清華大學 能源与动力工程系
Department of Energy and Power Engineering, Tsinghua University

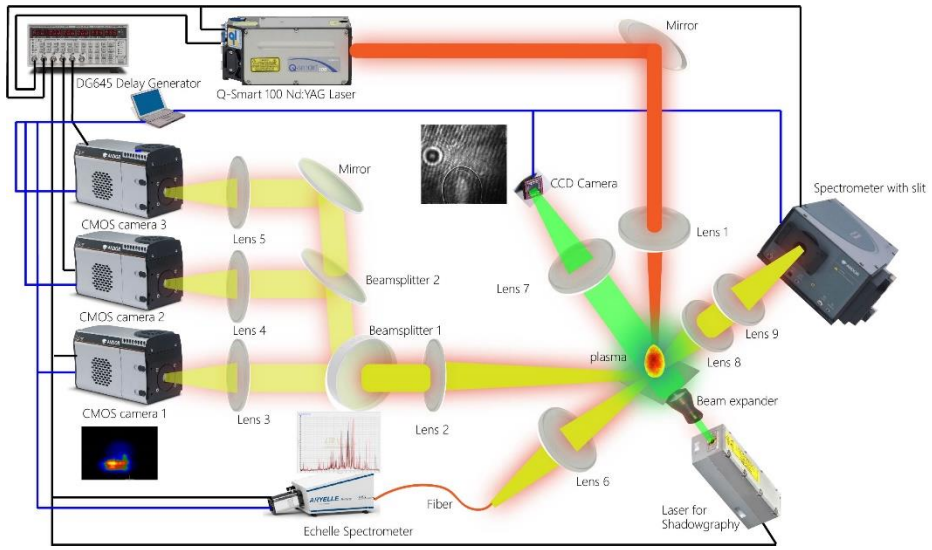
LIBS research group

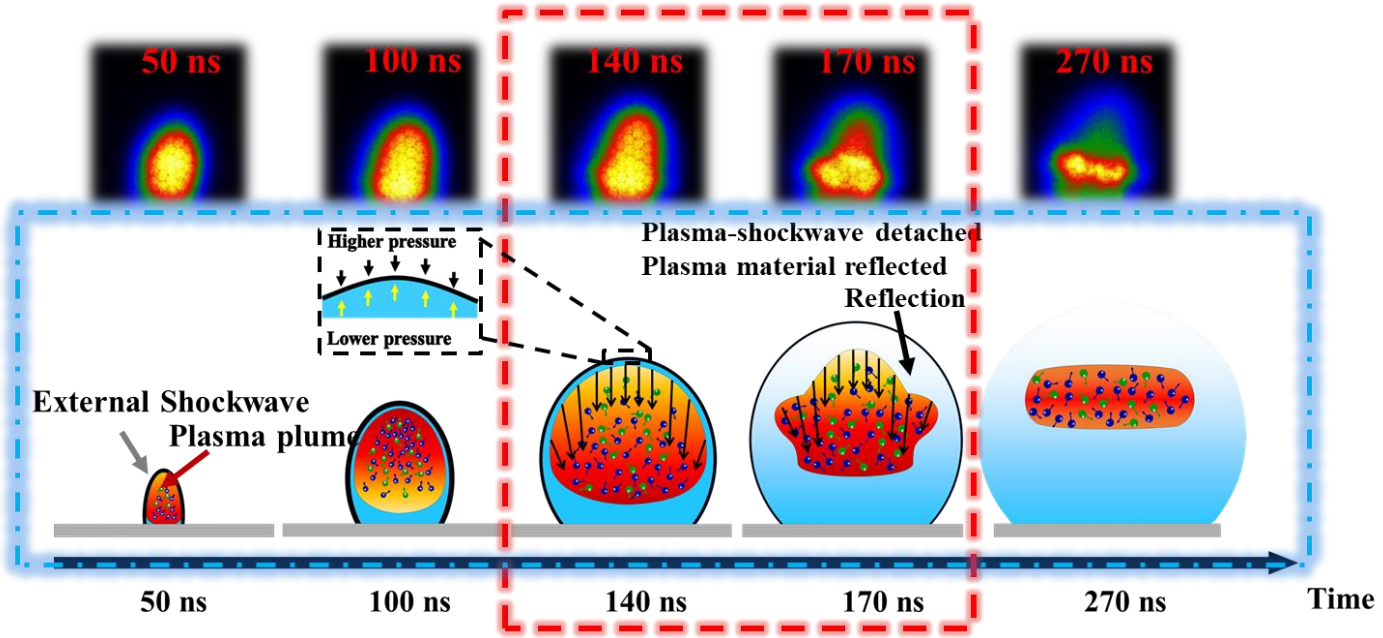
- Our group was initiated in 2008 with the research interest focused on fast and online coal analysis to underpin clean and efficient utilization of coal. With the deepening of research and development of economy and society, we devoted to improve the quantification performance of LIBS and promote the application of LIBS to various fields such as metal, cement, and mineral.

