Capturing radiation-induced microstructure evolution *in situ* through direct property monitoring

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Advanced materials development for nuclear systems is currently a time and resource intensive process relying on many iterations of material exposure and destructive testing. There exist few methods for characterizing irradiated material performance *in situ,* during exposure. Techniques such as *in situ* TEM or *in situ* Raman spectroscopy can provide local structural information during irradiation, but no current methods can continuously monitor bulk thermal and mechanical properties. Such a tool would provide the ability to map dose-property relationships at a resolution not previously possible, enhancing mechanistic understanding of irradiation-induced evolution. These methods could also be used to identify the onset of emergent irradiation-induced effects such as the transition from incubation to steady-state void swelling. For this purpose, we have identified transient grating spectroscopy (TGS) as an appropriate technique to obtain these dose-property relationships during irradiation. This method, by optically inducing and monitoring monochromatic surface acoustic waves on materials under investigation, is able to determine the elastic and thermal transport properties of a microns-thick layer at the surface of a sample, the same depth to which ion beams can impose damage. First, we demonstrated that this method is sensitive enough to measure changes in materials properties induced by radiation. Afterwards, we designed new optical geometries which enable second-scale time-resolved TGS measurements on dynamically changing materials. In addition, we developed new analytical methods through which multiple material properties, acoustic wave speed and thermal transport properties, may be extracted simultaneously from single-shot measurements. As proof-of-principle experiments, ion irradiation-induced property changes have been measured post-irradiation on pure, single crystal copper. In these copper samples, TGS measurements indicate the presence of volumetric void swelling, which is confirmed with scanning transmission electron microscopy (STEM). These developments tother show that TGS is capable of capturing irradiation-induced evolution in real time and motivate the design and commissioning of an *in situ* experiment for ion beam irradiation and TGS monitoring. To this end, an *in situ* TGS beamline experiment for concurrent ion beam irradiation and property monitoring has been developed on the 6 MV tandem accelerator at the Ion Beam Laboratory at Sandia National Laboratories. The *in situ* ion irradiation TGS (I3 TGS) facility has the ability to monitor material evolution at high temperatures in real time under ion bombardment. Using high-energy self ions, we are studying radiation damage effects on the thermomechanical properties of pure metals. In these experiments, irradiation-induced void swelling has been monitored at an orders-of-magnitude finer dose resolution than is possible with traditional methods. This tool has allowed the onset of swelling to be pinpointed in applied dose, a key consideration when developing new materials for use in nuclear systems, on the timescale of days rather than months or years. We are now able to provide the type of rapid, engineering-relevant data necessary to speed the innovation cycle in nuclear material development. Moving forward, these methods can be used as a screening tool to expedite the design and testing process for advanced nuclear materials.

Cody Dennett — Abstract for Doctoral Thesis Defense (2019).

Motivating background

Start with something that everyone in your audience cares about. The background should provide context for your problem or knowledge gap.

Problem statement or knowledge gap

What central question are you trying to answer? Focus in on the specific need that your research addresses; this is the primary motivation for your work.

"Here we show…"

State what you specifically did to solve the problem. Example statements might include: "We simulated/measured XYZ…"

Results

Briefly summarize your main results or conclusions that address the problem statement or knowledge gap. You can include key data but save the fine details for the main document.

Implications

Explicitly state the implications of your findings by linking back to the motivating background. What impact do your findings have on this area of research? Try to answer "so what?" and "now what" questions.