Depth profiling and thickness diagnosis of multilayer deposited samples using LPIR-LIBS technology

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During the operation of tokamak devices, plasma-facing components (PFCs) are exposed to high thermal loads and intense particle fluxes, resulting in plasma-wall interactions (PWI) that cause fuel retention, wall erosion, and impurity deposition. These issues present significant challenges to the performance of PFCs and the steady-state operation of tokamak devices. Laser-induced breakdown spectroscopy (LIBS), as a remote, *in situ* elemental diagnostic technique, demonstrates great potential for depth-profiling analysis of deposition layers on plasma-facing materials (PFMs).[1] However, the uneven radial distribution of laser energy and the complex structure of multilayer interfaces make accurate interface identification difficult. The precision of the thickness measurements of multilayer deposited samples significantly affects the quantitative analysis of impurity elements and is crucial for PWI research.

In this study, LIBS depth profiling of multilayer deposited samples was conducted in a vacuum environment of 5×10^{-5} mbar. A novel two-dimensional numerical model (LPIR model) was developed to account for key factors such as the laser beam profile and interface roughness.[2] The LPIR model was utilized to reconstruct the depth distribution profiles of multilayer samples, achieving a correlation coefficient exceeding 0.99 between experimental and simulated results, which validates the feasibility of the LPIR model. Furthermore, an interface localization method based on LPIR model predictions was proposed. For various thicknesses of deposited layers, the relative error between LIBS measurement results and actual thickness was approximately 5.1%, demonstrating the accuracy of the proposed approach.

To further address the influence of ablation rate on thickness determination, LIBS depth profiling was conducted on four-layer samples under various focusing conditions and laser fluences. The LPIR model was employed to reconstruct the corresponding depth profiles and quantify layer interface positions. The ablation rate was corrected based on the dependence of ablation behavior on laser fluence for different layers, and a thickness diagnosis method for multilayer deposited samples was proposed. [3] The effectiveness of this method was assessed by comparing calculated thicknesses with scanning electron microscope (SEM) measurements, demonstrating a substantial reduction in relative error after correction.

These results indicate that the LPIR model effectively explains the impact of laser profile and interface roughness on LIBS depth resolution, as well as reconstructs the LIBS depth distribution profile of multilayer deposited samples. With the LPIR model and the ablation rate correction method, the accuracy of interface location and thickness diagnosis of multilayer deposited samples has been significantly improved, which is crucial for the application of *in situ* LIBS diagnosis in PWI research.

References
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[3] S. M. Liu, *et al*, J. Anal. At. Spectrom. **39** (2024)

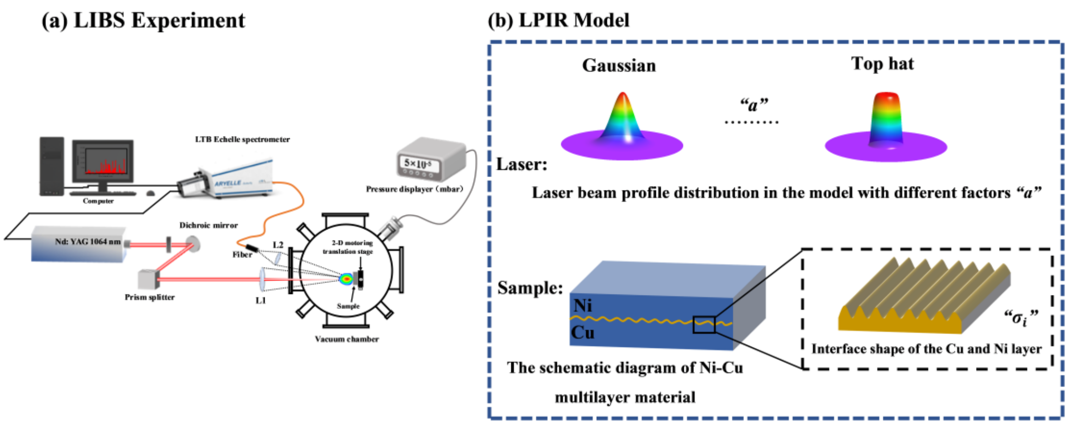

Figure 1 Schematic diagram of the (a) LIBS experimental setup, (b) LPIR model.