In-situ TEM ion irradiation studies of layered MAX phase materials

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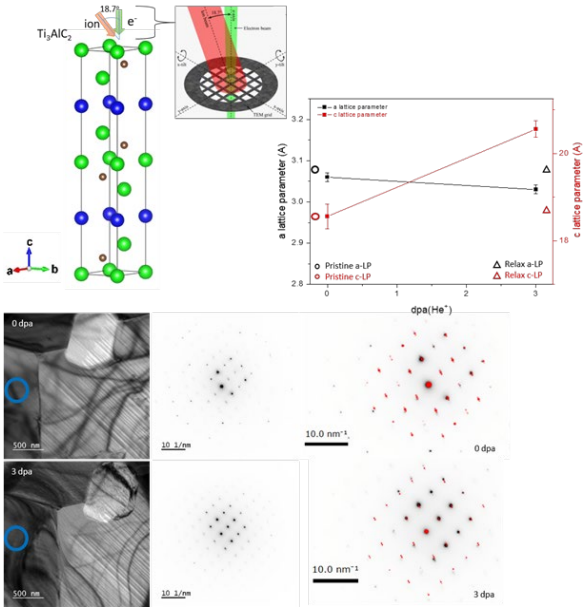
Materials in the core of a nuclear reactor are exposed to severe environments, particularly in future Generation IV nuclear systems, which perform in environments with high temperatures and high fluxes of fast neutrons, causing hundreds of displacements per atom (dpa) as well as substantial helium (He) doping by nuclear transmutation. MAX phases have attracted attention for their potential in nuclear materials due to their demonstration of high stabilities [1].

This study investigates the impact of sequential irradiation with light and heavy ion irradiation of MAX phases, specifically comparing the irradiation induced changes in Ti_3SiC_2 and Ti_3AlC_2. Cross sections of both MAX phases were prepared using focused ion beam milling. These were irradiated inside the MIAMI transmission electron microscopy (TEM), in situ TEM irradiation facility [2], first with 75 keV He+ ions at a dose of 2.6 x 10^{16} ions/cm² up to 3 dpa, and then with 600 keV Ar^{2}+ ions with a total fluence of 9.2 x 10^{16} ions/cm² up to 50 dpa, at both room temperature and 350°C. TEM imaging and diffraction are used during in-situ ion irradiation for direct observation of the microstructural and unit cell evolution. In-situ TEM observations indicate that both materials retained their crystal structures for the full irradiation dose. There was no observation of significant amorphization, phase transformations, He bubbles, or decomposition. The helium irradiation-induced damage, manifested as point defects, increases with damage level (dpa), resulting in anisotropic changes in lattice parameters in both structures up to ~ 9% and at both room temperature and irradiated temperatures. Interestingly, a significant recovery towards the as-synthesized unit cell parameters was observed post-irradiation within a few days of ambient storage at room temperature. Subsequent irradiation then followed similar irradiation damage profiles as the original pristine MAX phase with lattice parameter changes up to ~ 8% without significant amorphization, followed by another room temperature structural recovery when the irradiation is stopped. This observation of exceptional irradiation stability combined with room temperature recovery provides new evidence of the potential of MAX phases in protective coatings for nuclear applications and for radiation sensing and detection.

Graphic:



Keywords:

In-situ radiation, MAX-phases, radiation tolerance.

Reference:

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