Max-Planck-Institut für Plasmaphysik, EURATOM Association

Deuterium retention in bulk tungsten exposed to the outer divertor plasma of ASDEX Upgrade

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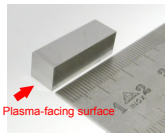
Introduction

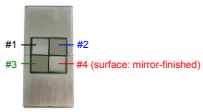
- **Tungsten (W)** is a promising material for the plasma-facing components of fusion reactors and will be used as the divertor baffle and dome armor in ITER.
- Either W-coatings (by PVD, VPS etc.) or bulk solid W material can be utilized. It is expected that bulk W can avoid the delamination of W-coating and achieve longer lifetime under erosion-dominant conditions.
- **ASDEX Upgrade (AUG)** has operated as full-W machine since 2007 campaign using different types of W-coatings, and is planning to introduce solid W tiles in the next step divertor configuration (Div-III) (*see P80A by A. Herrmann et al.*).
- One concern is the deep hydrogen diffusion and trapping / accumulation in the bulk, which can potentially cause tritium uptake in the plasma-facing wall.
- In this study, **Deuterium (D) retention in bulk W exposed to the AUG divertor plasma** is investigated to achieve a better understanding of the tritium inventory in W under the reactor plasma condition.

Experimental procedure

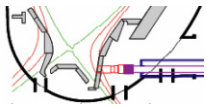
1. Bulk-W exposure experiment in ASDEX Upgrade

- 4 W blocks with the **lateral dimension of 8 × 8 mm** and **a thickness of 25 mm** were exposed to the outer divertor plasma by using the **AUG divertor manipulator system**.
- One of those blocks, its plasma-facing surface was "**mirror finished**", while the other three had "**machined surfaces**" as fabricated.
- Sample poloidal position: s ~ 1.17 m (several cm above the outer strike point)
- Plasma exposures: AUG shot # 25380 - # 25400
  Duration: **98 sec**.
  Total D fluence (measured by Langmuir probe located at same poloidal position): **1.9 × 10^{24} D/m²**
- Typical surface mean temperature: around 450-500 K





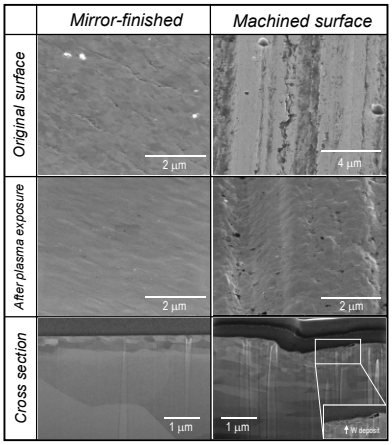
2. Post-mortem analyses



- W surface morphology change by the plasma exposure was examined by **scanning electron microscopy (SEM)** combined with focused ion beam (FIB) cross-sectioning method.
- D surface depth profile and retention up to ~ 7 μm in depth was measured by **nuclear reaction analysis (NRA)** with using D(^{3}He, p)^{4}He reaction.
- D desorption behaviour and total amount of D retention in the W bulk was determined by **thermal desorption spectroscopy (TDS)** with heating the sample from RT to 1270 K (ramp ~ 0.25 K/s).
- Comparison between NRA and TDS data can give the information about D accumulation in the W bulk

Results & Discussion

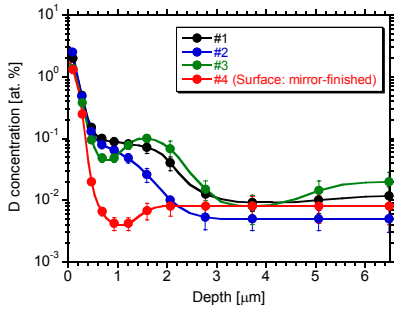
1. Surface modification by plasma exposure



- The plasma-facing surface was somewhat "smoothed" by plasma exposure in both mirror-finished and machined surfaces.
- Thin damaged zone seen at the top surface cross section of the mirror-finished sample is due to the mechanical polish.
- On the machined surface, local W redeposits were found on the "local plasma-shadowed" areas.
- No remarkable blister formation was observed. Also, no severe cracking / melting occurred in this plasma loading condition.

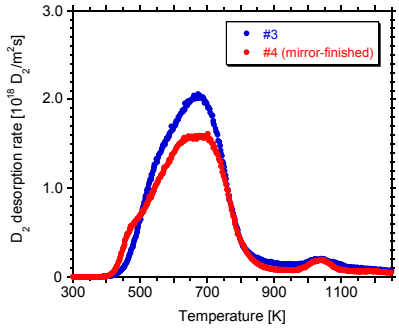
Results & Discussion

2. NRA result - D retention and depth profile at the surface



- D concentration peaked at the top surface.
- D in the sub-surface region (several μm) shows difference between mirror-finished and technical surfaces
- D concentration in the deeper-surface is eventually ~10^{-2} at.% for all cases.

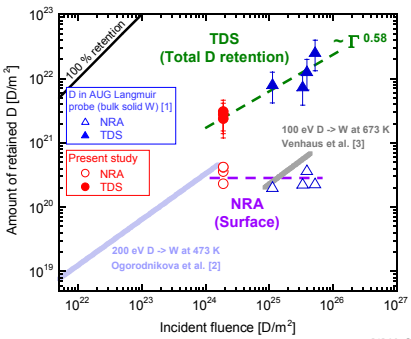
3. TDS result – D desorption behaviour and total D retention



- D desorption starts around 450 K - seems to reasonably agree to the surface temperature during the discharge.
- Broad D desorption at 500 – 800 K
- Total amount of D retention determined by TDS is one order of magnitude larger than that by NRA - ~ 90% of retained D is in the "bulk" (beyond ~ 7 μm in depth).
- If D concentration in the bulk is assumed as ~10^{-2} at.%, D diffusion of 4~5 mm (!) is necessary.
- D retention in W with "thickness scan" is to be investigated in lab. conditions.

W sample No.	D retention [D/m²]		Fraction of D in "bulk"
	NRA	TDS	
#1	4.21 x 10^{20}	N/A	N/A
#2	4.16 x 10^{20}	2.17 x 10^{21}	81%
#3	3.57 x 10^{20}	2.80 x 10^{21}	87%
#4	2.29 x 10^{20}	2.52 x 10^{21}	91%

4. Fluence dependence of D retention in bulk W: NRA vs TDS



- Comparison with our previous data [1]: D retention in Langmuir probes fabricated from solid W
- No clear dependence of D retention in the surface (NRA) - surface D concentration limited by surface temperature?
- Total D retention (TDS) increases with the incident fluence with nearly square root dependence - diffusion likely plays a role for D accumulation in bulk solid W.

[1] K. Sugiyama et al. Nuclear Fusion 50 (2010) 035001
[2] O.Ogorodnikova et al. J. Nucl. Mater. 313-316 (2003) 469
[3] T. Venhaus et al. J. Nucl. Mater. 290-293 (2001) 505

Summary

Deuterium (D) retention in bulk solid W samples exposed to the AUG outer divertor plasma is investigated:

- No blister formation, and no severe cracking / melting occurred in the present plasma loading condition.
- Around 90% of retained D is in the "bulk" beyond NRA detection range (~ 7μm). D concentration in W bulk should be < 10^{-2} at.%, meaning D diffusion of, at least, 4~5 mm is required.
- Effect of surface finalization - mirror-finished or machined-surface - makes still minor contribution to the overall D retention, because D is dominantly retained in the bulk.
- Total D retention in bulk W shows nearly square root dependence – D diffusion likely plays a key role for D accumulation in the bulk solid W material.

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