

## Contents

**Foreword** *XV*

**List of Contributors** *XIX*

**Preface** *XXIII*

- 1 Combustion Synthesis of Nitrides for Development of Ceramic Materials of New Generation** *1*  
*Inna P. Borovinskaya, Vazgen E. Loryan, and Vladimir V. Zakorzhevsky*
- 1.1 Introduction *1*
- 1.2 Peculiarities of Phase and Structure Formation of Metal and Nonmetal Nitrides in Combustion Mode *2*
- 1.2.1 Systems of Transition Metal of the IV–V Groups of the Periodic Table with Nitrogen *2*
- 1.2.1.1 Two Threshold Mechanisms of Combustion and Structure Formation *5*
- 1.2.1.2 Structural and Morphological Peculiarities of Silicon, Boron, and Aluminum Nitrides – Nanosized Powders *7*
- 1.3 Dependence of SHS Nitride Composition and Structure on Infiltration Combustion Mode *20*
- 1.3.1 Two Stages of SHS Process *21*
- 1.3.1.1 Nitride Dissociation *26*
- 1.3.1.2 Role of Nitrogen Admission to the Reaction Zone *30*
- 1.4 SHS Equipment for Powder Synthesis *32*
- 1.5 Synthesis of SHS-Ceramics Based on Silicon and Aluminum Nitrides and SiAlON Powders *33*
- 1.5.1 Silicon Nitride Powders and Items *33*
- 1.5.2 SiAlON Powders and Items *35*
- 1.5.3 Aluminum Nitride Powders and Items *37*
- 1.6 Direct Production of Materials and Items Based on Nitride Ceramics by SHS Gasostating *38*
- 1.6.1 Nitride Ceramics Based on SiAlONs *39*
- 1.6.2 Nitride Ceramics Based on BN *40*
- 1.6.3 Nitride Ceramics Based on AlN *42*

1.7	Conclusion	44
	References	44
<b>2</b>	<b>Combustion Synthesis of Boron Nitride Ceramics: Fundamentals and Applications</b>	<b>49</b>
	<i>Alexander S. Mukasyan</i>	
2.1	Introduction	49
2.1.1	Background: Brief Historical Overview	49
2.1.2	Key Properties and Markets Values	49
2.1.3	Applications of h-BN	51
2.1.4	Method of Synthesis: Advantages and Disadvantages	52
2.1.5	Combustion Synthesis in Gas–Solid Systems: General Definitions	53
2.2	Combustion in Boron–Nitrogen System	57
2.2.1	Thermodynamic Considerations	58
2.2.2	Conditions for Combustion Synthesis of Boron Nitride Material	59
2.3	Mechanism of Structure Formation in CS wave	62
2.3.1	Methods of Investigation of Structural Transformation in Combustion Wave	62
2.3.2	Mechanism of BN Formation	64
2.4	Combustion Synthesis of Nitride-Based Ceramics	67
2.4.1	CS of Boron Nitride Ceramics	68
2.4.2	Properties of BN Materials Synthesized by CS Technology	70
2.4.3	Examples of Special Application of CS-BN Ceramics	72
2.5	Final Remarks	72
	References	73
<b>3</b>	<b>Combustion Synthesis of Aluminum Nitride (AlN) Powders with Controlled Grain Morphologies</b>	<b>75</b>
	<i>Zhongqi Shi, Yoshinari Miyamoto, and Hailong Wang</i>	
3.1	Introduction	75
3.2	Combustion Synthesis of Quasi-Aligned AlN Nanowhiskers	76
3.2.1	Experimental Methods of Approach	76
3.2.2	Results and Discussion	78
3.3	Enhanced Thermal Conductivity of Polymer Composites Filled with 3D Brush-Like AlN Nanowhiskers by Combustion Method	83
3.3.1	Experimental Methods of Approach	84
3.3.2	Results and Discussion	84
3.4	Growth of Flower-Like AlN by Combustion Synthesis Assisted with Mechanical Activation	86
3.4.1	Experimental Methods of Approach	87
3.4.2	Results and Discussion	87
3.5	Combustion Synthesis of AlN Porous-Shell Hollow Spheres	90

