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Atomic Scale, 3-Dimensional Characterization of Radiation Effects in Tungsten for Fusion Applications

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The refractory metal tungsten is a promising candidate material for plasma facing components (PFCs) in future fusion reactors due in part to its low sputter yield, good thermal conductivity and low activation under transmutation. However, tungsten suffers from a very high brittle-to-ductile transition temperature (BDTT) of 400-500 °C [1]. This inherent brittleness is only exacerbated under irradiation due to the irradiation-induced defects and the formation of second phase precipitates containing the transmutation products Re and Os. [2,3] Here, we discuss the use of novel field ion microscopy (FIM) and atom probe tomography (APT) techniques to investigate radiation effects in irradiated tungsten.

In this study, both ion and neutron irradiated samples were characterized. Materials that were ion irradiated were either pure tungsten, or a tungsten-5at.% tantalum alloys and irradiated with 2 MeV W ions at between room temperature and 500 C to damage levels of up to 33 displacements per atom (dpa) as estimated using SRIM using the Kinchin-Pease method with an E_d of 68 eV. Neutron irradiation pure tungsten specimens were irradiated in the High Flux Isotope Reactor (HFIR) at Oak Ridge National Laboratory (ORNL). Ion irradiated samples were analysed in either a 3DAP-LAR FIM or a Cameca LEAP 3000X HR at Oxford; neutron irradiated samples using a Cameca LEAP 4000X HR at ORNL.

A series of FIM images taken during a typical evaporation sequence from the [222] planes of a W-Ta specimen are shown in Fig. 1. Out-of-sequence evaporation events are detected, observed as vacant sites in the inner positions of the plane. These preferential evaporation events can then be exploited to identify the Ta atoms in the W-Ta alloy. By imaging multiple consecutive planes, it is possible to build up a 3-dimensional image of the distribution of Ta atoms in the matrix, Fig. 2.

Atom probe tomography techniques are ideally suited to the investigation of second phase precipitates in tungsten, Fig 3. Here we will discuss the differences in the use of ion irradiation and neutron irradiation on the formation of these phases, and the composition of the precipitates in the identification of the dominant phases formed, sigma or chi.

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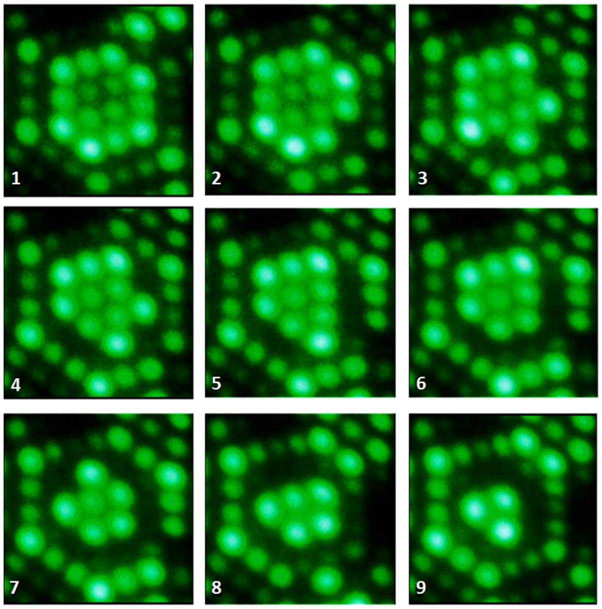

Fig 1: Sequential FIM images of the evaporation of a [220] plane in a W-5at.% Ta alloy. Out-of-sequence evaporation is observed.

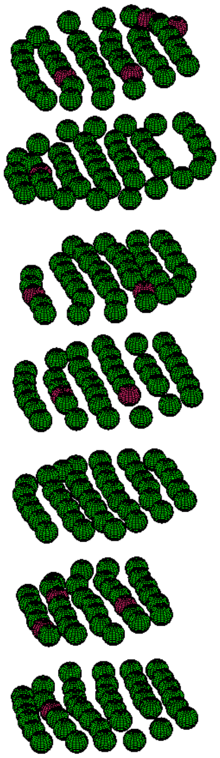

Fig 2: Reconstruction of data collected from sequential FIM images. Green spheres indicate W atoms; pink indicates tantalum.

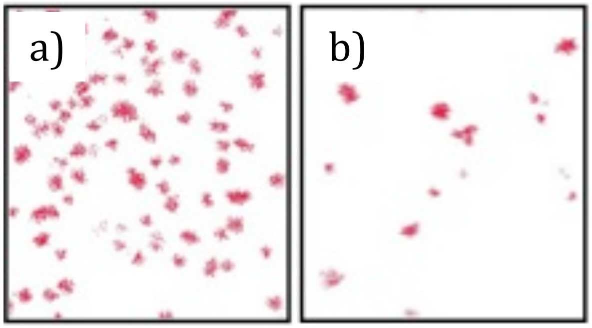

Fig 3: Re atom maps of an ion irradiated W-Re alloys, irradiated at temperatures of a) 300 and b) 500 °C.