



Nanobubble Dynamics in Helium Ion-Implanted Palladium

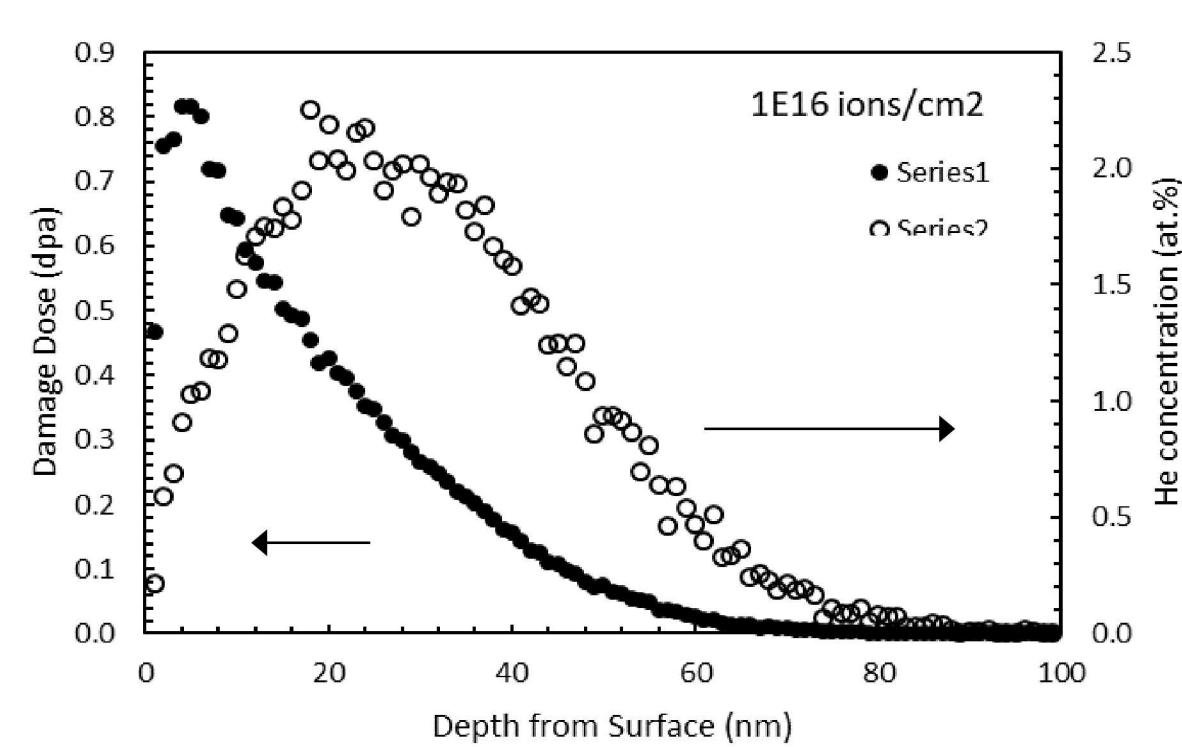
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Background

Helium nanobubbles are a common form of radiation damage that degrade the mechanical and electrical properties of metals. To better understand the process of bubble formation, we used transmission electron microscopy (TEM) to characterize the properties of helium bubbles in palladium metal.