3.5.1	Experimental Methods of Approach	90
3.5.2	Results and Discussion	91
3.6	Summary and Conclusions	93
	References	94
<b>4</b>	<b>Combustion Synthesis and Spark Plasma Sintering of <math>\beta</math>-SiAlON</b>	<b>97</b>
	<i>Xuemei Yi, Tomohiro Akiyama, and Kazuya Kurokawa</i>	
4.1	Introduction	97
4.1.1	$\beta$ -SiAlON	97
4.1.2	Combustion Synthesis (CS)	98
4.1.3	Spark Plasma Sintering (SPS)	98
4.2	CS of High-Purity $\beta$ -SiAlON and Densification by SPS	99
4.2.1	Reaction Mechanisms	99
4.2.2	Dense $\beta$ -SiAlON by CS and SPS	101
4.2.2.1	Combustion Synthesis of $\beta$ -SiAlON Powder	101
4.2.2.2	Spark Plasma Sintering of CSed Powders	102
4.2.2.3	Characterization of CS-SPSed $\beta$ -SiAlON	103
4.3	Physical Properties of CS-SPSed $\beta$ -SiAlON	108
4.3.1	Vickers Hardness	108
4.3.2	Thermal Conductivity	109
4.4	Corrosion Resistance	112
4.4.1	Oxidation Behavior in Air	112
4.4.1.1	Oxidation Kinetics	113
4.4.1.2	Microstructure of Oxide Scale	113
4.4.1.3	Reaction Mechanisms	116
4.4.2	Corrosion Resistance in Supercritical Water	118
4.5	Conclusions of This Chapter	122
	References	122
<b>5</b>	<b>Combustion Synthesis of AlN (<math>\text{Al}_3\text{O}_3\text{N}</math>), BN, ZrN, and TiN in Air and Ceramic Application</b>	<b>125</b>
	<i>Alexander A. Gromov, Filippo Maggi, Ekaterina V. Malikova, Julia I. Pautova, Alexander P. Il' in, Elena M. Popenko, Alexey V. Sergienko, Alexander G. Korotkikh, and Ulrich Teipel</i>	
5.1	Thermochemical Features of Aluminum Particles Combustion (Theoretical Background)	125
5.1.1	Aluminum–Oxygen Systems	127
5.1.2	Aluminum–Nitrogen Systems	129
5.1.3	Aluminum–Air Systems	129
5.2	Chemical Features of Metals Combustion in Air (Experimental Background)	131
5.2.1	Combustion of Aluminum Particles in Air	131
5.2.2	Combustion of Boron Particles in Air	132
5.3	Nitrides (Oxynitrides) Formation by Metal Powder Combustion in Air	133

- 5.3.1 Nitrides Formation at nAl/ $\mu$ Al and [nAl + ( $\mu$ Al/Zr Alloy)]  
Combustion in Air 134
- 5.3.2 Nitrides Formation at nAl Combustion in Air 134
- 5.3.2.1 CCP Microstructure 137
- 5.3.2.2 Effect of Additives on AlN Yield 141
- 5.3.3 AlN ( $\text{Al}_3\text{O}_3\text{N}$ ), ZrN, TiN Obtained by Combustion of Metal Powders  
and their Mixtures in Air 143
- 5.3.3.1 nAl 146
- 5.3.3.2  $\mu$ Al 148
- 5.3.3.3  $\mu$ Ti 149
- 5.3.3.4  $\mu$ Zr 149
- 5.3.3.5 Combustion Scenario 149
- 5.3.4 Nitrides Obtained by Combustion of  $\mu$ Ti/ $\mu$ Al and  $\mu$ Ti/ $\mu$ TiO<sub>2</sub>  
Mixtures in Air 152
- 5.3.4.1 Combustion of the Mixtures I ("Ti–TiO<sub>2</sub>") 154
- 5.3.4.2 Combustion of the Mixtures II ("Ti–Al") 154
- 5.3.5 Combustion Synthesis of Aluminum Oxynitride in Air 154
- 5.4 Application of the Synthesized Nitrides and Oxynitrides in Dense  
Ceramics 156
- 5.4.1 Nitride Ceramics on the Base of the CCP in the System  
"Zr–O–N" 156
- 5.4.2 Nitride Containing Ceramics on the Base of the CCP in the System  
"Al–O–N" 156
- 5.4.3 Technology of Nitride Ceramics Production on the Basis of the CCP  
in the System "Me(Al, Ti, Zr)–O–N" 159
- References 160
  
- 6 Combustion Synthesis of Nitrides of Vanadium, Niobium, and  
Tantalum 165**  
*Chun-Liang Yeh*
- 6.1 Introduction 165
- 6.2 Experimental Methods of Approach 166
- 6.3 Results and Discussion 167
- 6.3.1 Combustion Synthesis of Vanadium Nitride 167
- 6.3.2 Combustion Synthesis of Niobium Nitride 173
- 6.3.3 Combustion Synthesis of Tantalum Nitride 177
- 6.4 Conclusions 180
- References 183
  
- 7 Synthesis of Nitrides by SHS of Ferroalloys in Nitrogen 185**  
*Liudmila N. Chukhlomina, Yury M. Maksimov, and Lidiya N. Skvortsova*
- 7.1 Introduction 185
- 7.2 Synthesis of Silicon Nitride by Combustion of Ferrosilicon in  
Nitrogen 186