LIBS research group

Fundamental research: uncertainty origination

- We built a transient diagnosis platform of LIBS to investigate the plasma evolution and revealed the mechanism of LIBS uncertainty origination: Rayleigh-Taylor instability, surface roughness → initiate the instability → plasma evolution (mixing and expansion of plasma in ambient gas) → plasma frontier material dash-down and crash the lower part (critical period) → large instability of plasma morphology → signal uncertainty.





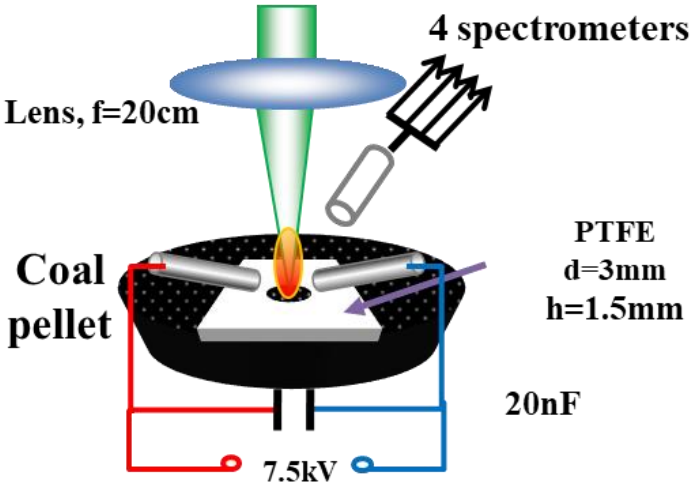
Mechanism of signal uncertainty generation for laser-induced breakdown spectroscopy,
YT Fu, WL Gu, ZY Hou, SA Muhammed, TQ Li, Y Wang, Z Wang, Frontiers of Physics 16 (2), 1-10

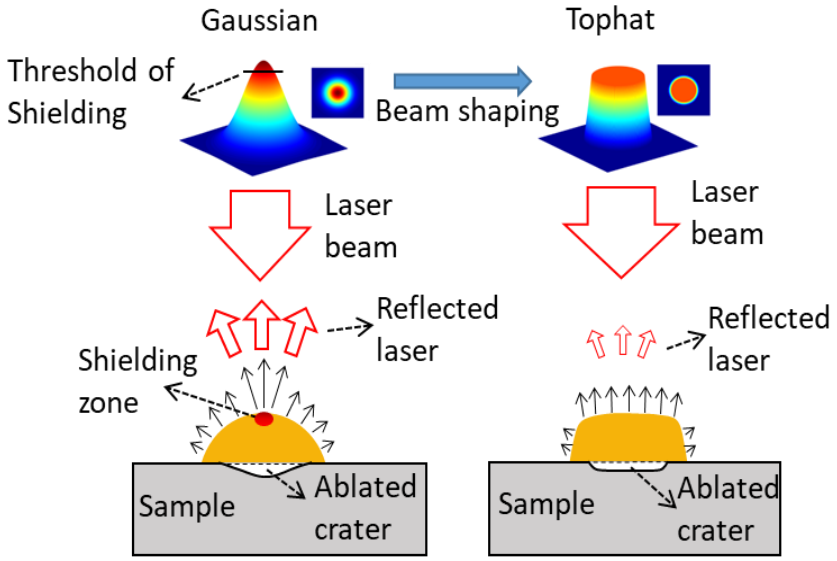
Recent Advances in Laser-induced Breakdown Spectroscopy Quantification: from Fundamental Understanding to Data Processing, Z Wang, MS Afgan, W Gu, Y Song, Y Wang, Z Hou, W Song, Z Li, TrAC Trends in Analytical Chemistry, 143(2021),116385

