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EDITORIAL

Recent technological progress in Asia from the First Asian Symposium on Laser-induced Breakdown Spectroscopy

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As an atomic emission spectroscopy technique, laser-induced breakdown spectroscopy (LIBS), first proposed by Breech and Cross in 1962 [1], has attracted much academic and industrial interest for its unique properties. By focusing a pulsed laser onto the surface of a target, laser-induced plasmas can be generated. The simplicity of sample preparation of the laser ablation process enables LIBS to directly analyze solid, liquid, or gaseous materials in the atmosphere, making it a convenient tool for chemical analyses. The unique features of LIBS such as requiring little or no sample preparation, allowing remote detection, and facilitating multiple elemental analyses have contributed to its rapid development in recent years.

Since LIBS was proposed in 1962, related research has quickly spread; however, the challenges of poor stability, reliability, and reproducibility remain. Since the 1990s, coinciding with significant improvement in performance of hardware such as the lasers, spectrometers, and detectors, LIBS research has reached prominence with various applications in different fields such as industrial production [2] and environmental monitoring [3]. To further develop LIBS and make it a more practical tool in chemical analyses, the first international LIBS conference, held in 2000 in Pisa, Italy, facilitated the formation of the international LIBS community. Since then, LIBS has entered an era of fast and comprehensive development.

Currently, three major LIBS communities, specifically, a Euro-Mediterranean Society (EMSLIBS), a North America Society (NASLIBS), and an Asian Society (ASLIBS), are jointly promoting LIBS science and technology. LIBS has been regarded as a "future superstar" for chemical analyses [4]. The present trend suggests large-scale commercialization of LIBS and the change from a "future superstar" to an "actual superstar".

Among the three major LIBS societies, ASLIBS has experienced the fastest growth although it is a later comer. In 2011, the first Chinese Symposium on LIBS (CSLIBS) was successfully held in Qingdao, hosted by the Ocean University of China, which laid the foundation for the formation of a Chinese LIBS community. The first special issue on CSLIBS was published in the journal "Frontiers of Physics" in 2012 [5, 6]. CSLIBS has rapidly developed since then, and has become the foundation of further LIBS development in Asia. One milestone is that the 8th International Conference on LIBS (LIBS2014) was successfully held at Tsinghua University in September, 2014, which made ASLIBS as one of the three major LIBS communities in the world [7–9]. The success of LIBS2014 was followed by the first Asian Symposium on LIBS (ASLIBS2015) in Wuhan, hosted by the Wuhan National Laboratory for Optoelectronics and Huazhong University of Science and Technology. The number of attendees at ASLIBS2015 was greater than 200 from 8 countries (who gave 37 oral presentations and displayed 40 posters). ASLIBS2015 focused on the growth and application of new LIBS principles and methods, including novel industrial applications. To promote the development of LIBS, many aspects of LIBS research were included in ASLIBS2015, such as analysis of liquids [10–15], nuclear industry applications [16–21], in-situ and on-line analysis of steel [21–25], analysis of soils and agricultural applications [26–29], coal analysis [30–34], and spectral data processing [35–41]. The first special issue regarding the Chinese LIBS community was published on

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the journal "Frontiers of Physics" in 2012 [5]; the second special issue was published in the journal "Plasma Science and Technology" after LIBS2014 [42]. The current special issue regarding ASLIBS2015, is the third special issue from Chinese LIBS community; it includes articles reviewing the progress of LIBS in Asia [43], coal analysis [44], fusion applications [45], and other applications [46–48].

As seen from ASLIBS2015, as a chemical analysis technique, LIBS is in a period of vigorous development in Asia. Although many challenges remain, significant achievements fundamentals, instrumentation, and applications have been made. (i) Regarding the fundamentals of LIBS, the sensitivity enhancement of LIBS has focused on signal enhancement with magnetic confinement [49–51], spatial confinement [52–55], fast pulse discharge [56, 57], and dual-pulse lasers [58–60]. Laser-induced fluorescence (LIF) in plasmas is another method used to realize highly selective enhancement in LIBS, namely LIBS-LIF [61]. (ii) Regarding instrumentation, more than eight groups in China are committed to manufacturing instruments for industrial production. Two research groups from the Huazhong University of Science and Technology and Sichuan University have developed desktop and portable LIBS systems [62, 63]. (iii) Regarding LIBS applications, the steel industry has been an important area. At present, several groups, including those at the Huazhong University of Science and Technology, Shenyang Institute of Automation, and the Chinese Academy of Sciences, are working in this area [64–67], with research topics gradually changing from basic research to in-situ and on-line detection. LIBS appears to be a very promising analysis method in mineral processing and metallurgy processes. Coal analysis is another field in which LIBS has great potential. Four groups, including the South China University of Technology [68–73], Tsinghua University [17], Shanxi University [72–75], and University of Tokushima [76, 77], have been concentrating on improving the analysis accuracy for different components of coal that affect coal quality. For applications in soil analysis, sample preparation proved useful for soil classification [78]. Novel methods [79–82], such as standard addition methods combined with wavelet transforms, and laser ablation assisted with spark have been used to improve the accuracy of soil analysis, and the application studies show that LIBS seems to be a potential technique [83–85]. In liquid analyses, the Ocean University of China first realized LIBS for underwater detection [86, 87]. Meanwhile, groups in Japan utilized electrodeposition with underwater LIBS for analyses of trace metals in aqueous solutions. Many novel methods have been introduced to detect liquid samples, including surface-enhanced LIBS [88], changing liquid samples from static to dynamic [89], absorbing samples using solids [91], and drying on metallic surfaces [92]. Data processing can be used to compensate for the shortcomings of hardware.

To improve the quality and quantity of LIBS information, data preprocessing methods were rapidly developed in recent years. Denoising [83–97], spectrum standardization [98, 99], continuous background removal [100], overlapping peak resolution [101], self-absorption correction [102, 103], data analysis methods including partial least squares (PLS) [104], the support vector machine [105], and random forest regression [106] model have received thorough study. Specifically, a novel method using the dominant-factor-based multivariate model has been proposed; it proved to be effective in terms of improving the accuracy and precision of LIBS [106].

In the future, LIBS, a promising technique with excellent features such as requiring little or no sample preparation, allowing remote detection, and facilitating multiple elemental analyses, will meet a large range of demands in various areas. However, poor stability, repeatability, and reproducibility remain important challenges. LIBS researchers are motivated to overcome these drawbacks to realize large-scale commercialization of LIBS.

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