Effect of Rhenium Addition on Tungsten Fuzz Formation in Helium Plasmas

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Introduction

- Tungsten is the candidate material for the divertor in ITER.
- 14MeV neutrons present in ITER will lead to the transmutation of tungsten to W-3.8At%Re-1.4At%Os following 5 years of operation [1].
- Exposure of tungsten to helium plasmas at temperatures above 800°C results in fuzzy tungsten [2].
- The helium-induced nanostructure, being very fragile in nature, could indeed pose severe problems in a fusion reactor in terms of material losses and dust formation.
- Therefore vital we understand the process of formation.
- Formation of fuzzy tungsten is affected by ion flux, temperature and exposure time.
- Literature suggests rhenium addition may result in decreased efficiency of production of helium induced nanostructure [3].
- Addition of rhenium under irradiated condition also results in increased brittle behavior of tungsten.
- Will the presence of rhenium in tungsten alter the kinetics and the process of helium induced damage creation?

Experimental Setup

Discs cut from rods of pure tungsten, tungsten-3% rhenium and tungsten-5% rhenium were polished to a mirror finish and cleaned in acetone, ethanol and deionized water. They were then exposed to helium plasmas in Magnum PSI and Pilot PSI for the conditions given in Table 1. Five samples highlighted in purple were exposed in Pilot, and the remaining samples in Magnum.

Table 1: Exposure Conditions

<table>
<thead>
<tr>
<th>Material</th>
<th>Average Temperature (°C)</th>
<th>Duration (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pure Tungsten</td>
<td>990</td>
<td>20</td>
</tr>
<tr>
<td>Pure Tungsten</td>
<td>960</td>
<td>30</td>
</tr>
<tr>
<td>Pure Tungsten</td>
<td>1110</td>
<td>100</td>
</tr>
<tr>
<td>Tungsten-3% Rhenium</td>
<td>960</td>
<td>10</td>
</tr>
<tr>
<td>Tungsten-3% Rhenium</td>
<td>960</td>
<td>100</td>
</tr>
<tr>
<td>Tungsten-5% Rhenium</td>
<td>970</td>
<td>10</td>
</tr>
<tr>
<td>Tungsten-5% Rhenium</td>
<td>970</td>
<td>100</td>
</tr>
<tr>
<td>Tungsten-5% Rhenium</td>
<td>1110</td>
<td>100</td>
</tr>
</tbody>
</table>

Results

Pilot

A disc of each alloy composition was exposed for 400 s at a temperature of approximately 1400 °C to helium plasmas with fluxes of the order of 10^{18} m^{-2} s^{-1} and energies of 30 and 35 eV. The tungsten disc had a diameter of 30 mm and the rhenium alloyed discs had diameters of 15 mm. All discs were approximately 1 mm thick. Focused Ion Beam was used to obtain 15 µm length cross sections in the region where the plasma beam hit the surface of the samples. The average depth was determined by taking depth measurements at 1 µm intervals along the cross sections. There is a small decrease in the depth of the fuzz between pure tungsten and tungsten-3% rhenium. There is a large decrease in fuzz depth from the 3% to 5% rhenium. Fuzz in pure tungsten is finer than in tungsten-rhenium. This suggests that the rhenium is causing the fuzz to form more slowly and that an earlier stage of growth is being seen in the rhenium samples.

SEM images of fuzz in a) pure tungsten, b) tungsten-3% rhenium, c) tungsten-5% rhenium

Cross sections of fuzz in a) pure tungsten, b) tungsten-3% rhenium and c) tungsten-5% rhenium and d) plot of the variation of fuzz depth and porosity with rhenium concentration for samples exposed for 400 s at 1400 °C in Pilot PSI.

Magnum

A disc of each alloy composition was exposed for 40,100 and 200 s at a temperature of approximately 970 °C to helium plasmas at fluxes of the order of 10^{17} m^{-2} s^{-1} and energies of 30 eV. The pure tungsten samples were 20 mm in diameter and the tungsten-rhenium discs were 15 mm in diameter. All the discs were 1 mm in thickness, apart from the pure tungsten that was exposed for 40s, which was 0.5 mm thick.

In this case the observations were quite similar to those in Pilot. In this experiment the fuzz appears to be more developed in the tungsten-5% rhenium samples in comparison to the 3% rhenium and pure tungsten samples. Lower magnification SEM images show the strong grain dependence of fuzz growth. It can be seen that as the time of exposure increases, the boundaries between the grains become less visible as the fuzz develops. It is known that grain size also strongly affects the development of fuzz, and from the low magnification images the grain size of the pure tungsten seems larger than the rhenium samples, which may have affected the fuzz growth. Fuzz growth is well aligned in early stages, which is clearly observed in the high magnification SEM images of the pure tungsten up to 100 s. Whereas, even at 100 s there is more disorder in the fuzz observed in the 5% rhenium sample, and after 200 s, the fuzz is well developed.

SEM images at low and high magnifications of tungsten, tungsten-3% rhenium and tungsten-5% rhenium samples exposed for 40, 100 and 200s at approximately 970 °C.

Summary/ Further Work

- For 400 s exposures, rhenium seems to inhibit the growth of fuzz.
- For 40-200 s exposures, fuzz grows more quickly in rhenium samples.
- TEM analysis of the fuzz observed in the Pilot samples is required.
- XPS analysis to determine the chemical composition of the surface is needed.
- Development of the mechanical properties of the samples in non fuzzy areas could also be investigated.
- Rhenium does seem to be affecting fuzz growth, but this effect differs between shorter and longer exposure times. Therefore it would be beneficial to conduct further plasma exposure experiments in order to build up a more detailed picture.

References