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

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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. In this study, toward the application for Large Helical Device (LHD), the feasibility of LIBS is examined at UCSD-PISCES and at the Heliotron-DR device in Kanazawa University.

Stark broadening parameters for W I lines were experimentally determined for the first time, which allowed to measure the electron density in laser-induced W plasmas.

Fig. 1 (a) shows the Ar ambient gas pressure, P_{Ar}, dependence of the average ablation rate (AAR) of W irradiated with a nanosecond (ns) Q-switched Nd:YAG laser (wavelength λ = 1064 nm, pulse width Δt_L = 5 ns, laser energy E_L = 230 mJ). The depth of the crater was measured with a laser confocal microscope. The AAR is found to be constant up to P_{Ar} ~ 20 Torr, and rapidly drop with a further increase in P_{Ar}. The W I 429.4 nm line intensity peaks at P_{Ar} ~ 20 Torr. The decrease in AAR and the emission intensity at P_{Ar} > 20 Torr is caused by the plasma shielding of the incident laser energy as well as by the obstruction of plasma expansion.

Depth profiling of Al (layer thickness ~4.4 μm) deposited on the W substrate was performed with the ns laser. The shot number dependence of emission intensity of Al I lines exhibits a gradual decay: the Al I lines were observed even after 30 shots. On the other hand, a quick decay was obtained with Al II lines, which disappeared after 4 shots. A selection of transitions is found to be important for depth profiling.

Collinear double-pulse LIBS (DP-LIBS) using two ns lasers was tested for signal enhancement in comparison with single-pulse LIBS (SP-LIBS). With an interpulse separation time Δt_{12} = 5.32 μs, the W I 429.4 nm line intensity was enhanced with DP-LIBS at $P_{Ar} \geq$ 100 Torr. This is caused by the local pressure reduction in front of the target. Namely, the first plasma pushes away the ambient gas, and thus the second plasma can expand, leading to a larger plasma volume and a higher signal intensity compared to SP-LIBS. By varying Δt_{12}, a further study will be carried out at lower P_{Ar}.

A LIBS system has been designed and developed at the Heliotron-DR device, Kanazawa University. A preliminary experiment was conducted with a ns laser (λ = 532 nm, Δt_L = 5 ns) and a USB small spectrometer borrowed. In Heliotron-DR, ~150 nm thick a-C:D layer was first deposited on the Si substrate in D plasma discharge with C_6D_6 injection. The sample was then transferred in the interlock chamber for LIBS analysis. As shown in Fig. 2, D I lines were observed at He background pressure P_{He} ~ 5 Torr, while not observed at P_{He} ~ 1 Torr. Thus, the background pressure can be a key parameter, and will be further explored together with the effect of gas species. Note that D I lines were not observed in the following shots, indicating that the layer was removed with one shot.

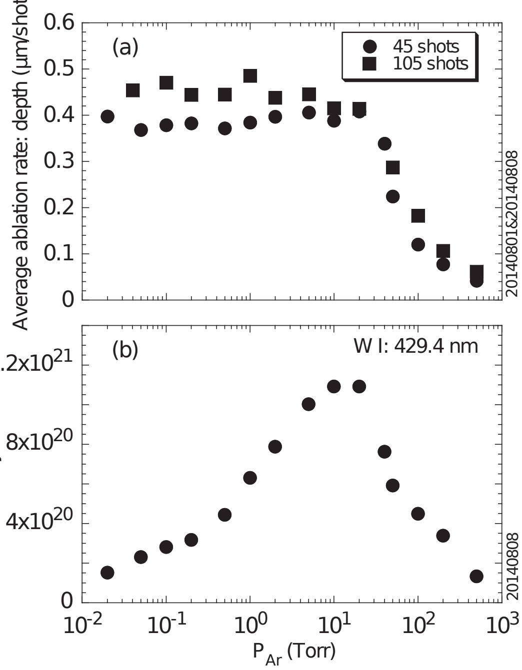

Fig. 1. P_{Ar} dependence of (a) W average ablation rate and (b) W I 429.4 nm line intensity.

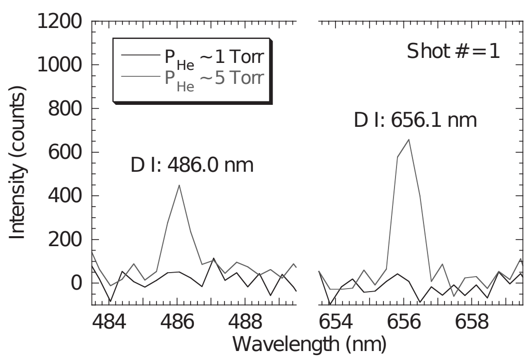

Fig. 2. D I line emission from a-C:D layer irradiated by a ns laser pulse at P_{He} ~ 5 Torr. Those lines were not seen at P_{He} ~ 1 Torr.

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