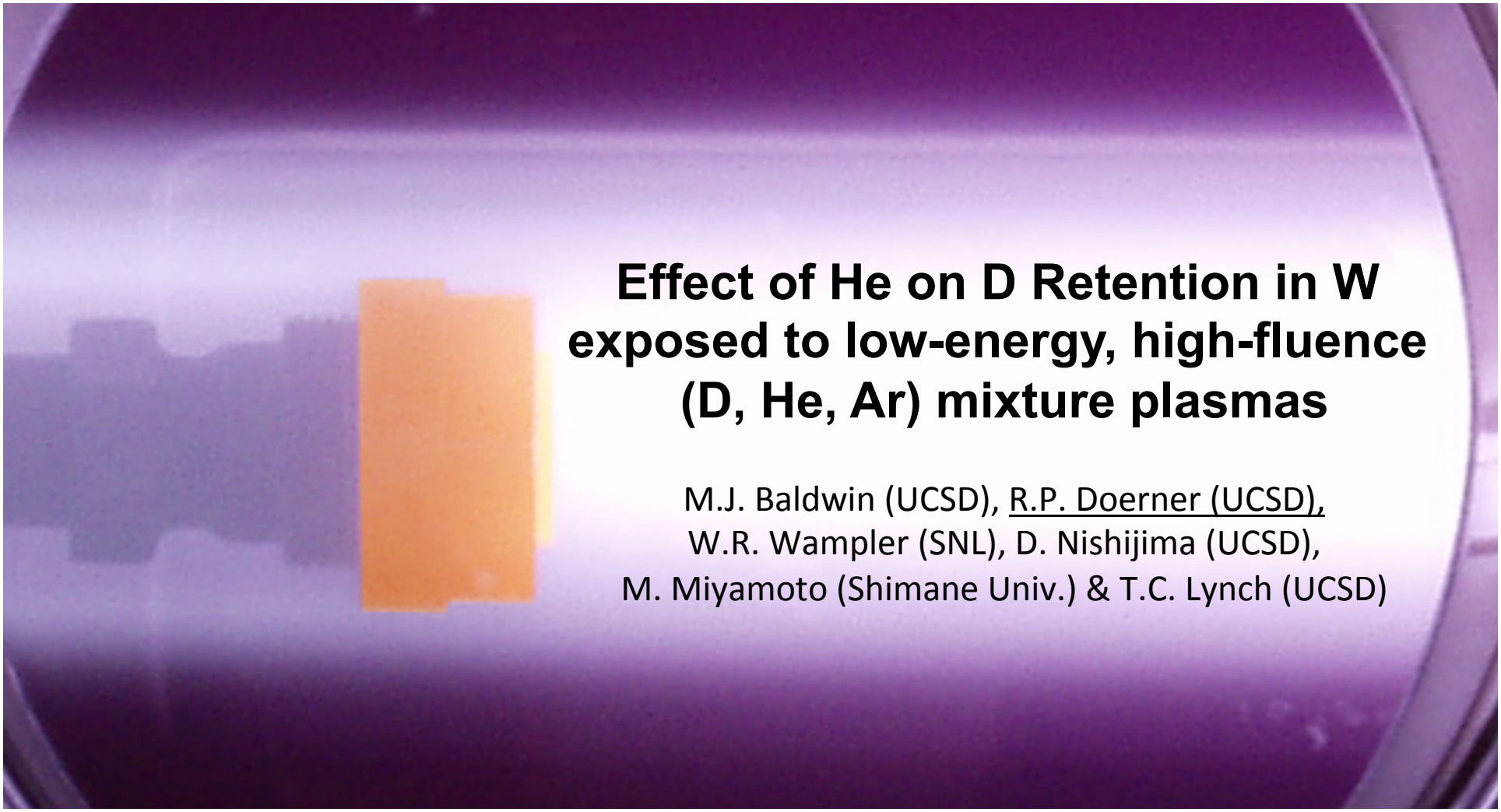

Effect of He on D Retention in W exposed to low-energy, high-fluence (D, He, Ar) mixture plasmas

