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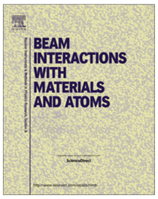

Assessing material properties for fusion applications by ion beams

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ABSTRACT

The plasma-facing materials in the ITER divertor area must withstand unusual events, such as the edge-localized modes (ELMS). At the point when an ELM occurs, up to 30% of the energy can be deposited on the plasma-facing boundary in the form of the heat and particle load causing material loss due to sublimation. Tungsten is a promising candidate as a plasma-facing material in the ITER divertor area since it has a high melting point, good thermal conductivity and low sputtering yield, which minimizes the plasma contamination. However their brittleness at low temperatures which is worsened by irradiation is an issue. One strategy to modulate the properties of tungsten is alloying this element with other refractory metals, such as tantalum that shows higher toughness, lower activation and higher radiation resistance.

In the present study tungsten-tantalum alloys (W-Ta) were produced by Ta implantation. The fundamental mechanisms which govern the behaviour of defect dynamics in W-Ta materials under reactor conditions, were simulated by the implantation of He and D. The microstructure observations of the W plates that after single Ta implantation revealed crater-like cavities and a more severe effect after D implantation. The effect increase with the increasing of D fluence. However at fluences higher than 10^{21}D/m the effect is reduced. In addition, blistering was observed in W-Ta plates implanted with He. The D retention in the W-Ta alloys increases with the implanted fluence with tendency for saturation for high fluences. Moreover the results show that D retention is higher after sequential He and D implantation than for single D implantation. The diffractogram of W-Ta alloys implanted with He evidenced the presence of broadened W peaks associated with stress induced by irradiation, which may cause internal stress field resulting in a distortion of the crystal lattice. These irradiation defects can be observed in the D release spectra where three peaks are associated with three types of defects in W and W-Ta implanted with He and D.

1. Introduction

Tungsten is considered one of the best materials for plasma facing applications in nuclear fusion devices, due to low activation, high melting point, low sputter erosion and low tritium retention/co-deposition [1]. It has excellent corrosion resistance and at temperatures over 1650 °C has the highest tensile strength. However in the low-temperature range of operating conditions, will be in the brittle regime [2] which is worsened by irradiation [3]. A strategy to increase the fracture toughness of W for nuclear fusion applications is to produce W alloys. Pure tantalum shows high toughness, low activation and high radiation resistance and, moreover, transmutes to W under high-energy neutron irradiation. This tends to retard the formation of the brittle sigma phase originating from transmutation of W to Os and Re [4]. However, Ta is a scarce commodity and its extensive use as plasma facing material cannot be envisaged for large devices.

In the present work W-Ta alloys were produced by Ta implantation at room temperature with a constant fluence of 2×10^{21} at/m^2 with an energy of 340 keV. In order to understand the fundamental mechanisms which govern the behaviour of defect dynamics of irradiation under reactor conditions, W-Ta materials were implanted at room temperature with 10 keV of He$^+$ with a constant fluence of 5×10^{21} at/m^2 and 5 keV of D$^+$ with fluences 10^{20}–10^{21} at/m^2 range. Scanning electron microscopy (SEM) coupled with energy dispersive X-ray spectroscopy (EDS), Rutherford backscattering spectrometry (RBS), nuclear reaction analysis (NRA), X-ray diffraction (XRD) and thermal desorption spectroscopy (TDS) were used to characterize the W alloys.

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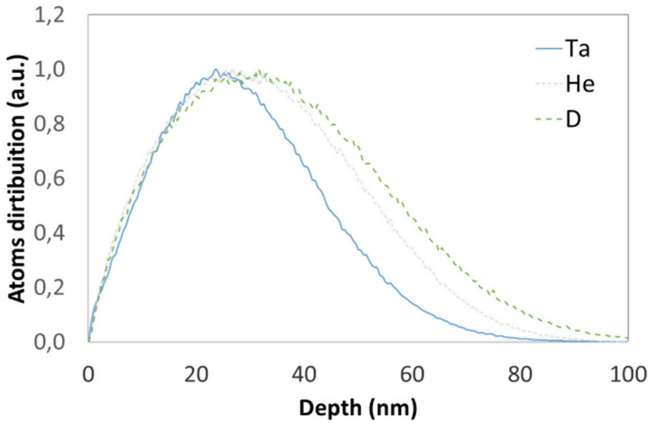

Fig. 1. SRIM simulation results of Ta, He and D versus penetration depth in W.

Table 1
Summary of implanted fluences in at/m^2 for Ta^{++} with an energy of 340 keV, He$^+$ with an energy of 10 keV and D$^+$ with an energy of 5 keV.

Sample	Ta^{++}	He$^+$	D$^+$
(a)	As-polished		
(b)	2×10^{21}		
(c)	2×10^{21}		5×10^{21}
(d)	2×10^{21}	5×10^{21}	
(e)	2×10^{21}	5×10^{21}	1×10^{20}
(f)	2×10^{21}	5×10^{21}	1×10^{21}
(g)	2×10^{21}	5×10^{21}	2×10^{21}
(h)	2×10^{21}	5×10^{21}	5×10^{21}

2. Experimental

A tungsten rod was cut in disks of 12 mm in diameter and 2 mm thick. The metallographic preparation involved grinding with SiC paper and polishing with 6, 3 and 1 μm diamond suspensions. The W-Ta alloys were produced by Ta implantation at room temperature with a constant fluence of 2×10^{21} at/m^2 with an energy of 340 keV.

