Helium bubbles retard recrystallization in tungsten by limiting subgrain growth

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Recrystallization of tungsten plasma facing components (PFCs) in fusion devices is detrimental to their fatigue life, and mitigation methods of recrystallization are therefore desirable. He plasma exposure, a natural consequence of the deuterium-tritium reaction, has been shown to retard recrystallization, the mechanism of which was generally attributed to the Zener pinning of high angle grain boundaries during the grain growth stage of recrystallization. However, neither the pinning pressure was quantified nor its influence on the nucleation stage of recrystallization was considered, limiting our understanding and exploitation of this beneficial phenomenon. Here, we conducted interrupted annealing experiments of tungsten specimens after He plasma exposure at 1573 and 1673 K using an electron beam. For each 15-30 min of annealing, a fixed area was examined by electron backscatter diffraction (EBSD) to detect recrystallized grains and transmission electron microscopy (TEM) to observe subsurface He bubbles. We found that recrystallization was delayed at 1573 K but not at 1673 K. More importantly, site-specific TEM imaging revealed that recrystallization was retarded even when the grain boundaries of the recrystallized grains were not pinned by He bubbles, which directly contradicted previous explanations. Additionally, the calculation of the driving pressure, the Zener pinning pressure, and the boundary curvature retarding pressure revealed that grain growth is unfavourable, in which the contribution of the Zener pinning pressure was weak. Instead, recrystallization and its suppression were caused by nucleation, as supported by EBSD analysis of the nucleation rate. A mechanism based on He bubble limited subgrain growth and suppressed nucleation was then proposed and correctly predicted the recrystallization results at 1573 K. However, for the 1673 K annealing case, bubble coarsening and dislocation climb may have assisted subgrain growth and resulted in the loss of the retarding effect. Overall, we demonstrate that He bubble limited subgrain growth as a viable mechanism of retarding recrystallization. Moreover, we expect it to be a powerful tool for identifying the regime of retarded recrystallization for tungsten PFCs in fusion devices.

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