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Ammonia production, isotopic exchange and sticking on materials relevant to Fusion reactors: tungsten and 316L stainless steel

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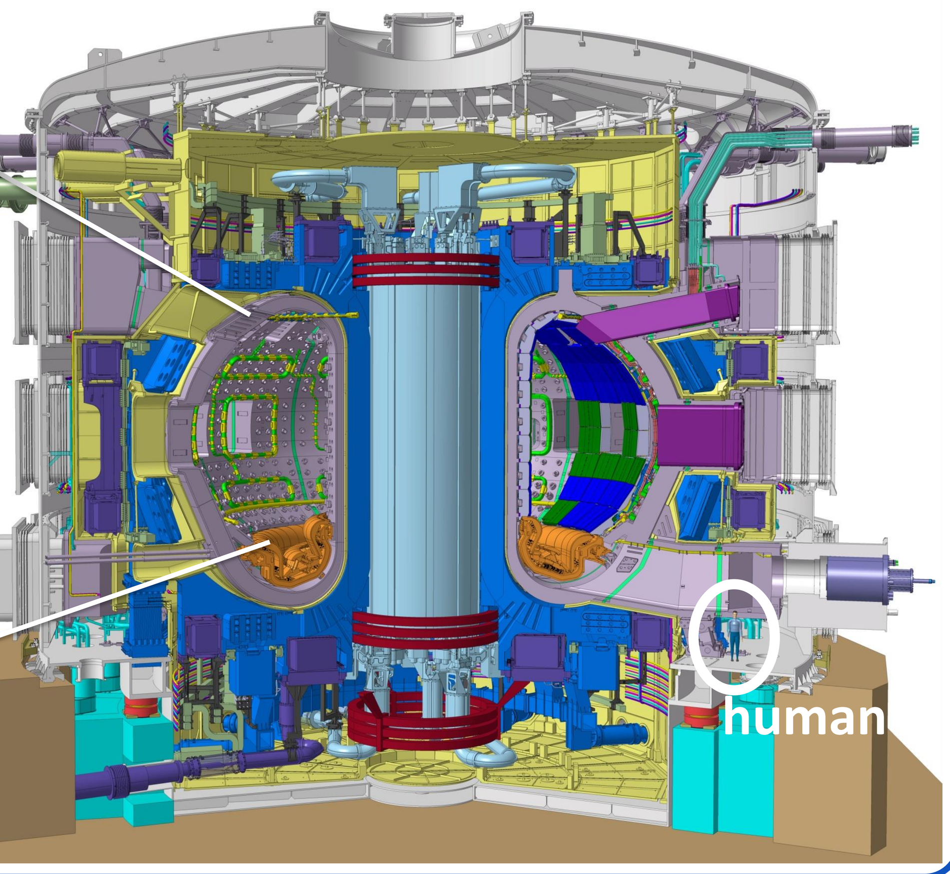
Abstract

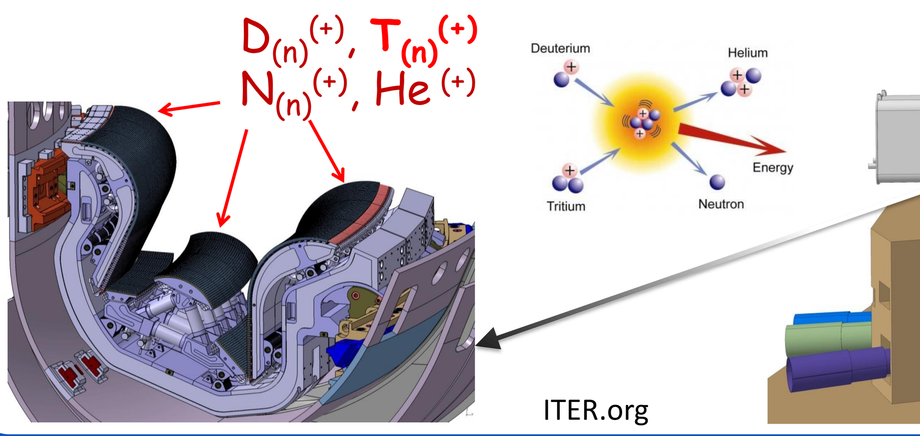
- **To maintain power fluxes to plasma facing components within tolerable limits, nitrogen-seeding in the edge plasma is considered**
- **Ammonia production has been observed in thermonuclear fusion reactors such as JET and ASDEX-Upgrade**
- **ITER will use a D/T mix → radioactive NT_3 expected → nuclear safety regulation imposes a stringent control of NT_3 within the reactor.**
- **It is necessary to understand the mechanism of ammonia production and where tritiated ammonia will stick on the reactor vessel**