Afterwards the W-Ta samples were implanted with He$^+$ ion beams of 10 keV and/or D$^+$ ion beams of 5 keV, using the new Ion Beam Deceleration System installed at the high flux ion implanter of "Laboratório de Aceleradores e Tecnologias de Radiação, Instituto Superior Técnico" Lisbon [5]. The He$^+$ and D$^+$ irradiation energies were determined with the SRIM software package [6] in order to obtain similar implantation depth ranges for all species as can be observed in (Fig. 1). A summary of the implantation conditions is given in Table 1. All samples entries in the table should carry the same reference in all figures.

Microstructural observations were performed with a JEOL JSM-7001F scanning electron microscope (SEM) equipped with EDS. Polished surfaces were investigated before and after implantation with secondary electrons (SE) and backscattered electrons (BSE) signals.

To investigate D and He retention properties of the samples, gas-desorption profiles were measured using RBS and NRA with ^{3}He$^+$ ion beams of 750–2200 keV range in order to evaluate the retained D amount in the samples using the D(^{3}He,p)α reaction, the detector for RBS was place at a backscattering angle of 165° and the NRA detector at 140°.

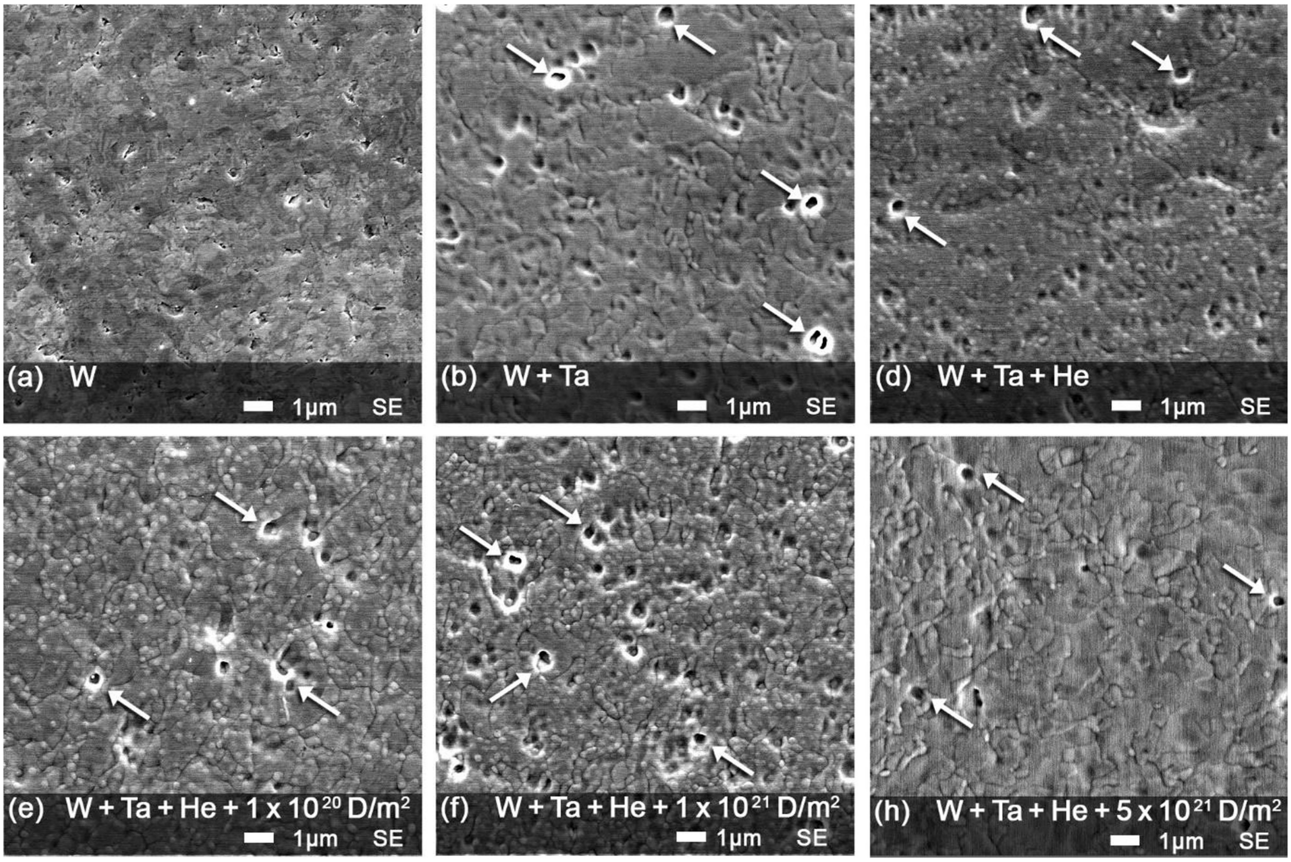

Fig. 2. SE Images showing according to reference Table 1 (a) as-polished W, (b to h) after Ta^{++} implantation with 2×10^{21} at/m^2, (d to h) implanted with He$^+$ 5×10^{21} at/m^2, and D$^+$ implanted with (e) 1×10^{20} at/m^2 (f) 1×10^{21} at/m^2 and (h) 5×10^{21} at/m^2. Cavities are depicted by white arrows.

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