Role of PKA Spectrum & PKA Density in Defect Production and Implications for H-isotope Trapping in Tungsten

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ABSTRACT & CONCLUSIONS

- A broad range of PKA spectra and defect density were produced by He, B & Au ions while keeping the same penetration range & overall dpa
- For the same dpa, positron analysis reveals a higher damage due to 3 MeV He ions compared to 10 MeV B ions. This could be due to self-clustering of He and the consequent additional defect formation
- However, SIMS analysis indicates lesser D-trapping in He-irradiated samples compared to Au & B irradiated samples. PAS results hint that this could be due to the occupation by He atoms of the vacancy competes with deuterium

MOTIVATION

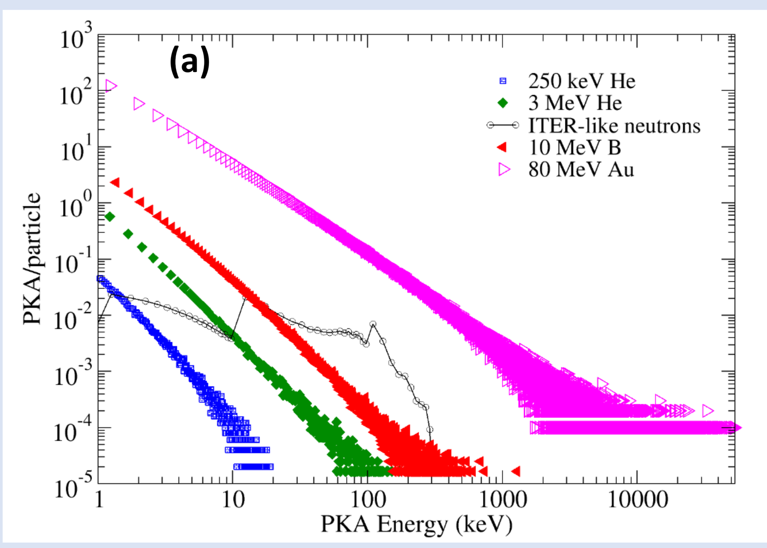
- Tungsten's performance as a divertor armor material raises global concerns due to the accumulated radiation damage and subsequent tritium retention by 14 MeV neutrons and α-particles in a fusion power reactor
- Ion irradiation is often used to simulate neutron damage. However, the role of PKA spectrum and the consequent defect structure in H-isotope trapping is unclear
- We address this by using ion irradiation experiments with different mass, energy and PKA density and the defect formation is studied using positron annihilation, TEM and SIMS.