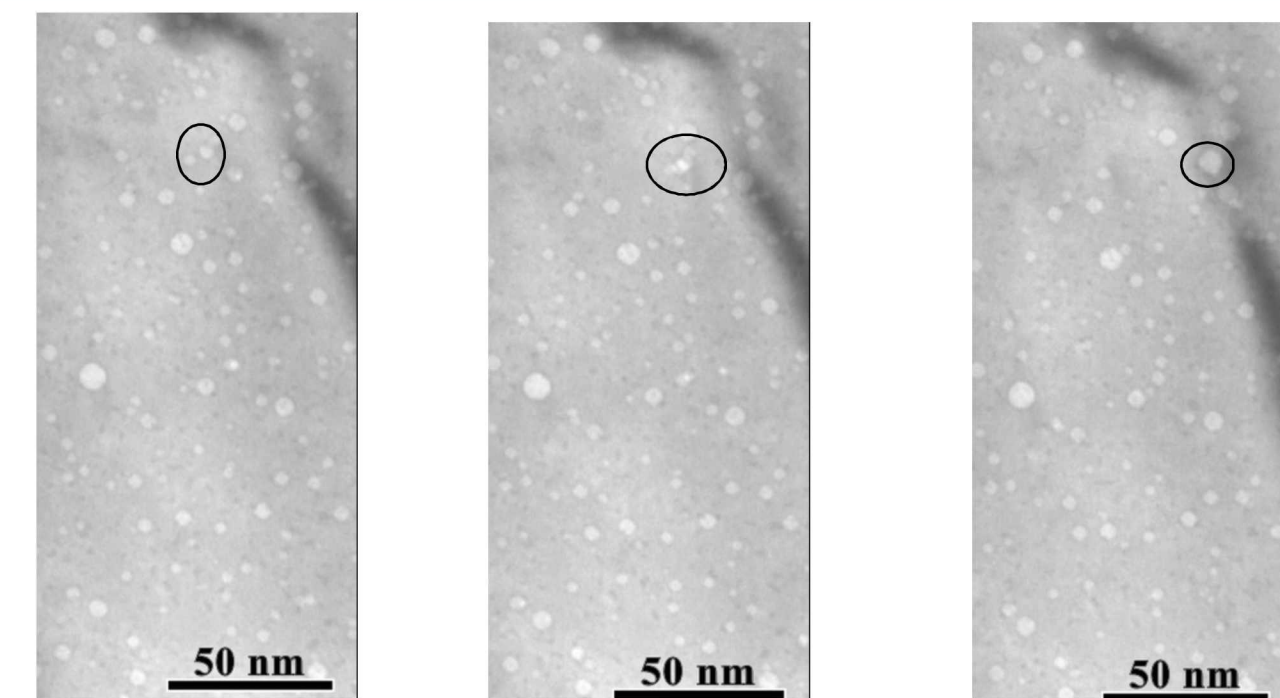
Theoretical profile for 10 keV He implantation in Pd



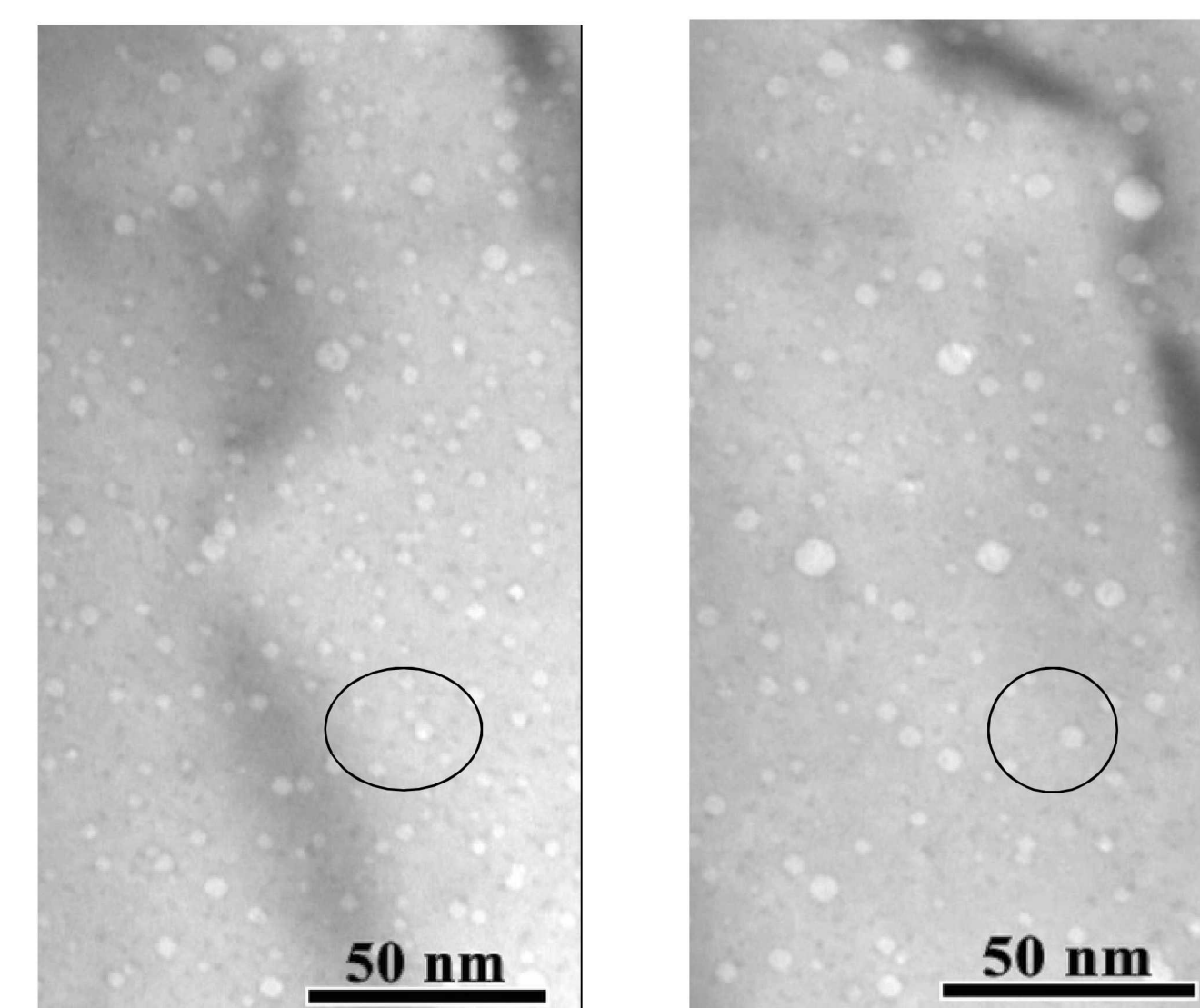
10 keV helium ions are predicted to stop a few tens of nm into the sample. The helium also displaces metal atoms nearer the surface before it stops.

