Hydrogen retention in MeV ion irradiated (H, Fe, W) and neutron irradiated tungsten

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◎Background

- ✓ MeV ion irradiation is used as a proxy for neutron damage to study how irradiation damage increases hydrogen retention in tungsten (W).
- ✓ Despite numerous contributions in this area of research, it remains an open question how well surrogate MeV ion irradiation approximates neutron damage in W.
- ✓ Neutron irradiated W samples will soon be available to better clarify the characteristics of neutron damage under Japan-US collaboration, PHENIX[1].
- ✓ To enable comparison to neutron-irradiated samples, it is desirable at this stage to survey the nature of MeV ion irradiation effects in W.
- ✓ However such comparative exercise is often hindered by the differences in irradiation or exposure conditions amongst the different groups (e.g. flux, temperature, etc).

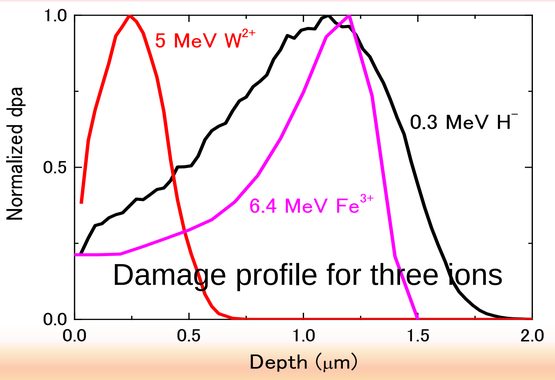
[1] Y. Katoh et al., Fusion Science and Technology Vol. 72 , 2017.

◎Purpose of this work

- ✓ Question : **Can MeV ion irradiation be a proxy for neutron irradiation induced hydrogen trapping sites in tungsten?**
- ✓ Compare hydrogen retention behavior in W following MeV ion damage by H, Fe and W ions, in terms of trapping energy and trap site density.
- ✓ Compare these data with neutron-irradiated W data (preliminary)

◎ Experimental conditions

- ✓ Ion damage (6.4 MeV Fe, 5.0 MeV W, 0.3 MeV H) 473 K or 573 K
- ✓ Neutron damage (0.06 dpa, fission reactor) at 323 K
- ✓ D implantation : 1 keV D, atomic D at 473 K and 573 K



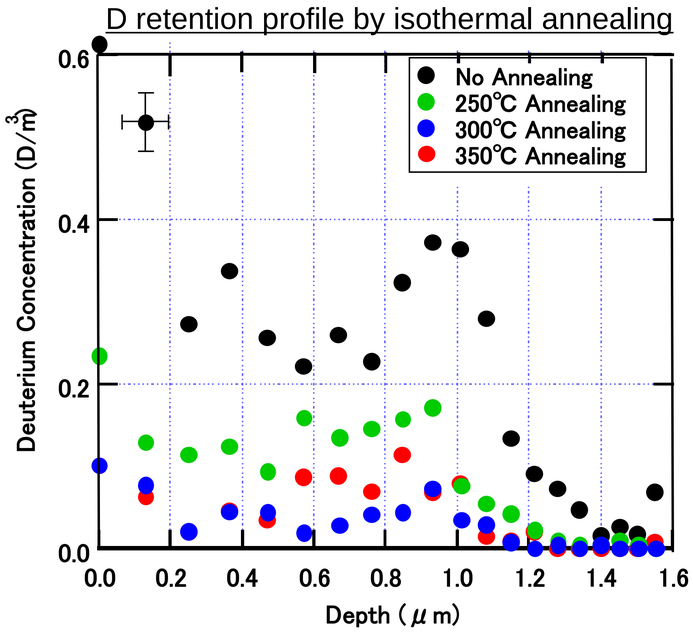
◎ Summary

- ✓ **Ion or neutron damaged W usually has multiple trap sites. In this study, trap energies at the strongest trap sites and trapped D concentration for ion damaged (0.3 MeV H, 6.4 MeV Fe, 5 MeV W) and neutron damaged (fission reactor) W were compared.**
- ✓ **Trap energies for H, Fe, and W damaged W showed similar (~1.9 eV). N-damaged W could have similar trap sites (inconclusive here).**
- ✓ **Trap site densities (trapped D concentration at same dpa and temperature) are also similar for three types of ion damaged W.**

