Hydrogen Retention in Tungsten Materials Studied by Laser Induced Desorption

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### Introduction

Tritium retention in plasma facing components (PFCs) due to plasma wall interactions is one of the most critical safety issues for ITER and future fusion devices. Tungsten is foreseen as PFC material in the divertor of ITER and the most promising candidate of PFCs in future reactors. Its fuel retention behaviour is subject of present R&D.

In this work the retention of fuel (deuterium) in bulk tungsten has been studied applying laser induced desorption (LID). This method allows the local measurement of hydrogen isotopes and is also proposed for in situ diagnostic at ITER to monitor tritium retention.

Trapping of hydrogen in tungsten is strongly dependent on material properties and temperature during plasma exposure. Both effects can influence the results obtained by laser induced desorption spectroscopy.

### Diagnostic Method

**Laboratory:**
Laser Induced Desorption with Quadrupole Mass Spectrometer

**LID:** Nd:YAG laser: λ = 1.064 µm, E = 40 J, tLaser = 3 ms, absorbed intensity: P/A ≤ 2 NW/m², I = 6 cm focussing lens

**GMS:** scan: 1.5 µm au 1 s, pressure calibration in H₂, D₂, CH₄, CD₄...

**TEXTOR:** Laser Induced Desorption Spectroscopy

Nd:YAG laser: λ = 1.064 µm, E = 40 J, tLaser = 3 ms, absorbed intensity: P/A ≤ 500 NW/m², I = 30 cm focussing lens

**LID-GMS experimental set-up in laboratory:**

**High Flux Exposure (Pilot-PSI):**

unpolished Goodfellow tungsten, annealed at 1273 K for >1 hour high flux: 2x10¹² D/m² with 10 s exposure time

**ECR Plasma Exposure:**

unpolished Plansee-tungsten, annealed at 1200K for 1 hour low flux: 10¹⁰ D/m² at 370 K deuterium inventory: TDS: 7.5x10¹⁰ D/m² with 18 s exposure time ECR heated plasma with 38 eV

**Laser Heating Simulation:**

1D-code for diffusion of heat and particles: TAMP² (S. R. Longhetti et al., Nucl. Fusion 39, 2007) assumes initial D profile up to 9 µm with 3 µm decay length performing standard heating pulse (500 MW/m², 3 ms)

### Results

#### TEXTOR Tokamak Plasma Exposure

unpolished Goodfellow tungsten, annealed at 1273K for >1 hour medium flux: 1.5x10¹³ D/m² with 110 s exposure time surface temperature: 400 - 650 K, temperature excursions 100 - 150 eV D and minority impurity fluxes of C (2 %), O and He bulk W plate on root limiter, sample tip at 47.3 cm (LPS): 46 cm exposed: ρ ≤ 5x10⁻¹⁰m²/s, T ≥ 30 eV post mortem analysis by LID:

1.) laser heating pulse 500 MW/m², α mm, 1800 K
2.) melting by laser: 1.6 Gw/m², α 2 mm, >4000 K

#### High Flux Exposure (Pilot-PSI)

unpolished Goodfellow tungsten, annealed at 1273K for >1 hour high flux: 2x10¹² D/m² with 10 s exposure time Tₚ = 500 - 580 K, temperature profile according to beam profile, direct water cooling: 1.2 eV, 3.7x10¹² m⁻³ with additional -55 V biasing

#### ECR Plasma Exposure

unpolished Plansee-tungsten, annealed at 1200K for 1 hour low flux: 10¹⁰ D/m² at 370 K deuterium inventory: TDS: 7.5x10¹⁰ D/m² with 18 s exposure time ECR heated plasma with 38 eV

#### Laser Heating Simulation

NRA scan over laser spots qualitatively shows the lateral D depletion in the first 7 µm

NRA depth profiles quantitatively prove <83% desorption in first 7 µm and decrease of surface concentration by – factor 19.00. Compare with diffusion modeling!

**Summary**

This work: Laser induced desorption and QMS detection, comparison with NRA and slow ramp thermal desorption

Loading conditions: 470 ≤ Tₚ ≤ 1500 K

fluence: 2x10¹² D/m² ≤ 1 ≤ 2x10¹³ D/m²

Laser desorption (single heating pulse)

> 90 % of fuel from a-C H layers on W, C, CFC and from bulk C

> 83 % from bulk W, for τ = (450 K, Plansee material)

• decrease of released hydrogen with increasing loading temperature down to ~ 20 %

Reasons:

- deep diffusion of part of H in the material for high Tₚ or long.,
- different material properties with increased hydrogen storage on traps with higher energy deposition

Local spot melting releases all stored fuel within depth of ~100 µm

Strategy: frequent desorption of the same monitoring spots on first wall before the fuel is out of laser desorption range

Results in context to literature and community values:

### Conclusion

The results of this work are important for understanding and predicting hydrogen retention in the divertor of ITER and future fusion devices. The use of laser induced desorption spectroscopy as a diagnostic tool for in situ monitoring of tritium retention is proposed. Further studies are needed to explore the effects of different plasma conditions and material properties on hydrogen retention and desorption.

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*For further information and data, please refer to the original paper.*