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:

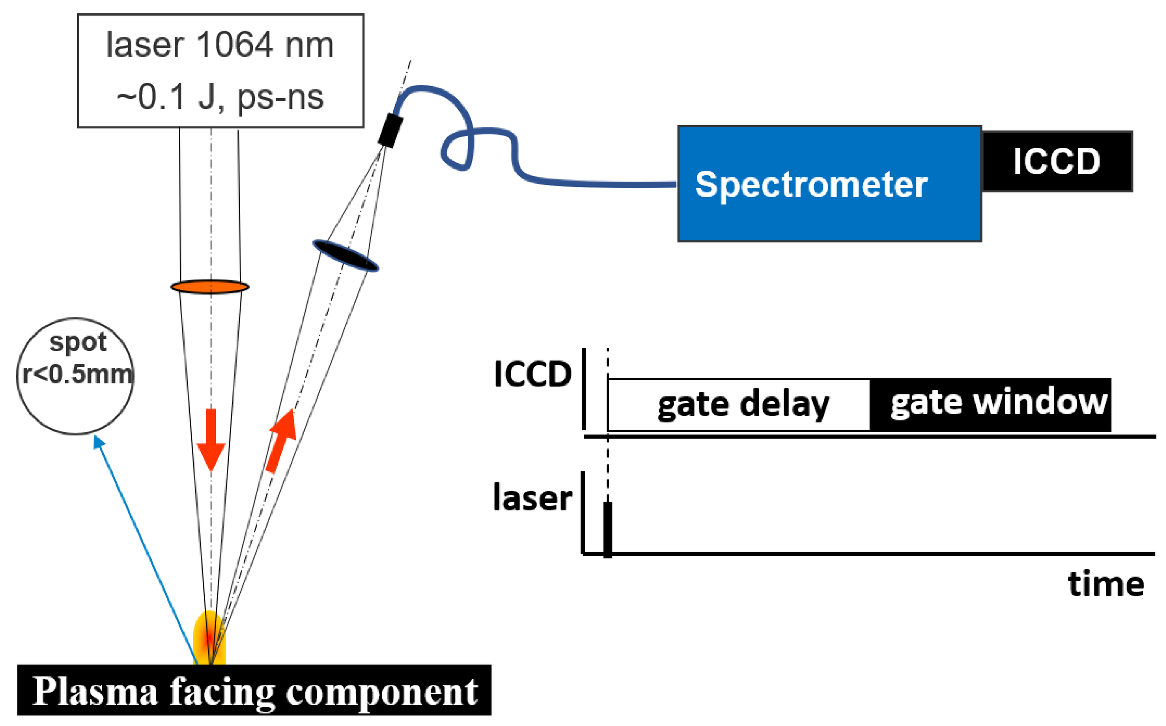
- LIBS was validated in different labs where composition depth profiles were measured in ITER-like coatings and deposits: depth profiles with resolution of 25-100 nm and deuterium (D: substitute for tritium (T)) sensitivity levels of below 10^{16} D/cm^2 were measured.
- Demonstration of remote handling application of LIBS on a multipurpose deployer inside the Frascati-Tokamak-Upgrade (FTU).

The achievements underline the capability of a LIBS based retention monitor, which complies with the requirements for JET and ITER operating in DT 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.