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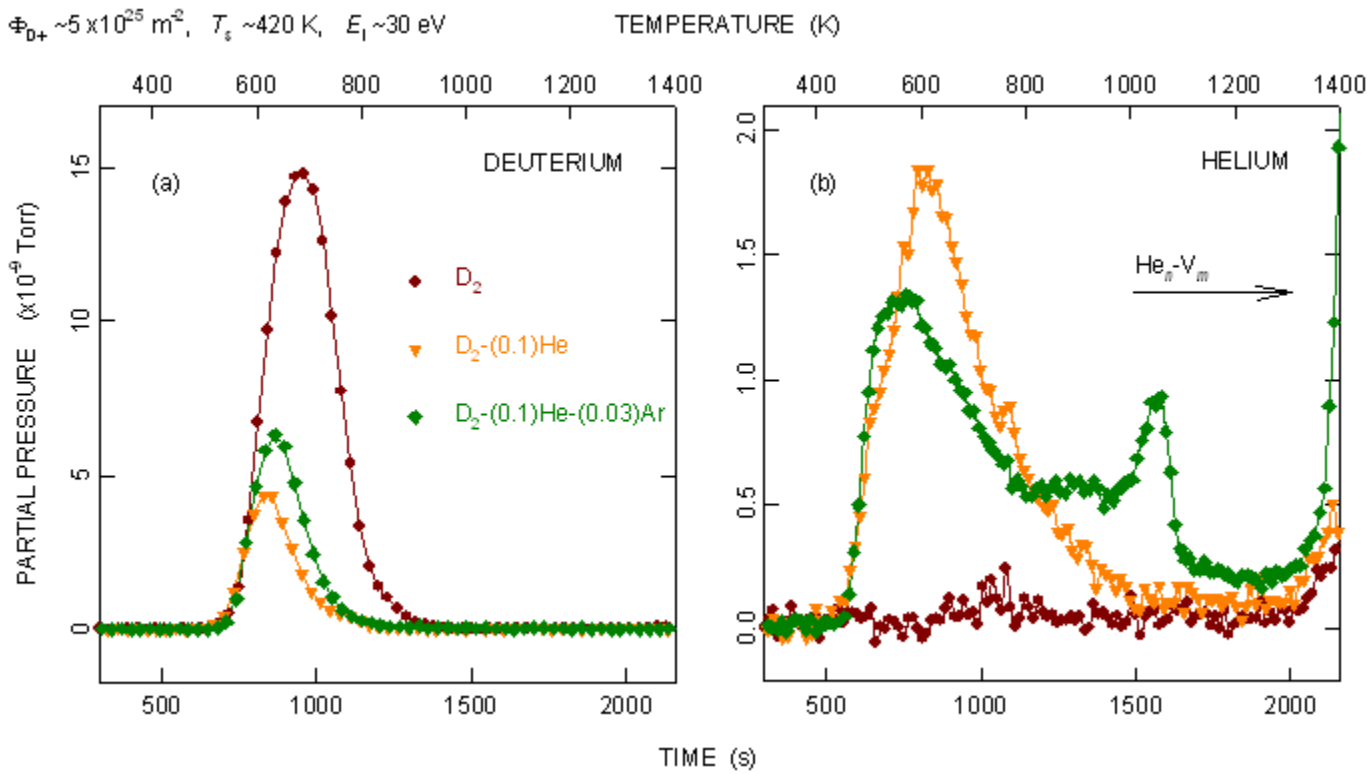
Introduction

- Retention in W is an issue relevant to ITER and future DEMO.
- **Database for H,D,T in W is large. Mixed D_2-He database is small.**
- **Above fluences of ~10^{25} m^{-2} (H, D, T) ions, W retains an inventory ϕ_{HDT} of:**
  - **~10^{20} m^{-2} (300 K), ~10^{22} m^{-2} (~550 K), <10^{20} m^{-2} (above 700 K).**
    [E.g. – R. A. Causey, JNM 300 (2002)]
- From **400–800 K, scatter in ϕ_{HDT} is substantial** (> 1 order of mag.).
  - Attributable to … material grade, incident-ion energy, blisters etc …
  - In 2009, PISCES/SNL, Shimane Univ. and IPP report **reduced ϕ_D in W, caused by He uptake** during mixed (D, He) plasma exposure. [Miyamoto *et al.*, NF 49 (2009), W. R. Wampler & Doerner, NF 49 (2009), Alimov *et al.* ,PScripta T138 (2009)]
  - **Reduced ϕ_D associated with He nano-bubbles in near surface**.
- Current work explores reduced ϕ_D effect against:
  - **Known 400-800 K scatter.**
  - **Exposure temperature, RT-1120 K.**
  - **He ion flux/fluence.**
  - **3% Ar 'extrinsic radiator' in plasma.**
  - **He plasma pre-treatment condition.**

