

Abstract

The Dual Fluid Reactor (DFR) is a new concept of a high-temperature reactor using fast neutrons. In the DFR, both the fuel and the coolant are liquid. As a fuel, molten salts or liquid metals are considered, while lead or lead-bismuth may be used as coolants. DFR is extremely economical due to its high power density, and thanks to its high efficiency, DFR can reduce the production prices of electricity, industrial heat and hydrogen. Construction materials for DFR must be resistant to very high temperatures, corrosion and radiation, which is why ceramic materials such as silicon carbide, zirconium carbide and titanium carbide are considered. Investigating new materials for use in the nuclear industry is time-consuming and very expensive due to neutron irradiation in the reactor. It is possible to use heavy ions instead of neutrons to study radiation damage. In this way, the exposure time is reduced from dozens of years to a few days.

This work focuses on examining the possibility of using ions as a surrogate for neutron radiation damage in silicon carbide. Despite the fact that the impact of radiation on this material has been the subject of research since the mid-last century, not everything is fully understood yet. As ions pass through the matter, they lose their energy through collisions with atoms or through interactions with electrons leading to ionization and excitation. At low energies, nuclear losses dominate, and at high energies, electronic losses prevail. Electronic energy loss may lead to a significant increase in temperature in the ion path, resulting in local melting and amorphization or annealing of defects. For intermediate energies (ranging from several hundred keV to several tens of MeV), a coupling of nuclear and electronic energy loss effects can be expected. Additionally, swift heavy ions can produce in the target material ion tracks leading to local melting and changes of the crystal structure, which can be described within a thermal spike model. The aim of this work is to improve the understanding of ion radiation damage formation in SiC, precisely in this energy range.

The basis of the research was an experiment involving the bombardment of a single crystal of silicon carbide with Si and C ions of different energies to obtain various number of crystal defects at different stopping power values. Both the case when the ion energies are very low and nuclear losses dominate, as well as the case when the ion has high energies and electronic losses dominate, were considered. The number of crystal defects and their depth distributions were experimentally determined using the Rutherford backscattering spectrometry in channeling mode and compared with Monte Carlo simulations performed applying the McChasy code. The effect of the deposited energy in silicon carbide samples was investigated through calculations based on both the thermal spike model and a molecular dynamics approach. The results showed that electronic energy deposition can heat the centre of the ion path and repair crystal lattice defects. This effect was also confirmed experimentally by externally heating the targets during irradiation and annealing the targets after irradiation, supporting the use of SiC ceramics as a construction material for future high-temperature nuclear reactors.