doi:10.1017/S1431927622008133
Microsc. Microanal. 28 (Suppl 1), 2022

3D Nanoscale Analysis of Implanted Deuterium in Tungsten using Atom Probe Tomography

Martin S. Meier[1], Paul A. J. Bagot[1], Anthony Hollingsworth[2], Anke Wohlers[2], Michael P. Moody[1] and Daniel Haley[1]

[1] Department of Materials, University of Oxford, 16 Parks Road, Oxford, OX1 3PH, United Kingdom
2 UKAEA – United Kingdom Atomic Energy Authority, CCFE, Culham Science Centre, Abingdon, Oxon, OX14 3DB, United Kingdom
* Corresponding author: martin.meier@materials.ox.ac.uk

Fusion energy is a potential future energy source that is safe and sustainable. The most advanced concept for fusion power plants are Tokamaks, where hydrogen isotopes (deuterium and tritium) are fused into helium in a plasma within a toroidal vacuum chamber. The plasma facing walls are exposed to a number of adversarial conditions, such as high temperatures and thermoshocks, neutron radiation and implantation of hydrogen and helium. In current tokamaks, a divertor in the toroidal chamber is used to remove helium from the plasma, and is subjected to high fluxes of hydrogen isotopes leading to radiation damage radioactive inventories of tritium. Currently, tungsten is considered a leading candidate material for use in divertors [1]. Therefore, characterisation methods are needed to understand the hydrogen damage and retention in tungsten in tokamak reactors.

Most established microscopy techniques have a low sensitivity to hydrogen and cannot resolve low concentrations of hydrogen [2]. However, Atom Probe Tomography (APT), has the same sensitivity for all elements, including hydrogen. In this study, we use newly developed APT protocols to accurately extract hydrogen contents from simulated divertor materials.

We conduct APT on self-irradiated tungsten samples (2 MeV energy), serially implanted with deuterium. This leads to the accumulation of deuterium primarily in the radiation damaged (and defect-rich) layer near the sample surface, which we can track via APT. The samples are coated with iridium as a surface marker, and APT specimens are directly extracted from the surface exposed to the radiation and implantation.

Figure 1 shows the APT ions maps for iridium, carbon and oxygen, and deuterium, respectively, in a tungsten specimen. It is seen that the iridium clearly indicates the position of the surface, enabling accurate depth measurements through the length of the reconstructed tip. Carbon and oxygen are clustered, due to the radiation damage in the sample. The deuterium ion map clearly shows that retention is occurring not uniformly in the material, but depth dependent, as expected.

These APT experiments demonstrate that it is possible to obtain accurate deuterium depth profiles with high spatial resolution. In Figure 2, depth profiles of deuterium and carbon, oxygen in a tungsten sample are shown, in comparison to the radiation damage distribution predicted by the complementary SRIM simulation [4]. It is seen that the retention of deuterium is highest in a layer of approximately 150 to 220 nm depth, corresponding to a maximum in the concentration of carbon and oxygen. Interestingly, we did not observe co-segregation of deuterium with the carbon-oxygen clusters, meaning that it is most likely not the clusters themselves that retain deuterium. Rather, the clusters appear to sit in a layer where the high radiation damage has led to the highest concentration of deuterium retaining defects. This layer of maximum measured deuterium retention (150-220 nm) is slightly deeper than the layer of maximum damage as estimated by the simulation (100-200 nm).

