Laser Induced Breakdown Spectroscopy for studying tritium retention in fusion reactors

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Laser Induced Breakdown Spectroscopy (LIBS) is a powerful method to investigate retention of plasma fuel and composition of co-deposited layers on plasma-facing components (PFCs) during non-operational phases of fusion reactors. The applicability of LIBS in a tokamak environment was recently demonstrated [1] in an extensive measurement campaign at JET following the final shutdown of the device after 40 years of plasma operations. The campaign showed also that LIBS measurements can be successfully performed in a hostile environment with activated PFCs and in the presence of tritium (T) from deuterium (D)-tritium plasma discharges. Presently, a LIBS system is being designed for the full-tungsten (W) tokamak WEST, which is a relevant testbed for solutions foreseen in ITER [2]. Several European laboratories, under the EUROfusion Consortium, together with colleagues from the UK Atomic Energy Authority and CEA Cadarache, have participated in the development projects. In this contribution we will review the development work required and lessons learnt from the different European projects where LIBS is to be transferred from a laboratory setup into a working tool in fusion reactors.

The projects have shown that implementation of a working LIBS diagnostics for a fusion reactor requires designing and constructing a compact, lightweight system that can be mounted on the existing remote handling system of the particular device. The necessary spectrometer system needs also to be capable of distinguishing different isotopes of hydrogen from each other as well as other typical impurities during maintenance conditions. The JET measurement campaign has provided data from >800 measurement points all over the vessel providing a unique opportunity to compare the LIBS results with those offered by standard *post mortem* analysis techniques. Depth profiles of different elements can be reliably reconstructed and concentrations for the hydrogen isotopes H, D, and T can be individually extracted. Preliminary results from JET indicate T to remain at low levels on all the studied samples, most likely due to intense cleaning of the vessel after the most recent DT plasma operations. Another key take-home message is that execution of a LIBS campaign will hugely benefit from pre- and post-experiments in laboratory conditions with realistic samples extracted from the particular fusion device. This way, optimal parameters for the actual measurements can be determined and the obtained results can be properly validated. Such investigations are being made in the T-compatible laboratory facilities of VTT. Finally, the multitude of data available from LIBS measurement campaigns will require new methodology to be developed for interpreting the obtained spectra. Tools based on machine learning are considered instrumental to this end [3] and in the future new algorithms and approaches based on, e.g., surrogate models will be further developed.

[1] J. Likonen *et al.,* to be published in the PFMC 2025 Conference; [2] A. Favre *et al.*, Phys. Scr. **99** (2024) 035609; [3] P. Gąsior *et al.*, Phys. Plasmas **31** (2024) 052507

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