Tutorial on

Advances in Transmission Electron Microscopy for Probing Irradiation Effects

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Characterizing the impact of irradiation on the microstructure of future fusion reactor materials is vital for predicting their performance. Transmission electron microscopy (TEM) remains one of the tools of choice for this task, because it allows one to directly see the microstructure from the micrometer down to the atom. This tutorial will review with examples the various techniques in TEM that can serve the purpose, starting from the basics and progressing towards the most recent methods and techniques: TEM methods include those based on diffraction contrast imaging as well as phase contrast imaging benefiting from optics corrected for spherical aberration, with technical advances made on the cameras, for an improved spatial resolution. Scanning transmission electron microscopy (STEM) with the advent of the spherical aberration correction is becoming ubiquitous in the field not only for imaging but for the spectroscopy of the X-ray energy dispersion (EDS) and electron energy loss (EELS), which allowed turning the black-and-white TEM image into a colored one because of the added atomic chemistry and bonding information. This was enabled by numerous advances in EDS and EELS technology. Additionally informed by diffraction for crystal and strain analyses in each pixel, STEM gave rise to the 4D STEM method. It is now gaining further traction because it can be simultaneously augmented by EDS information, providing a wealth of data within a single acquisition. To recover the third dimension, the new tilt-less stereoscopy in STEM mode and also the coupling to atom probe tomography are helpful. The analysis of TEM data progressed as well, both in imaging and spectroscopy, thanks to advances in software and the development of artificial intelligence. Examples of recent radiation damage studies that advanced the field or benefited from the most recent TEM methods will be presented.