MICROSTRUCTURE AND PHASE STATE OF SILICON CARBIDE IRRADIATED WITH HELIUM IONS

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Silicon carbide (SiC) is an important semiconductor material of potential applications for electronic device fabrication and for structural components in fusion energy systems. A fundamental understanding of the accumulation and recovery of irradiation damage in SiC is needed to advance technological applications [1].

The samples were prepared at the Lykov Institute of Heat and Mass Transfer by binding two fractions of SiC powders M5 and M50 (grain size 5 microns and 50 microns, respectively) using a thermoplastic binder based on paraffin P-2 and subsequent silicification at a temperature of 1800° with and a pressure of 0.13 Pa [2].

The samples were irradiated with He ions with an energy of 40 keV at RT at the DC-60 linear heavy ion accelerator (Institute of Nuclear Physics, Nur-Sultan, Kazakhstan). Irradiations with helium ions were carried out with fluences 1×10^{14}, 1×10^{15}, 1×10^{16}, 5×10^{16} and 2×10^{17} sm^{-2}.

The structural and phase state of the initial and irradiated silicon carbide samples was studied by X-ray diffraction analysis (XRD), atomic force microscopy (AFM) and scanning electron microscopy (SEM).

The calculation of energy losses was carried out in the SRIM 2013 program. The concentration and dpa for each dose were calculated and their maximum are listed in Table 1. The maximum concentration of helium ions is reached at a depth of 348 nm. As can be seen from Figure 1, the highest energy losses of helium ions occur in a layer about 60 nm thick.

Table 1. SRIM simulation results

Dose, cm^{-2}	1×10^{14}	1×10^{15}	1×10^{16}	5×10^{16}	2×10^{17}
He, at. %	0.009	0.09	0.9	5	18
dpa	0.006	0.06	0.6	3	12

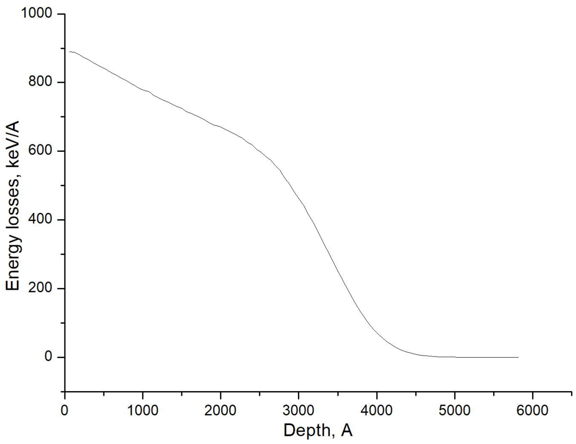

Fig. 1. Energy loses of He ions in SiC samples.

The results of studies of the phase composition showed that the initial samples are a multiphase system: SiC-6H – hexagonal (P63mc) syngony, Si – cubic (Fd-3m) syngony, SiC-15R – trigonal (R3m) syngony, as can be seen from Figure 2. The main phase is SiC-6H (about 80%), the content of the SiC-15R phase is about 20%, Si is less than 5%.

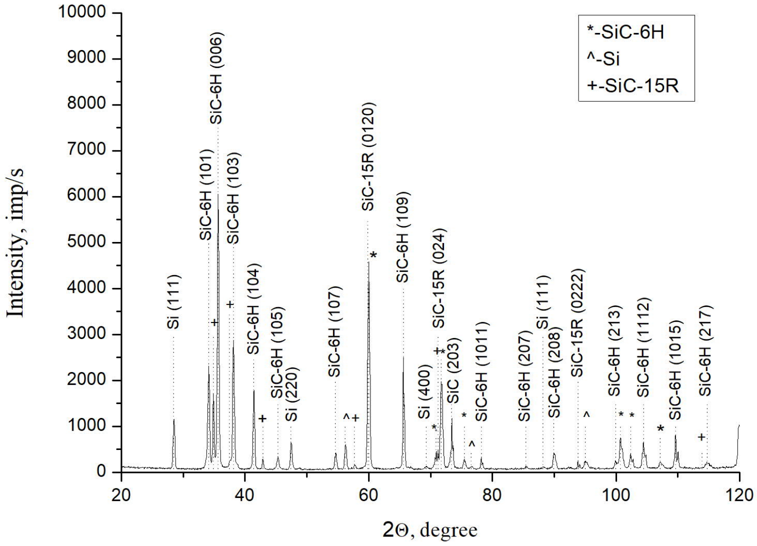

Fig. 2. X-ray diffraction pattern of the initial SiC sample.