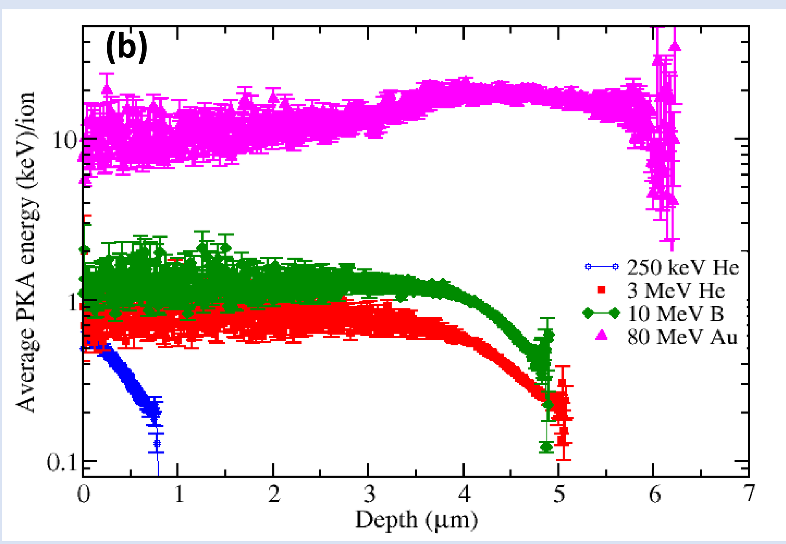
ION-IRRADIATION EXPERIMENTS

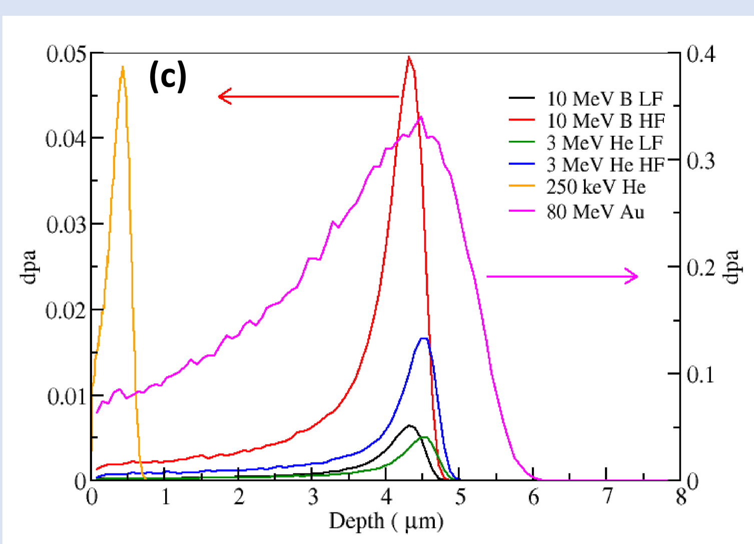
- Ion-irradiation experiments by using different ion mass and energy
- The average range is nearly the same except one case
- Cold-rolled W-foil samples of 99.96 weight-% purity (Princeton Sci.corp) and 8 x 8 x 0.1 mm^3 size were annealed in vacuum for 1 hour
- RC1-set annealed at 1858 K in Ar + 8%H
- RC2-set annealed at 1873 K in vacuum (< 10^{-6} mbar)
- Highly textured samples obtained after annealing

Irradiation Conditions

Ions (ID)	Energy MeV	Range μm	Fluence 10^{19}m^{-2}	DPA Ed = 90eV
He	0.25	0.6	5	0.022
He(HEF1)	3	4	0.75	0.001
He(HEF2)	3	4	2.25	0.003
B (BF1)	10	4	0.13	0.001
B (BF2)	10	4	1	0.01
Au (Au)	80	4	1.3	0.22







The (a) no. of PKA as a function of energy (b) average PKA energy & (c) DPA as a function of depth for different ions