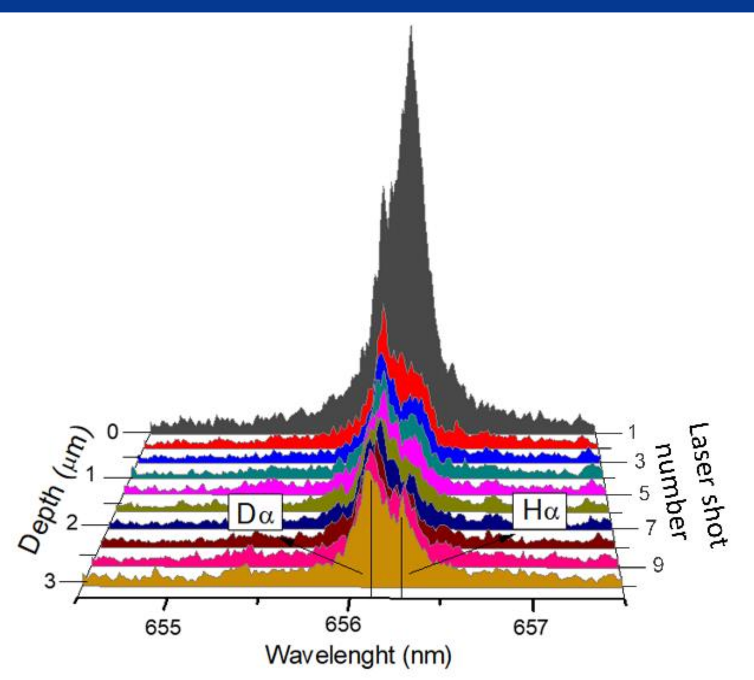


A so-called calibration-free LIBS (CF-LIBS) method is used to quantify the material composition from the spectra. The procedure is based on Boltzmann plots providing relative composition of the surface. Using the overall surface density and knowing the induced crater volume, the absolute composition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

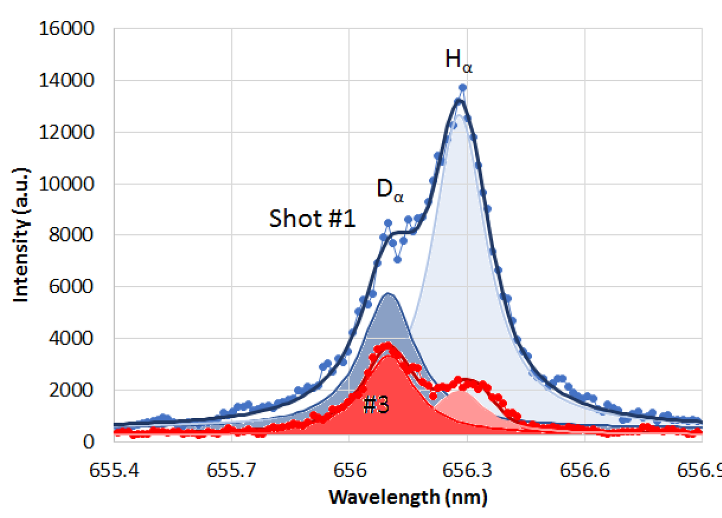
To obtain accurate composition results, the following conditions should be fulfilled for CF-LIBS:

- Stoichiometric 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

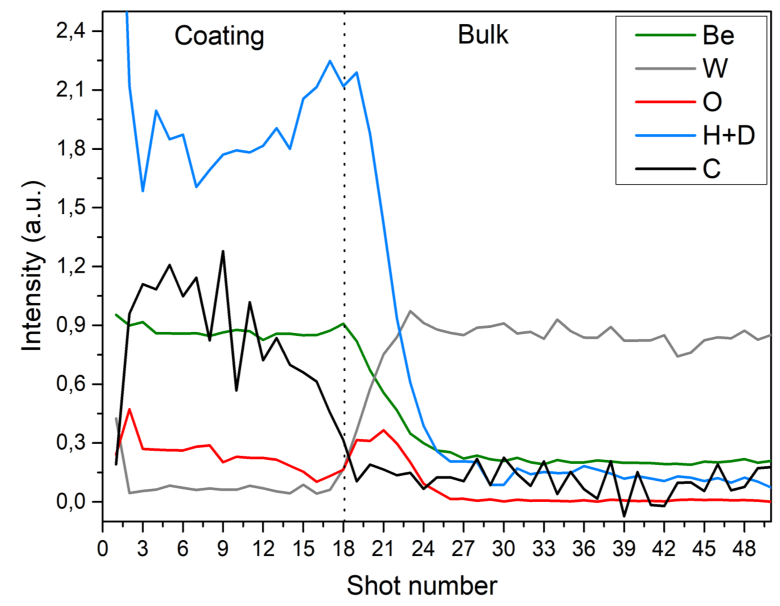


LIBS analysis of Be-W-D coating samples (2 µm thick) at low Ar ambient pressure. The decaying tendency of D_α and H_α spectral lines for the first 10 laser shots can be seen.

