Max-Planck-Institut für Plasmaphysik

Behaviour of Tin under Low-Temperature Deuterium Plasma Irradiation

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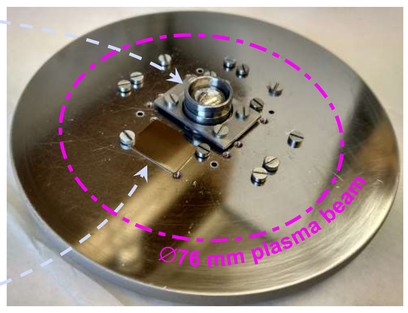
Motivation

- **Liquid metals as alternative to solid W divertor? (see, e.g. [1])**
  - Avoid brittle failure, melt damage, neutron damage…
- **Tin: low evaporation rate up to about 1000 K, no known solid hydrides, endothermic H solubility [2]**
  - Promising heat load handling capability [1, 3]
  - Very little actual data on D retention
  - Indication for chemical erosion by volatile SnD_4 formation [4, 5]
- **Systematic study below and above melting point of Sn (505 K):**
  - D retention and release after Sn exposure to D plasma
  - Sn net erosion and nearby re-deposition by mass loss measurements and Mo witness samples

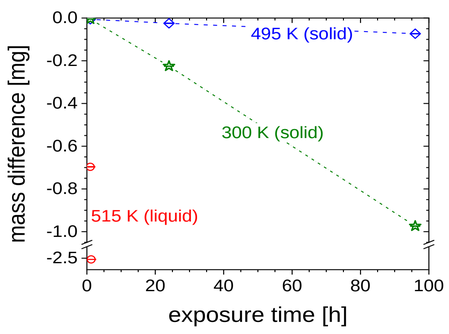
Experiment details

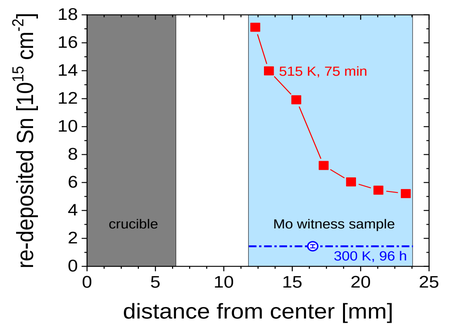
- **Low-temperature ECR plasma source *PlaQ* [6]**
  - Ion flux: ~1.2x10^{20} D/m^{2}s (97% from D_3^+)
  - -25 V bias (+ 7 V plasma potential): ~11 eV/D from D_3^+
  - ~100x more D^0 than D ions
  - Absolute temperature accuracy: ±5 K
- **Sn samples:**
  - 99.999% purity (Kurt J. Lesker Co.)
  - Cu crucible with ~2 µm W coating, 10 mm inner diameter
  - Pre-molten & degassed in vacuum at 523 K for 2 h, slow heating and cooling
  - Typical mass of Sn: ~2.6 g
- **Mo witness samples:**
  - ~12x15x0.5 mm^3, mechanically polished



Mass loss & re-deposition

- **SDTrimSP 6.00 [7] simulations:**
  - Sputtering threshold ≥ 50 eV
  - Maximum ion energy (D^+): ~32 eV
    ➔ expected: *chemical* erosion (if any)
- **300 K:**
  - Strong mass loss by chemical erosion
  - Small re-deposition on Mo witness sample
- **495 K:**
  - Much smaller erosion
    ➔ sponge-like structure!
  - No measureable re-deposition
  - Erosion of small Sn droplets from 2nd Mo sample
- **515 K:**
  - Very large mass loss, strong scatter
    ➔ ejection of Sn droplets due to bursting gas bubbles
  - Sn droplets found on witness samples





Conclusions

- **Large part of D retention in Sn apparently within gas bubbles**
  - Small, near-surface bubbles for 300 K exposure
  - Thick, sponge-like, porous layer for 495 K exposure
  - Large gas bubble below Sn droplet for 515 K exposure
- **Release practically all D up to melting point (505 K) for solid Sn exposure**
- **D release until long after melting for liquid Sn exposure**
- **Strong chemical erosion at 300 K, weaker at 495 K**
  - Possibly linked to formation of sponge-like layer
  - Some re-deposition of Sn on Mo at 300 K
  - 495 K: no measurable Sn re-deposition; erosion of small Sn droplets
- **Erosion at 515 K dominated by droplet ejection due to bubble bursts**
  - Deposition of Sn spray on Mo sample
- **Wetting of W by Sn at 515 K under D plasma exposure ➔ oxide removal?**

