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Investigating the temperature dependence of helium bubble dynamics in plasma exposed tungsten via in-situ TEM annealing

Soon Han Bryan Teo[1], Matt Thompson[1], Maryna Bilokur[1], Dhriti Bhattacharyya[2,3], Cormac Corr[1]
[1] Department of Materials Physics, Research School of Physics, Australian National University.
[2] Australian Nuclear Science and Technology Organisation.
[3] School of Materials Science and Engineering, University of New South Wales.
E-mail (speaker): soon.teo@anu.edu.au

The International Thermonuclear Experimental Reactor's (ITER) decision to operate with a full tungsten (W) divertor has spurred further interest in the material's prospects[1, 2]. W is the favoured plasma-facing material in fusion reactors such as ITER due to its high melting point and low tritium retention. Given the harsh conditions in a reactor plasma-facing component's lifetime remains a crucial aspect of study to minimize interruption to tokamak operations[3, 4].

In-situ TEM annealing and imaging were performed on polycrystalline bulk W samples pre-exposed at either 573 K or 1013 K to a pure helium (He) plasma to a fluence of 10^{25} m^{-2} to investigate the thermal evolution of He bubbles. It was found that annealing temperatures had little effect on the bubble dynamics for the lower temperature exposure of 573 K. Elongated bubble structures remained in the sample throughout the annealing process. There is minimal change in the average bubble size and number density. However, annealing had a significant effect on the higher temperature exposure of 1013 K. Bubbles were found to be trapped in large clusters, and increasing the annealing temperature caused a significant increase in the average bubble size accompanied by a decrease in bubble number density. The experimental observations are supported by theoretical calculations developed by Hammond *et al*. that show a simultaneous increase in the average bubble size and an overall decrease in He atoms retained within bubbles as the annealing temperature increased for the higher exposure temperature sample. These trends in the bubble dynamics with annealing temperature suggest that Ostwald ripening dominates annealing bubble growth at annealing temperatures up to 1000 K, whereby bubble growth is determined by the different pressures of different bubble sizes rather than through bubble migration and coalescence.

References:

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[2]: Pitts, R.A., et al., *A full tungsten divertor for ITER: Physics issues and design status:* Journal of Nuclear Materials, 2013. **438:** p. S48-S56.
[3]: Roth, J., et al., *Recent analysis of key plasma wall interactions issues for ITER*. Journal of nuclear materials, 2009 **390**: p.1-9
[4]: Pitts, R.A., et al., *Physics basis for the first ITER tungsten divertor.* Nuclear Materials and Energy, 2019 **20**: 100696

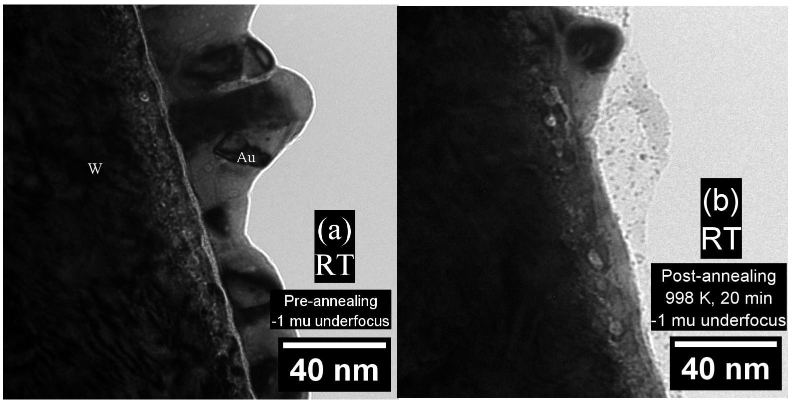
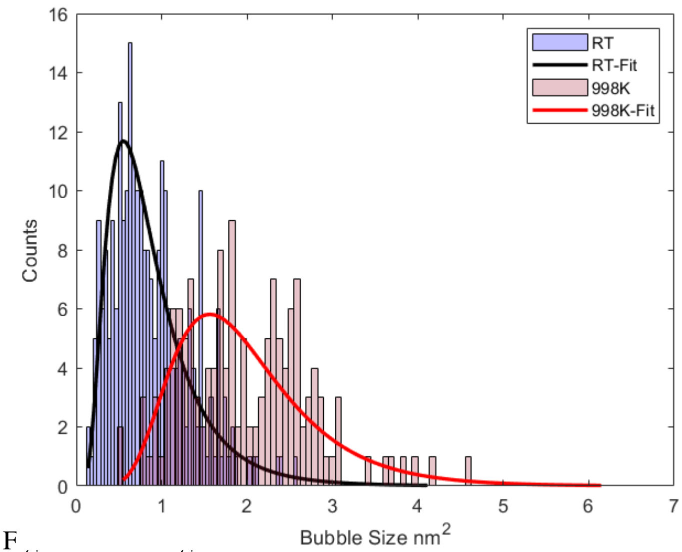


Figure 1:1 μm under-focus TEM micrographs of in-situ annealed W exposed to He plasma at 1013 K. The annealing temperatures was (a) room temperatures (f) room temperature after the sample was heated and held at 998 K for 20 minutes.



F f individual bubbles pre-annealing and post-annealing at 998K after 20 minutes in the high-temperature exposure sample at 1 μm under-focus, fitted to a log-normal distribution.