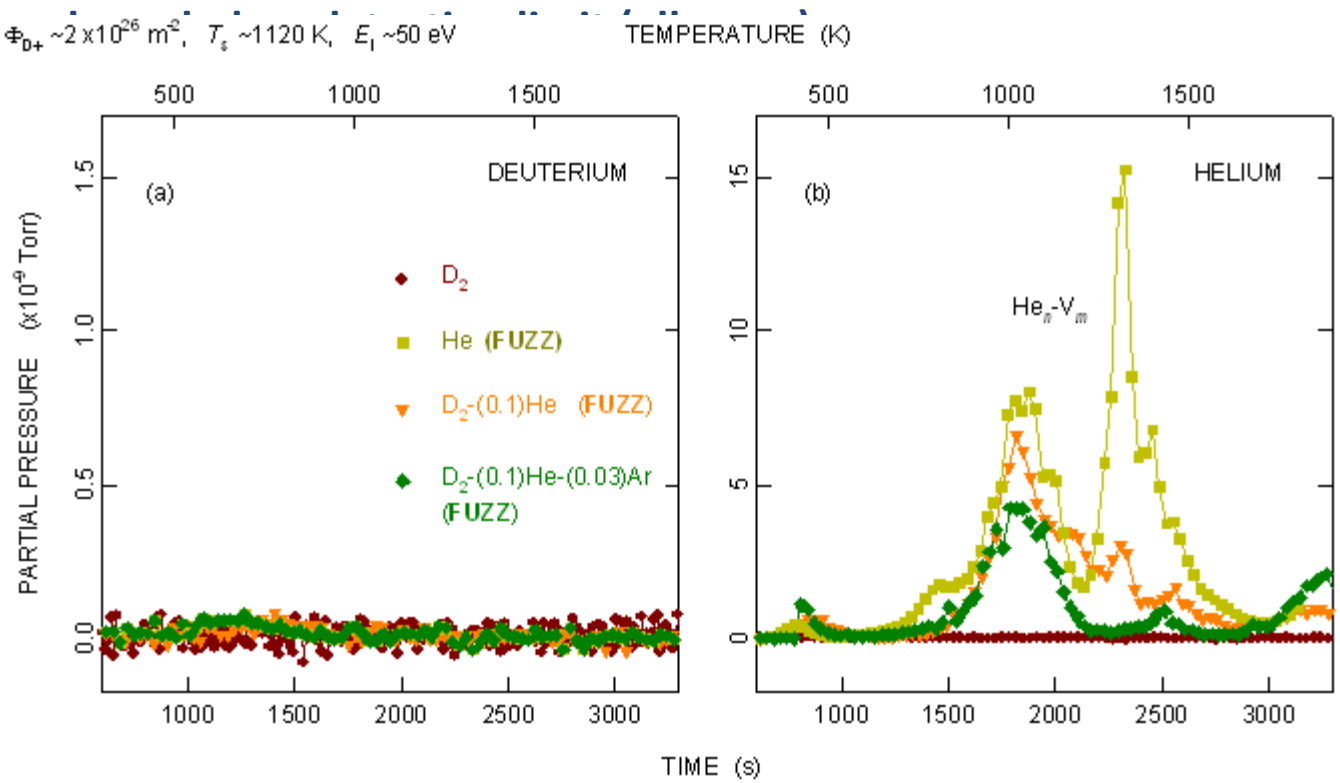
At 420 K, He lowers ϕ_D in W

- **TDS data for W exposed to mixed (D_2-He-Ar) plasma at divertor/FW relevant T.**
- He (10%) relevant to divertor, but FW likely ~1% [Behrisch *et al.*, JNM. 313–6 (2003)]
- **D_2 level reduced by He but same release T. He release from degen. He_n-V_m.**
- **Ar (3%)** effects He release, but little effect on D_2 release.



