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Impact of alloying and exposure temperature on He retention and He thermal dynamics in W-based materials

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Bulk tungsten (W), sputtered W and sputtered alloys comprising of W-5%(wt)Ta, W-3%(wt)Cr, W-4%(wt)-3%(wt)Cr were exposed to a low energy helium (He) plasma in the MagPIE linear plasma device at 573 K (LT) and 1050 K (HT). The dependence of He retention and He bubble dynamics on the alloying elements and sample temperature during plasma exposure were investigated using TDS, TEM, GISAXS and ERDA.

TDS of the samples up to 1673 K showed that desorption of He has a clear dependence on sample temperature, with more He being released during the process from the HT samples[1]. He desorption from the LT samples was negligible beyond ~ 800 K. Desorption peaks from the HT samples coincided with temperatures where large bubbles (~10s of nm in diameter) that are present only in the HT samples disappear during in-situ TEM annealing up to 1073 K. HT WTaCr shows the lowest concentration of such large bubbles amongst the sputter deposited materials.

Smaller bubbles in the LT bulk W sample were stable and remained unchanged with annealing up to 998 K observed during in-situ TEM annealing [2]. This suggests that desorption due to annealing below 800 K originates from interstitial He clusters rather than small bubbles. The stability of bubbles in the LT sputter-deposited materials was more difficult to determine due to the additional stress-relief mechanism of nanocolumnar microstructures, which complicated imaging.

GISAXS analysis of LT and HT bulk W samples annealed ex-situ up to 998 K corroborated the TEM observations. He bubble radial distribution from the LT bulk W samples were unchanged regardless of thermal history. On the other hand, a rightward shift in the radial distributions was observed in the HT samples with increasing annealing temperatures [1]. Follow-up GISAXS experiments have been conducted to study the He bubble radial distributions in the sputtered materials. However, inelastic scattering from the surface and nano-columnar structures is a significant challenge during the fitting process.

He retention of bulk W samples was measured before and after TDS by TOF-ERDA. Both HT bulk W samples retain more He than their LT counterparts. Further TOF-ERDA experiments are planned to understand the effects of alloying on the retention of He that TDS cannot capture.

This difference in annealing behaviours with sample temperature is attributed to the self-nucleation mechanism of interstitial He clusters at higher temperatures. In the LT case, implanted He is likely to occupy existing defects, remain as interstitials or emitted from the surface. Additionally, Monte-Carlo simulations have suggested that He-V complexes formed at 900 K can emit He atoms [3]. The emission of He from these clusters may be the reason for an Ostwald ripening-like growth mechanism for smaller bubbles observed during in-situ TEM annealing of the HT bulk W sample.

These results may help explain temperature-dependent plasma-material interactions such as recrystallisation suppression. These results also expand the knowledge surrounding He bubble dynamics to help improve the predictions of component lifetime and plasma-material interactions in post-ITER devices. Lastly, the plasma-material interactions of several alternatives to bulk W have been and will continue to be tested to obtain a more comprehensive understanding of the plasma-material interactions of W alloys. The study of these alloys would not only bridge the existing gap between binary WTa/WCr alloys and HEAs involving both elements, but also enhance the discussion surrounding alternatives to bulk W in future demonstration and commercial reactors, particularly from the perspective of He plasma-material interactions.

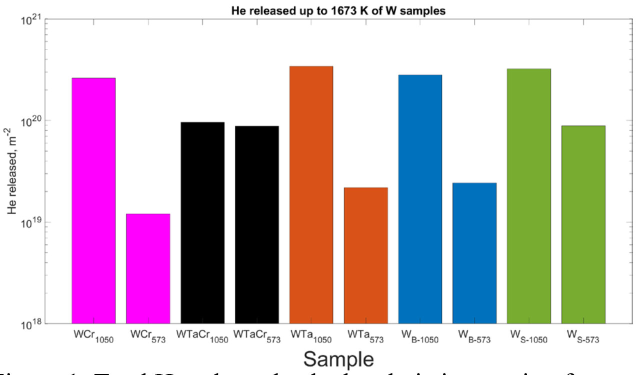

Figure 1: Total He released calculated via integration from the TDS desorption spectra up to 1673 K.

[1] Teo, S.H.B., et al., *Thermal evolution of helium bubbles in tungsten by GISAXS and TDS.* Journal of Nuclear Materials, 2025. **604**: p. 155524.

[2] Teo, S.H.B., et al., *Investigating the temperature dependence of helium bubble dynamics in plasma exposed tungsten via in-situ TEM annealing.* Materialia, 2024. **35**: p. 102110.

[3] Valles, G., et al., *Temperature dependence of underdense nanostructure formation in tungsten under helium irradiation.* Journal of Nuclear Materials, 2017. **490**: p. 108-114.