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doi:10.1017/S143192761005364X
Microsc. Microanal. 16 (Suppl 2), 2010

Local Area Volume Change in Ion-irradiated SiC Measured by Electron Energy Loss Spectroscopy

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Silicon carbide (SiC) and its composite materials are proposed for a range of applications in advanced nuclear fission and fusion reactors [1-2]. SiC is also proposed as a promising wide band gap semiconductor for high-temperature, high-power, and high-frequency microelectronic and optoelectronic device applications [3]. Thus, understanding of irradiation-induced behavior in SiC is of great importance to predicting material performance in different applications. A number of previous studies have revealed that SiC undergoes significant volume expansion when amorphized by ion irradiation. Since material performance is affected by volume expansion, extensive experimental studies have been performed. However, the volume expansion data show significant scatter ranging from ~8 to ~20 % [4-6]. In addition, while the average volume expansion across the entire irradiation depth determined in many previous studies, the measurement of local volume change as a function of depth across entire irradiation region is clearly necessary to accurately determine the volume changes.

This study determines the depth profile of local volume changes occurring in ion-irradiated SiC in as-irradiated and in annealed samples using a transmission electron microscopy (TEM) equipped with electron energy loss spectroscopy (EELS) and discusses possible mechanisms of volume expansion.

A single crystalline (0001) 6H-SiC wafer was irradiated with 2MeV Pt ions 7^{o} off from the surface normal to fluences of 2.1×10^{13}, 4.7×10^{13}, and 2.2×10^{15} cm^{-2} at 150 K using a 3 MV tandem accelerator facility in Pacific Northwest National Laboratory. Rutherford backscattering spectrometry along channeling direction (RBS/C) measurement was performed *in situ* at 300 K to obtain information about lattice disorder. Thermal annealing was performed at 770 K using a vacuum furnace operated at $\sim1\times10^{-6}$ Torr. Cross-sectional TEM samples were prepared by a combination of tripod polishing and Ar ion milling techniques. TEM and EELS analyses were performed using 200 kV JEOL JEM-2010 TEM equipped with a Gatan Imaging Filter 2000.

Figure 1 shows cross sectional bright-field TEM images for 2.1×10^{13} cm^{-2} as-irradiated (a) and its annealed (b) samples. The depth profiles of low energy loss spectra obtained from the local area denoted with spot numbers 1 to 9 in Fig. 1(a) are shown in Fig.2. Note that while the plasmon-loss peak position for undamaged SiC (spot 9) is 22.11 eV, those in the irradiation damage region vary from 22.09 (spot 1) through 21.69 (spot 6) to 21.94 (spot 8). The local volume expansion from spot 1 to spot 8 is estimated using a simple relationship of $[E_{plasmon}\text{ (virgin)}/E_{plasmon}\text{ (damaged)}]^2-1$ [7]. The depth profile for the annealed sample is also obtained in a similar manner. It is found that the depth profile of volume expansion in the as-irradiated sample matches well with both the lattice disorder profile measured by RBS/C (not shown) and the local dose profile calculated by SRIM 2008 code (not shown) [8]. It provides direct evidence of defect generation in the crystalline structure as a mechanism for initial volume expansion. The volume expansion profile in the annealed sample (not shown) decreases due to point defect annihilation and damage recovery. By comparing volume expansion and relative disorder profiles in 2.1×10^{13}, 4.7×10^{13}, and 2.2×10^{15} cm^{-2}

samples, it is revealed that volume expansion in amorphous SiC continues to increase from 7 to 14 %, where it appears to saturate [9].

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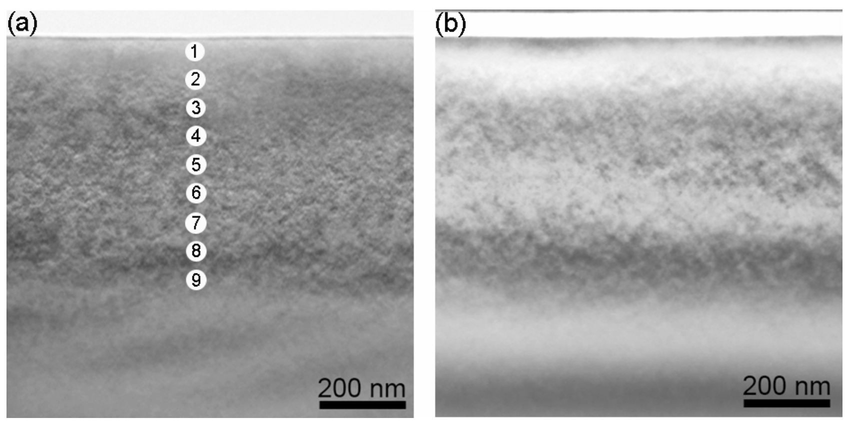

FIG.. 1 Cross sectional BF images of SiC: (a) irradiated with 2 MeV Pt to 2.1×1013 cm-2 at 150 K and (b) following thermal annealing at 770 K.

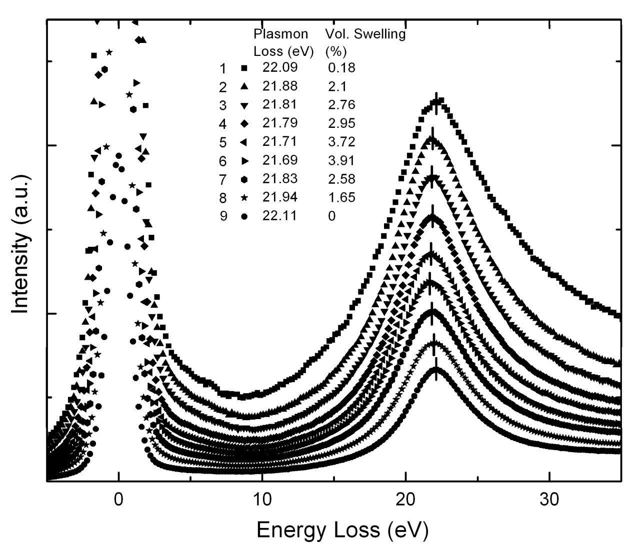

FIG. 2 Depth profile of low energy loss spectra from the as-irradiated sample (2.1×10^{13} cm^{-2}) shown in Fig.1(a).

https://doi.org/10.1017/S143192761005364X Published online by Cambridge University Press