PKA density

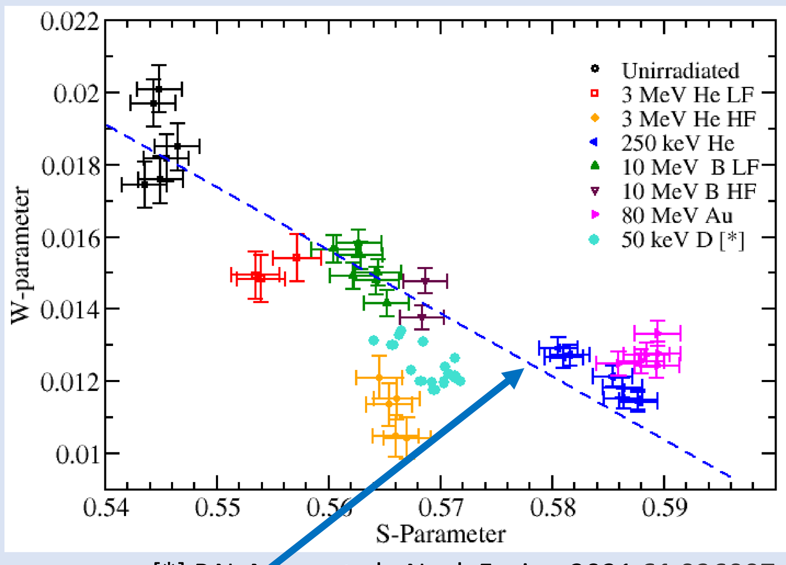
$$\rho_{PKA} = N_{PKA}/V_{cascade}$$

80 MeV Au ~ 10^{23} m^{-3}
10 MeV B ~ 10^{19} m^{-3}
3 MeV He ~ 10^{18} m^{-3}
250 keV He ~ 10^{20} m^{-3}

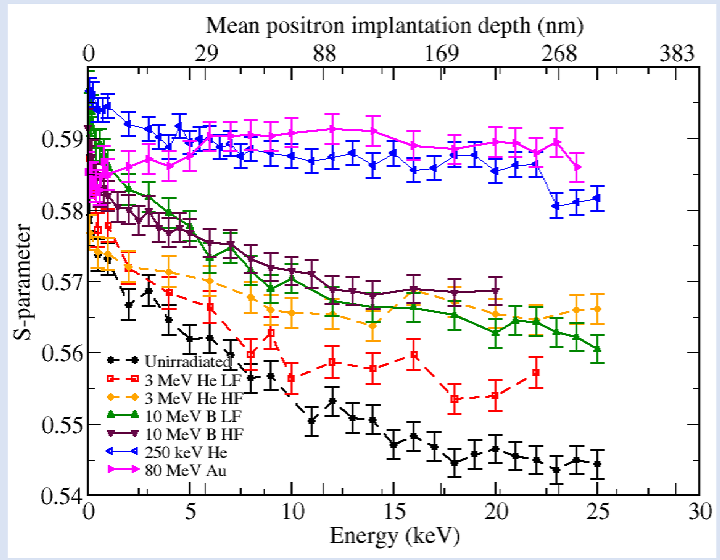
ANALYSIS & DISCUSSION

Positron Doppler-broadening & lifetime (τ) measurements indicate more defects in He-irradiated samples for small dpa & PKA density

Slow e$^+$ beam annihilation measurements
S-parameter → from valance electrons information about vacancies
W-parameter → from core electrons chemical element