dpa = displacements per atom

Results



An example of moving and coalescing bubbles can be seen in the corner.



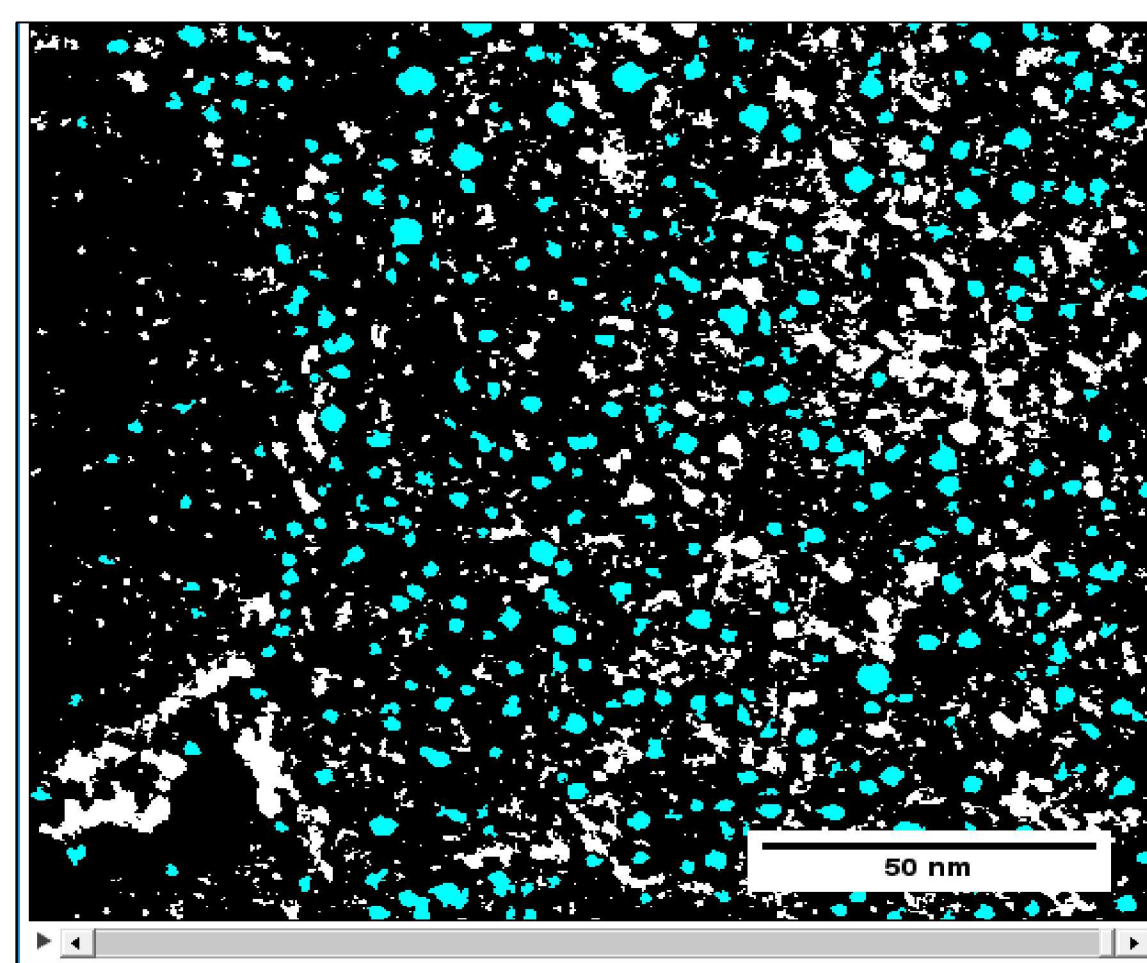