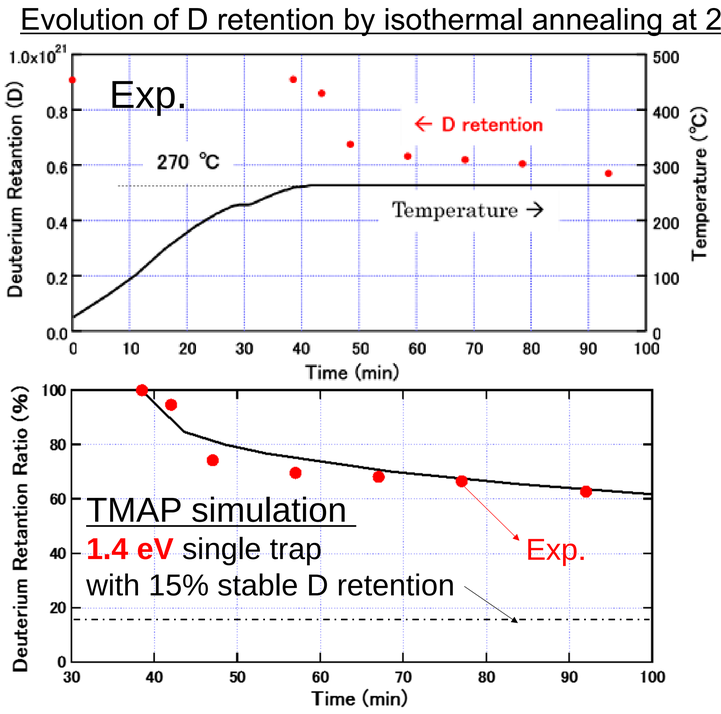
◎ Results from 0.3 MeV H damaged W

Damage : **~1.2dpa** (max 200℃ during ion damage)
D ion fluence: **5.0×10^{24} D^+/m^2 (200 ℃)(D ion)**
Post annealing time : **10h**

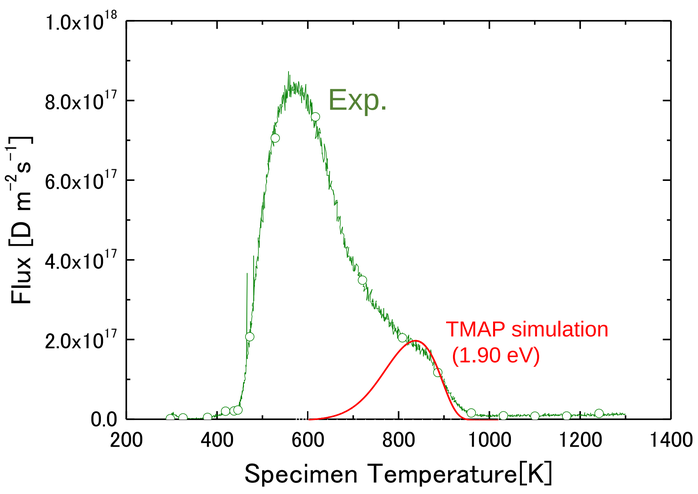
D retention profile by isothermal annealing



Evolution of D retention by isothermal annealing at 270 ˚C



Thermal Desorption Profile (0.1 K/s)



High temperature tail agrees with the 1.90 eV trap site

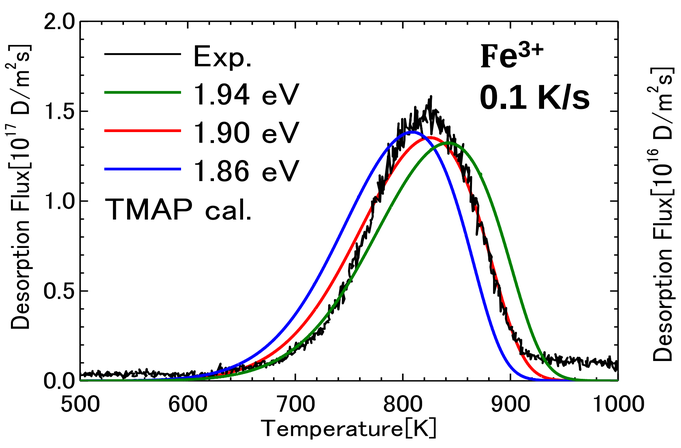
Post annealing at **250 °C** : ~61 % reduction compared with at 200 °C
at **300 °C** : ~87 %
at **350 °C** : ~82 %
At ~ **300 °C**, about **85 %** of D retained at **200 °C** is thermally released.

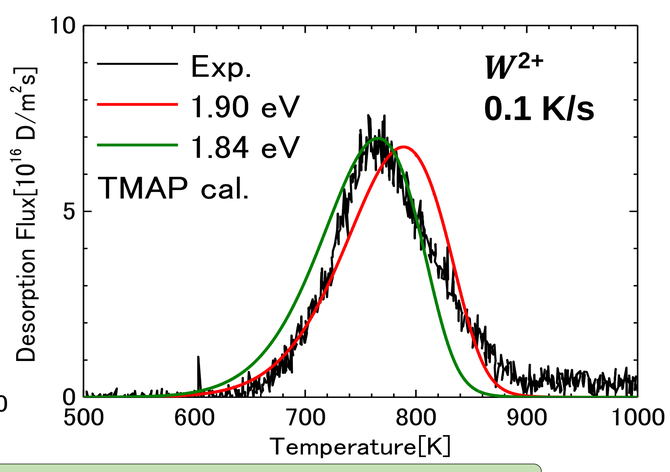
✓Assumption of **~1.4 eV** trap and **~1.9 eV** trap agrees well with the results from isothermal annealing and thermal desorption.

