

CONTENTS

Preface	v
Préface	vii
Acknowledgements	ix
Affiliation	ix
1. Introduction	1
<i>M. Moisan and J. Pelletier</i>	
Appendix 1.1. - Frequency bands for industrial, scientific and medical applications	8
2. Physical principles of microwave plasma generation	
<i>C.M. Ferreira, M. Moisan and Z. Zakrzewski</i>	
2.1. Introduction	11
2.2. Physical phenomena in microwave discharges	13
2.3. The microwave discharge as a constituent of the plasma source	42
2.4. Classification of RF and microwave discharges	49
3. Kinetic modeling of microwave discharges: influence of the discharge stimulating frequency	
<i>C.M. Ferreira and M. Moisan</i>	
3.1. Introduction	53
3.2. Changes in the EEDF as a function of the field frequency	54
3.3. Rate of creation of active species as a function of the plasma stimulating frequency in argon-dominated gas mixtures	69
3.4. Effects of electron-electron collisions	74
3.5. Multi-step ionization. Collisional-radiative models	82
3.6. Conclusion	90

4. Plasmas sustained within microwave circuits*Z. Zakrzewski, M. Moisan and G. Sauvé*

4.1.	Introduction	93
4.2.	Plasma sources based on resonant cavities	94
4.3.	Waveguide-based plasma sources	100
4.4.	Simplified (non self-consistent) modeling of reduced gas pressure discharges with a localized active zone	104
4.5.	Modeling of waveguide-based discharges	115

5. Surface-wave plasma sources*M. Moisan and Z. Zakrzewski*

5.1.	Introduction	123
5.2.	Surface-wave and other traveling-wave sustained discharges	123
5.3.	Properties of the azimuthally symmetric surface wave propagating along uniform plasma columns (summary of theory)	125
5.4.	Maintenance processes and simplified modeling of the surface-wave discharge	131
5.5.	Launching and propagation of surface waves sustaining a plasma column	138
5.6.	Practical realization of surface-wave plasma sources	146
5.7.	Experimental verification of the simplified discharge model	157
5.8.	A practical guide to using surface-wave plasma columns	166

6. Principles of magnetically assisted microwave discharges*J. Margot, T.W. Johnston and J. Musil*

6.1.	Introduction	181
6.2.	Charged particle losses in magnetoplasmas	181
6.3.	Radial density profiles in magnetoplasmas from diffusion-controlled to free-fall regime	187
6.4.	Wave-to-plasma power transfer mechanisms	189
6.5.	Using an electromagnetic plane wave to sustain a magnetoplasma: a working example	195
6.6.	Wave propagation in waveguides completely or partially filled with plasma	205

7. Operation and properties of magnetically assisted high frequency discharges intended for applications*J. Margot and R.A. Gottscho*

7.1.	Introduction	213
7.2.	Static magnetic field configuration in HF discharges	214
7.3.	Electromagnetic wave coupling to a magnetoplasma	214
7.4.	Devices to achieve HF magnetoplasma discharges	215
7.5.	Ion transport in HF magnetoplasma discharges	222
7.6.	Conclusion	225

8. Surface-wave-sustained plasmas in static magnetic fields for the study of ECR discharge mechanisms*J. Margot and M. Moisan*

8.1.	Introduction	229
8.2.	Wave-to-plasma power transfer: basic mechanisms and parameters	230
8.3.	Surface-wave dispersion and attenuation properties along a plasma column when submitted to a static, axial magnetic field B_0	234
8.4.	Characteristics of the wave electric field intensity in the plasma	238
8.5.	Summary and conclusion	246

9. Interest of plasma confinement and its limits*J. Pelletier, Y. Arnal and M. Moisan*

9.1.	Introduction	249
9.2.	Background	249
9.3.	Uniformity of plasma-surface interaction	256
9.4.	Plasma homogeneity through multipolar magnetic field confinement: experimental evidence	264
9.5.	Limits of plasma confinement	266
9.6.	Conclusion	268
Appendix 9.1. - Perturbation of a plasma by a substrate		269

10. Discharges confined by multipolar magnetic fields*R. Burke and J. Pelletier*

10.1. Introduction	273
10.2. Pioneering works	273
10.3. Comparison of multipolar magnetic field arrangements	279
10.4. Operation of the filament-excited discharge	282
10.5. Electrostatic confinement of a homogeneous discharge	285
10.6. Modeling of a hot cathode discharge	291
10.7. Effects of multipolar magnetic confinement	296
10.8. Conclusion	300

11. Ambipolar diffusion model of multipolar plasmas*G. Matthieussent and J. Pelletier*

11.1. Introduction	303
11.2. Collisional diffusion in a two-dimensional magnetic field	304
11.3. Application of the diffusion model to multipolar plasmas	309
11.4. Plasma density and potential profiles in multipolar discharges: numerical results	316
11.5. Conclusion	324
Appendix 11.1. - Main parameters of an argon multipolar discharge	325
Appendix 11.2. - Mobilities and diffusion coefficients for electrons and ions in a magnetic field	328
Appendix 11.3. - Diffusion coefficients of a plasma submitted to a magnetic field	332
Appendix 11.4. - Magnetic potentials and fields in a multipolar configuration	333
Appendix 11.5. - Diffusion equation in the (λ_b, μ_b) coordinate system	346

12. Homogeneity in multipolar discharges: the role of primary electrons*J. Pelletier and G. Matthieu*

12.1. Introduction	351
12.2. Plasma homogeneity in multipolar discharges: experimental evidence and theoretical aspects	351
12.3. Trajectories of primary electrons	357
12.4. Results from numerical calculations	370
12.5. Mechanisms of selective peripheral ionization	377
12.6. Conclusion	379
Appendix 12.1. - Trapping of primary electrons in a multipolar magnetic field: irreversibility of the collisional mechanism	380

13. High frequency sustained multipolar plasmas*C. Pomot and J. Pelletier*

13.1. Introduction	385
13.2. Multipolar plasmas sustained by RF discharges	385
13.3. Multipolar plasmas sustained by microwave discharges	391
13.4. Control of process parameters in microwave multipolar plasmas	397
13.5. Density limitations in microwave multipolar plasmas	410
Appendix 13.1. - Substrate biasing with periodic signals: calculation of the DC bias voltage	414

14. Distributed electron cyclotron resonance (DECR) plasmas*M. Pichot and J. Pelletier*

14.1. Introduction	419
14.2. The concept of DECR reactors	420
14.3. Experimental setup and current performances	422
14.4. Reactor scale-up and other configurations	428
14.5. Conclusion	434

15. Applications of microwave plasmas in microcircuit fabrication*J. Paraszczaak and J. Heidenreich*

15.1. Introduction	435
15.2. Plasma deposition and etching systems	437
15.3. Materials for use in microwave based plasma systems	444
15.4. Microwave field applicators	445
15.5. Pancake microwave plasma reactors and plasma processing	446
15.6. ECR systems	473
15.7. Concluding remarks	489
Index of symbols	499
Index	513