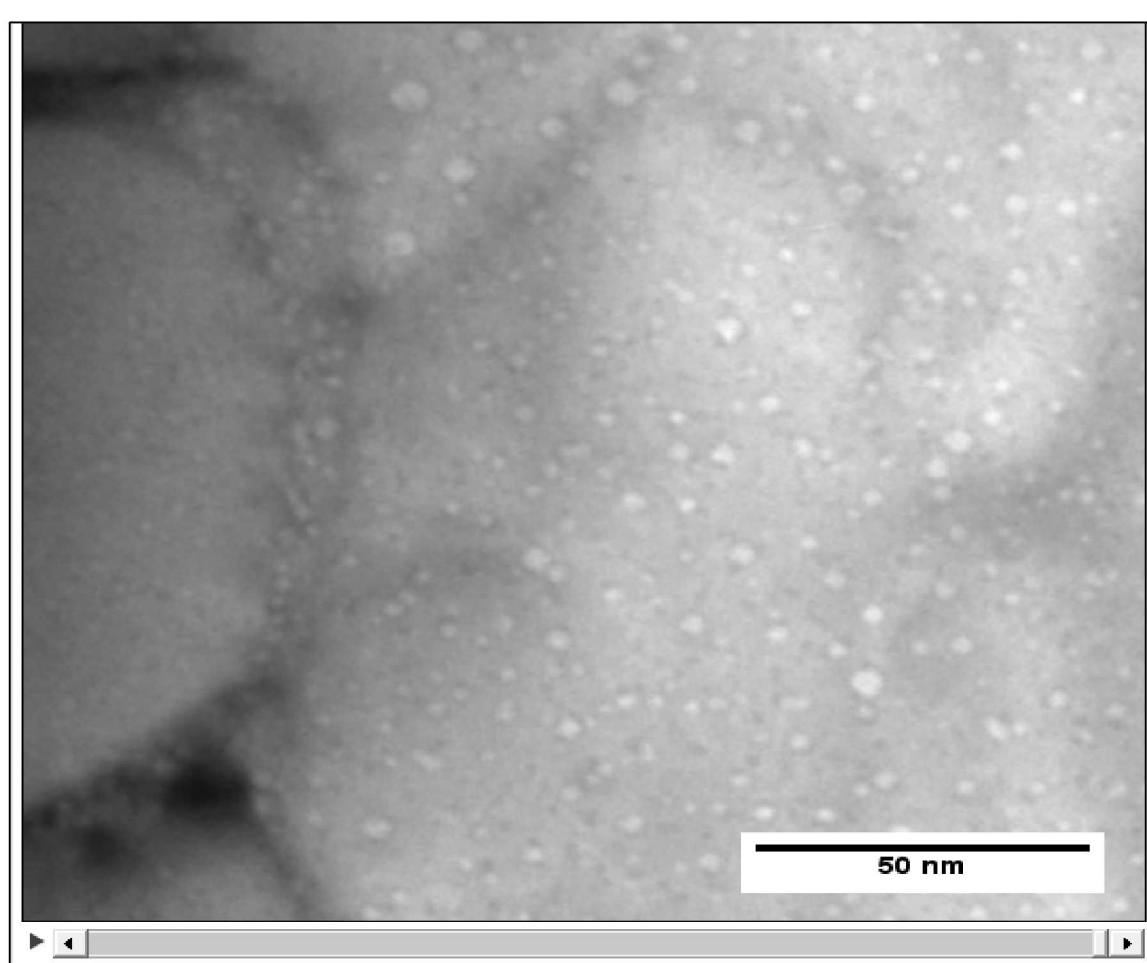
The highlighted region shows an example of helium nanobubbles disappearing in the sample, presumably due to coalescence with the surface.

