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Investigation of Microstructural Changes and Mechanical Behavior in Silicon Carbide under 158 MeV Xenon Ion

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1. Introduction

In nuclear reactors, the release of gases from fission products and the accumulation of light and heavy atoms, such as helium, hydrogen and xenon, during operation can significantly alter the structural integrity of reactor materials [1]. These gases may migrate and cluster, forming gas bubbles and inducing stress, which leads to defects within protective layers like silicon carbide (SiC) [2]. SiC, is used in nuclear applications due to its excellent thermal conductivity, mechanical strength, and radiation resistance. However, under extreme irradiation conditions, SiC's structural, chemical, and mechanical properties can degrade [3], reducing its effectiveness as a protective barrier. Understanding SiC's response to irradiation is crucial for enhancing its performance in high-radiation environments. Hence, this study investigates the effects of room temperature swift heavy ion (SHI) irradiation, using 158 MeV Xe^{26+} ions at fluences of 1×10^{10} cm^{-2}, 1×10^{11} cm^{-2}, and 1×10^{13} cm^{-2} on polycrystalline 3C-SiC. The primary aim of this research is to evaluate changes in microstructural characteristics and mechanical properties resulting from SHI irradiation.

1. Results

In this study, Raman spectroscopy, Atomic Force Microscopy (AFM), and Vickers hardness indentation were employed to study the microstructural changes and mechanical properties of the samples. Figure 1 shows Raman spectra before and after irradiation to different fluences. Raman spectroscopy revealed defect production at all irradiation fluence levels, with higher fluences inducing greater damage compared to lower ones. Specifically, irradiation at the highest fluence of 1×10^{13} cm^{-2} led to significant defect development, indicating considerable structural disturbance. The longitudinal optical (LO) peak at 965 cm-1 of SiC shifted noticeably towards higher wavenumbers as the fluence increased, signifying the introduction of compressive stress due to ion-induced lattice distortion that alters the atomic arrangement of the SiC crystal structure. Additionally, the transverse optical (TO) to longitudinal optical (LO) intensity ratio increased with higher fluence levels, indicating progressive degradation of the crystal structure and a growing degree of lattice disorder, with defects such as vacancies and interstitials contributing to this disruption.

Hardness measurements showed an initial increase from 29.72 GPa to 37.28 GPa at intermediate fluences, suggesting defect-induced strengthening; however, at the highest fluence, hardness decreased to 30.17 GPa, reflecting the effects of reduced surface roughness from irradiation-induced wear. This interaction between defect accumulation and hardness highlights the effects of ion irradiation on the mechanical properties of SiC, leading to both strengthening and softening behaviors that vary with fluence.

1. References

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