


David A. Cremers and
Leon J. Radziemski

Handbook of **LASER-INDUCED** BREAKDOWN SPECTROSCOPY

 WILEY

Hardcover: 302 pages

Publisher: John Wiley & Sons
(July 11, 2006)

Language: English

ISBN: 0470092998



DC on the left and LR on the right

Foreword xi

Preface xiii

Acronyms, Constants and Symbols

xvii

1 History

1

1.1 Atomic Optical Emission Spectrochemistry (OES)

1

1.1.1 Conventional OES

1

1.1.2 Laser OES

1

1.2 Laser-Induced Breakdown Spectroscopy (LIBS)

2

1.3 LIBS History 1960–1980

6

1.4 LIBS History 1980–1990

9

1.5 LIBS History 1990–2000

11

1.6 Active Areas of Investigation, 2000–2002

15

References

16

2 Basics of the LIBS Plasma

23

2.1 LIBS Plasma Fundamentals

23

2.1.1 Spectral Lines and Line Profiles

25

2.1.2 Determining Electron Densities from Spectral Line Widths

27

2.1.3 Plasma Opacity

30

2.1.4 Temperature and Thermodynamic Equilibrium

31

2.2 Laser-Induced Breakdown

36

2.2.1 Breakdown in Gases

36

2.2.2 Post-Breakdown Phenomena in Gases

39

2.2.3 Breakdown In and On Solids, Aerosols and Liquids

39

2.2.4 Post-Breakdown Phenomena on Solid Surfaces

41

2.3 Laser Ablation

43

2.4 Double or Multiple Pulse LIBS

47

2.5 Summary

49

References

50

| | | |
|----------|--|-----------|
| 3 | Apparatus Fundamentals | 53 |
| 3.1 | Basic LIBS Apparatus | 53 |
| 3.2 | Lasers | 54 |
| 3.2.1 | Laser Fundamentals | 54 |
| 3.2.2 | Types of Lasers | 55 |
| 3.2.3 | Properties of Laser Light Important for LIBS | 58 |
| 3.2.4 | Generation of Additional Wavelengths | 60 |
| 3.2.5 | Double Pulse Operation | 61 |
| 3.3 | Optical Systems | 62 |
| 3.3.1 | Focusing and Light Collection | 62 |
| 3.3.2 | Lenses | 63 |
| 3.3.3 | Fiber Optic Cables | 65 |
| 3.4 | Methods of Spectral Resolution | 69 |
| 3.4.1 | Introduction | 69 |
| 3.4.2 | Spectral Resolution Devices | 70 |
| 3.5 | Detectors | 83 |
| 3.6 | Detection System Calibrations | 88 |
| 3.6.1 | Wavelength Calibration | 88 |
| 3.6.2 | Spectral Response Calibration | 90 |
| 3.7 | Timing Considerations | 93 |
| 3.8 | Methods of LIBS Deployment | 94 |
| | References | 96 |

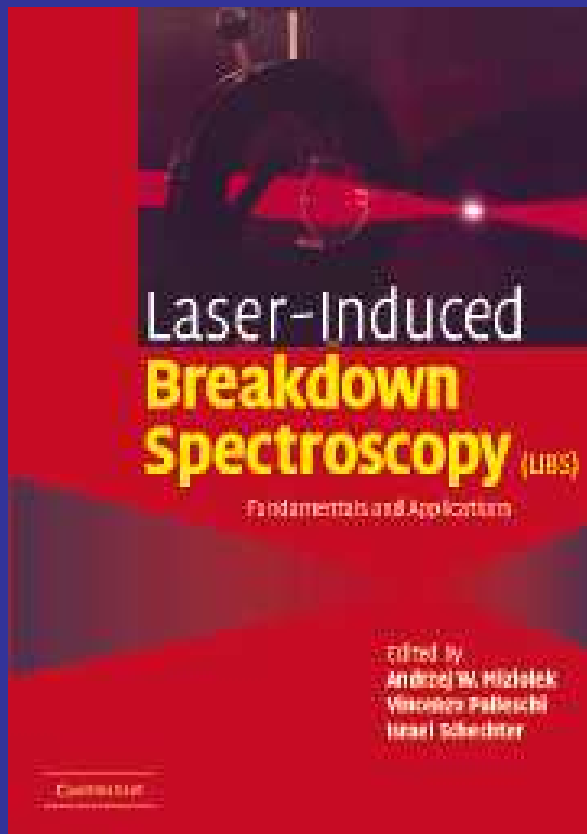
| | | |
|----------|---|------------|
| 4 | Determining LIBS Analytical Figures-of-Merit | 99 |
| 4.1 | Introduction | 99 |
| 4.2 | Basics of LIBS Measurements | 99 |
| 4.3 | Precision | 105 |
| 4.4 | Calibration | 107 |
| 4.4.1 | Calibration Curves | 107 |
| 4.4.2 | Calibration Standards | 113 |
| 4.5 | Detection Limit | 115 |
| 4.6 | Accuracy | 115 |
| | References | 116 |
| | | |
| 5 | Qualitative LIBS Analysis | 119 |
| 5.1 | Introduction | 119 |
| 5.2 | Identifying Elements | 119 |
| 5.3 | Material Identification | 122 |
| 5.4 | Process Monitoring | 125 |
| 5.4.1 | Experimental | 126 |
| 5.4.2 | Results | 127 |
| 5.4.3 | Conclusions | 133 |
| 5.5 | Material Sorting/Distinguishing | 133 |
| 5.5.1 | Surface Condition | 134 |
| 5.5.2 | Type of Analysis | 134 |
| 5.5.3 | Sorting Materials of Close Composition | 136 |
| 5.6 | Site Screening Using LIBS | 137 |
| | References | 141 |