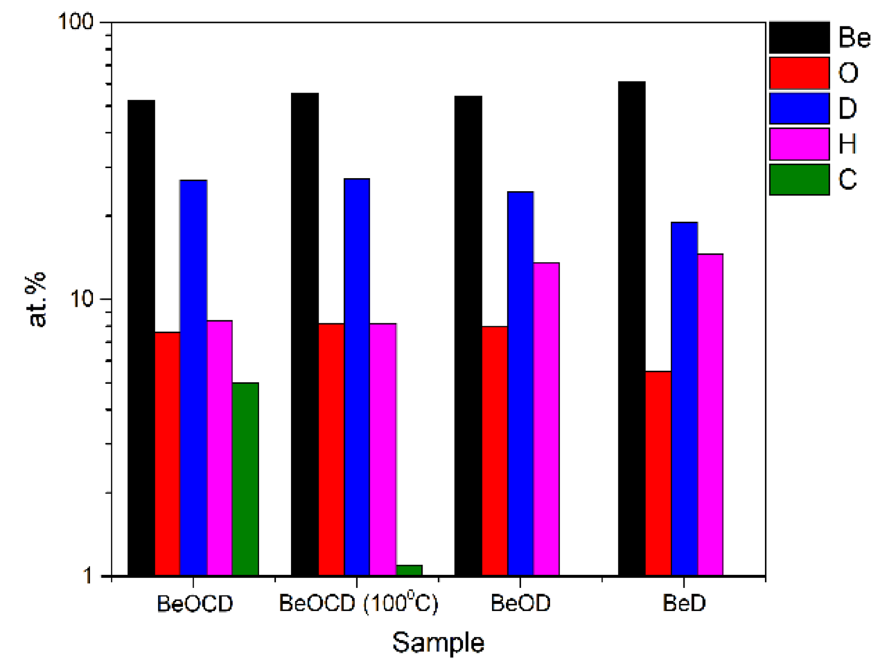


LIBS spectrum corresponding to 1st and 3rd laser shots. The used fitting functions for the D_α and H_α spectrum are shown. Averaged value for D content was in agreement with TDS: 5·10^{17} D/cm^2.

Determination of fuel content in Be compounds

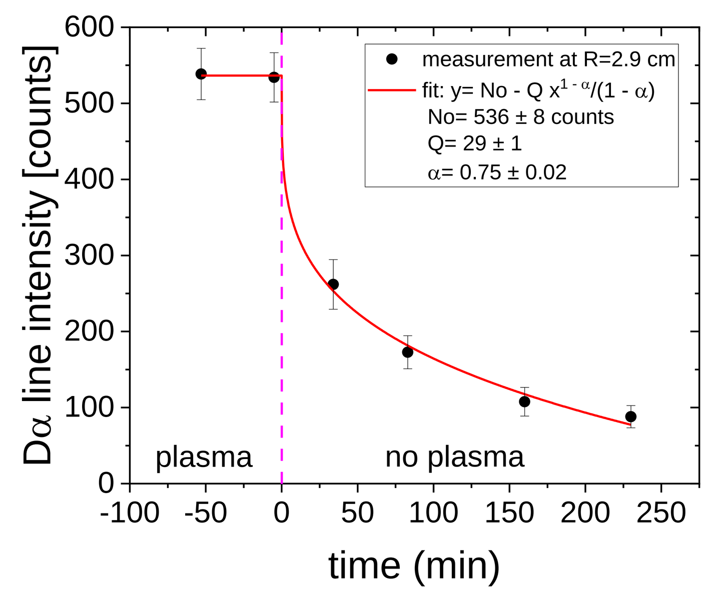


LIBS depth profiles of a Be-O-C-D sample, showing the limit of the coating deposited layer at the laser shot number 18.

