

Ultrafast Laser Delayering with In Situ LIBS for Sub-Micron Depth-Resolved Metrology

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Laser-induced breakdown spectroscopy (LIBS) offers rapid, in situ elemental analysis, but applying LIBS to high-resolution depth profiling in multilayer stacks is often constrained by a fundamental trade-off: conditions that enhance plasma emission and spectral stability can also increase the ablation increment and degrade interface fidelity. In this work, we establish an ultrafast laser-LIBS delayering workflow designed to maintain spectra suitable for iterative analysis while achieving sub-micron scale material removal per pass.

A systematic process map is constructed by benchmarking key operating parameters including pulse energy, repetition rate, scan speed, and burst operation. The objective is to identify regimes that balance controlled depth of cut, stable line emission, and repeatability over many delayering cycles. Using these operating windows, we achieve reproducible delayering with removal increments below one micrometer per pass, while preserving spectra suitable for depth resolved interpretation. Depth progression is monitored using 2D LIBS intensity maps to localize lateral compositional variations and 3D reconstructions to track how those variations evolve as deeper material becomes exposed. Distinct spectral transitions are observed at layer interfaces, enabling interface tracking and layer by layer compositional readout without separating delayering from chemical identification.

This ultrafast LIBS delayering approach provides a practical route to micrometer scale, depth resolved chemical characterization of complex layered structures. It supports faster failure analysis, process monitoring, and materials development where thin interfaces and spatial nonuniformity are critical.

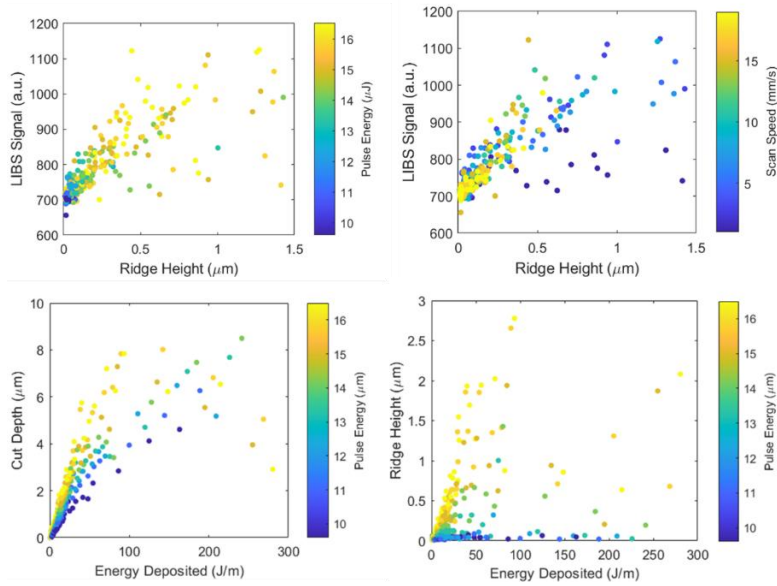


Figure 1: Relationship between laser process parameters and ablation outcomes. Results show a strong linear correlation between energy deposited and cut depth, while LIBS signal and ridge height exhibit higher variance influenced by pulse energy (μJ) and scan speed (mm/s).

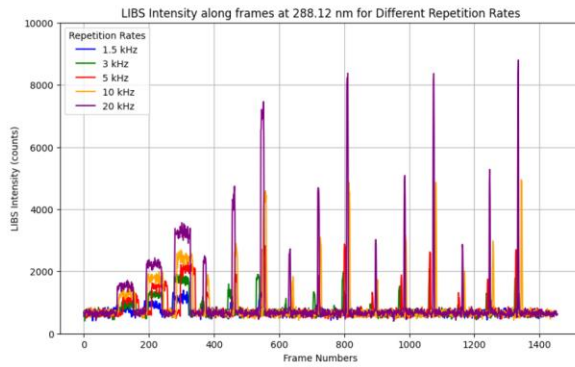


Figure 2: Benchmarking parameters to achieve less than 1 μm depth of cut

LIBS info:

Titanium-Silicon edge side:
First Vs. Last signal

Material	EPP	Rep Rate	Scan Speed	Iteration	Burst mode
Ti-Si	60 μJ	10 kHz	5 mm/s	150	N

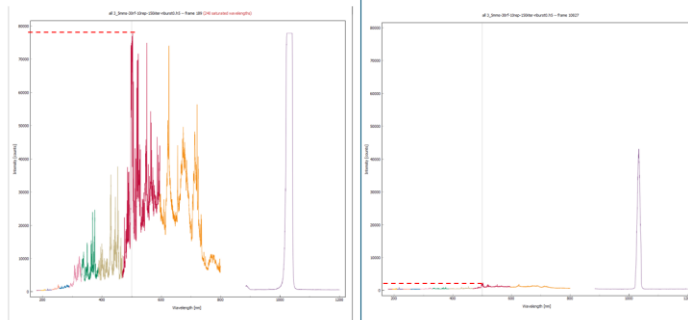


Figure 3: LIBS spectral evolution during deep-trench 3D mapping of a Ti-Si interface. A comparison between the initial signal (left) and final signal (right) after 150 iterations shows a significant intensity decay across the 200–800 nm range, indicating a transition from the Ti-rich surface to the underlying substrate layer