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Ion-driven Permeation Experiments and Modelling

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For the prediction of hydrogen isotope (HI) diffusion, retention and permeation in future fusion devices basic data are needed for fusion-relevant materials. These data needs pertain not only to the foreseen first-wall material Tungsten (W) but also to alloys (such as so-called tungsten heavy alloys or oxidation-resistant W alloys) and more complex materials such as functionally graded materials or tungsten-fiber reinforced tungsten foreseen to be used in first-wall or divertor components. As a first step towards an improved understanding of complex materials, the influence of interfaces on diffusion and permeation is a topic that deserves further attention.

For the investigation of permeation through fusion-relevant materials IPP has built and commissioned a new experimental device named TAPAS for the investigation of ion-driven permeation (IDP). TAPAS is an add-on experiment to the high-current ion source SIESTA [1]. In TAPAS a well-characterized, monoenergetic, mass-selected, high-current ion beam impinges on a thin foil of the material to be investigated. The permeation of the implanted ion species trough this foil is detected with a quadrupole mass spectrometer. With this device IDP through pure materials, alloys, layered systems (e.g., W layer on steel) and more complex materials can be investigated as long as foils with sufficiently low thickness can be produced. In 2020/2021 TAPAS has been thoroughly optimized and characterized. After further optimization of the ion source and ion beam optics TAPAS provides now a D_3^+ beam with a current density of up to 10^{20} D $m^{-2}s^{-1}$. The neutral fraction in the beam has been reduced to about 0.1 %. The ion energy can be varied from about 100 eV per D to about 1500 eV per D. The temperature of the foil can be varied between about 300 K up to 1000 K.

First measurements for a thin W layer (600 nm) on EUROFER97 were conducted. They show clear indication of the substantial influence of surface oxide layers on the measured permeation fluxes. Next measurements will focus on the materials EUROFER97 and tungsten. EUROFER97 samples will be prepared following the identical sample preparation procedure as used in Forschungszentrum Jülich, Germany (FZJ) for GDP measurements and ion-driven permeation of deuterium will be studied as a function of incident ion energy and sample temperature. These experiments will be performed in close coordination with FZJ (A. Houben) to allow comparison of GDP and IDP in EUROFER. In addition, IDP in tungsten and in radiation-damaged tungsten are planned.

Experimental data of D permeation in EUROFER97 and tungsten will be compared to modelling from the diffusion-trapping codes TESSIM and/or TMAP. Further modelling activities aim at a description of permeation across material interfaces and calculation of trapping and de-trapping cross-sections for continuous Trap-Diffusion Models from first principles.

References:
[1] R. Arredondo, M. Oberkofler, K. Schmid, T. Schwarz-Selinger, W. Jacob, and R. Neu: "SIESTA: A High Current Ion Source for Erosion and Retention Studies", Review of Scientific Instruments and Methods, 89, 103501 (10pp) (2018). doi: 10.1063/1.5039156

Primary author: Dr JACOB, Wolfgang (Max-Planck Institute for Plasma Physics)

Presenter: Dr JACOB, Wolfgang (Max-Planck Institute for Plasma Physics)

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