References:

[1] J.W. Coenen et al., Phys. Scr. T159 (2014) 014037

[2] M.B. Bever, C.F. Floe, Trans. AIME 156 (1944), 149-159

[3] A. Vertkov et al., Fus. Eng. Des. 117 (2017) 130-134

[4] D.T. Elg et al., Plasma Chem. Plasma Process. 38 (2018) 223-245

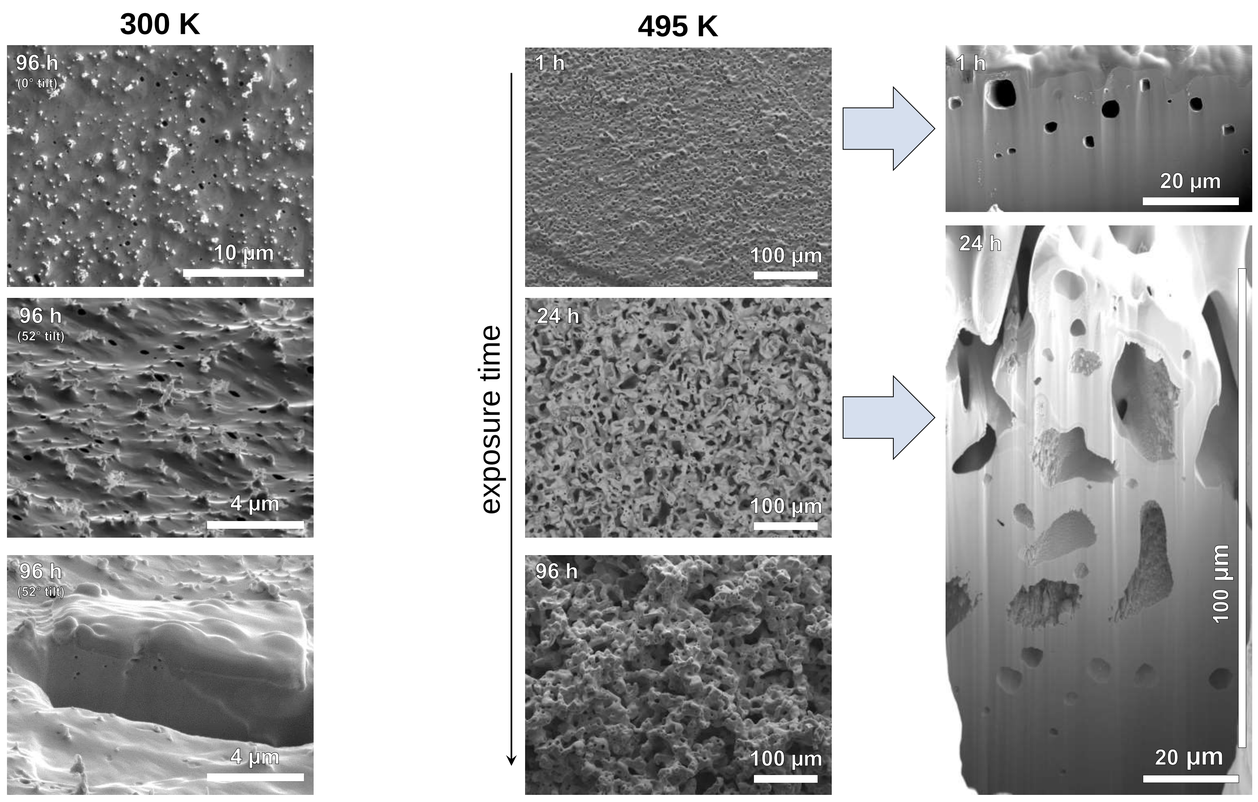
[5] T.W. Morgan et al., Plasma Phys. Control. Fusion 60 (2018) 014025

[6] A. Manhard et al., Plasma Sources Sci. Technol. 20 (2011) 015010

[7] A. Mutzke et al, SDTrimSP Version 6.00, IPP 2019-2 (2019)