| | | |
|----------|--|------------|
| 6 | Quantitative LIBS Analysis | 143 |
| 6.1 | Introduction | 143 |
| 6.2 | Effects of Sampling Geometry | 143 |
| 6.3 | Other Sampling Considerations | 147 |
| 6.4 | Particle Size and Incomplete Vaporization | 151 |
| 6.5 | Use of Internal Standardization | 152 |
| 6.6 | Chemical Matrix Effects | 153 |
| 6.7 | Example of LIBS Measurement: Impurities in Lithium Solutions | 155 |
| 6.7.1 | Objective | 155 |
| 6.7.2 | Experimental | 156 |
| 6.7.3 | Results | 158 |
| 6.7.4 | Discussion of Results | 163 |
| 6.8 | Reported Figures-of-Merit for LIBS Measurements | 164 |
| 6.9 | Conclusions | 168 |
| | References | 168 |

| | | |
|----------|---|------------|
| 7 | Remote LIBS Measurements | 171 |
| 7.1 | Introduction | 171 |
| 7.2 | Conventional Open Path LIBS | 173 |
| 7.2.1 | Apparatus | 173 |
| 7.2.2 | Focusing the Laser Pulse | 174 |
| 7.2.3 | Collecting the Plasma Light | 178 |
| 7.2.4 | Results Using Conventional LIBS | 179 |
| 7.3 | Stand-off LIBS Using Femtosecond Pulses | 182 |
| 7.3.1 | Conventional Remote LIBS Using Femtosecond Laser Pulses | 182 |
| 7.3.2 | Remote Analysis by Femtosecond Pulse Produced Filamentation | 184 |
| 7.3.3 | Teramobile | 185 |
| 7.3.4 | Remote LIBS Using Femtosecond Pulses | 186 |
| 7.4 | Fiber Optic LIBS | 187 |
| 7.4.1 | Fiber Optics for Light Collection | 187 |
| 7.4.2 | Fibers for Laser Pulse Delivery | 189 |
| 7.4.3 | Applications of Fiber Optics | 192 |
| | References | 195 |

| | | |
|----------|---|------------|
| 8 | Examples of Recent LIBS Fundamental Research, Instruments and Novel Applications | 197 |
| 8.1 | Introduction | 197 |
| 8.2 | Fundamentals | 197 |
| 8.3 | Calibration-Free LIBS (CF-LIBS) | 201 |
| 8.4 | Laser and Spectrometer Advances | 203 |
| 8.5 | Surface Analysis | 205 |
| 8.6 | Double Pulse Studies and Applications | 208 |
| 8.7 | Steel Applications | 210 |
| 8.8 | LIBS for Biological Materials | 211 |
| 8.9 | Nuclear Reactor Applications | 212 |
| 8.10 | LIBS for Space Applications | 214 |
| | References | 223 |
| 9 | The Future of LIBS | 227 |
| 9.1 | Introduction | 227 |
| 9.2 | Expanding the Understanding and Capability of the LIBS Process | 227 |
| 9.3 | Widening the Universe of LIBS Applications | 229 |
| 9.4 | Factors that will Speed the Commercialization of LIBS | 230 |
| 9.4.1 | LIBS Standardization and Quantification | 230 |
| 9.4.2 | Routine LIBS use in Industrial Applications | 230 |
| 9.4.3 | Availability of Components and Systems | 231 |
| 9.5 | Conclusion | 232 |
| | References | 233 |

| | | |
|---|--|------------|
| Appendix A | | |
| | Safety Considerations in LIBS | 237 |
| A.1 | Safety Plans | 237 |
| A.2 | Laser Safety | 237 |
| A.3 | Generation of Aerosols | 238 |
| A.4 | Laser Pulse Induced Ignition | 239 |
| | References | 239 |
| Appendix B | | |
| | Recommended Methods for Commencing LIBS | |
| | Research on a Variety of Samples | 241 |
| | References | 243 |
| Appendix C | | |
| | Representative LIBS Detection Limits | 245 |
| | C.1 Detection Limits from the Literature | 245 |
| | C.2 Uniform Detection Limits | 263 |
| | References | 265 |
| Appendix D Major LIBS References | | 271 |
| Index | | 275 |



Laser Induced Breakdown Spectroscopy

Edited by Andrzej Miziolek

U.S. Army Research Laboratory, USA

Vincenzo Palleschi

Istituto per I Processi Chimico-Fisici, Italy

Israel Schechter

Technion - Israel Institute of Technology, Haifa, Israel

Hardback

(ISBN-13: 9780521852746 | ISBN-10: 0521852749)

Available from August 2006

Cambridge University Press 2006