ITER wall conditions

SS316L vacuum vessel (60 m²)
background gases (H_2, NH_3…)
+ E_k > 50 eV (charge exchange neutral)

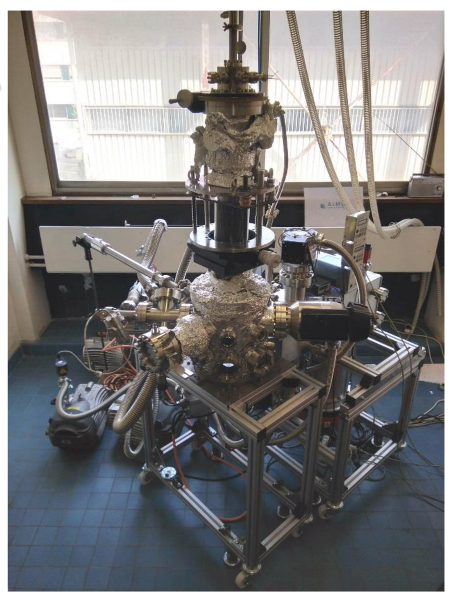
Tungsten divertor (200 m²)
+ E_k < 50 eV (ion and neutral)

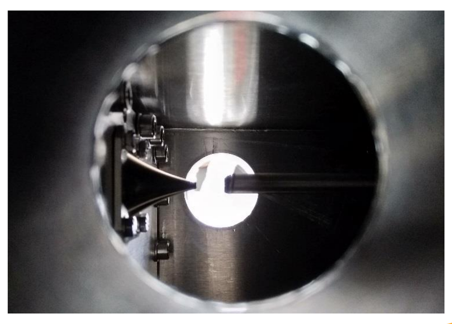




Experimental methods (UHV)

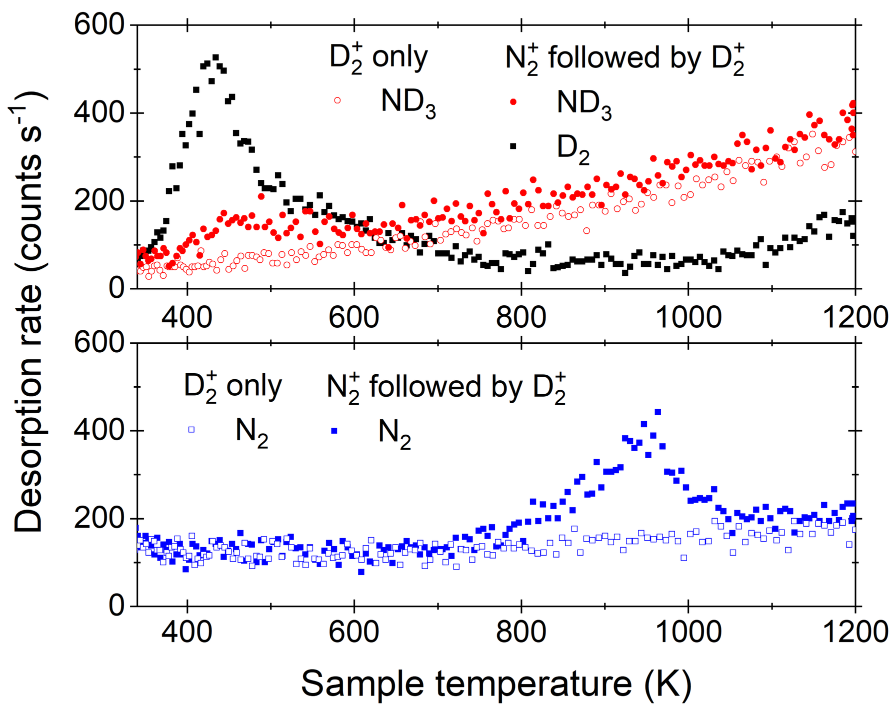
- Poly-W: ALMT, 99,99%, native oxide
- 316L steel: Goodfellow, Fe > 60%, Cr 18%, Ni 10%, Mo 3%, Mn <2%, Si <1%, N <0.1%, P <0.045%, C <0.03%, S <0.03%
- W: 1000 K anneal (native oxide is left)
- SS316L: 800 K anneal (avoid sublimation)
- Ammonia production: co-implantation with 250eV/N (D) ion sources
- Ammonia sticking: supersonic molecular beam





