DEFECT PRODUCTION IN CERAMICS* — S.J. Zinkle (Oak Ridge National Laboratory) and C. Kinoshita (Kyushu University)

Extended Abstract

A review is given of several important defect production and accumulation parameters for irradiated ceramics. Materials covered in this review include alumina, magnesia, spinel, silicon carbide, silicon nitride, aluminum nitride and diamond. Whereas threshold displacement energies for many ceramics are known within a reasonable level of uncertainty (with notable exceptions being AlN and Si_3N_4), relatively little information exists on the equally important parameters of surviving defect fraction (defect production efficiency) and point defect migration energies for most ceramics. Very little fundamental displacement damage information is available for nitride ceramics. The role of subthreshold irradiation on defect migration and microstructural evolution is also briefly discussed.

Based on a review of published experimental measurements, the threshold displacement energies for SiC, diamond and alumina (oxygen sublattice) should be revised downward from previously recommended values (cf. Table 1). Additional E_d measurements on BeO, $MgAl_2O_4$ and SiC are needed to supplement the existing data base. Furthermore, experimental E_d measurements are particularly needed for AlN and Si_3N_4, where no data currently exist.

Considerable uncertainty exists regarding the quantitative values of point defect migration enthalpies in ceramics. Some of this uncertainty is likely associated with ever-present impurity trapping effects, which increase the apparent migration energy. On the other hand, radiation induced diffusion processes such as ionization induced diffusion or subthreshold elastic collisions may produce low apparent migration energies during irradiation. The available data (Table 2) indicate that interstitials are mobile in MgO and Al_2O_3 at temperatures well below room temperature, whereas vacancies become mobile above ~200°C in both materials. The significant interstitial mobility at room temperature has not been taken into account in numerous published radiation effects studies on Al_2O_3 and MgO. Further experimental radiation effects studies at liquid helium temperatures (combined with isochronal annealing) would be valuable in determining the interstitial migration energies for all ceramic materials.

Very few reliable measurements of the surviving defect fraction (displacement damage efficiency) exist for ceramics. Most of the published work was performed at room temperature, and the data analysis did not account for likely correlated and uncorrelated recombination of point defects. Therefore, the reported values are typically an underestimate of the surviving defect fraction. The limited number of cryogenic irradiation studies on MgO and Al_2O_3 suggest that the surviving defect fraction is ~0.3 for both materials over a wide range of PKA energies (0.1-100 keV). This apparent independence on PKA energy is in sharp contrast to work performed on light metals such as aluminum, where the surviving defect fraction (relative to the NRT calculated displacements) varies from ~1 to ~0.5 as the PKA energy increases from ~0.1 to ~50 keV. Additional experimental work is needed to evaluate the importance of correlated and uncorrelated point defect recombination effects (in conjunction with ionization induced diffusion) on the measured defect production rates in ceramics.

There is considerable evidence that the irradiation spectrum (particularly ionizing radiation) can have a pronounced effect on the microstructural evolution in ceramics and semiconductors. Recent work on MgO, Al_2O_3 and $MgAl_2O_4$ suggests that a dramatic transition in the microstructural

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evolution occurs at a certain ratio of the electronic to nuclear stopping power. The observed microstructure in these materials also appears to be sensitive to the magnitude of the ionizing radiation dose rate. On the other hand, ionizing radiation does not appear to have a pronounced influence on the microstructure of some ceramics such as SiC. Further work is needed to quantify the role of ionizing dose rate and PKA spectrum on the microstructural evolution of ceramics.

Table 1. Recommended threshold displacement energies in ceramics

Material	Threshold displacement energy	Comments
Al_2O_3	E_d^{Al}~20 eV, E_d^{O}=50 eV	previous "standard" value for E_d^{O} was 76 eV
MgO	E_d^{Mg}=55 eV, E_d^{O}=55 eV	good agreement among 5 studies
CaO	E_d^{O}=60 eV	only 1 known measurement
$MgAl_2O_4$	E_d^{O}=60 eV	only 1 known measurement
ZnO	E_d^{Zn}~50 eV, E_d^{O}=55 eV	moderate uncertainty in E_d^{Zn}
BeO	E_d^{Be}~25 eV, E_d^{O}~70 eV?	large uncertainty in data
UO_2	E_d^{U}=40 eV, E_d^{O}=20 eV	only 1 known measurement
SiC	E_d^{Si}~40 eV?, E_d^{C}=20 eV	large uncertainty in E_d^{Si}
graphite	E_d^{C}=30 eV	extensive data base
diamond	E_d^{C}=40 eV	4 known measurements

Table 2. Summary of experimental and calculated point defect migration energies in MgO and Al_2O_3

Material	Point defect	Migration energy
MgO	Mg vacancy	2.0-2.3 eV
"	O vacancy	2.0-2.5 eV
"	Mg, O interstitials	0.5-1.5 eV
"	Mg, O interstitials	$\leq$0.2 eV
Al_2O_3	Al vacancy	1.8-2.1 eV (<1 eV)
"	O vacancy	1.8-2 eV (1.1 eV)
"	Al, O interstitials	0.2-0.8 eV