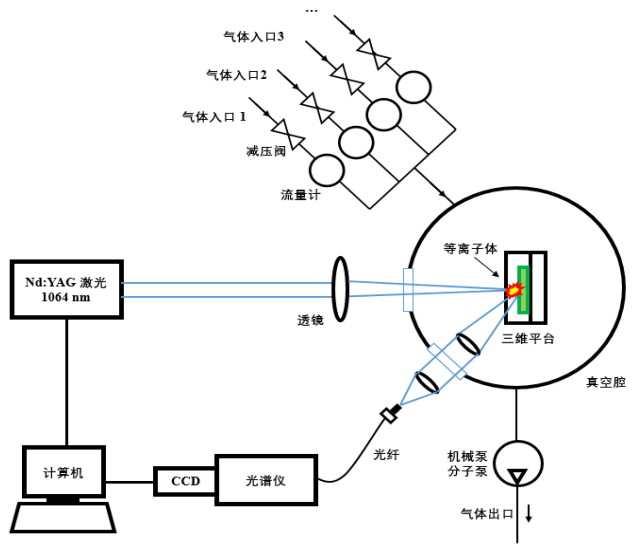
LIBS research group

Key technology: plasma modulation

- We developed a series of plasma modulation technologies to regularize the interaction of laser-sample-plasma-ambient gas, so as to reduce the fluctuation of plasma morphology and improve the repeatability of LIBS signal.
  - Spatial confinement, beam shaping, gas mixture, etc.







LIBS research group

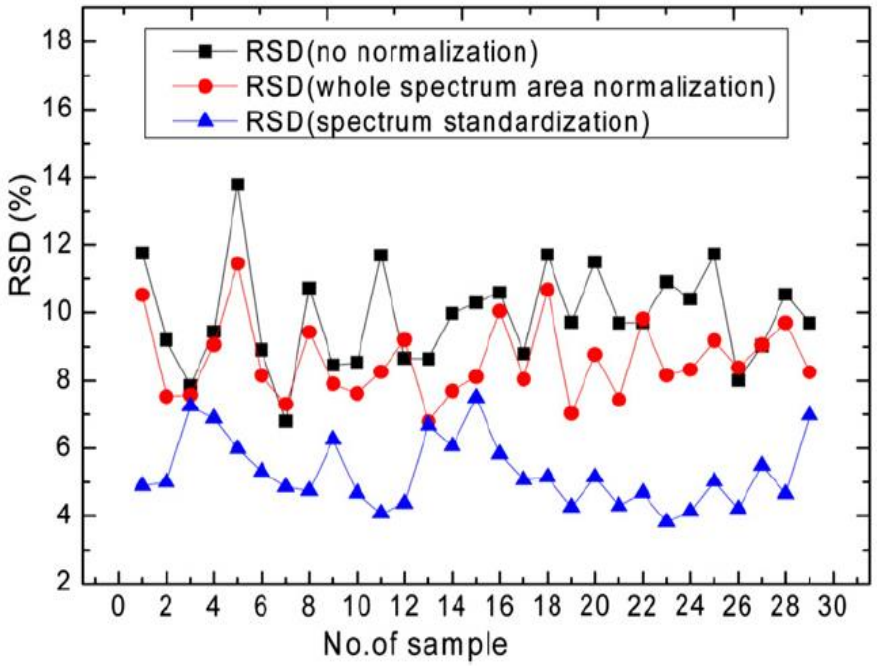
Key technology: spectrum standardization