NH_3 production measurements on W

- Ammonia (ND_3) production has been detected with a Quadrupole Mass Spectrometer (QMS) at m/z=20 only when N and D co-implantation are performed (excludes D_2O)
- **ND_3 desorption** occurs in the same temperature window than D_2 desorption **(350 – 650 K)**
- N_2 desorption occurs well after ND_3 and D_2 desorption

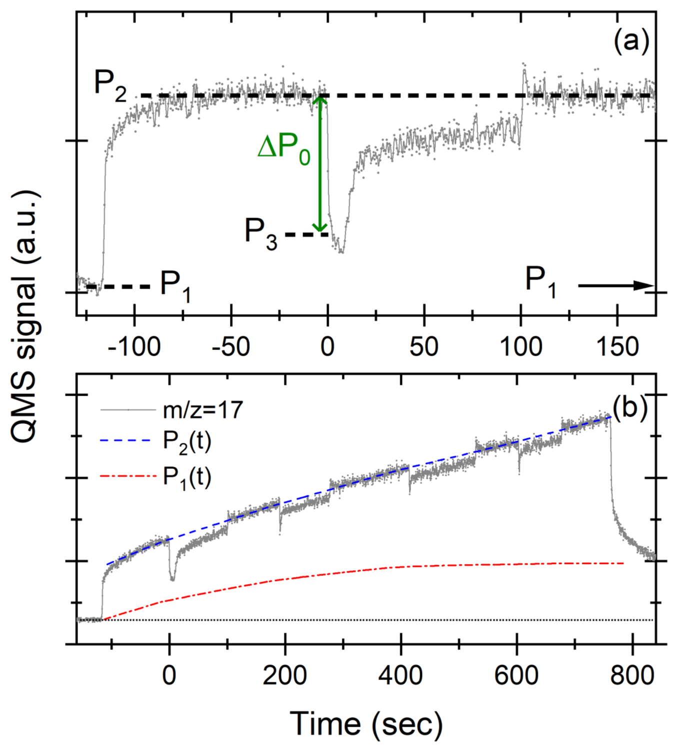


NH_3 sticking measurements

- Difficult for NH_3 because it is a sticky molecule on the vacuum chamber walls (316L)

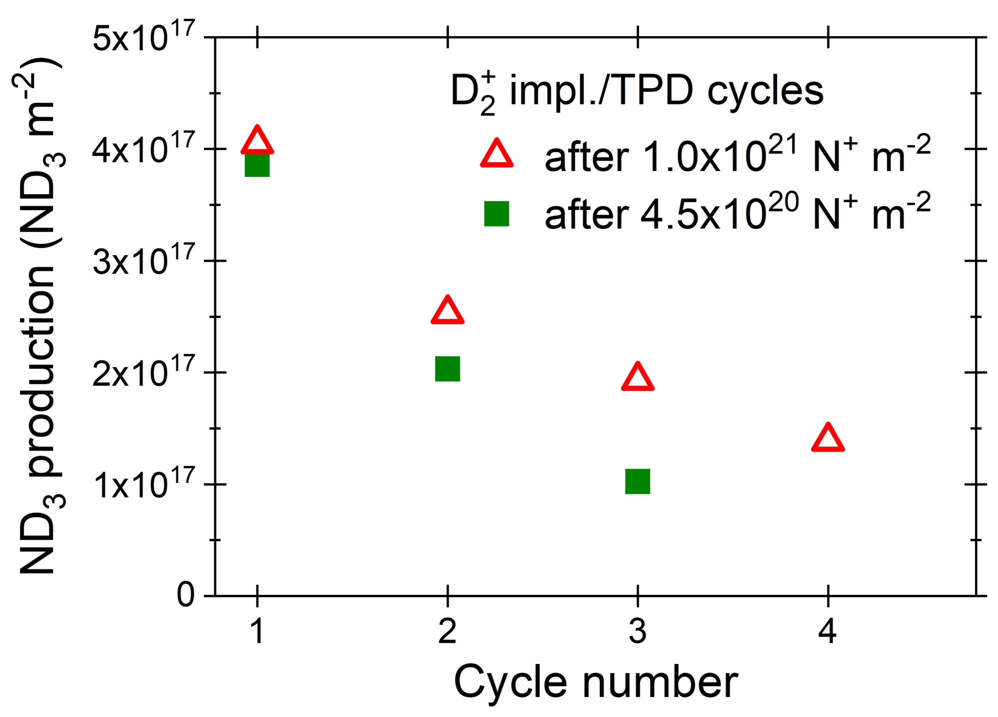
$$S_0 \simeq \frac{|\Delta P_0|}{P_2(t) - P_1(t)} \qquad S(t) \simeq \frac{P_2(t) - P(t)}{P_2(t) - P_1(t)}$$

