FUNDAMENTAL RADIATION EFFECTS PARAMETERS IN METALS AND CERAMICS* — S. J. Zinkle (Oak Ridge National Laboratory)

Extended Abstract

Useful information on defect production and migration can be obtained from examination of the fluence-dependent defect densities in irradiated materials, particularly when a transition from linear to sublinear accumulation is observed. Analysis of electrical resistivity and TEM data indicates that the fraction of freely migrating interstitials at 300K in 14-MeV neutron irradiated copper is ~10 to 12% of the NRT displacement value. It is interesting to note that similar freely migrating interstitial fractions of ~10% are estimated for neutron-irradiated MgO and Al_2O_3 near 300 K. At temperatures where interstitials are mobile (>50 K in Cu), the defect cluster density in pure copper is initially proportional to the dose and often exhibits a square root dose dependence above ~10^{-4} displacements per atom (dpa). This fluence dependence (determined from electrical resistivity and TEM studies) helps to resolve a long-standing controversy on the fluence dependence of radiation hardening. The activation energy for annealing Stage V (stacking fault tetrahedra evaporation) in copper has been measured to be 0.84 $\pm$0.03 eV. The temperature where recovery stage V is initiated in stainless steel is comparable to that of copper, but further work is needed to determine the stage V activation energy in steel. Void swelling in high-purity copper requires the presence of gas atoms such as oxygen or helium. The helium generated in copper during neutron irradiation is sufficient to stabilize void embryos even at low doses.

Further work is needed on several intriguing reported radiation effects in metals. The supralinear defect cluster accumulation regime in thin foil irradiated metals needs further experimental confirmation, and the physical mechanisms responsible for its presence need to be established. Self-organization of defect clusters occurs readily in commercially available Ni during irradiation. However, it is not clear whether defect cluster alignment can occur in bulk neutron- or ion-irradiated pure copper. The possible roles of impurities and differences in displacement cascade evolution on defect cluster patterning need to be examined.

Radiation hardening and the associated reduction in strain hardening capacity in FCC metals is a serious concern for structural materials. In general, the loss of strain hardening capacity is associated with dislocation channeling, which occurs when a high density of small defect clusters are produced (stainless steel irradiated near room temperature is a notable exception). Detailed investigations of the effect of defect cluster density and other physical parameters such as stacking fault energy on dislocation channeling are needed. Although it is clearly established that radiation hardening depends on the grain size ("radiation-modified Hall-Petch effect"), further work is needed to identify the physical mechanisms. In addition, there is a need for improved hardening superposition models when a range of different obstacle strengths are present.

Due to a lack of information on point defect diffusivities and the increased compexity of radiation effects in ceramics compared to metals, many fundamental radiation effects parameters in ceramics have yet to be determined. Optical spectroscopy data suggest that the oxygen monovacancy and freely migrating interstitial fraction in fission neutron irradiated MgO and Al_2O_3 are ~10% of the NRT displacement value. Ionization induced diffusion can strongly influence microstructural evolution in ceramics. Therefore, fundamental data on ceramics obtained from highly ionizing radiation sources such as electrons must be treated with appropriate caution to determine if it is influenced by ionization induced diffusion effects. $MgAl_2O_4$ is considerably more sensitive to ionization induced diffusion effects than MgO or Al_2O_3. Systematic investigations are needed to determine the sensitivity of a broad range of ceramics to ionization induced diffusion.

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