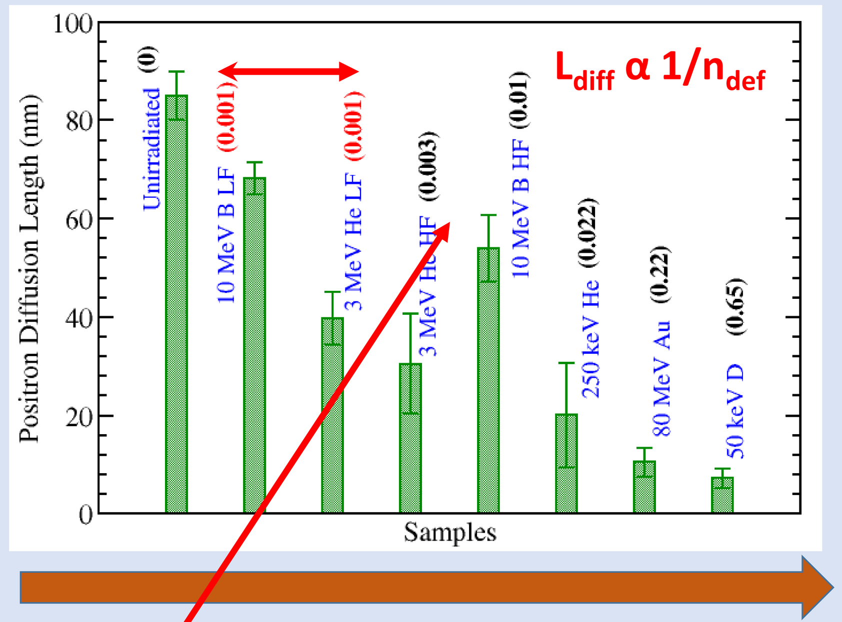


[*] P.N. Maya et al., Nucl. Fusion 2021 61 036007

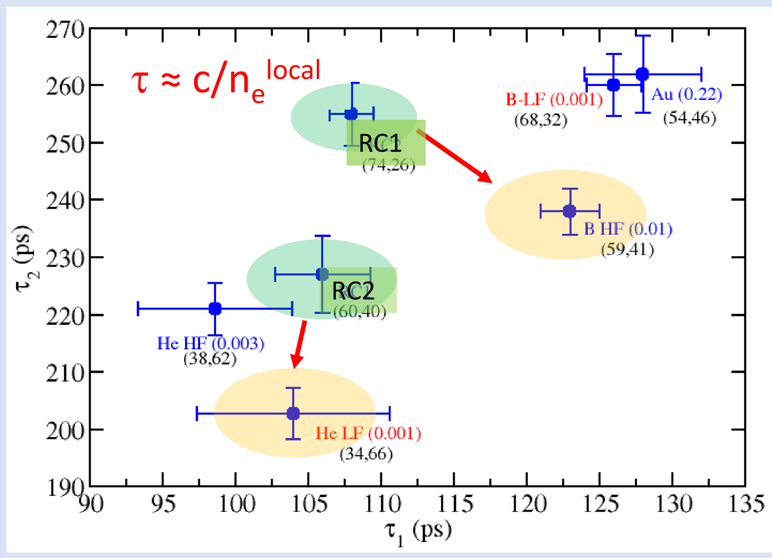


Samples on the same line → Similar type of defect environment

Lifetime measurements: Sandwich type ^{22}Na positron source
Two-lifetime fit to the timing spectra of 511 keV γ–rays emitted due to e$^-$-e$^+$ annihilation: τ_1 → intrinsic lifetime, τ_2 → Defect lifetime
Information depth ~ 16 μm



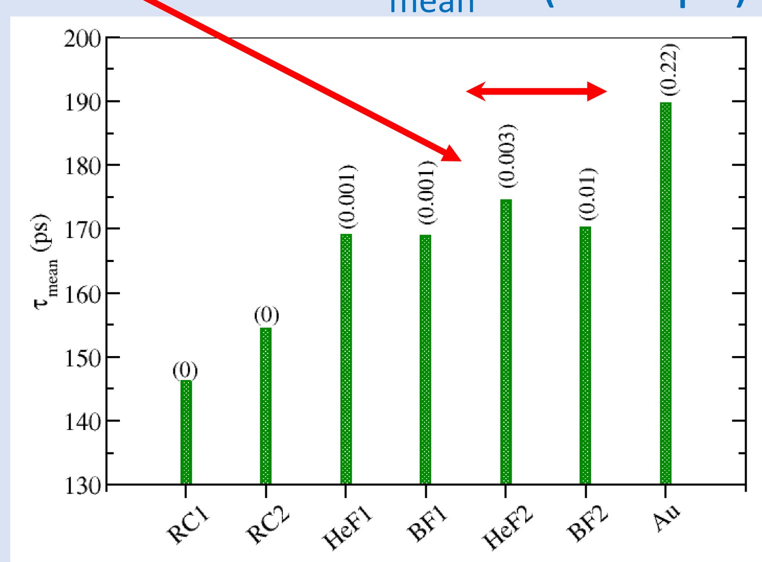
Increasing defects



Movement in τ_1-τ_2 space indicated by red arrows from the recrystallized to irradiated

