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Picosecond laser-induced ablation for depth-resolved analysis of first wall components in fusion devices

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Monitoring the fuel content of plasma-facing components is a key challenge for fusion devices like Wendelstein 7-X (W7-X) [1], equipped with graphite PFCs or ITER with beryllium/tungsten components. In the case of ITER, it is essential to limit the tritium content in the first wall to comply with safety regulations and to sustain the tritium cycle. In W7-X the measurement and control of the hydrogen content in the first wall mandatory to achieve stable long pulse operation. Laser-Induced Breakdown Spectroscopy (LIBS) and Laser-Induced-Desorption (LID) [2] are suitable to determine the fuel retention ex-situ in extracted PFCs or in-situ in the vacuum vessel during or between plasma discharges. However, the self-consistent quantification is challenging as the emission is a non-equilibrium process and often a comparative measurement with pre-characterized reference samples is mandatory.

A combination of LIBS and residual gas analysis is an alternative approach: For volatile sample components, the linearity of the quadrupole signal to gas pressure simplifies the calibration and reduces uncertainties. We use a Nd:YVO4-laser (λ3rd=355 nm) with a pulse duration of τ=35ps and pulse energies up to E=40mJ. With a spot size diameter on the sample of x=0.7mm we achieve a depth resolution of Δh=100nm for graphite samples without significant matrix mixing effects.

We present a series of composition analysis of poloidal and toroidal locations on graphite limiter tiles of W7-X, exposed to hydrogen plasma in OP1.1. Erosion- and deposition-dominated zones could be identified. In addition, graphite divertor tiles exposed in OP1.2a are analyzed. In contrast to ms-LID, the heat penetration depth of ps-laser-induced-ablation is smaller than the ablation rate. Consequently, all retained hydrogen from the sample is removed and quantitative depth-resolved hydrogen retention information (O(1022/m2)) is gained.

[1] T.S. Pedersen et al., Nucl. Fusion 55 (2015)126001.
[2] G. De Temmerman et al., Nuclear Materials and Energy (2016)2352-1791.

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