LIBS for monitoring of tritium and impurities in the first wall of fusion devices

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Abstract

Laser-Induced Breakdown Spectroscopy (LIBS) is the most promising method for quantitative in-situ determination of fuel retention in Plasma-Facing Components (PFCs) in ITER and beyond. Here we present the latest developments in view of ITER requirements, wherein two pathways were set out in this research:

- LIBS was validated in different labs where composition depth profiles were measured in ITER-like coatings and deposits: depth profiles with resolution of 25-100 nm and deuterium (D): substitute for tritium (T) sensitivity levels of below 10¹⁴ D/cm² were measured.
- Demonstration of remote handling application of LIBS on a multipurpose deployer inside the Frascati-Tokamak-Upscale (FTU).

The achievements underline the capability of a LIBS based retention monitor, which complies with the requirements for JET and ITER operating in D² with Be wall and W divertor.

Typical LIBS setup and analysis

In LIBS, a very small amount of material (µg) is ablated from the surface by a short (ns-ps) laser pulse. The ablated material is excited and ionized, and will emit light at characteristic wavelengths, which is detected by a spectrometer.

The spectra are recorded by a fast ICCD camera, using a delay (relative to the laser pulse) and short detection window, to assure light detection during local thermal equilibrium of the plasma plume.

A so-called calibration free LIBS (CF-LIBS) method is used to quantify the material composition from the spectra. The procedure is based on Boltzmann plots providing relative composition of the surface. Using the overall surface density and knowing the induced crater volume, the absolute composition and D content can be determined.

To obtain accurate composition results, the following conditions should be fulfilled for CF-LIBS:

- Stochiometric ablation.
- The electron temperature (T_e) and density (n_e) of the LIBS plasma should be accurately determined from multiple spectral lines.
- Local Thermodynamical Equilibrium

Determination of fuel content in Be-W-D

LIBS analysis of Be-W-D coating samples (2 µm thick) at low Ar ambient pressure. The decaying tendency of D₂ and H₂ spectral lines for the first 10 laser shots can be seen.

LIBS spectrum corresponding to 1st and 3rd laser shots. The used fitting functions for the D₂ and H₂ spectrum are shown. Averaged value for D content was in agreement with TDS: 5.10¹² D/cm².

Conclusions and outlook

- With CF-LIBS low concentrations of fuel and other elements were successfully measured in PFM (Be, W, etc.) and associated deposits, verified by other methods.
- ps-LIBS has advantage in comparison with ns-LIBS for the measurement of hydrogen content due to smaller thermal effect and lower ablation rate.
- Fuel retention measurements with DP LIBS features best performance in terms of SNR and distinguishability of the lines from H isotopes, also extension of the lifetime of the plasma plume by other methods, e.g., spark discharge (SDELIBS), is very beneficial here.
- LIBS at atmospheric pressure is challenging, but this was in FTU circumvented by using a flow of shielding gas or by using compact confinement cylinder.
- LIBS system was successfully implemented on the FTU robotic arm.