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In-situ High Temperature Ion Irradiation Transmission Electron Microscopy to Understand Fission Product Transport in Silicon Carbide of TRISO Fuel

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Certain metallic fission products are found to transport into and/or through the SiC layer of tristructural isotropic (TRISO) nuclear fuel particles, and various studies have been undertaken to understand this transport behavior [1, 2]. The grain boundaries and triple junctions tend to be a pathway for fission product transport and, in some cases, trapping or precipitation in the form of multi-phased complex compounds, as shown in Figure 1.

This work explores in-situ transmission electron microscopy (TEM) on unirradiated and neutron-irradiated TRISO fuel particles that couples a heating stage up to 1200°C and an ion beam at energies up to 48 MeV. In-situ Ion Irradiation Transmission Electron Microscope (I^3TEM) facility at the Sandia Ion Beam Laboratory has been used in this study. The I^3TEM consists of a 200 kV JEOL 2100 high-contrast TEM, a 10 kV Colutron ion gun and a 6 MV Tandem accelerators for ion implantation/irradiation [3,4]. These combined capabilities allow observation of structural-defects-assisted fission product transport and precipitation in the SiC layer of TRISO fuel in real time.

The objective of this in-situ nano-scale investigation is to determine the role of structural defects such as grain boundaries and stacking faults in the transport of solutes in the β-SiC in the vicinity of grain boundaries and triple junctions, as shown in Figure 1. Another important aspect of this study is to understand the possible silver (Ag)-assisted inter- and intragranular fission product transport. This project has used both unirradiated and neutron irradiated SiC from the Advanced Gas Reactor (AGR)-1 and AGR-2 experiments to accomplish a comparative study through ion implantation and microscopic observation in the 500-800°C temperature range. This research utilized 2.8MeV gold (Au^{4+}) ions at fluences up to 3.5 x 10^{15} ions/cm^2 for high temperature ion irradiation of SiC layer of TRISO fuel (Figure 2).

The post-ion irradiation characterization has been carried out using transmission electron microscopy methods such as precession electron diffraction (PED), and scanning (S)TEM, chemical analysis by energy dispersive spectroscopy (EDS). The results demonstrate the location of fission products in relation to the defects (voids) and dislocations after EDS analysis.

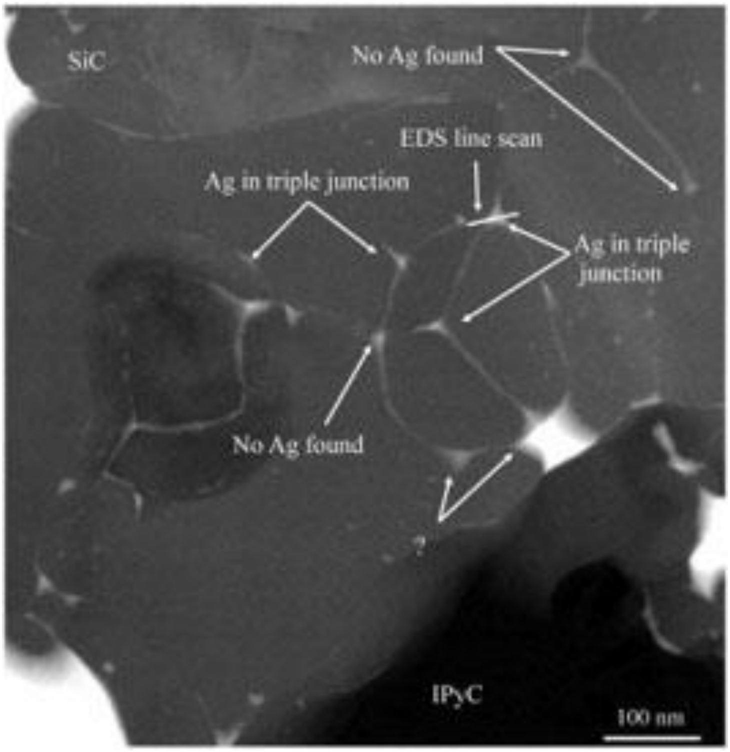

Figure 1. The precipitation of fission product precipitates at SiC grain boundaries and triple junctions in a neutron irradiated TRISO particle [2].

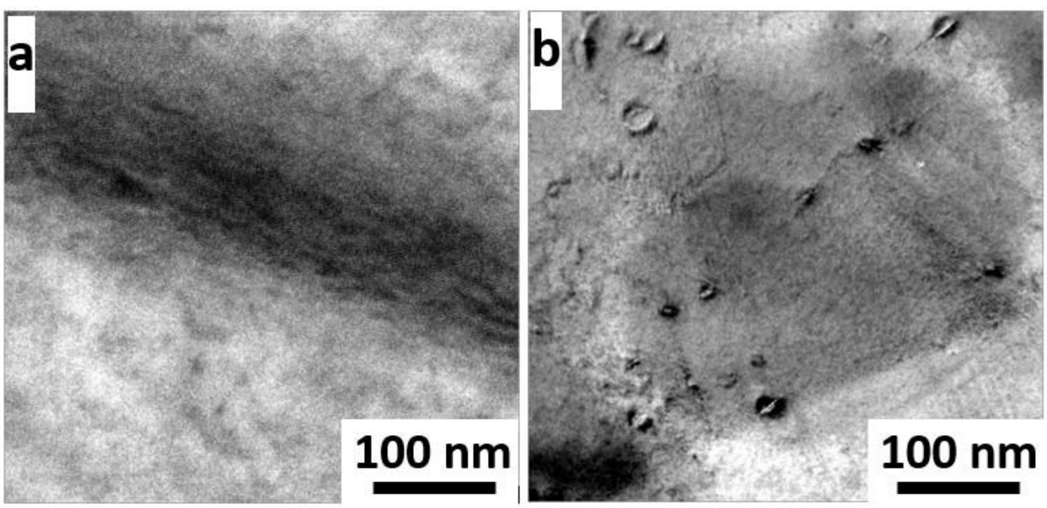

Figure 2. (a) the neutron irradiated AGR1-632-035 particle before Au4+ ion implantation, (b) the same particle after Au4+ ion implantation shows some ion-irradiation-induced dislocation loops.

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