Material performance in extreme radiation environments is central to the design of advanced nuclear reactors. Radiation induces significant damage in form of dislocation loops and voids in irradiated materials, eventually leading to failure of materials. Conventional materials with coarse grained microstructures cannot satisfy the demands for much greater radiation dose, exceeding 200 displacements-per-atom (dpa) over 80 years, necessary for new-generation nuclear reactors. Such daunting scientific challenge calls for the discovery of innovative materials with order of magnitude enhancement in radiation tolerance over existing materials. Comparing to conventional materials, nanostructured materials have gained increasing attention as these materials have an order of magnitude greater density of built-in defects, such as grain boundaries, layer interfaces and surfaces, which are sinks for radiation-induced point defects. The goal of this thesis is to investigate the role of interfaces in certain nanostructured materials in aggressively mitigating radiation damage, and assist the design of novel nanostructured materials with superior radiation tolerance.

Cu, a low stacking fault energy metal with face centered cubic (FCC) structure is typically severely damaged under radiation environments. Hence we applied two strategies to alleviate radiation damage in Cu, including the topics on Cu/Fe and Cu/Co multilayers and nanotwinned Cu with nanovoids. The major findings of these studies include the followings.

- He ion irradiated nanostructured Cu/Fe and Cu/Co multilayers show a prominent size effect on mitigation of radiation damage, that is films with smaller layer thickness (h) have less radiation damage. More importantly, for the first time, our results illustrate that similar to incoherent interfaces, coherent immiscible interface is also effective to alleviate radiation induced damage. In general the magnitude of radiation hardening and defect cluster density are both less at smaller h than those with larger h, as interfaces can effectively reduce density of radiation induced defect clusters. Here we show, however, an opposite size dependent strengthening behavior in He ion irradiated immiscible coherent Cu/Co multilayers, that is films with smaller h have greater radiation hardening. Such unusual size dependent strengthening could be explained via a transition from partial dislocation transmission (before radiation) to full dislocation transmission (after radiation) dictated strengthening mechanisms due to formation of He bubbles at layer interface. Besides the ex-situ study on radiation damage and radiation hardening, in situ radiation experiments in transmission electron microscope (TEM) reveal a layer interface affected zone in Cu/Fe multilayers. The accumulative defect density (acquired over a period of time) in Cu/Fe 100 nm multilayers varies as a function of distance to the layer interfaces, supporting the long postulated hypothesis that layer

**Dissertation Abstract**

**Publications and short vita**


[9] C. Sun, D. Bufford, Y. Chen et al., In situ study of defect migration kinetics in nanoporous Ag with enhanced radiation tolerance, Scientific Reports, 4: 3737 (2014)


interface is effective defect sinks.

Radiation leads to void growth and subsequent void swelling. However, here by using in situ heavy ion irradiation in a transmission electron microscope we show that, pre-introduced nanovoids in nanotwinned Cu efficiently absorb radiation-induced defects accompanied by gradual elimination of nanovoids, enhancing radiation tolerance of Cu. In situ studies and atomistic simulations revealed that such remarkable self-healing capability stems from high density of coherent and incoherent twin boundaries that rapidly capture and transport point defects and dislocation loops to nanovoids, which act as storage bins for interstitial loops. This study describes a counterintuitive yet significant concept: deliberate introduction of nanovoids in conjunction with nanotwins enables unprecedented damage tolerance in metallic materials.

References:

Vitae

Youxing Chen earned his B.S in Materials Science and Engineering from Chongqing University, 2006, China, and M.S in Materials Science from Shanghai Jiaotong University, 2010, China. He was recruited by Dr. Zhang in Sep. 2010 for his Ph.D study.