

Contents

Preface IX

1	Synthesis and Processing of Nanostructured Films, and Introduction to and Comparison with Plasma Electrolysis	1
1.1	Why Nanostructures Are Important	1
1.2	Different Types of Nanostructures	4
1.3	Ability of Plasma Electrolysis in Nanostructure Fabrication	6
1.4	Relation Between Plasma Electrolysis and Nanotechnology	9
1.5	Growth Process of Nanostructured Films	12
1.6	Electrolyte-Based Methods	12
1.6.1	Electrodeposition	13
1.6.2	Electroless Deposition	14
1.6.3	Plasma Electrolysis	14
1.7	Non-Electrolyte-Based Methods	15
1.7.1	Hydrolysis	15
1.7.2	Hydrothermal	15
1.7.3	Sol–Gel Methods	16
1.8	Introduction to Plasma Electrolysis	20
	References	20
2	Introduction to Plasma Concepts and Discharge Configurations	23
2.1	What Is Plasma?	23
2.2	Plasma Categorization	24
2.3	Atmospheric Pressure Plasmas	25
2.4	Applications of Atmospheric Plasma Methods	27
2.4.1	Spectroscopic Analysis	27
2.4.2	Material Processing	28
2.4.3	Surface Treatments	28
2.4.3.1	Surface Pre-Treatments	28
2.4.3.2	Surface Coating	29

2.4.4	Bulk Material Treatments	31
2.5	Optimization of Plasma Parameters for Fabrication of Uniform Nanostructures	31
2.5.1	Design of Orthogonal Array and Signal-to-Noise Analysis	31
2.5.1.1	Analysis of Variance (ANOVA)	32
2.5.1.2	Size of Nanocrystalline Carbonitrides of Coatings	33
2.5.1.3	Determination of Optimal Levels	34
2.5.1.4	Confirmation Run	35
2.5.2	Surface Response Method	36
	References	40
3	Characterization of Nanocrystalline Hard Coatings and their Use for Layers Fabricated by Plasma Electrolysis	43
3.1	Evaluation of Hardness for Nanostructured Coatings	43
3.2	Characterization of Nanostructured Coatings by X-Ray Diffraction and Nuclear Reaction Analysis	46
3.3	Evaluation of Plasma Electrolytic Layers	50
3.3.1	Average Size of Nanocrystallites for PE Layers	50
3.3.2	Mechanical Properties for PE Layers	52
3.3.3	Electrochemical Properties for PE Layers	57
3.3.4	Coating Roughness for PE Layers	61
	References	63
4	Nanocrystalline Plasma Electrolytic Saturation	65
4.1	Classification of Plasma Electrolysis	65
4.2	Nanostructures Fabricated by the Plasma Electrolytic Saturation Process	66
4.3	Characteristics of Cathodic Plasma Electrolysis	68
4.3.1	Current–Voltage Trend	69
4.3.2	Electrolyte	69
4.3.3	Substrates	77
4.4	Mechanism of Cathodic Plasma Electrolysis	78
4.5	Morphological Aspects of Achieved Nanostructures	79
4.5.1	Correlation Among Nanostructure and Properties of Layers	79
4.5.2	Electrochemical Properties of Nanostructured Layers	80
4.5.3	Mechanical Properties of Nanostructured Layers	83
	References	83
5	Corrosion Properties of Nanostructured Coatings Made by Plasma Electrolytic Saturation	85
5.1	Anti-Corrosion Properties of Nanostructured PES Coatings	85
5.2	Relation Among Nanostructure and Corrosion Properties	97
5.3	Optimization of Plasma Electrolytic Saturation Treatment	99
5.3.1	Applied Voltage	102
5.3.2	Applied Current	110

5.3.3	Treatment Time	111
5.3.4	Electrolyte Composition	113
5.3.5	Pulse Parameters	114
5.3.5.1	Frequency and Duty Cycle	114
5.3.5.2	Wave Shape	122
5.4	Substrate Study	128
	References	137
6	Mechanical Properties of Nanostructured Coatings Made by Plasma Electrolytic Saturation	139
6.1	Hardness	139
6.2	Roughness	145
6.3	Wear Protection	152
6.4	Relation Among Nanostructure and Mechanical Properties	162
6.5	Optimization of Plasma Electrolytic Saturation Treatment	164
6.5.1	Applied Voltage	166
6.5.2	Applied Current	167
6.5.3	Treatment Time	168
6.5.4	Electrolyte Composition	169
6.5.5	Pulse Parameters	171
6.5.5.1	Frequency and Duty Cycle	173
6.5.5.2	Wave Shape	179
6.6	Duplex Treatments	180
	References	193
7	Advantages and Disadvantages of Plasma Electrolysis	195
7.1	Industrial Application of the Technology	196
7.1.1	Fabrication of Ultra-Hard Nanocomposite Coatings	196
7.2	Performance of Plasma Electrolytic Saturation Coatings	203
7.2.1	Electrolyte	203
7.2.2	Applied Current	205
7.2.3	Cell Design	206
7.3	Potential Application of the Technology	207
7.4	Economic Assessment of the Technology	208
	References	209
8	Nanostructured Coatings Made by Plasma Electrolytic Oxidation	211
8.1	Fabrication of Nanocomposites by Anodic Plasma Electrolysis	211
8.2	Examples of Nanocomposite Coatings Fabricated by the PEO Process	212
8.2.1	Si ₃ N ₄ /TiO ₂ Nanocomposite Coating	212
8.2.1.1	Fabrication Method	212
8.2.1.2	Nanostructural Investigation	213
8.2.1.3	Mechanical Properties	216
8.2.2	Cu/TiO ₂ Nanocomposite Coating	222

- 8.2.2.1 Fabrication Method 222
 - 8.2.2.2 Nanostructural Investigation 222
- 8.3 Duplex Treatments 227
 - 8.3.1 Fabrication Method 228
 - 8.3.2 Nanostructural Investigation 230
 - 8.3.3 Electrochemical Properties 230
- References 235
- 9 Conclusions 237
- Index 243