



# Contents

<b>1. The Plasma State</b> . . . . .	1
1.1 Characterization of Plasma . . . . .	1
1.1.1 The Temperature of the Plasma . . . . .	1
1.1.2 Plasma Density . . . . .	3
1.1.3 Plasma Oscillation . . . . .	3
1.2 Classification of Plasma . . . . .	4
1.2.1 Cold Plasma . . . . .	4
1.2.2 Thermal Plasma . . . . .	6
<b>2. Reactions in Plasmas</b> . . . . .	11
2.1 Collision Phenomena . . . . .	11
2.1.1 Velocity Distribution of Particles . . . . .	11
2.1.2 Elastic and Inelastic Collisions . . . . .	13
2.1.3 Collision Frequency and Mean-Free Path . . . . .	14
2.1.4 Reaction Cross Section . . . . .	17
2.2 Excitation and Ionization . . . . .	18
2.2.1 Internal Energy . . . . .	18
2.2.2 Excitation and Ionization Processes . . . . .	26
2.2.3 Excitation and Ionization by an Electron Collision . . . . .	26
a) Excitation and Ionization of an Atom . . . . .	26
b) Excitation and Ionization of a Molecule . . . . .	29
2.2.4 Excitation and Ionization by Collisions of Energetic Ions or Neutral Particles . . . . .	32
a) Thermal Ionization . . . . .	34
b) Penning Ionization . . . . .	34
c) Ionization by Collisions Among Excited Particles . . . . .	35
2.2.5 Photo-Excitation and Photo-Ionization . . . . .	35
2.3 Recombination . . . . .	36
2.3.1 Recombination Processes . . . . .	36
2.3.2 Ion-Electron Recombination . . . . .	37
2.3.3 Ion-Ion Recombination . . . . .	38
2.4 Ion-Molecule Reactions and Reactions Involving Negative Ions . . . . .	39
2.4.1 Attachment and Detachment . . . . .	39
2.4.2 Ion-Molecule Reaction . . . . .	40
2.5 Transport Phenomena . . . . .	43
2.5.1 Drift . . . . .	43
2.5.2 Diffusion . . . . .	46

<b>3. Generation of Cold Plasma</b> . . . . .	49
3.1 Electrical Breakdown and Starting Voltage . . . . .	49
3.1.1 Static Electric Field . . . . .	49
3.1.2 Alternating Electric Field . . . . .	50
3.2 Glow Discharge . . . . .	52
3.2.1 General Characteristics . . . . .	52
3.2.2 Potential Distribution . . . . .	54
3.2.3 Normal Glow and Abnormal Glow . . . . .	57
3.2.4 Hollow Cathode Discharge . . . . .	57
3.3 High-Frequency Discharge . . . . .	59
3.3.1 Generation of High-Frequency Discharge . . . . .	59
3.3.2 Potential Distribution and Self-Bias . . . . .	62
3.3.3 Plasma Potential . . . . .	67
3.4 Microwave Discharge . . . . .	69
3.4.1 Generation of Microwave Discharge . . . . .	69
3.4.2 Electron Cyclotron Resonance . . . . .	71
<b>4. Plasma Diagnostics</b> . . . . .	74
4.1 Optical Spectroscopy . . . . .	74
4.1.1 Optical Emission Spectroscopy . . . . .	74
4.1.2 Optical Absorption Spectroscopy . . . . .	81
4.1.3 Laser-Induced Fluorescence Spectroscopy . . . . .	82
4.1.4 Coherent Anti-Stokes Raman Spectroscopy . . . . .	85
4.1.5 Optogalvanic Spectroscopy . . . . .	87
4.2 Probes . . . . .	91
4.2.1 Langmuir Single Probe . . . . .	92
4.2.2 Double Probe . . . . .	95
4.2.3 Emissive Probe . . . . .	96
4.3 Particle Measurements . . . . .	97
4.3.1 Mass Spectrometry . . . . .	97
4.3.2 Energy Analysis of Ions . . . . .	101
4.4 Others . . . . .	102
4.4.1 Electron-Spin Resonance . . . . .	102
4.4.2 Microwave Diagnostics . . . . .	105
<b>5. Cold Plasma and Thin Film Formation</b> . . . . .	107
5.1 Interactions of Cold Plasma with Solid Surfaces . . . . .	107
5.1.1 Adsorption and Trapping . . . . .	107
5.1.2 Sputtering . . . . .	111
5.1.3 Secondary-Electron Emission . . . . .	114
5.1.4 Chemical Reactions on Solid Surfaces . . . . .	119
5.2 Application of Cold Plasma to Thin Film Deposition . . . . .	122
5.2.1 Classification of Deposition Processes . . . . .	122
5.2.2 General Considerations of Plasma Processes . . . . .	124

<b>6. Physical Vapor Deposition Under Plasma Conditions . . . . .</b>	<b>126</b>
6.1 Sputter Deposition . . . . .	126
6.1.1 Features of Sputter Deposition . . . . .	126
6.1.2 Reactor Configuration . . . . .	130
6.1.3 Reactive Sputter Deposition . . . . .	134
6.1.4 Morphology and Characteristics of the Films . . . . .	137
6.2 Ion Plating . . . . .	140
6.2.1 Reactor Types and Features . . . . .	140
6.2.2 Applications of Ion Plating . . . . .	145
<b>7. Chemical Vapor Deposition Under Plasma Conditions . . . . .</b>	<b>149</b>
7.1 Plasma-Enhanced Chemical Vapor Deposition . . . . .	149
7.1.1 Reaction Mechanisms . . . . .	149
7.1.2 System Design . . . . .	151
7.1.3 Applications of Plasma Enhanced CVD . . . . .	159
a) Amorphous Silicon . . . . .	159
b) Silicon Nitride . . . . .	166
c) Amorphous and Diamond-Like Carbon . . . . .	171
d) Other Materials . . . . .	172
7.2 Plasma Polymerization . . . . .	173
7.2.1 Features of Plasma Polymerization . . . . .	173
7.2.2 System Design . . . . .	173
7.2.3 Plasma Polymer . . . . .	175
7.3 Other Techniques . . . . .	177
7.3.1 Plasma Stream Transport . . . . .	177
7.3.2 Chemical Transport in Plasmas . . . . .	179
7.3.3 Film Deposition Using Electron Cyclotron Resonance Plasma Sources . . . . .	182
<b>8. Surface Modification by Cold Plasma . . . . .</b>	<b>185</b>
8.1 Surface Treatment for Metals and Semiconductors . . . . .	185
8.1.1 Ion Nitriding and Ion Carburizing . . . . .	185
8.1.2 Plasma Nitriding . . . . .	188
8.1.3 Plasma Oxidation and Plasma Anodization . . . . .	190
8.1.4 Hydrogen Neutralization in Semiconductors . . . . .	193
8.1.5 Other Techniques for Metal Surface Treatment . . . . .	193
8.2 Modification of Polymer Surfaces . . . . .	194
<b>References . . . . .</b>	<b>195</b>
<b>Further Reading . . . . .</b>	<b>216</b>
<b>Subject Index . . . . .</b>	<b>221</b>