○Results from 6.4 MeV Fe and 5 MeV W damage

Damage : **~1.4dpa** (**300℃** during ion damage) D atom fluence: **7.0×10^{22} D/m^2 (300 ℃)**

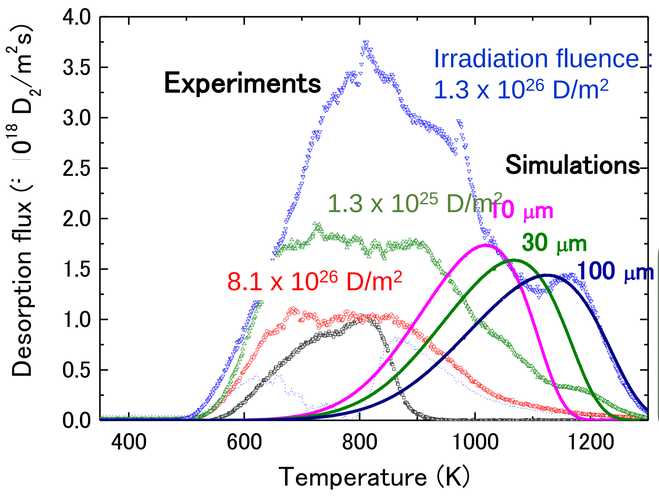
Thermal desorption profile for Fe and W damaged W





For both Fe and W damaged W, trap energies agree with 1.84-1.94 eV.

Thermal desorption profile for neutron irradiated W

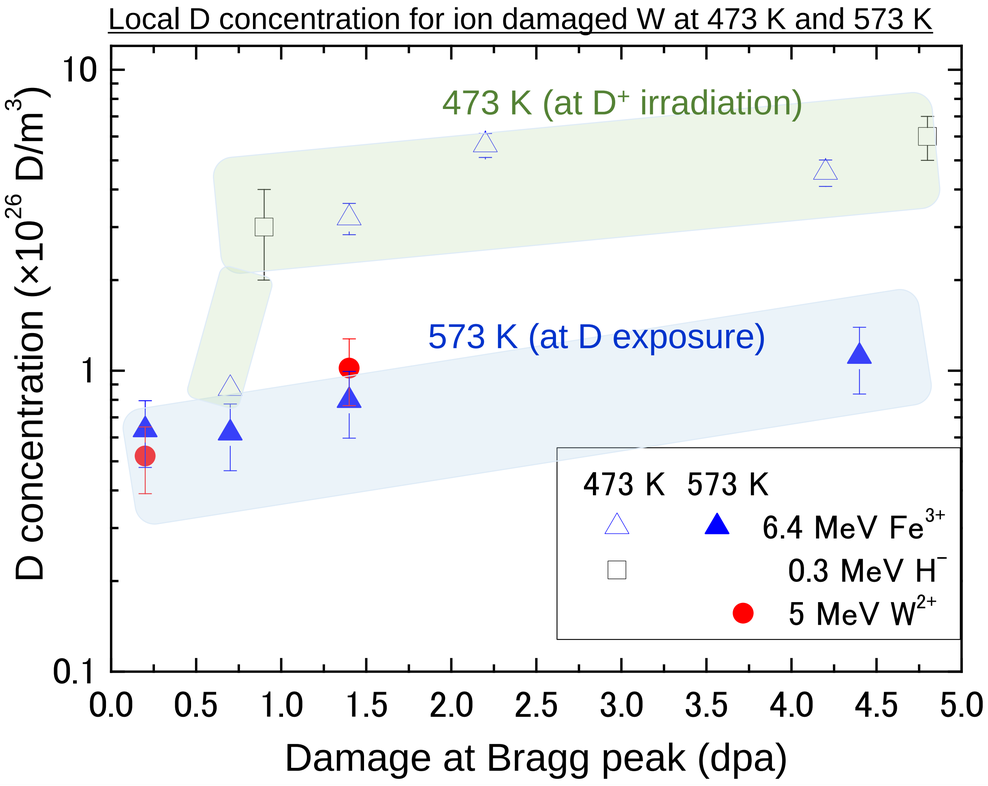


Neutron irradiation: 0.06 dpa, 563 K
D plasma exposure at 473 K
D retention :
n-damage: 3.2×10^{21} D/m^2
No damage: 7.6×10^{20} D/m^2
D concentration =
(Damaged – No damage)/Depth

By assuming uniform depth profile up to 100 μm, high temperature tail extending to 1300 K seems to agree with TMAP simulation (1.9 eV). → **Needs more study (depth profile would help much)**

○Retention for three types of ion damage W

Local D concentration for ion damaged W at 473 K and 573 K



- ✓ H, Fe, W damaged W have similar high energy trap site (~1.9 eV)
- ✓Neutron damaged W might have similar trap site, but more studies (depth profile etc.) needed
- ✓Under same dpa and temperature, different ion damaged W have similar trap site density.