At 1120 K, ϕ_D below Det. Lim.

- **TDS data for W exposed to mixed (D_2-He-Ar) plasma at strike point relevant T.**
- He causes FUZZ to grow on target PMI surfaces at 1120 K.
- **Thermal release only from degen. He_n-V_m.**
- **D** Φ_{D+} ~2 x10^{26} m^{-2}, T_s ~1120 K, E_i ~50 eV



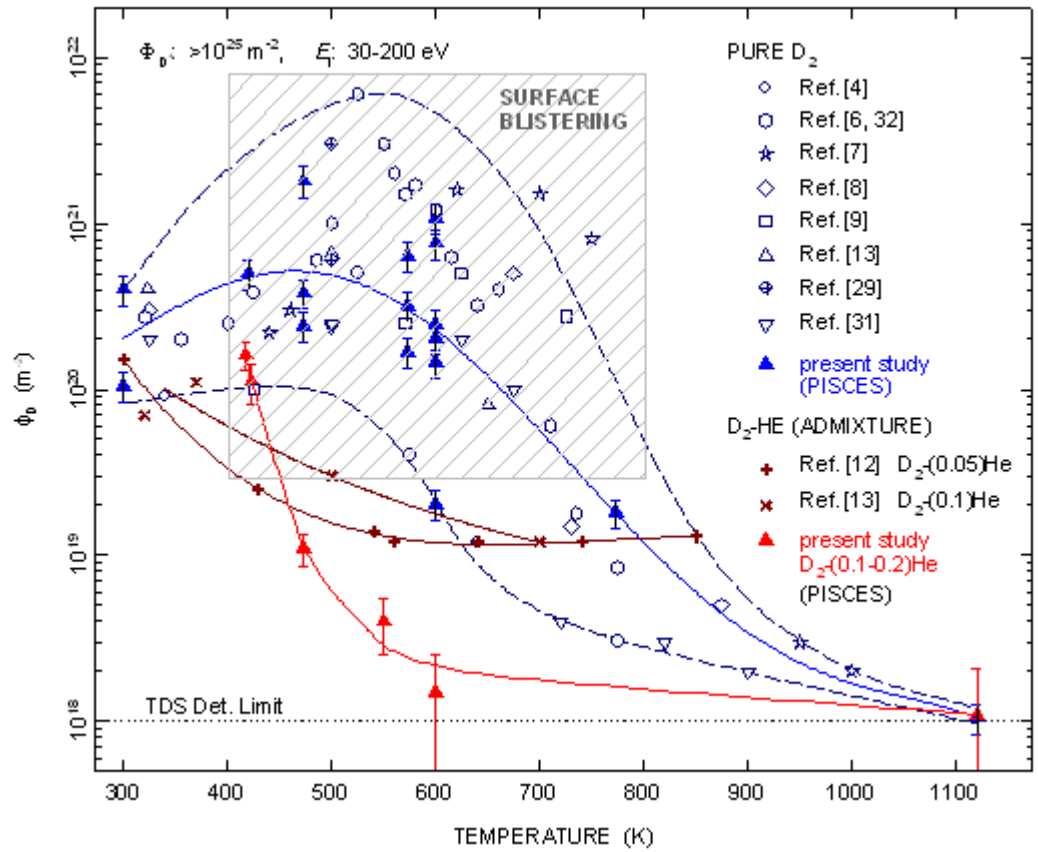
ϕ_D below scatter in (D-He) plasma exp.

[Baldwin *et al.*, NF (20011) (submitted)].

- **ϕ_D peaks ~550 K in D2 plasma exposed W.** Blisters often found.
- **In mixed (D_2-He) plasma, blisters are inhibted**

  E.g. Miyamoto *et al.*, NF 49 (2009).
- **ϕ_D falls beyond ~450 K.**
- PISCES data agree with Refs. [12, 13] mixed (D-He) plasma exposure.

