

Contents

Preface	xiii
Acknowledgments	xv
Introduction.....	xvii

CHAPTER 1 The impact of fields on materials at microwave and radio frequencies 1

Introduction	2
1.1 High-Frequency Fields Imposed on Uniform Materials.....	2
1.2 Fields at Material Boundaries in RF/Microwave Frequencies	8
1.3 Material/Field Issues of Interest in Applicator/Probe Design	16
1.4 Classification of Materials at High Frequencies.....	20
References	30

CHAPTER 2 Fundamentals of field applicators and probes at radiofrequencies and microwave frequencies.....34

Introduction	35
2.1 Basic Applicator/Probe Definitions.....	35
2.2 Applicator/Probe Figures of Merit.....	38
2.3 Categorization of Applicators/Probes by Useful Field Type: E or H	42
2.4 Resonance in Applicators/Probes	45
2.5 Common Properties and Applications as Heating Devices and Sensors	57
2.6 Common Practical Issues in Applicator and Probe Design.....	62
References	66

CHAPTER 3 Electric field (capacitive) applicators/probes68

Introduction	69
3.1 Characteristics and Applications of Capacitive Applicators and Probes.....	69
3.2 Parallel-Plate E -Field Applicator with Stratified Dielectric Layers: Equivalent Circuit and Field Calculations.....	83
3.3 Resonance, Coupling, and Circuit Issues.....	89

3.4 Fringing-Field, Interdigital, and Stray-Field	
Applicators and Probes	94
3.5 Electric Field Applicators and Systems for Material	
Heating (RF Heating)	101
References	109
Further Reading.....	111

CHAPTER 4 Single-mode microwave cavities for material processing and sensing112

Introduction	113
4.1 General Description and Applications of Single-Mode	
Cavity Applicators/Sensors	114
4.2 Methods for Determination of Field Distribution,	
Material Effects, Coupling, and Electrical Parameters	
of Single-Mode Cavities.....	118
4.3 Material Loading Impact in Single-Mode Cavities:	
Approximate and Rigorous Methods	130
4.4 Other (Non-TM _{0n0}) Single-Mode Cavity Types	
for Materials Interaction	134
4.5 Power/Signal Source and System Design Issues	
in Single-Mode Microwave Cavities.....	142
4.6 Application Examples of Single-Mode Applicators/	
Probes.....	147
4.7 The General Process for the Design of Single-Mode	
Cavities for Material Interactions.....	148
References	149

CHAPTER 5 Microwave multimode cavities for material heating.....153

Introduction	154
5.1 Field Patterns, Modes, and Energy Distribution.....	154
5.2 Methods to Improve the Field and Heating	
Uniformity in Multimode Cavity Applicators	165
5.3 Energy Coupling and System Issues in Multimode	
Heating Systems	169
5.4 Manipulation of Energy Distribution Using Susceptors	
and Field Modification Devices	172
5.5 Special and Alternative Multimode Applicator	
Configurations.....	176
References	180

CHAPTER 6	Applicators and probes based on the open end of microwave transmission lines.....	184
	Introduction	185
	6.1 Common Characteristics of Open-Ended Transmission-Line Structures	185
	6.2 TEM-Mode Open-Ended Transmission-Line Applicators	188
	6.3 Open-Ended Coaxial Transmission-Line Probes	192
	6.4 Open-Ended Waveguide, Horn, and Cavity Applicators	205
	References	215
	Further Reading.....	218
 CHAPTER 7	 Magnetic field and inductive applicators and probes at high frequencies.....	 219
	Introduction	220
	7.1 <i>H</i> -Field Probes: Categorization of Applications and Applicator/Probe Types at High Frequencies	221
	7.2 Fundamentals of Inductive Applicator Design	228
	7.3 Solenoid/Helical and Spiral Coils at High Frequencies	239
	7.4 Energy Deposition into Materials and High-Frequency Induction Heating	245
	7.5 Circuit Parameters and Design in Magnetic Field Applicators	254
	7.6 Special Topics in Magnetic/Inductive Applicators	260
	References	265
 CHAPTER 8	 RF/microwave applicators and systems for joining and bonding of materials.....	 269
	Introduction	270
	8.1 Physical Configurations in High-Frequency Joining.....	271
	8.2 RF Fusion Welding of Thermoplastics: Applicator and System Considerations.....	274
	8.3 Systems and Circuit Issues in RF Welding.....	285
	8.4 Applicators and Systems for Microwave Welding and Joining.....	287
	8.5 Magnetic Field/Inductive Applicators for Joining of Materials.....	292

8.6 Application Example: Microwave Edge Welding of Flexographic Printing Plates	295
References	297
Further Reading	300

CHAPTER 9 Design considerations for applicators in continuous-flow microwave/radio frequency processing.....	301
Introduction	302
9.1 General Considerations for Continuous RF/Microwave Material Processing Systems.....	303
9.2 Preparation for Continuous Process Design and Collection of Basic Data	306
9.3 RF Parallel-Plate Continuous Processes for Granular Media.....	308
9.4 Microwave Continuous Processing of Solids	316
9.5 Emissions Reduction Methods to Improve Safety of Microwave Processes	325
References	332
Further Reading.....	334

CHAPTER 10 Plasma applicators at RF and microwave frequencies.....	335
Introduction	336
10.1 Applications and Configurations of RF/Microwave Plasmas for Materials Processing.....	336
10.2 Common Topics to RF/Microwave Plasma Applicators.....	339
10.3 RF Applicators for Capacitively Coupled Plasmas	342
10.4 Microwave Plasma Applicators.....	348
10.5 Inductive Plasma Applicators.....	354
10.6 Alternative, Advanced RF/Microwave Plasma Applicators.....	358
References	360

Appendix A2.1: Mode chart for cylindrical cavities.....	365
Appendix A2.2: Human safety regulations on maximum exposure to electromagnetic fields at high frequencies	367

Appendix A2.3: Frequency allocations for industrial, scientific, and medical (ISM) applications	369
Appendix A3.1: Impedance/Admittance and electric field solutions for a parallel-plate applicator with dual layers of real dielectric materials.....	371
Appendix A3.2: Mathematica™ worksheet for derivation of dual-layer parallel plates with real dielectrics	375
Appendix A4.1: Field analysis of TM_{0n0} cylindrical cavities with two concentric layers of real dielectric at the axis.....	377
Appendix A4.2: Mathematica™ Notebook for Computation of Single-mode TM_{0n0} Cavities for Material Heating and Sensing Applications.....	381
Appendix A5.1: Analysis of an Example of Rectangular Cavity Mode for Power Density.....	385
Appendix A5.2: Mathematica™ Notebook for Computation of Possible Modes Over a Given Bandwidth for a Rectangular Multimode Cavity	387
Appendix A6.1: Mathematica Worksheet for Finding the Admittance and Equivalent Circuit Parameters of the Open-ended Coaxial Probe.....	389
Appendix A6.2: Mathematica™ Notebook for Impedance of the Extended Center Conductor Coaxial Line.....	391
Appendix A6.3: Admittance of Open-ended Waveguide with Dielectric Material Loading.....	393
Appendix A7.1: Field Analysis of Circular Loop Applicator.....	395
Appendix A7.2: Mathematica™ Program for Eddy Current Induction Into a Conductive Cylinder.....	399
Index	411