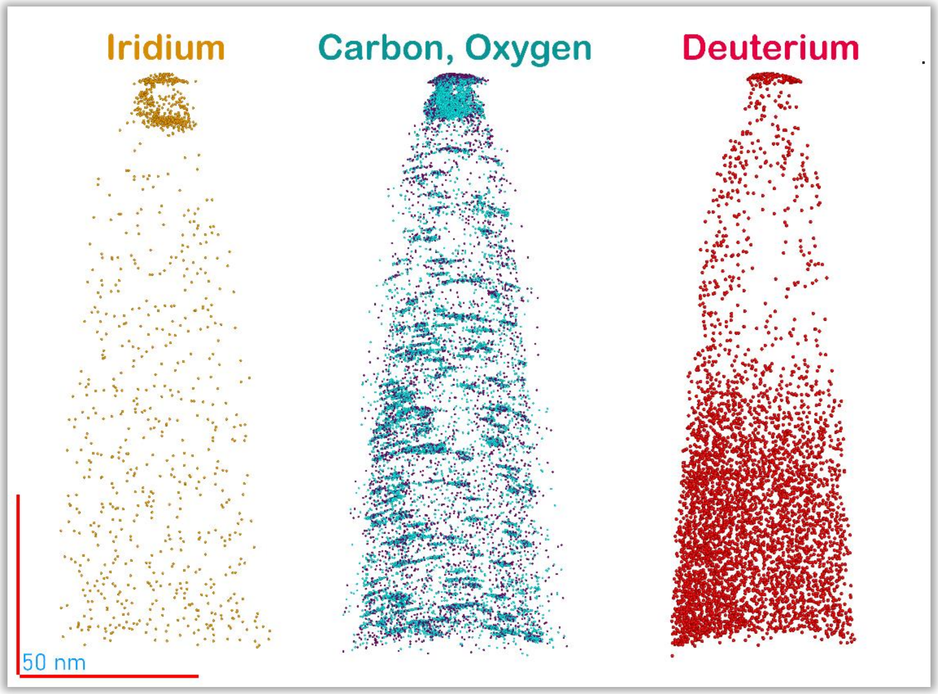

Figure 1: APT tip of a radiation damaged, deuterium implanted tungsten tip, with iridium as a surface marker. Carbon and oxygen are clustered due to radiation damage. Implanted deuterium can be accurately measured via APT.

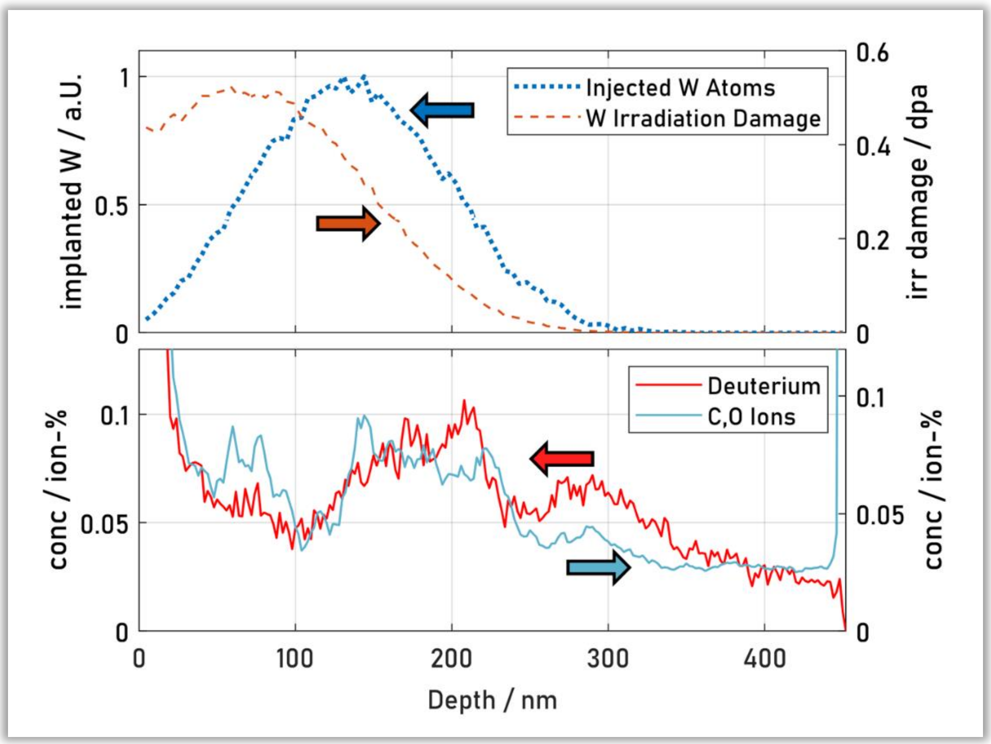

Figure 2: A) SRIM prediction of depth of radiation damage and depth distribution of injected ions (arbitrary units) in in our material from W-self irradiation, B) measured fractions of deuterium and carbon-oxygen ions in an APT tip. It is seen that deuterium retention is highest in the layer of highest

https://doi.org/10.1017/S1431927622008133 Published online by Cambridge University Press

carbon, oxygen contents. These layers are slightly deeper than the layers of maximum damage as estimated by simulation.

References

[1] J. Linke et al., "Challenges for plasma-facing components in nuclear fusion," Matter and Radiation at Extremes, vol. 4, no. 5, p. 056201, 2019/09/01 2019, doi: 10.1063/1.5090100.

[2] C. N. Taylor, "Hydrogen and its detection in fusion and fission nuclear materials – a review," J. Nucl. Mater., Article vol. 558, 2022, Art no. 153396, doi: 10.1016/j.jnucmat.2021.153396.

[3] G. Sundell, M. Thuvander, and H. O. Andren, "Hydrogen analysis in APT: Methods to control adsorption and dissociation of H-2," (in English), Ultramicroscopy, Article; Proceedings Paper vol. 132, pp. 285-289, Sep 2013, doi: 10.1016/j.ultramic.2013.01.007.

[4] J. F. Ziegler, M. D. Ziegler, and J. P. Biersack, "SRIM – The stopping and range of ions in matter (2010)," Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms, vol. 268, no. 11, pp. 1818-1823, 2010/06/01/ 2010, doi: https://doi.org/10.1016/j.nimb.2010.02.091.