Evolution of Sn surface

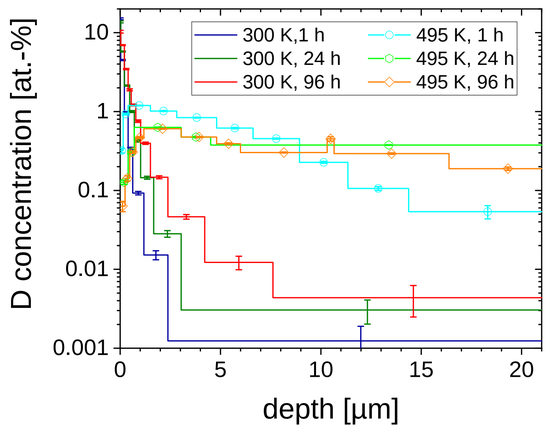
- **300 K:**
  - Small bubbles near surface; unstable during electron beam imaging!
  - Dune-like surface, ridges crowned by Cu- and Fe-rich precipitates ➔ erosion morphology
- **495 K:**
  - Formation of sponge-like, highly porous layer ➔ up to 250-500 µm thick after 96 hours
- **515 K:**
  - Sn droplet quickly starts wetting W coating, then rises out of crucible ➔ large cavity below Sn
  - Gas amount in cavity ~2000x larger than anticipated based on diffusion ➔ convection in melt
  - Smaller bubbles found in Sn ➔ rise to surface and burst, or get dragged to bottom by melt motion

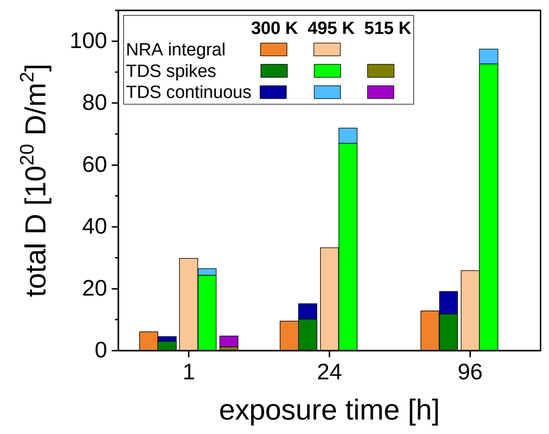


Deuterium retention & release

Deuterium depth profiling: ^{3}He(D, p)^{4}He NRA

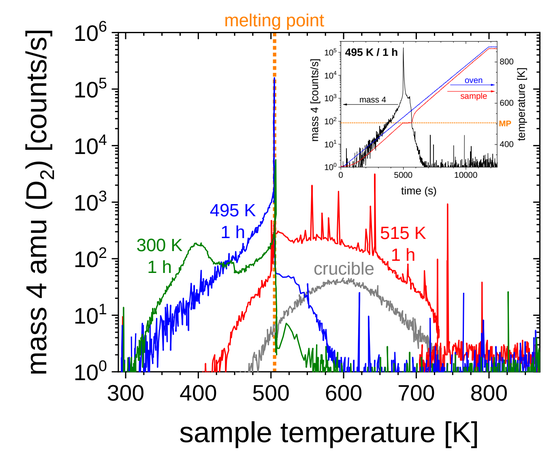
- **300 K:**
  - D retention concentrated at surface
  - Increasing fluence ➔ growing tail into bulk
  - NRA total amount corresponds approximately to spike in TDS spectra
- **495 K:**
  - Larger total inventory, less peaked profiles
  - Depletion of D at surface ➔ sponge-like structure!
  - 1 h exposure: D contained mostly within first 20 µm ➔ thickness of bubble layer!
  - Longer exposure times: significant amount of D beyond analysis range (compare also to TDS!)
- **515 K:**
  - D concentration in Sn at or below detection limit (≤ 5x10^{-5} at.-%) within NRA range
  - D assumed to be mostly within gas bubbles





Thermal Desorption Spectroscopy

- **Solid exposure (300 and 495 K; Sn without crucible):**
  - D_2 Release starts already at room temperature
  - Massive release spike at melting point
    ➔ Dominates D_2 release
    ➔ D release stops after end of melting phase
  - Additional peak at ~400 K for 300 K exposure
  - D released almost exclusively as D_2
- **Liquid exposure (515 K; Sn in crucible):**
  - Continuous signal + spikes
    ➔ D release continues until long after melting point
  - Smaller spikes ➔ bubbles rising to surface
  - Large spikes ➔ Sn droplet rising due to expansion of large gas bubble, and then collapsing
  - Strong HD release in addition to D_2
  - In contrast to NRA: D retention comparable to sample exposed for 1 h at 300 K



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