

## **In-situ TEM observation of oxidation and radiation damage**

Yang, Y.<sup>1</sup>, Hu, J.<sup>2</sup>, Xin, H.<sup>3</sup>, Huang, Q.<sup>4</sup>, Shan, Z.<sup>5</sup>, Hosemann, P.<sup>6</sup> and Li, J.<sup>7</sup>

<sup>1</sup> MIT, United States, <sup>2</sup> Argonne National Laboratory, United States, <sup>3</sup> Brookhaven National Laboratory, United States, <sup>4</sup> Ningbo Institute for Material Engineering and Technology, China, <sup>5</sup> Xi'an Jiaotong University, China, <sup>6</sup> UC Berkeley, United States, <sup>7</sup> MIT, United States

Nuclear cladding serves as the direct container of fuels. Its ability to maintain integrity under high temperature, high pressure, corrosive environments and radiation damage is pivotal for the safe operation of nuclear reactors. However, the challenges resulted from materials degradation in harsh conditions in reactors has not been satisfactorily overcome, significantly limiting the cycle life of nuclear fuels and the safety margins of reactors. Therefore, it is vital to study the underlying mechanism in these corrosion and radiation damage processes, in order to develop better cladding materials.

Recent development of advanced TEMs has enabled direct visualization of corrosion (e.g., via environmental TEM) and radiation damage (e.g., IVEM-Tandem) at micro/nano/atomic scale. These experiments may provide new insight into the phase transformation process led by corrosion or radiation-damage. Here we present in-situ experiments of oxidation in Zr-4 alloy (Fig. 1), as well as heavy ion irradiation in MAX phase materials (Fig. 2). In the oxidation experiments of Zr-4, we not only observe the nucleation process of monoclinic ZrO<sub>2</sub> and tetragonal ZrO<sub>2</sub>, but also the phase transformation between these two oxides. In the irradiation experiments of MAX phase materials, we discovered a phase transformation which doubles the spacing of each layers.

### **Acknowledgement:**

This research used resources of the Center for Functional Nanomaterials, which is a U.S. DOE Office of Science Facility, at Brookhaven National Laboratory under Contract No. DE-SC0012704. The IVEM facility at Argonne National Laboratory is supported by DOE-Office of Nuclear Energy.

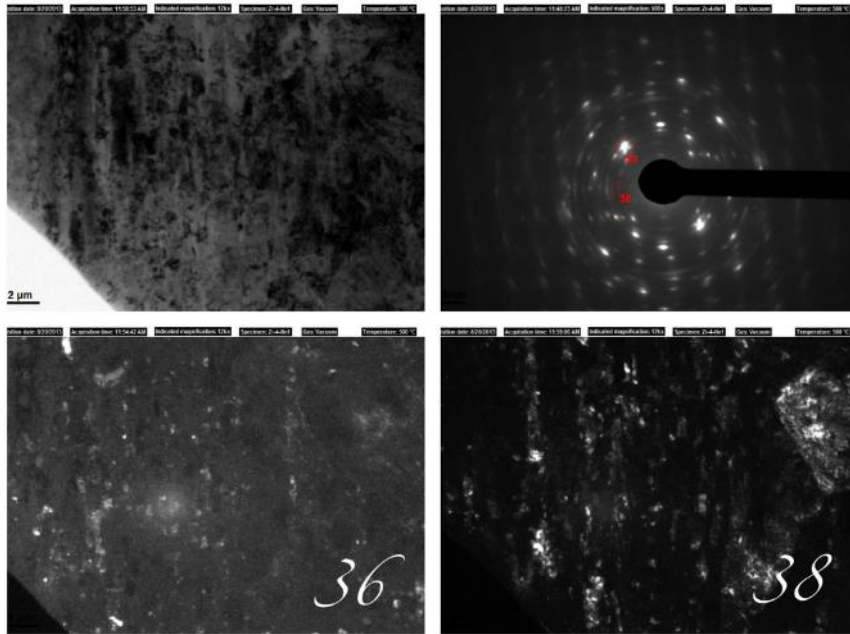


Fig.1. Zr-4 after oxidation in oxygen at 823K. (a) Bright field TEM images; (b) Selective area diffraction showing the existence of oxides. Note that originally this area was a single crystal. (c-d) Dark-field images using a diffraction spot, showing the oxide grains embedded inside the matrix after oxidation.

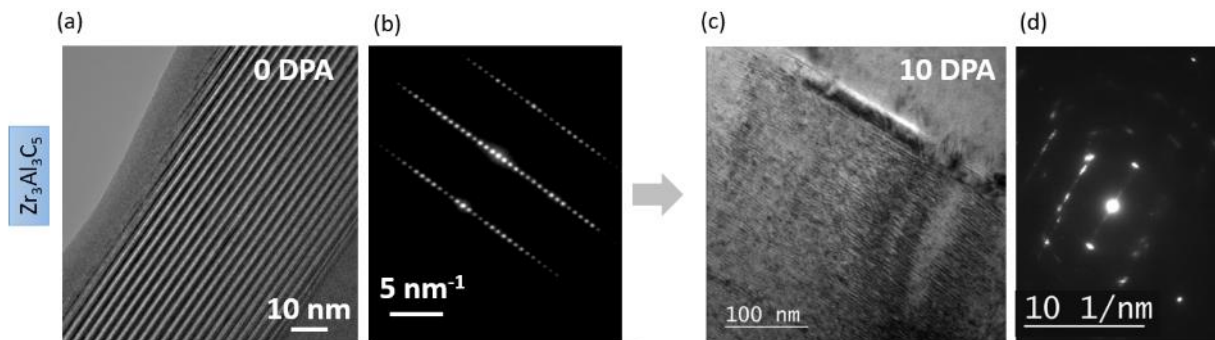


Fig. 2. (a-b) Bright-field image and selected area diffraction of  $Zr_3Al_3C_5$  before irradiation; (c-d) Bright-field image and selected area diffraction of  $Zr_3Al_3C_5$  after 1 MeV  $Kr^{++}$  irradiation ( $\sim 10$  DPA).