- *What happens in/to the W surface with He uptake?*



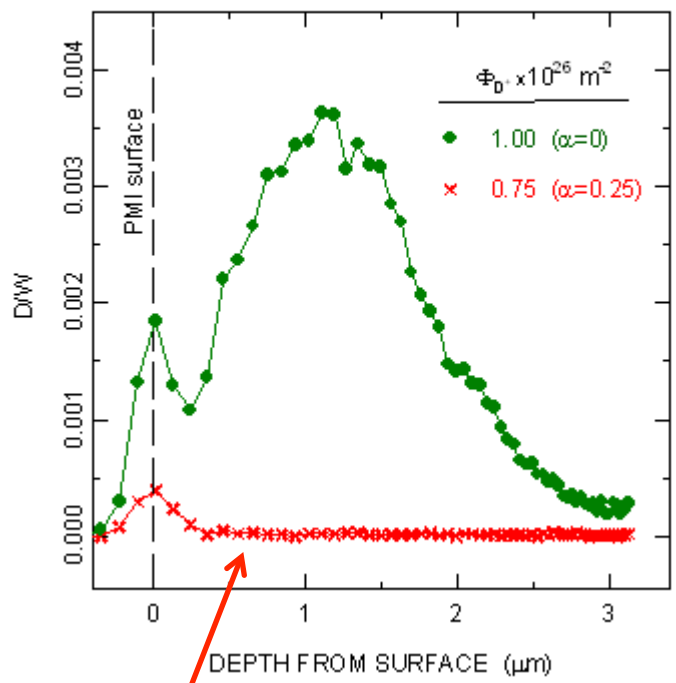
[4] Alimov and J. Roth, PScripta, 128 (2007) **[6]** Shu, *et al.* FED, 83 (2008) **[7]** Sharpe *et al.*, JNM, 390 (2009) **[8]** Tokunaga *et al.* JNM 337 (2005) **[9]** Causey *et al.*, JNM 266 (1999) **[12]** Alimov *et al.* ,PScripta T138 (2009) **[13]** Ogorodnikova, *et al.*, JAP 109 (2011) **[28]** Alimov doi: 10.1016/j.jnucmat.2011.01.088 **[31]** Luo, *et al.*, FED 81 (2006)

He uptake affects D profile.

- NRA D conc. profiles : D(^{3}He,p)α, 2.5 MeV $^3He^+$ (WR Wampler - SNL).
- D restricted at surface (<50 nm) in **mixed D_2-He** plasma, compared to **pure D_2.**
- He pretreat gives **similar effect**, but **low He flux/fluence** is ineffective.

Single step (D, He) exposure

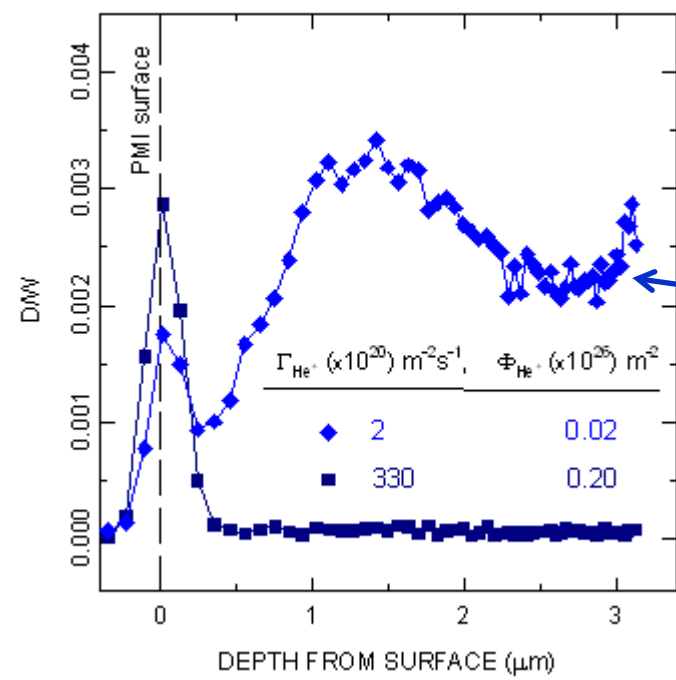
(**D_2-αHe**) T_s= 473 K, E_{ion}= 50 eV