$$S(\theta) = F \int_{t_0}^{t} S(t)dt \qquad \textbf{F: flux}$$



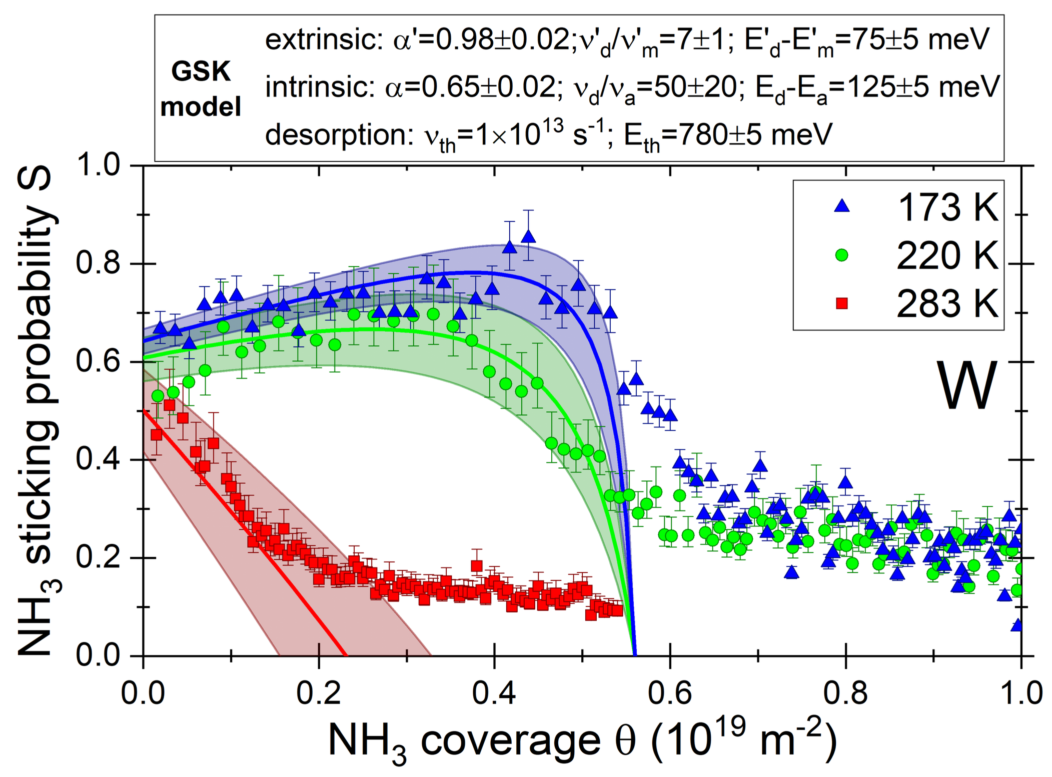
NH_3 production mechanism on W

- Cycles of ND_3 production from a saturated N layer in W is realized by repeating D implantation and desorption up to 750 K (i.e. keeping the N layer in W after desorption)
- A linear (exponential ?) decay of ND_3 production is observed
- The total quantity of ND_3 produced is less than 2% of available Nitrogen in the layer
- Total consumption of N is about 16% of the W surface atomic density

