

Fusion plasma - materials interactions simulated with ion and molecular beams experiments

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Harnessing nuclear fusion's power is the goal of the ITER tokamak, an international experiment that will confine magnetically a hot plasma of hydrogen isotopes to produce energetic helium ions and neutrons. Power exhaust will be realized on the divertor tiles made of tungsten (W). A detailed understanding of the interaction of fusion fuel with W is needed, because tritium is a scarce and radioactive element. In this contribution, we will give an overview of experimental studies realized on ITER relevant materials as well as on new materials explored for DEMO prototypes.

A prime focus of interest concerns fusion fuel trapping in W. In general, hydrogen trapping is possible in the bulk of W at structural defects (vacancies, grain boundaries...) as well as at the surface of W, the latter being usually neglected. In a joint experimental-modeling study, we have shown that both grain boundaries trapping and near-surface native oxide trapping explains the room temperature hydrogen degassing of W materials. Using an ion beam and surface science techniques, we demonstrated that hydrogen trapping in presence of W native oxide is different than trapping at clean W surfaces contaminated with oxygen atoms, which should have implications in terms of fuel recycling at the divertor and could impact the control of fusion plasma [1].

Besides, about 10% of the plasma-exposed surfaces of ITER will be made of 316L stainless steel. We recently demonstrated that these surfaces will emit ammonia molecules because of the natural nitrogen content of SS316L which easily diffuses towards the surface and reacts with hydrogen isotopes from the plasma. To understand how this potential source of tritiated ammonia could influence the nuclear safety requirement of ITER, we performed molecular beam experiments and built a kinetic model to estimating ammonia contribution to the tritium inventory [2].

Finally, the presence of the fusion product He in W affects hydrogen trapping and induces W swelling and damaging. He being not soluble in most metals, it was predicted 40 years ago that He clusters could nucleate homogeneously and self-trap by emission of a Frenkel-pair in the metal lattice. Using He ion beams, we demonstrated that He self-trapping occurs in W, indeed [3]. High Entropy Alloys (HEA) are a new class of materials that should reduce He-induced swelling of metals. Preliminary results on fusion fuel trapping in HEA will be presented.

[1] A. Dunand *et al.*, Nucl. Fusion 62, 054002 (2022)

[2] M. Minissale *et al.*, J. Phys. Chem. C 124, 17566 (2020)

[3] A. Dunand *et al.*, Nucl. Mater. Energy 34, 101324 (2023)