Effect of helium pre-irradiation on the recrystallization and thermal shock performance of tungsten

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High heat flux loads will lead to recrystallization and grain growth of tungsten plasma facing material, resulting in a decrease in toughness and thermal shock resistance. Our previous study [1] indicated that helium (He) plasma irradiation would affect the recrystallization behavior of tungsten. Therefore, it is important to investigate the effect of helium irradiation on the recrystallization behavior of tungsten and its influence on the thermal response under transient thermal loads.

Rolled tungsten samples were exposed to He plasma (50 eV, 2×10²⁶ He/m², 573 K) and high-energy He ion beam (2 MeV, 1×10¹⁸ He/m², 300 K), respectively. Then they were annealed at 1473 K for 1 h. For comparison, rolled tungsten without He pre-irradiation was annealed at the same condition for a reference (named as blank sample). The annealed samples were exposed to ELM-like thermal loads in the high-energy electron beam experimental platform EMS-60. The testing conditions were 100 pulses with the duration of 1 ms and absorbed power densities of 0.15 and 0.66 GW m⁻². The base temperature of the testing was room temperature. Scanning electron microscopy (SEM) accompanied with electron backscatter diffraction (EBSD) was used to analyze the surface morphology and the microstructure evolution after annealing and thermal shock tests.

After annealing, the recrystallization fraction of the blank sample reaches to 50%, and however, it reduces to 18% and 8% in the case of He plasma and high-energy He ion pre-irradiation, respectively. It indicates that He irradiation has a significant inhibitory effect on the recrystallization behavior of the rolled tungsten. Thermal shock cycling test results show that cracks are formed in the blank samples and He plasma pre-irradiated tungsten when the absorbed power density is in the range of 0.25-0.3 GW/m². For the He ion pre-implanted tungsten, the cracking threshold is increased to > 0.3 GW/m². Additionally, surface roughening is noticeable for the blank samples, while slight plastic deformation is observed on the surface of the He pre-irradiated samples. The thermal performance in terms of surface roughening and cracking exhibits a close relationship with the recrystallization fraction of tungsten.

The presented results in this work indicate that He irradiation has a certain retarding effect on tungsten recrystallization behavior. Moreover, comparing to He plasma irradiation, high-energy He ion implantation significantly improves the performance of tungsten under thermal shocks.