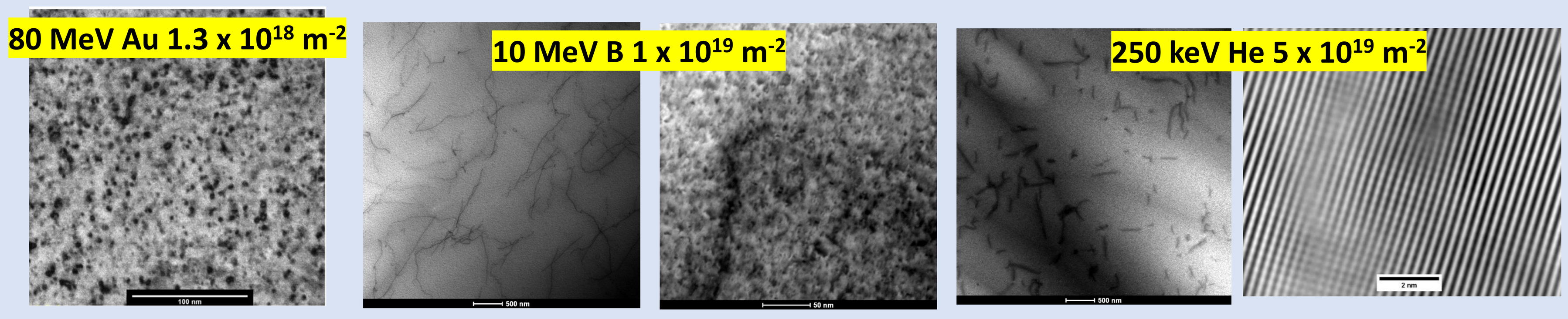
Lower L_{diff} → higher defects
Higher τ_{mean} → higher defects

Mean-lifetime τ_{mean} & (net dpa)

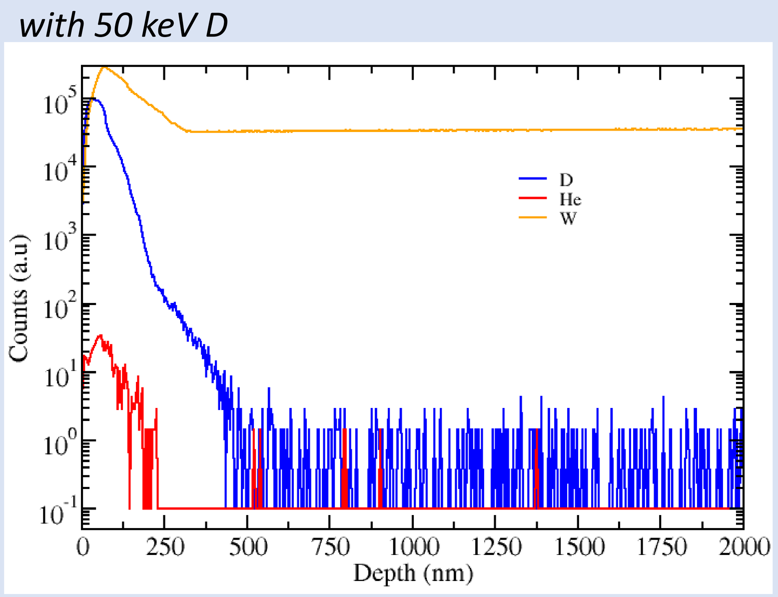


Different types of defects formed for different ions & PKA density

TEM shows B-irradiation forms dense dislocation lines & Au-irradiation cause dense clusters. 250 keV He-irradiation shows both dense lines and clusters [P.N. Maya et al., Nucl. Fusion 2019 59 076034, P. Sharma et al., 2019 Micro and Microanal, 25(6), 1442]



Depth profile of He and D measured using SIMS in samples irradiated with 250 keV He irradiated with 50 keV D



SIMS analysis also shows high He content at the near-surface for 3 MeV irradiation

From SIMS it is also seen that He profile closely follows C & Mo impurity profiles

SUMMARY

The nature of the defects formed by different ions is different for the same dpa and similar ion penetration range

He-ions seem to produce more defects for same dpa as confirmed by PAS. This could be due to He-self-clustering creating additional vacancies. He trapping at vacancies is also seen in PAS

Initial SIMS analysis indicates lesser D-trapping in He-irradiated samples compared to Au & B irradiated samples

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