

In-situ 4D-STEM imaging to develop a fundamental understanding of coupled transport of vacancies

Sean Mills¹, Yang Yang² and Andrew M Minor³

¹University of California Berkeley, Berkeley, California, United States, ²UC Berkeley, United States, ³Group Lead for Corporate R&D, United States

Extreme nuclear reactor environments require materials to maintain their integrity all while a range of processes act in unison to degrade their performance. One of the key features of these processes is that defects, such as vacancies and interstitials, directly limit or accelerate the corrosion rates. Until recently, the capabilities to directly measure vacancy concentration have been limited to bulk techniques such as positron annihilation [1] or x-ray diffraction measurement of lattice parameters. There is still a lack of techniques that would enable direct mapping of point defects using electron microscopy. However, the recent development of four dimensional scanning transmission electron microscopy (4D-STEM) with high-speed direct electron detectors provides high resolution mapping of lattice parameters at the nanoscale [2]. Combined 4D-STEM, high resolution STEM-EDX/EELS elemental mapping and computational modeling based on density functional theory allows for multimodal determination of both structure and chemistry. This procedure for measuring vacancy concentration via 4D-STEM closely follows the differential thermal expansion method of measuring concentrations of point defects [3]. Building from this approach, we will explore structural and chemical measurements of alloys with different vacancy concentrations. Specifically, we have looked at boundaries and interfaces where rapid transport occurs during a series of diffusional process, such as diffusion induced grain boundary migration [4]. This extensive study will fundamentally improve the understanding of coupled corrosion and irradiation processes and provide a new pathway for engineering materials designed in future nuclear energy systems.

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