Sample preparation

A palladium wire was annealed to grow the grain size of the sample. The wire was then processed by a focused ion beam to cut a thin section from it. A portion was made thin enough (<100 nm) to allow electrons to pass through for TEM imaging. It was then implanted with helium ions at 10 keV to a dose of about 10^{16} ions/cm². The sample was heated during implantation to 400 C and in the microscope to higher temperatures during imaging.

Bubble Analysis

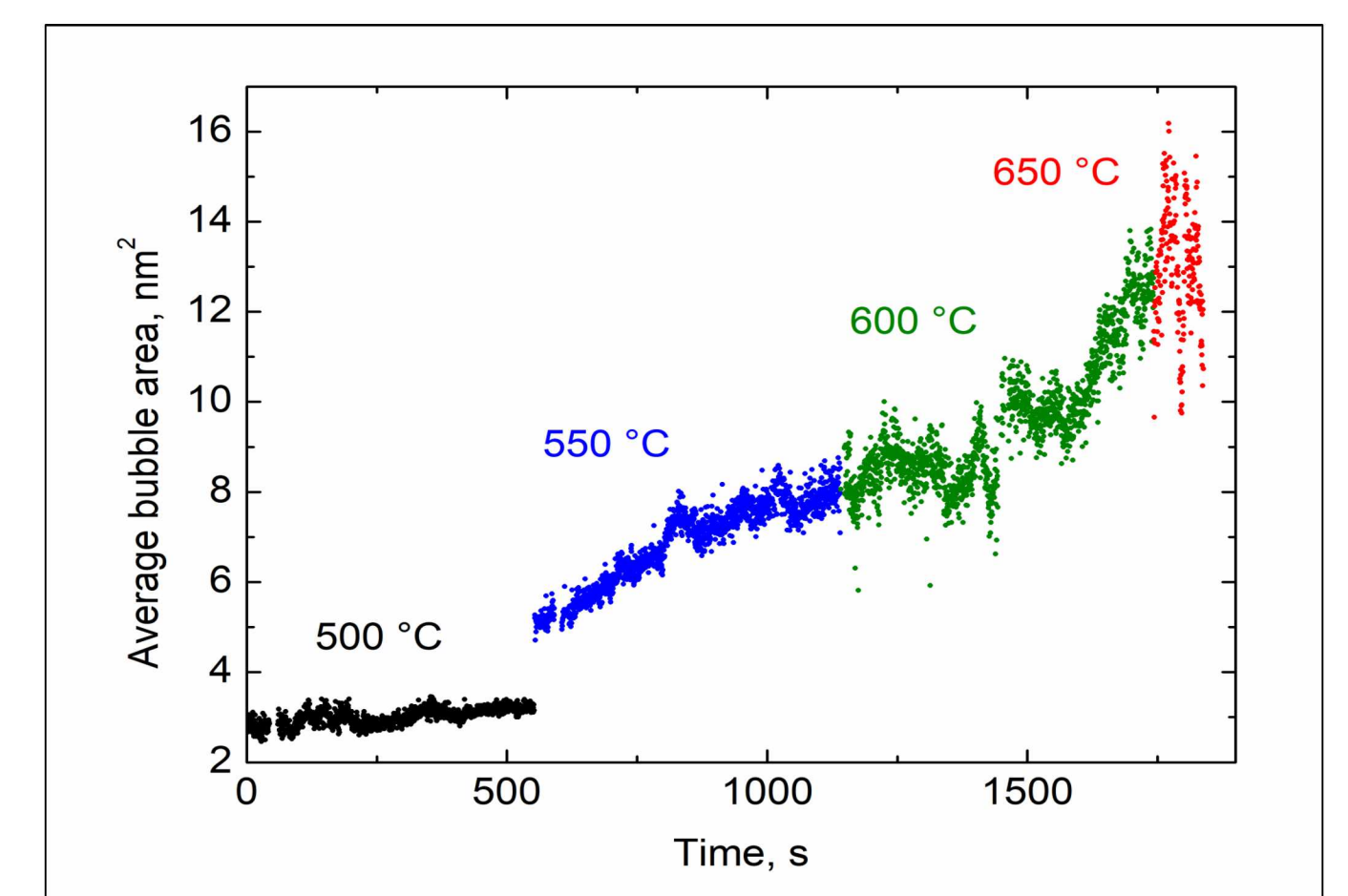
- Movies of bubbles were recorded on an in-situ heating stage in the TEM. Movies were converted to a series of TIFF images for processing. We developed an automated method to distinguish bubbles from other image features, and measure their size and position versus time.
- Used Fiji Image J software to pre-process frames
- *Analyze Particles* tool compiles list of bubble sizes in a frame. Circularity filter removes some grain boundaries and spots accidentally detected as bubbles