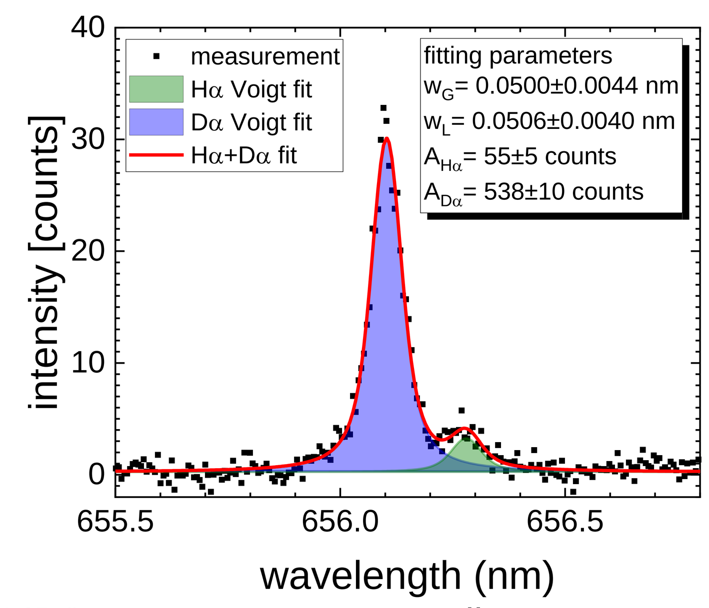


Relative elemental composition determined by CF-LIBS of the whole deposited layer for four different samples.

