

Materials Science & Engineering Doctoral Defense

Structural stability and radiation tolerance of nanocrystalline
Cu-Ta for extreme applications

School for Engineering of Matter, Transport and Energy

Soundarya Srinivasan

Advisor: Kiran Solanki

Abstract

Nanocrystalline (NC) materials are of great interest to researchers due to their multitude of properties such as exceptional strength and radiation resistance owing to their high fraction of grain boundaries that act as defect sinks for radiation-induced defects, provided they are microstructurally stable. In this dissertation, radiation effects in microstructurally stable bulk NC copper (Cu)- tantalum (Ta) alloys engineered with uniformly dispersed Ta nano-precipitates are systematically probed. Towards this, both ex-situ and in-situ irradiations using heavy (self) ion, helium ion, and concurrent dual ion beams (He+Au) followed by isochronal annealing inside TEM were utilized to understand radiation tolerance and underlying mechanisms of microstructure evolution in stable NC alloys. With systematic self-ion irradiation, the high density of tantalum nanoclusters in Cu-10at.%Ta acted as stable sinks in suppressing radiation hardening, in addition to stabilizing the grain boundaries as well; while the large incoherent precipitates experienced ballistic mixing and dissolution at high doses. Interestingly, the alloy exhibited a microstructure self-healing mechanism, where with a moderate thermal input, this dissolved tantalum eventually re-precipitated, thus replenishing the sink density. The high stability of these tantalum nanoclusters is attributed to the high positive enthalpy of mixing of tantalum in copper which also acted as a critical driving force against atomic mixing to facilitate re-precipitation of tantalum nanoclusters. Furthermore, these nanoclusters proved to be effective trapping sites for helium, thus sequestering helium into isolated small bubbles and aid in increasing the overall swelling threshold of the alloy. The alloy was then compositionally optimized to reduce the density of large incoherent precipitates (Cu-3at.%Ta) without compromising on the grain size and nanocluster density which resulted in consistent and more promising response to high dose self-ion irradiation. In-situ helium and dual beam irradiation coupled with isochronal annealing till 723 K, also revealed comparable microstructural stability and enhanced ability of Cu-3Ta in controlling bubble growth and suppressing swelling compared to Cu-10Ta indicating a promising improvement in radiation tolerance in the optimized composition. Overall, this work helps advancing the current understanding of radiation tolerance in stable nanocrystalline alloys and aid developing design strategies for engineering radiation tolerant materials with stable interfaces.



June 9, 2021; 10 AM;

Zoom Link: <https://asu.zoom.us/j/87589601006>