Transmission Electron Microscopy & Tomography Investigation into the Morphological Evolution of Ge upon Ion Irradiation

B. R. Yates[1,2*], B. L. Darby[1,3], K. Hattar[2], K. S. Jones[1]

[1]*Department of Materials Science and Engineering, University of Florida*
100 Rhines Hall, PO Box 116400, Gainesville, FL 32611

[2]*Sandia National Laboratories,*
1515 Eubank Blvd. SE, Albuquerque, NM 87123

[3]*Varian Semiconductor Equipment Associates,*
35 Dory Road, Gloucester, MA 01930

*Corresponding Author: bradyates@ufl.edu

The decomposition of Ge into a porous structure under high-dose irradiation has been known to occur and studied for several decades. However, the microstructural evolution as a function of irradiation species and substrate crystallinity has not been well documented. In addition, previous studies have relied on traditional 2D electron microscopy imaging techniques which can often inhibit complete and accurate quantification and discretization of the structure due to overlapping *nm*-scale features. In conjunction with traditional imaging, state of the art electron tomography 3D reconstruction techniques have enabled us to thoroughly investigate the microstructure of porous Ge as a function of time or implanted dose. In this study, the morphological evolution of porous Ge following high-dose irradiation has been investigated using transmission electron microscopy (TEM) and subsequent 3D tomographic reconstructions. Undoped (001) Ge and evaporated amorphous and poly-crystalline Ge films have been irradiated with ions ranging from Si^+ to Bi^+ at an energy such that the projected range of the ions was approximately 150 nm using Monte Carlo simulations to a dose no greater than 5×10^{17} ions/cm^2 for all investigated species. Cross-sectional (XTEM) and plan view (PTEM) samples were fabricated using focused ion beam and traditional ion milling. TEM analysis was completed using a JEM 2100 with a tomography stage with a ±82° range of tilt to allow for the collection of a tilt series for processing into 3D reconstructions. For all samples characterized, the mean pore dimension increased as a function of irradiation dose across the investigated range. In addition, experimental results have shown evidence of a drastically different microstructure produced upon irradiation of substrates of differing crystallinity. Interestingly, despite all samples turning amorphous prior to decomposing into porous Ge, it is shown that as-deposited Ge films tend to form spherical voids as opposed to cylindrical voids for the single-crystal samples. The significance of substrate crystallinity prior to irradiation is discussed with respect to the porous Ge evolution. In addition, the mechanisms for void nucleation and subsequent evolution are discussed with a focus on the data obtained from the tomographic reconstructions obtained from various experimental conditions.

**This work is supported by the Division of Materials Science and Engineering, Office of Basic Energy Sciences, U.S. Department of Energy both at Sandia and under grant DE-FG02-07ER46443. Sandia National Laboratories is a multi-program laboratory operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin company, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.*