Two step, He pretreat, D plasma exposure

(**He**) T_s= 473 K, E_{ion}= ~30-50 eV

(**D_2**) T_s= 473 K, E_{ion}= 50 eV, Φ_{D+} = 5-8 x10^{26} m^{-2}



PISCES

Comparable TEM (next slide)
Φ_D reduced

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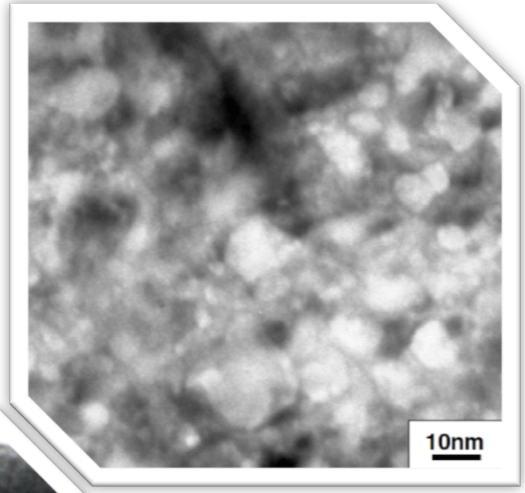
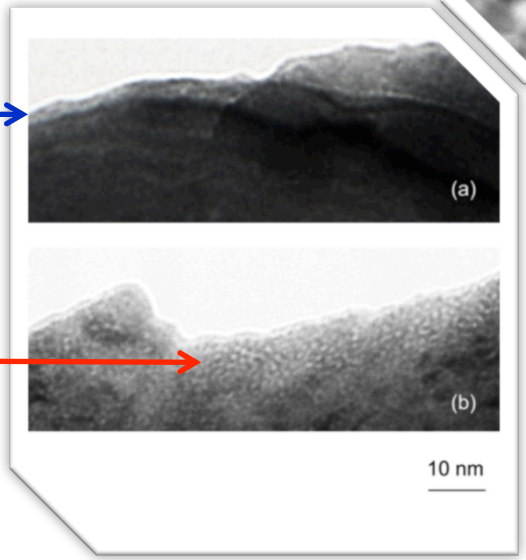
Comparable TEM (next slide)
Φ_D not reduced

TEM: He nano-bubbles → reduced ϕ_D

- TEM work done at Shimane Univ. Japan.
- **In D_2-He plasma, blisters are inhibited on surface with He nanobubbles.**
- **He plasma pretreatment gives similar result, but He^+ flux/fluence important.**
- Pre-thinned, W TEM target
  (LOW He^+ flux/flu. pretreat + D_2 plasma)
  → No nanobubbles,
  ϕ_D not reduced.
- W target FIB cross-section
  (HIGH He^+ flux/flu. D_2-He plasma)
  → Nanobubble surface layer,
  ϕ_D reduced.
- TEM supports notion of **'Interconnected return pathways to PMI surface' → D migration to bulk interrupted** [Miyamoto et al., PSI19, in press].



