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Detection of defects in displacement-damaged tungsten and iron

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Due to their advantageous properties, tungsten (W) and steels are the main candidates for plasma-facing and structural materials for future fusion reactors. However, exposure to 14 MeV neutrons from D-T fusion reaction in nuclear environment will introduce significant displacement damage, altering the crystal structure of the materials and affecting their physical properties. To examine displacement damage created in the W and Fe lattice (the primary constituent of steels), we employed Rutherford backscattering spectrometry in channeling configuration (RBS-C), a well-established technique for characterization of lattice disorder and defect evolution induced by irradiation. Disorder was quantified by analysing the change in the ion yield of light ions backscattered along a specific crystallographic direction [1].

MeV heavy ion irradiation was used as surrogate for the displacement damage neutrons will cause. W and Fe single crystals (SC) were irradiated at two different doses (0.02 and 0.2 dpa), at two temperatures (300 and 800 K) for W and at 300 K for Fe. Our goal was to create samples containing different amounts of defects with different nature. In W samples open volume defects (vacancies and vacancy clusters) were analysed by positron annihilation spectroscopy while interstitial-type defects were characterized by transmission electron microscopy (TEM) analysis. Dislocation lines and loops of different sizes were observed in W (111) SC, depending on the irradiation dose and temperature.

Multi-energy RBS-C spectra analysis was used to study the disorder in the materials and to obtain complementary information to the TEM analysis. For the first time for W, we employed molecular dynamics (MD) simulations of overlapping cascades as input for the RBSADEC code [2], to simulate the RBS-C spectra. These simulations showed remarkable agreement with the experiment for the lower dose sample, while discrepancies at higher doses are attributed to the formation of large dislocation structures observed by TEM, which cannot be formed in finite-size MD cells [3]. Presentation of ongoing work will include new simulation results with a larger MD cell and different MD potential for the high dose and high-temperature samples. Preliminary first results on irradiated Fe SCs will be presented and discussed.

References:
[1] Feldman et al., Academic Press, San Diego, (1982), pp. 88–116
[2] Zhang et al. Phys. Rev. E 94, 043319 (2016).
[3] Markelj et al, Acta Materialia 263 (2024) 119499

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