Figure 3 shows the dependence of the relative change of the lattice parameter *a* and *c* on the dose. These graphs can be divided into 3 parts. The first part is up to the dose of 1×10^{16} cm^{-2}. This site is characterized by the accumulation of helium and defects (interstitial atoms and vacancies), as well as their clustering [3]. The relative change in both parameters in absolute value increases, the difference is in the stresses: compressive stresses in the direction of parameter *a* and tensile stresses in the direction of parameter *c*. The next part is the dose of 1×10^{16} cm^{-2}. In this area, there is a drop in residual strain. This is due to the fact that helium bubbles are formed, which are sinks for defects [4]. Consequently, for both parameters, the relative change drops sharply. And in the third section (5×10^{16} - 2×10^{17} cm^{-2}), deformation increases again. This is due to the growth of bubbles and, consequently, an rise in stresses. It should also be noted an increase in the lattice parameter *a* and a decrease in *c*. Such a change in the crystal lattice occurs as a consequence of irradiation growth. This irradiation effect is characteristic of HCP metals, especially zirconium [5].

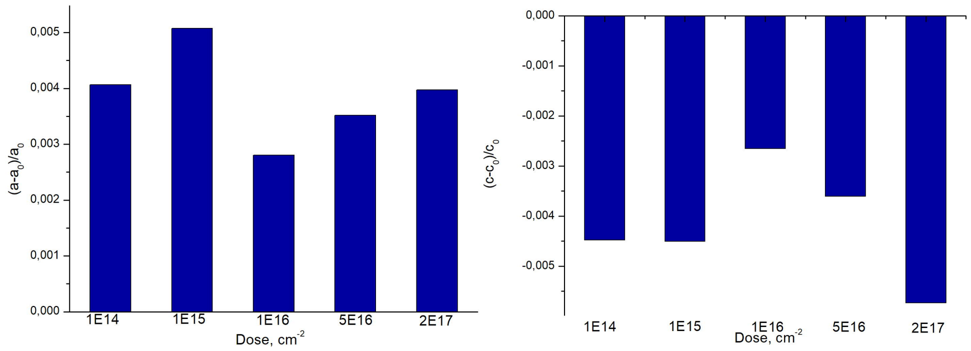

Fig.3. Dependence of relative change of lattice parameters *a* (a) and *c* (b) of 6H-SiC on the radiation dose of SiC samples irradiated with He ions.

Based on the results of AFM, it can be concluded that the roughness increases with increasing dose (fig. 4), which is also confirmed by literature [6]. Also, results demonstrate that implantation with He ion produces bubbles and swelling on the surface at higher doses.

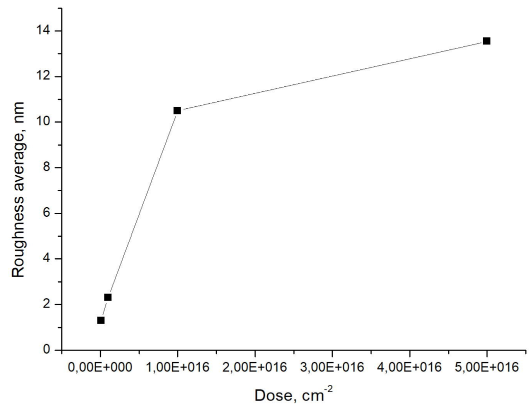

Fig. 4. Atomic force microscopy roughness graph.

Figure 4 shows the SEM images of the initial and irradiated samples. On the initial sample, the elemental contrast makes it possible to identify grains of silicon carbide, and silicon between them (which is related to the technology of sample preparation). At a dose of 1×10^{15} cm^{-2}, a grain structure is observed, but with a further increase in the dose, the amorphization of the near-surface layer occurs, what is confirmed by the literature [7].

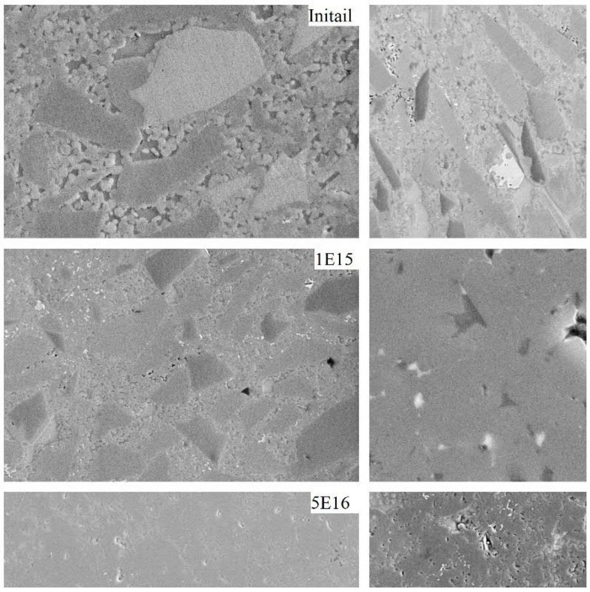

Fig. 5. Results of scanning electron microscopy.

Thus, when SiC is irradiated with helium ions with energy 40 keV, an increase in deformation is observed, but at a dose of 1×10^{16} cm^{-2}, stress relaxation occurs, due to which the deformation decreases. The roughness also increases and the near-surface layer is amorphized.

References

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