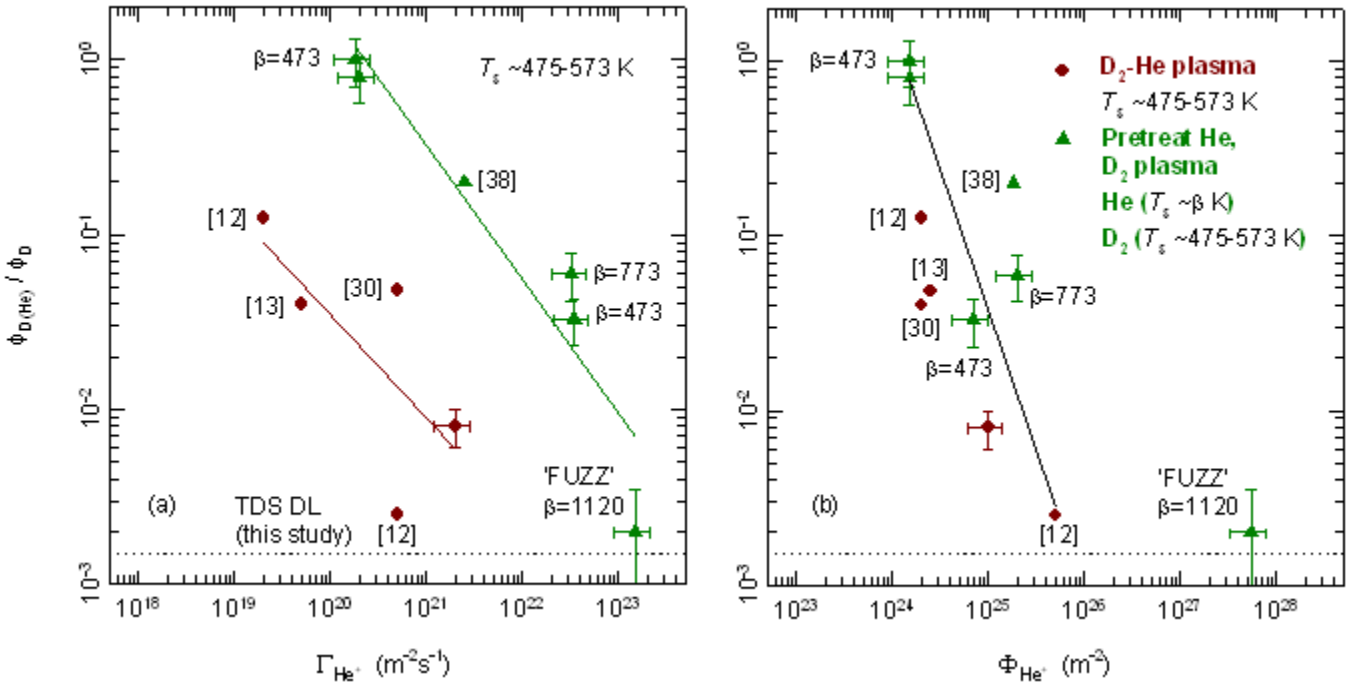
[Miyamoto *et al.*, NF 49 (2009)]



[Baldwin *et al.*, NF (20011) (submitted].

ϕ_D reduced as Φ_{He} passes ~10^{24} m^{-2}

- Reduced retention $\phi_{D(He)}/\phi_D$ at 475-573 K, plotted against Γ_{He} and Φ_{He} in **D_2-He plasma** and seq. **He, D_2 plasma** exposures (& literature values).
- $\phi_{D(He)}/\phi_D$ decreases at lower Γ_{He} in **D_2-He plasma**, compared w/ **pretreat He, D_2 plasma** cases, but Φ_{He} is about same.
- In [Lee, *et al.*, JNM 360 (2007)], Φ_{He}~10^{24} m^{-2} → ϕ_{He}~$5\cdot10^{20}$ m^{-2}. In [Iwakiri *et al.*, JNM 307 (2002)], ϕ_{He}~$5\cdot10^{20}$ → onset for dense surface nanobubble field.



[Baldwin *et al.*, NF (20011) (submitted]

[12] Alimov *et al.* ,PScripta T138 (2009)
[13] Ogorodnikova, *et al.*, JAP 109 (2011)
[30] Miyamoto *et al.*, JNM (2011) doi:10.1016/j.jnucmat.2011.01.008
[38] D. Nishijima *et al.*, JNM.337 (2005)

Summary

- Retention in W is currently an issue relevant to ITER and future DEMO.
- In burning plasma W PFC's will be subject to energetic He.

- **TEM → He nanobubbles in W surfaces (< 50 nm layer) exposed to energetic He.**
- **TDS → Reduced ϕ_D in W with He uptake, but D release kinetics are unaffected.**
  - Ar (~3%) has minimal influence on ϕ_D reduction.
  - W 'FUZZ' retains no detectible D at 1120 K (D_2-He plasma)
    W 'FUZZ' retains no detectible D at 523 K (pretreat He, D_2 plasma).
- **NRA → Inhibited D migration to the bulk w/ D trapped only in first < 50 nm.**

- **Lower ϕ_D in W occurs (below scatter) in D_2-(0.1-0.2)He plasma (450-1100 K).**

- **At 475-573 K (blister region), retention reduction $\phi_{D(He)}/\phi_D$, is increasingly effective as Φ_{He} passes ~10^{24} m^{-2}, in both D_2-He plasma, and pretreat He, D_2 plasma, cases.**

- Interconnected return pathways to PMI surface due to nanobubble growth is suspected as the mechanism that interrupts D transport to bulk [W. R. Wampler & Doerner, NF 49 (2009)].