- It was assumed that the uncertainty of LIBS can be attributed to the deviation of plasma state from a standard plasma state (with standard temperature T, electron density n_e and total number density of species n_s).
- Spectrum standardization method was proposed to compensate the deviation of plasma state from the standard plasma state: dT, dn_e and dn_s, so as to reduce the uncertainty of LIBS.

$$I_{ij}(n_s,T,n_e) \approx I_{ij}(n_{s0},T_0,n_{e0}) + \left(\frac{\partial I_{ij}}{\partial n_s}\mathrm{d}n_s + \frac{\partial I_{ij}}{\partial T}\mathrm{d}T + \frac{\partial I_{ij}}{\partial n_e}\mathrm{d}n_e\right)\Big|_{(n_{s0},T_0,n_{e0})}$$

$$I_{ij}(n_{s0},T_0,n_{e0}) \approx I_{ij}(n_s,T,n_e) - (K_1\mathrm{d}n_s + K_2C\mathrm{d}T + K_3C\mathrm{d}n_e)$$

$$I_{ij}(n_{s0},T_0,n_{e0}) = K_0C = K_0\frac{b_1I_{ij} + b_2I_T + b_5}{1 - b_3\left(\ln\left(\frac{I_2}{I_1}\right) - \left(\ln\left(\frac{I_2}{I_1}\right)\right)_0\right) - b_4\left(\Delta\lambda_{\mathrm{stark}} - (\Delta\lambda_{\mathrm{stark}})_0\right)}$$



A spectrum standardization approach for laser-induced breakdown spectroscopy measurements, Z Wang, L Li, L West, Z Li, W Ni,Spectrochimica Acta Part B: Atomic Spectroscopy 68, 58-64

A simplified spectrum standardization method for laser-induced breakdown spectroscopy measurements, L Li, Z Wang, T Yuan, Z Hou, Z Li, W Ni, Journal of Analytical Atomic Spectrometry 26 (11), 2274-2280

Key technology: dominant factor based model

- Dominant factor: based on physical laws, with a wide range of application, reliable
- Statistical method correction: compensate the residue of dominant factor with full spectrum
- Improve the accuracy and robustness of calibration model