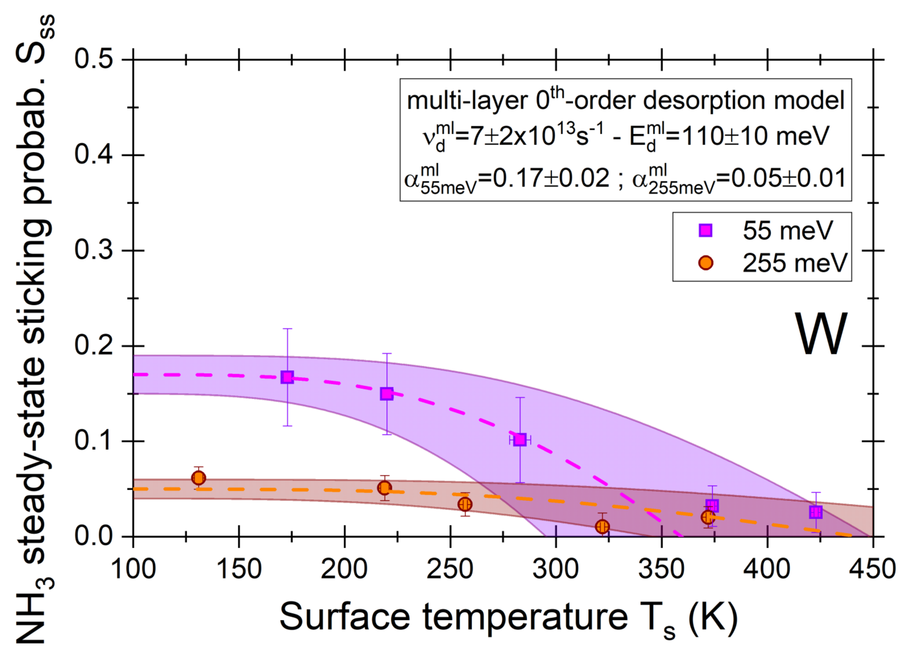


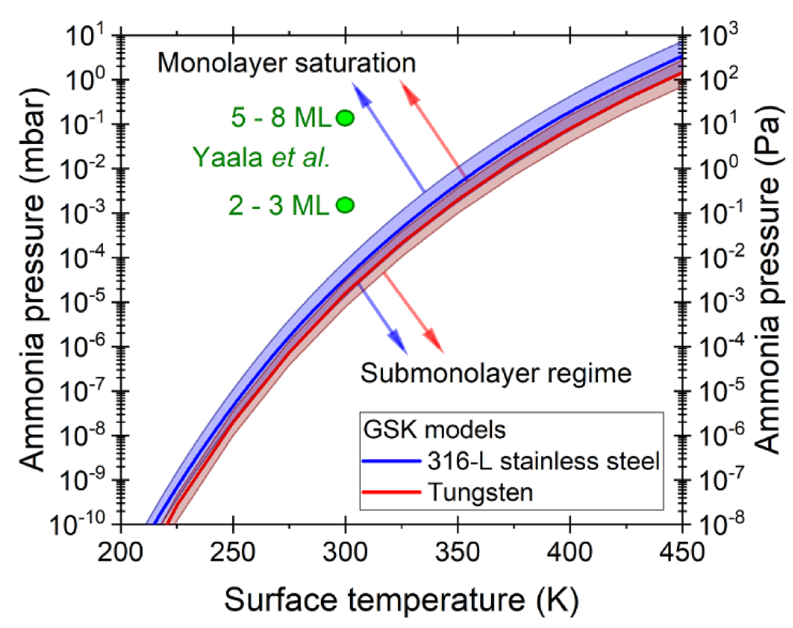
- N surface density consistent with SD.TRIM calculations (Meisl *et al.*, New J. Phys, **16** (2014) 093018)
- **ND_3 production surface-limited** (N diffusion negligible <750 K)

Sticking probability as a function of materials temperature and NH_3 coverage



A two precursors adsorption model & an island-based multi-layers adsorption model are able to reproduce all our sticking results and are consistent with Yaala *et al.* (Nuc. Fusion **58** (2018) 106012) experiments





Published results: M. Minissale *et al.*, J. Phys. Chem. C 124, (2020) 17566

Conclusion

Ammonia production is surface-limited on tungsten. Ammonia sticking on tungsten and 316L stainless steel is mediated by two precursors. Transient and steady-state surface coverage depend on NH_3 pressure and materials temperature and are described by the present models.