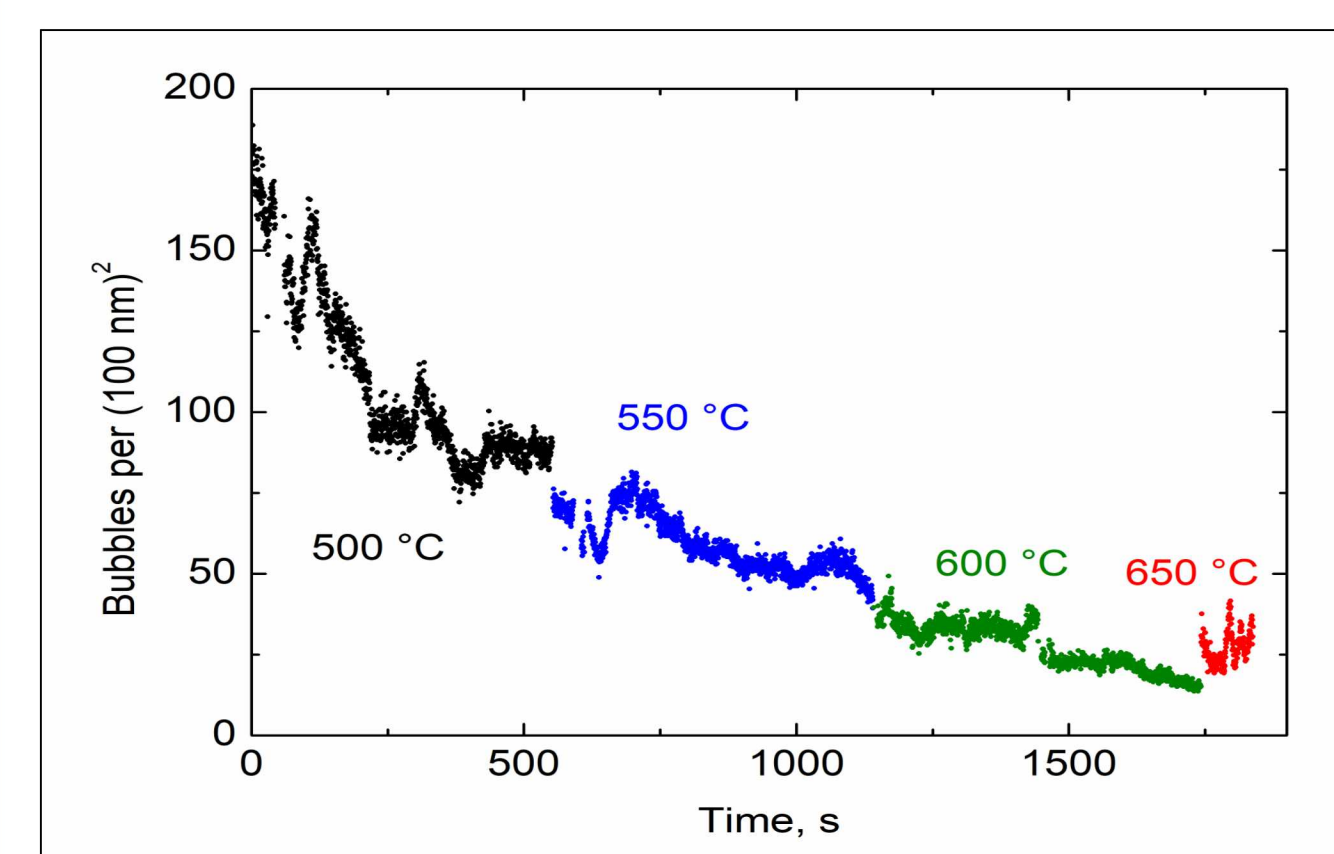
Figures show original and Analyze Particle images.

Data Analysis

The average bubble area increases as the sample is heated.



The number of bubbles per unit area decreases as the sample is heated (as does the total bubble area).



These statistical trends can be explained by the coalescence mechanisms described above. If bubbles grow due to transport of lattice-trapped helium into bubbles, this is less important.

Conclusion

Helium bubbles form in palladium when it is implanted with helium ions. At temperatures well below the melting point of the metal, bubbles can migrate and coalesce. Coalescence can occur on a timescale of seconds or less. Coalescence of bubbles with the surface is a mechanism for release of helium from the metal.