Dominant Factor

- Self-absorption

$$C_i = C_0 \ln\left(\frac{bC_0}{a + bC_0 - I_i}\right)$$

⇩

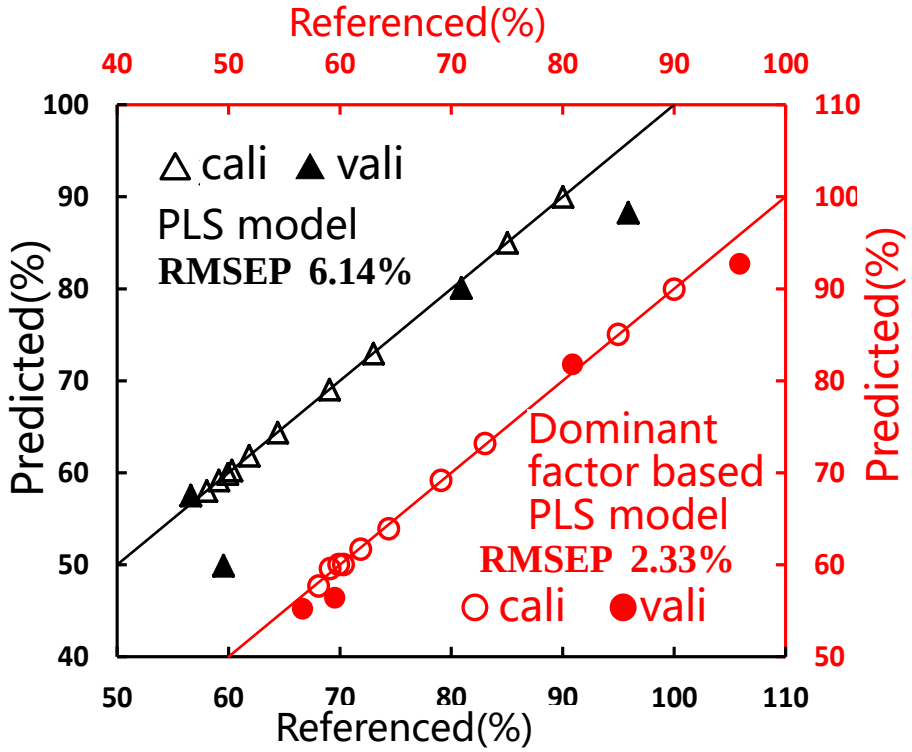
- Interference

$$C_i = C_0 \ln\left(\frac{bC_0}{a + bC_0 - I_i}\right) + g(I_k)$$

⇩

PLS Correction using full spectral information

$$C_i = C_0 \ln\left(\frac{bC_0}{a + bC_0 - I_i}\right) + g(I_k) + \sum_{j=1}^{n} b_j I_j + b_0$$

