, owning to its excellent thermal and mechanical properties. However, there are only a few reports concerning on further improvement of W-K material and its irradiation effects. In order to understand the performance of W-K as plasma facing materials (PFMs), systematic investigations on fabrication and irradiation are very necessary based on W-K binary system.

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Table 1
Relative densities and K content of samples corresponding to sintering conditions.

System	Temperature (°C)	Pressure (MPa)	Holding time(min)	Relative density (%)	K content (ppm)
W	1900	100	4	95.06	–
W-K(I)	1900	100	4	94.84	12
W-K(Π)	1900	100	4	94.63	68
W-K(III)	1450	200	0	93.23	74
W-K	Commercial			93.63	40

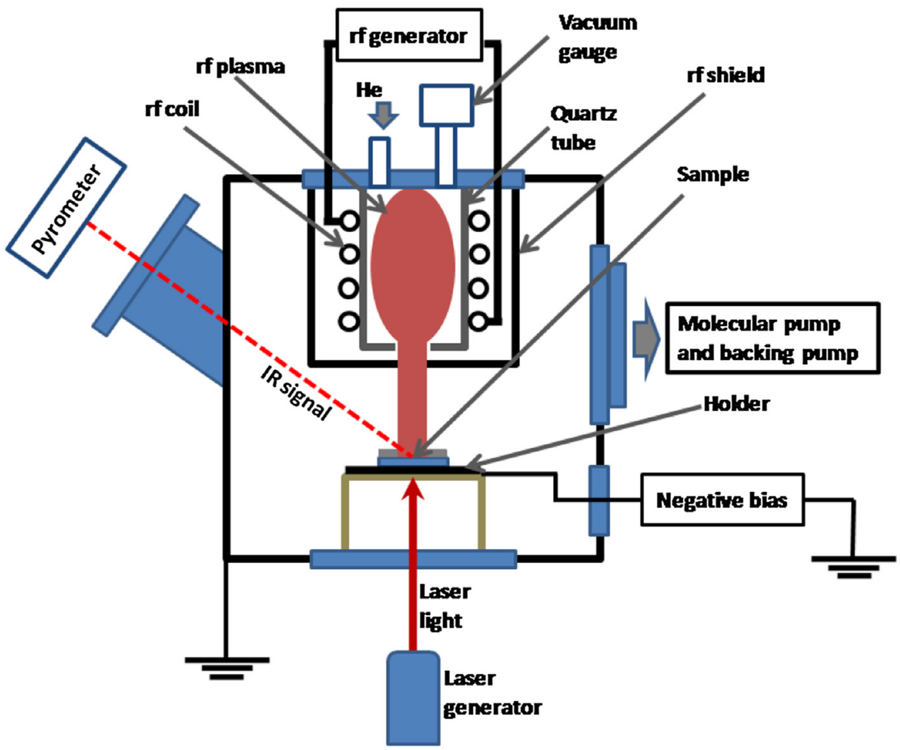

Fig. 1. Schematic graph of the plasma irradiation testing platform.

In this paper, the irradiation effects of SPS-sintered W-K ingots with different density, potassium content and grain size under low energy helium plasma were investigated. The SPS-sintered pure W and commercial W-K (sintered through traditional AKS doping method [14,15]) are taken for comparison. Moreover, the helium bubbles formation, evolution and their interaction with potassium bubbles in W-K will be discussed.

2. Experimental

2.1. Fabrication

W-K disk-like specimens were fabricated by SPS using powder metallurgy method; they were 15 mm in diameter and 2 mm in thickness. Two kinds of composited W-K powder, mixed through potassium evaporation under vacuum condition, were used as raw materials for sintering. One is 300 ppm in potassium content; the other is 500 ppm in potassium content. The sintering parameters are listed in Table 1, and more details about the sample fabrication are described in previous publication [16]. SPS-sintered pure W and traditionally AKS doped commercial W-K with 40 ppm K were used for comparison.

2.2. Pretreatment

Sample surfaces were polished to mirror like by diamond powder and cleaned under ultrasonic condition. Before ion irradiation, samples were annealed in vacuum at 1000 °C for 2 h to release residual stress.

2.3. Irradiation

The samples were heated to the intended temperature 600 °C using an in-situ laser-beam heater as the background vacuum was 2.5×10^{-4} Pa. During irradiation, ion energy was fixed at 120 eV by controlling the bias voltage, including the plasma potential of 20 eV measured by Langmuir probe in this lab. The fluence (1×10^{23} m^{-2}) to each sample was measured based on the plasma flux, which was 10^{20} ions/m^2 s. The irradiated samples were then cooled down under vacuum condition. The schematic graph of the plasma irradiation testing platform is shown in Fig. 1. More details are similar with the previous works carried out in this group [17,18].

2.4. Characterization

Sample density was measured by a full automatic density meter (GH-120D) based on the Archimedes principle. The microtopography was characterized by metallurgical microscope (UMT 203i) after annealing. The particle size was analyzed by Image-pro-plus program, and the final size distribution data was fitted by Lognormal function in Origin program. The potassium content was measured by inductively coupled plasma source mass spectrometer (ICP-AES, A6300). Atomic force microscopy (AFM, DI 3100) and field emission scanning electron microscopy (FESEM, JEOL JSM-