Contents

Chapter I An In	stroduction to Microwave Plasma Spectrometries	J			
1.1	Introduction]			
	1.1.1 Historical Background	2			
	1.1.2 The Present Status of Microwave Plasma				
	Spectrometry	4			
1.2	Energy Flow between Microwave Plasma and				
	Analyte	4			
	1.2.1 Microwave Power Absorption by the				
	Plasma	4			
	1.2.2 Plasma–Sample Interaction	6			
	1.2.3 Analyte Excitation and Ionization	7			
	1.2.4 Summary: Energy Flow Diagram	8			
1.3	1.3 Microwave Plasma Generation				
	1.3.1 Microwave Plasma Geometries (Configurations)	12			
	1.3.2 Power Density versus Plasma Stability	13			
1.4	Basic Physical Characteristics of a Microwave Plasma				
	Discharge				
1.5	Spectroscopic Techniques Employing Microwave				
	Induced Plasmas	17			
Refe	erences	18			
	nmentation for Microwave Induced Plasma Optical sion Spectrometry	23			
2.1	The Components of a Microwave Induced Plasma				
	Optical Emission Spectrometry System	23			
2.2	Microwave Induced Plasma Torches	20			
	2.2.1 Torch Designs	27			

RSC Analytical Spectroscopy Monographs No. 12

Microwave Induced Plasma Analytical Spectrometry

By Krzysztof J. Jankowski and Edward Reszke

© The Royal Society of Chemistry 2011

Published by the Royal Society of Chemistry, www.rsc.org

x	Contents	Contents
---	----------	----------

xi

		2.2.2 The Importance of Vertical Positioning of a		4.3 Working with Microwave Plasmas	95
		Microwave Induced Plasma Torch	30	4.4 General Rules and Methods	96
	2.3	Pros and Cons of the Microwave Induced Plasma		References	97
		Technique	30		
	Refe	erences	34	Chapter 5 Optical Emission Spectrometry with Microwave Plasmas	98
6 1		in to district the of Missesses		5.1 Origins of Atomic Spectra	98
Chapter 3		iples of Operation and Construction of Microwave	27	5.2 Basic Spectroscopy Practice	101
	Plasn	na Cavities	37	5.2.1 Spectral Line Intensity	101
	2.1	E and H town Dischanges at Different Cas Drassums		5.2.2 Background Correction	101
	3.1	E- and H-type Discharges at Different Gas Pressures	27	5.2.3 Transient Signal Measurement	102
		and Frequencies	37	5.3 Instrumentation	103
	2.2	3.1.1 Choice of Operating Frequency	39	5.3.1 Spectrometer Configurations	103
	3.2	Some Basic Knowledge about Microwave	20	5.3.2 The Use of Echelle Optics to Observe the	
		Transmission Lines and Resonant Cavities	39	Emission from Microwave Plasmas	104
		3.2.1 Requirements for an Ideal Microwave	4.4	5.3.3 Interference Filters	105
		Cavity	44	5.3.4 Instruments Based on Fibre Optics	106
		3.2.2 What Makes a Good Microwave Plasma?	45	5.3.5 Detection Systems	106
		3.2.3 Sample Introduction into a Microwave	46	5.4 The Microwave Induced Plasma Spectrum: General	
	2.2	Plasma General Classification of Possible Microwave Plasma	40	Description	108
	3.3		47	5.5 Provisional Wavelength Tables Specific for	
		Sources	47	Microwave Induced Plasma Spectra	111
		3.3.1 E-type Microwave Plasma Sources	47 71	References	118
		3.3.2 H-type Microwave Plasma Sources	71		
		3.3.3 Hybrid EH-types of Microwave Plasma	77	Chapter 6 Introduction of Gases and Vapours into Microwave Plasmas	121
	2.4	Sources Making Angular shared Microwaya Plagmas	77 79		
	3.4	Making Annular-shaped Microwave Plasmas 3.4.1 Introducing the Symmetry of Microwave	19	6.1 Introduction	121
				6.2 Continuous Gas Introduction	124
		Energy Coupling and Making a Doughnut-shaped Plasma	79	6.3 Hydride Generation and Related Techniques	125
		3.4.2 Plasma-to-doughnut Shape Approaches	81	6.4 Generation of Other Gaseous Species	127
		3.4.3 Making the Annular-shaped Microwave	01	6.5 Microwave Induced Plasma Coupling with Gas	
		Plasma	81	Chromatographic Techniques	128
	3.5	The Concept of Microwave Cavities with Rotating	01	6.5.1 Atomic Emission Detector	130
	3.3	Microwave Fields	83	6.6 Solid-phase Microextraction	133
		3.5.1 Comments on Plasma Contamination in the	0.5	6.7 Quantitative Analysis of Gases	134
		New Capacitive Microwave Plasma		References	135
		Systems	87		
	3.6	Final Remarks: Thinking of the Future	89	Chapter 7 Solution and Slurry Nebulization Coupling with Microwave	
		References		Plasmas	141
	KCI	erences	90	- 145AA40	
Chanter	4 Micr	owave Safety	94	7.1 Nebulization Techniques Compatible with Microwave	
Chapter .		onar wasty		Plasmas	141
	4.1	Introduction	94	7.2 Plasma Tolerance to Solvent Loading	142
		Microwave Frequencies Permitted to be Used in		7.3 Nebulizer Designs	144
		Analytical Instrumentation	94	7.3.1 Pneumatic Nebulizers	144

