ABSTRACT & CONCLUSIONS

- A broad range of PKA spectra and defect density were produced by He, B & Au ions while keeping the same penetration range & overall dpa.
- For the same dpa, positron analysis reveals a higher damage due to 3 MeV He ions compared to 10 MeV B ions. This could be due to self-clustering of He and the consequent additional defect formation.
- However, SIMS analysis indicates lesser D-trapping in He-irradiated samples compared to Au & B irradiated samples. PAS results hint that this could be due to the occupation by He atoms of the vacancy competes with deuterium.

MOTIVATION

- Tungsten’s performance as a divertor armor material raises global concerns due to the accumulated radiation damage and subsequent tritium retention by 14 MeV neutrons and α-particles in a fusion power reactor.
- Ion irradiation is often used to simulate neutron damage. However, the role of PKA spectrum and the consequent defect structure in H-isotope trapping is unclear.
- We address this by using ion irradiation experiments with different mass, energy and PKA density and the defect formation is studied using positron annihilation, TEM and SIMS.

ION-IRRADIATION EXPERIMENTS

- Ion-irradiation experiments by using different ion mass and energy.
- The average range is nearly the same except one case.
- Cold-rolled W-foil samples of 99.96 weight-% purity (Princeton Sci.corp) and 8 x 8 x 0.1 mm³ size were annealed in vacuum for 1 hour.
- RC1-set annealed at 1858 K in Ar & 8%H.
- RC2-set annealed at 1873 K in vacuum (< 10⁻⁶ mbar).
- Highly textured samples obtained after annealing.

Irradiation Conditions

<table>
<thead>
<tr>
<th>Ions (ID)</th>
<th>Energy MeV</th>
<th>Range μm</th>
<th>Fluence 10¹⁵m⁻²</th>
<th>DPA Ed = 90eV</th>
</tr>
</thead>
<tbody>
<tr>
<td>He</td>
<td>0.25</td>
<td>0.6</td>
<td>5</td>
<td>0.022</td>
</tr>
<tr>
<td>He(F1)</td>
<td>3</td>
<td>4</td>
<td>0.75</td>
<td>0.001</td>
</tr>
<tr>
<td>He(F2)</td>
<td>3</td>
<td>4</td>
<td>2.25</td>
<td>0.003</td>
</tr>
<tr>
<td>B</td>
<td>10</td>
<td>0.33</td>
<td>1</td>
<td>0.001</td>
</tr>
<tr>
<td>B(F1)</td>
<td>10</td>
<td>4</td>
<td>1.3</td>
<td>0.01</td>
</tr>
<tr>
<td>Au(Au)</td>
<td>80</td>
<td>4</td>
<td>1.3</td>
<td>0.22</td>
</tr>
</tbody>
</table>

The (a) no. of PKA as a function of energy (b) average PKA energy & (c) DPA as a function of depth for different ions

PKA density

\[ p_{PKA} = \frac{N_{PKA}}{N_{cascade}} \]

80 MeV Au ~ 10¹⁸ m⁻³
10 MeV B ~ 10¹⁶ m⁻³
3 MeV He ~ 10¹⁸ m⁻³
250 keV He ~ 10²⁰ m⁻³

ANALYSIS & DISCUSSION

Positron Doppler-broadening & lifetime (τ) measurements indicate more defects in He-irradiated samples for small dpa & PKA density.

Slow e⁻ beam annihilation measurements

- S-parameter → from valance electrons
- W-parameter → from core electrons

Lifetime measurements: Sandwich type

- ²²Na positron source

Two-lifetime fit to the timing spectra of 511 keV γ-rays emitted due to e⁻-e⁻ annihilation:

- \( \tau_1 \rightarrow \) Intrinsic lifetime
- \( \tau_2 \rightarrow \) Defect lifetime

Information depth ~ 16 μm

TEM shows B-irradiation forms dense dislocation lines & Au-irradiation cause dense clusters. 250 keV He-irradiation shows both dense lines and clusters.

Depth profile of He and D measured using SIMS in samples irradiated with 250 keV He irradiated with 80 keV D.

SIMS analysis also shows high He content at the near-surface for 3 MeV irradiation.

From SIMS it is also seen that He profile closely follows C & Mo impurity profiles.

SUMMARY

- The nature of the defects formed by different ions is different for the same dpa and similar ion penetration range.
- He-ions seem to produce more defects for same dpa as confirmed by PAS. This could be due to He-self-clustering creating additional vacancies. Trapping at vacancies is also seen in PAS.

Initial SIMS analysis indicates lesser D-trapping in He-irradiated samples compared to Au & B irradiated samples.

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Role of PKA Spectrum & PKA Density in Defect Production and Implications for H-isotope Trapping in Tungsten

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