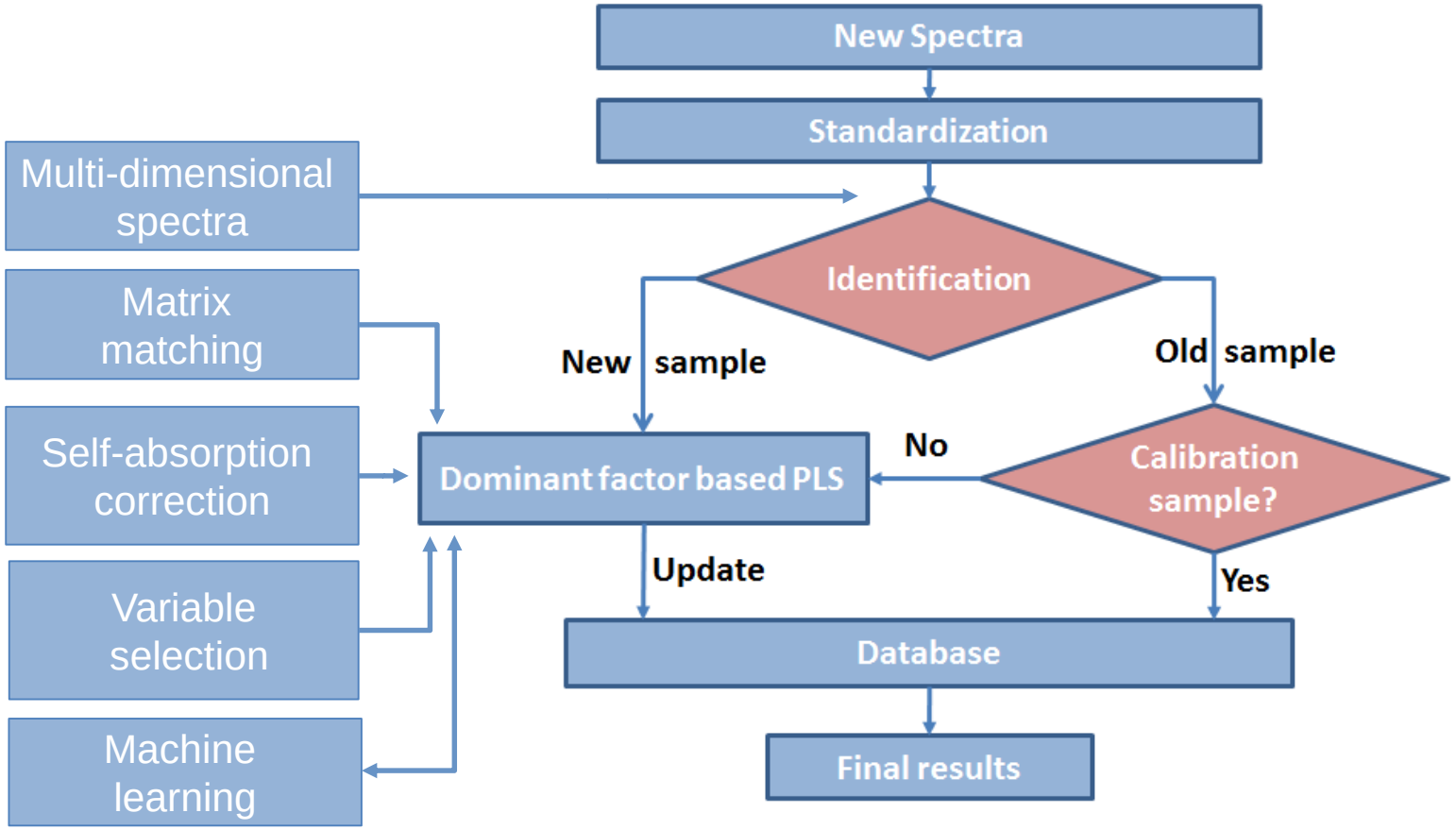


A multivariate model based on dominant factor for laser-induced breakdown spectroscopy measurements, Z Wang, J Feng, L Li, W Ni, Z Li, Journal of Analytical Atomic Spectrometry 26 (11), 2289-2299

LIBS research group

Key technology: hybrid quantification model

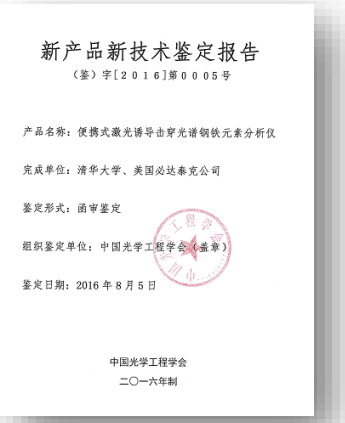
- We firmly believe that quantification model has to be based on the principle of LIBS and combined with modern machine learning methods
- We developed a set of methods to improve the measurement repeatability, reproducibility, sensitivity, accuracy, and matrix adaptability



LIBS research group

Application

- Our patented technology has been licensed and transferred to companies at home and abroad.
- A set of LIBS products and systems have been developed and applied in different fields including coal, metal, and cement etc.


新产品新技术鉴定报告

（鉴）字[2016]第0005号

产品名称：便携式激光诱导击穿光谱钢铁元素分析仪

完成单位：清华大学、美国必达泰克公司

鉴定形式：函审鉴定

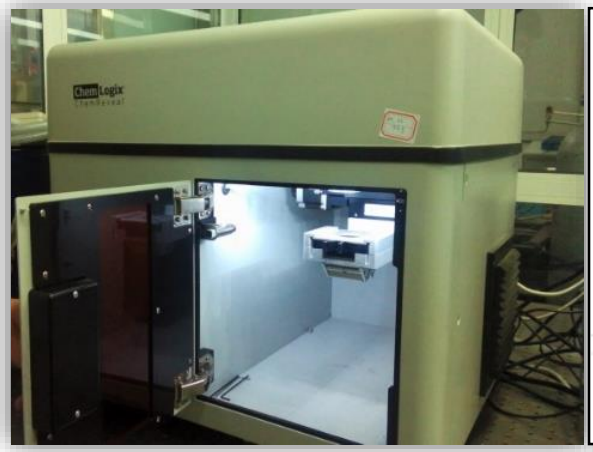
组织鉴定单位：中国光学工程学会（盖章）

鉴定日期：2016年8月5日

中国光学工程学会

二〇一六年制

Handheld steel analyzer




鉴定证书

证书编号：2016060Z号

送检单位 清华大学

计量器具名称 ChemReveal台式LIBS煤质分析仪

型号/规格 3764-COAL

制造单位 清华大学和美国TSI公司（TSI Incorporated）联合生产

批准人

核验员

检验员

鹤壁市质量技术监督检验测试中心

检验日期 2016年06月08日

Desktop coal analyzer

Online coal analysis system

Online cement analysis system

LIBS research group

Contribution to LIBS society

- 2014, held the 8th International Conference on LIBS
- 2015, initiated the Asian Symposium on LIBS
- 2016, initiated the LIBS Committee of China
- 2019, initiated the International Summit on LIBS and held the 1st International Summit on LIBS
- Attended LIBS related conferences more than 30 times