Outgassing

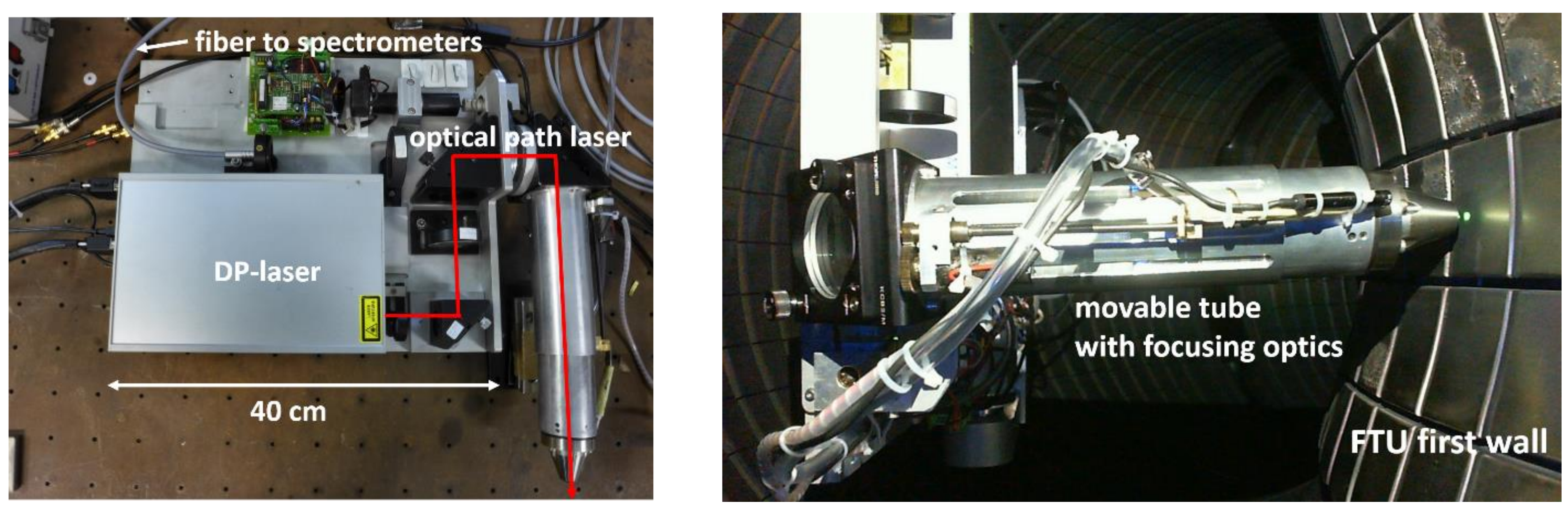


LIBS signal of D_α line measured directly after plasma exposure in PSI-2. Fit assumes that outgassing decay follows a single power law with exponent α.

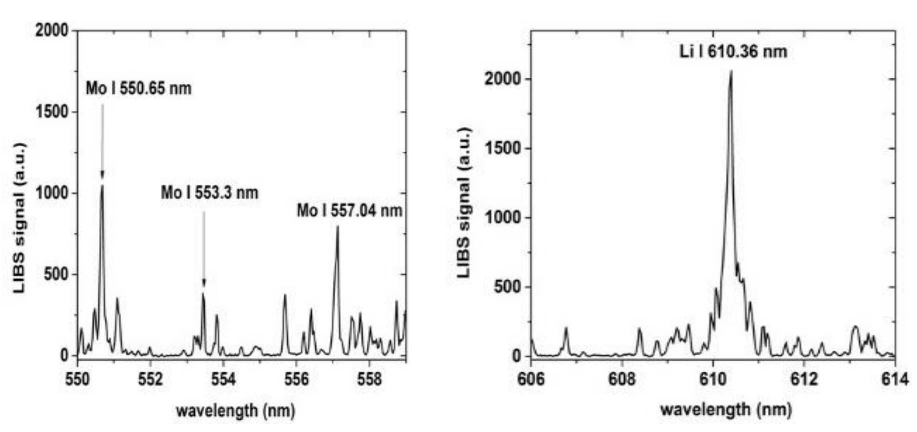


LIBS spectrum corresponding to one of the data points of left figure.

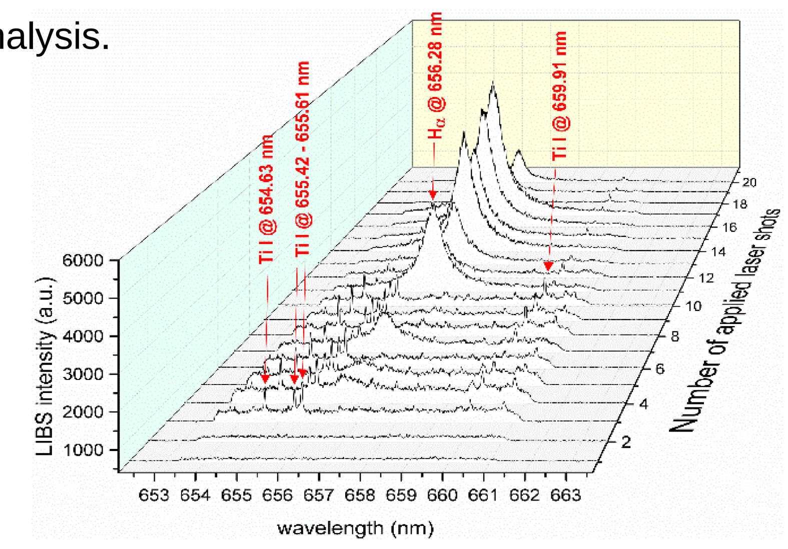
Remote handling application of LIBS in FTU



Robotic arm used in FTU for *in situ* LIBS analysis.



Parts of broadband LIBS spectrum recorded in FTU.



High-resolution depth profiling LIBS analysis on a stainless steel element of the FTU.

Conclusions and outlook

- With CF-LIBS low concentrations of fuel and other elements were succesfully measured in PFMs (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 succesfully implemented on the FTU robotic arm.

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