xii	Co	ntents	Contents			xiii
	7.3.2 Ultrasonic Nebulizers	146			10.2.1 Non-spectral Interferences in Microwave	
	7.3.3 Spray Chambers and Desolvation Systems	148			Plasmas	191
	7.3.4 Flow Injection Analysis	151		10.3	Calibration Strategies	193
7.4					General Analytical Characteristics of MWP-OES	195
,.	Sample Classes	151		10.5		196
7.5		154		10.6	•	
7.6		155			Sources	197
7.3		156		Refe	rences	199
7.8		150				
7.0	Nebulization	157	Chapter 11	Anal	ytical Applications of MWP-OES	203
P 4	eferences	158	•	•		
IX	references	150		11.1	Microwave Plasma Spectroscopic Techniques:	
Chamton 9 Cali	id Sampling Techniques for Microwave Plasmas	162			Overview of Practical Uses	203
Chapter o Son	lu Sampinig Techniques for Microwave Trasmas	102			11.1.1 Types of Analyses	205
8.	1 Introduction	162		11.2	Selected Applications of MWP-OES in	
8.2		102			Environmental Analysis	207
0.2	_	163		11.3		
	or Vapour 8.2.1 Spark and Arc Ablation	163			Analysis	208
	8.2.2 Laser Ablation	164		11.4	Selected Applications of MWP-OES in Industrial	
	8.2.3 Electrothermal Vaporization	165			Analysis	209
8		167		11.5	Selected Applications of MWP-OES in Geological	207
8.4		168		11.5	Analysis	212
8.:		100		11.6	Selected Applications of MIP-OES in Speciation	212
0	Introduction	171		11.0	Studies	212
Q	6 Analysis of Powdered Samples by CPI-MWP-OES	172		Refer	rences	213
References		175		ICIC	rences	413
K	ciciences	173	Chanter 12	Non-	emission Microwave Plasma Spectroscopic Techniques	
Charter 0 On	timination of the MWD OFS System	178	Chapter 12		Fandem Sources	222
Chapter 9 Op	timization of the MWP-OES System	170		unu ,	and the Sources	
0	1 What do we Optimize?	178		12.1	Microwave Plasma Atomic Absorption Spectrometry	222
9.	9.1.1 Sample Introduction System-related Parameters	178			12.1.1 Instrumental Setup	222
	9.1.2 Source-related Parameters	179		12.2	Microwave Plasma Atomic Fluorescence	
	9.1.3 Spectrometer-related Parameters	180			Spectrometry	225
9.		180		12.3	Microwave Plasma Mass Spectrometry	227
9.		100			Microwave Plasma Cavity Ringdown Spectroscopy	230
λ.	(Sample) Parameters	182			Tandem Sources and Miscellaneous	231
9.	4 Optimizing Plasma Parameters for Trace	102			rences	232
٦.	Analysis	183				
Ω	5 Instrument Tests	185	Chapter 13	The 1	Future for Microwave Plasma Spectrometry	238
	eferences	186			1 v	
IX.	0101011000	100	Appendix			240
Chapter 10 A	nalytical Performance of MWP-OES	189				
Chapter 10 II			Subject Ind	ex		243
10	0.1 Introduction	189				

190

10.2 Interferences in MWP-OES