LIBS research group

Selected publications

- Z Wang, MS Afgan, W Gu, Y Song, Y Wang, Z Hou, W Song, Z Li, Recent Advances in Laser-induced Breakdown Spectroscopy Quantification: from Fundamental Understanding to Data Processing, TrAC Trends in Analytical Chemistry, 143(2021),116385
- W. Song, Z. Hou, W. Gu, H. Wang, J. Cui, Z. Zhou, G. Yan, Q. Ye, Z. Li, Z. Wang, Industrial at-line analysis of coal properties using laser-induced breakdown spectroscopy combined with machine learning, Fuel, 306 (2021) 121667.
- W. Gu, W. Song, G. Yan, Q. Ye, Z. Li, M.S. Afgan, J. Liu, Y. Song, Z. Hou, Z. Wang, Z. Li, A data preprocessing method based on matrix matching for coal analysis by laser-induced breakdown spectroscopy, Spectrochimica Acta Part B: Atomic Spectroscopy, 180 (2021) 106212.
- Y. Fu, W. Gu, Z. Hou, , M.S. Afgan, T. Li, Y. Wang, Z. Wang, Mechanism of signal uncertainty generation for laser-induced breakdown spectroscopy, Frontiers of Physics, 16 (2020) 22502.
- W. Song, Z. Hou, M.S. Afgan, W. Gu, H. Wang, J. Cui, Z. Wang, Y. Wang, Validated ensemble variable selection of laser-induced breakdown spectroscopy data for coal property analysis, J Anal Atom Spectrom, 36 (2021) 111-119.
- J. Yu, Z. Hou, Y. Ma, T. Li, Y. Fu, Y. Wang, Z. Li, Z. Wang, Improvement of laser induced breakdown spectroscopy signal using gas mixture, Spectrochimica Acta Part B: Atomic Spectroscopy, 174 (2020) 105992.
- Z. Hou, M.S. Afgan, S. Sheta, J. Liu, Z. Wang, Plasma modulation using beam shaping to improve signal quality for laser induced breakdown spectroscopy, J Anal Atom Spectrom, 35 (2020) 1671-1677.
- T. Li, Z. Hou, Y. Fu, J. Yu, W. Gu, Z. Wang, Correction of self-absorption effect in calibration-free laser-induced breakdown spectroscopy (CF-LIBS) with blackbody radiation reference, Anal Chim Acta, 1058 (2019) 39-47.
- S. Sheta, M.S. Afgan, Z. Hou, S.-C. Yao, L. Zhang, Z. Li, Z. Wang, Coal analysis by laser-induced breakdown spectroscopy: a tutorial review, J Anal Atom Spectrom, 34 (2019) 1047-1082.
- Y. Fu, Z. Hou, T. Li, Z. Li, Z. Wang, Investigation of intrinsic origins of the signal uncertainty for laser-induced breakdown spectroscopy, Spectrochimica Acta Part B: Atomic Spectroscopy, 155 (2019) 67-78.
- Y. Fu, Z. Hou, Z. Wang, Physical insights of cavity confinement enhancing effect in laser-induced breakdown spectroscopy, Optics Express, 24 (2016) 3055-3066.
- Z. Hou, Z. Wang, T. Yuan, J. Liu, Z. Li, W. Ni, A hybrid quantification model and its application for coal analysis using laser induced breakdown spectroscopy, J Anal Atom Spectrom, 31 (2016) 722-736.

LIBS research group

- We'll keep on working to improve the quantification performance of LIBS and promote LIBS to other fields
- Make the "future superstar" to real "superstar"!