§25. In-situ LIBS Measurements of Hydrogen Isotope Retention and Material Mixing

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Surface analyses of plasma-facing materials (PFMs) have been, so far, performed generally by removing tiles from devices after a several-month long experimental campaign or by using a material probe system. However, it will be more limited in obtaining tiles in future devices with D-T plasma operations such as ITER. Thus, *in situ* monitoring of PFMs is quite beneficial to explore plasma-material interaction (PMI). Furthermore, *in situ* monitoring is desired to expedite PMI studies in current devices. Laser-induced breakdown spectroscopy (LIBS) is expected to be a promising technique for *in situ* monitoring of plasma-facing surfaces in fusion devices[1)], since remote sensing is possible and no surface preparation is necessary. In this study, the feasibility of LIBS is examined at UCSD-PISCES and at the Heliotron-DR device in Kanazawa University toward the application for the Large Helical Device (LHD). Nanosecond Nd:YAG lasers with the output wavelength of 1064 nm and ~6 ns pulse width were used.

Collinear double-pulse (DP) LIBS was tested with a tungsten target at a low background pressure of ~5 mTorr to mimic a fusion environment. We succeeded in obtaining ~2x signal enhancement by changing the inter-pulse separation time between two pulses compared to single-pulse (SP) LIBS. Another advantage of DP-LIBS was found; the signal to continuum intensity ratio is higher than SP-LIBS.

To investigate the mechanisms of the signal enhancement with DP-LIBS, images of laser-induced W plasmas were taken with an ICCD camera. Fig. 1 presents false color images of W plasmas at background Ar gas pressure P_{Ar} = 100 Torr produced by (a) SP-LIBS with laser energy E_L = 230 mJ and (b) DP-LIBS with E_{L1} = E_{L2} = 115mJ. For SP-LIBS, the peak intensity exists right above the target surface, indicating that the plasma expansion is restricted due to collisions with background Ar atoms. In the case of DP-LIBS, the peak intensity is ∼5 mm away from the surface, and the plasma volume is larger than that with SP-LIBS. This is because the plasma produced by the first pulse pushes away the surrounding gas in front of the target, and thus the second plasma easily expands. This leads to a larger plasma volume and then a higher signal intensity.

A W thin layer (~100 nm thickness) on a C substrate was analyzed with SP-LIBS. W I lines were clearly observed, and the sharp transition between the W layer and the C substrate was also seen.

The detection of He in W was attempted. First, a W sample was exposed to He plasma in PISCES-A at sample temperature ~773 K, incident ion energy ~50 eV, and He^+ fluence ~$5x10^{25}$ m^{-2}. In this condition, the thickness of He bubble layer in the near-surface region is around 20-30 nm. A He I line at 587.5 nm was successfully detected with SP-LIBS (P_{Ar} = 1 Torr, E_L = 230 mJ), as shown in Fig. 2.

To assess the calibration-free (CF) LIBS method, a steel sample with a known composition was analyzed. A reasonable composition was obtained with CF-LIBS, although the derived composition depends on LIBS parameters such as the background gas pressure.

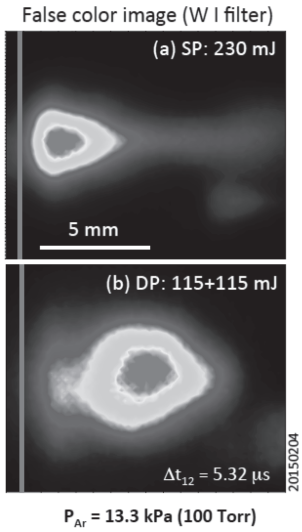

Fig. 1. False color images of laser-induced W plasmas taken with a narrow bandpass filter (430.2 nm, FWHM = 3 nm) at P_{Ar} = 100 Torr. (a) SP-LIBS (b) DP-LIBS.

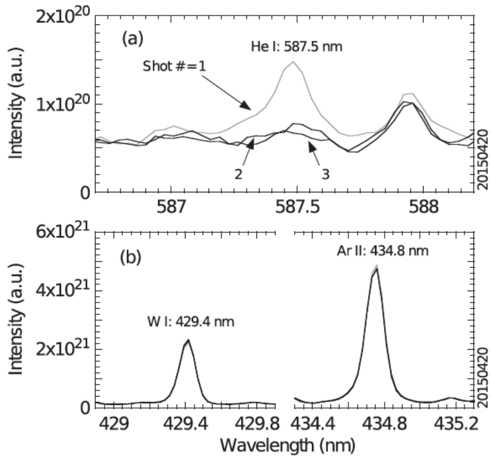

Fig. 2. Laser-induced plasma spectra, showing (a) He I 587.5 nm line and (b) W I 429.4 nm and Ar II 434.8 nm lines from W pre-exposed to He plasma.

1) Philipps, V. et al..: Nuclear Fusion **53** (2013) 093002.