Precise real-time elemental detection is essential for industrial applications such as mining, pharmaceuticals, biological and medical waste management, aerosol analysis, and space exploration. A fast, contactless, and accurate method is highly desirable in these fields. Laser-induced breakdown spectroscopy (LIBS) has emerged as a powerful technique due to its rapid, multi-elemental, and quasi non-invasive detection capabilities. However, its sensitivity and precision in quantitative trace-element analysis require further enhancement.

This study explores two advanced LIBS-based approaches: microwave-assisted LIBS (MW-LIBS) and laser-induced fluorescence-assisted LIBS (LIBS-LIF) to improve elemental quantification. MW-LIBS enhances plasma characteristics by sustaining laser-induced plasma with microwave discharge, increasing plasma volume and extending its lifetime to hundreds of milliseconds. In contrast, LIBS-LIF improves detection sensitivity by selectively re-exciting specific elemental transitions using a secondary tunable laser.

A compact MW-LIBS system was developed using a synthesizer-driven microwave generation unit, replacing conventional bulky magnetron-based sources. This portable setup was applied to metallic targets under low-pressure argon conditions, demonstrating significant signal enhancement. Meanwhile, the LIBS-LIF configuration, incorporating an optical parametric oscillator (OPO)-based tunable laser, achieved detection limits down to the parts-per-billion (ppb) range. This method was successfully applied to soil phosphorus and carbon spectral band analysis, showcasing its potential for environmental and agricultural monitoring.

These findings highlight the transformative potential of MW-LIBS and LIBS-LIF for high-sensitivity elemental analysis. Their applications extend beyond traditional industrial use, offering promising solutions for environmental sustainability, precision agriculture, and fusion-related material diagnostics.