- 7.2.1 Nitriding Degree of Combustion Products and Burning Rate Versus Main SHS Parameters 186
- 7.2.2 Filtration Combustion Modes of Ferrosilicon in Nitrogen 188
- 7.2.3 Dilution of Initial Ferrosilicon by Previously Nitrided Ferrosilicon 190
- 7.2.4 Influence of Content of Silicon in Initial Fe–Si Alloys on SHS of Silicon Nitride 192
- 7.2.5 Mechanism of Structure and Phase Formation of Silicon Nitride during Combustion of Ferrosilicon in Nitrogen 195
- 7.3 Synthesis of Vanadium Nitride by Combustion of Ferrovandium in Nitrogen 199
- 7.4 Synthesis of Niobium Nitride by Combustion of Ferroniobium in Nitrogen 204
- 7.5 Synthesis of Titanium Nitride by Combustion of Ferrotitanium in Nitrogen 206
  - 7.5.1 Features of Ferrotitanium Nitriding 207
  - 7.5.2 Phase-Formation Processes of Titanium Nitrides During Combustion of Ferrotitanium in Nitrogen 210
- 7.6 Combustion of Ferrochromium in Nitrogen and Synthesis of Chromium Nitride 213
- 7.7 Combustion of Ferroboron in Nitrogen and Synthesis of Boron Nitride 215
- 7.8 Application Prospects of Products of Combustion of Ferroalloys in Nitrogen 217
  - 7.8.1 Application of Fe-Containing Composite Materials Based on Silicon and Boron Nitride for the Catalytic Destruction of Dissolved Organics 219
  - 7.8.2 Boron Nitride-Based Composites in Combined Processes of Degradation of Dissolved Organics and Generation of Molecular Hydrogen 224
- 7.9 Conclusions 226  
References 227
  
- 8 Halides in SHS Azide Technology of Nitrides Obtaining 229**  
*Georgy V. Bichurov*
  - 8.1 Introduction 229
  - 8.2 The Use of Ammonia Halides 231
  - 8.3 The Use of Halides of Elements to be Nitrided 232
  - 8.4 The Use of Complexing Halides of Elements to be Nitrided and Alkaline Metals 233
  - 8.5 The Use of Complexing Halides of Ammonia and Elements to be Nitrided 234
  - 8.6 The Use of Halides for Obtaining Refractory Compositions 234
  - 8.7 Efficiency of Use of Halides in Azide SHS Systems 235
  - 8.8 Chemical Stages of Formation of Nitrides in a Mode SHS-Az 236

8.9	Property of SHS-Az Powders	241
8.10	Property of SHS-Az Ceramics	243
8.11	The Synthesis of Nanostructural SHS-Az Powders	246
8.11.1	Nitride of Titanium, Boron, and Silicon	246
8.11.2	Aluminum Nitride	252
8.12	Conclusion	261
	References	261
<b>9</b>	<b>AlN Ceramics from Nanosized Plasma Processed Powder, its Properties and Application</b>	<b>265</b>
	<i>Laima Trinkler, Baiba Berzina, and Eriks Palcevskis</i>	
9.1	Introduction: AlN Ceramics, its Characteristics and Application	265
9.2	Production of AlN Ceramics from Nanosized Plasma Processed Powder	266
9.2.1	Manufacturing of AlN Nanopowder	266
9.2.2	Production of AlN Ceramics with High Thermal Conductivity	269
9.3	Properties of AlN Ceramics from Nanosized Plasma Processed Powder	272
9.3.1	Dielectric Properties	272
9.3.2	Luminescence Properties	274
9.3.2.1	Experimental Details	274
9.3.2.2	Photoluminescence	275
9.3.2.3	Afterglow	278
9.3.2.4	Thermoluminescence	279
9.3.2.5	Optically Stimulated Luminescence	281
9.3.2.6	Fading of TL and OSL Signal	282
9.3.2.7	Luminescence Mechanism	282
9.4	Practical Application of Luminescence Properties of AlN Ceramics	286
9.4.1	Dosimetric Properties	286
9.4.1.1	TL and OSL After Exposure to Ionizing Radiation	287
9.4.1.2	TL and OSL after Exposure to UV Light	288
9.4.1.3	Estimation of AlN Ceramics as Dosimeter Material	289
9.4.2	Using Long-Lasting Luminescence	290
9.4.3	Using of Translucent Doped AlN Ceramics as Solid-State Lasers	290
9.5	Conclusions	291
	References	291
<b>10</b>	<b>An Overview of the Application of Nitrides and Oxynitrides in Photocatalysis and Electrocatalysis</b>	<b>295</b>
	<i>Justin S. J. Hargreaves and Andrew R. McFarlane</i>	
10.1	Introduction	295
10.2	Preparation	297

10.2.1	Ammonolysis	297
10.2.2	Preparation Using $N_2/H_2$ Mixtures	298
10.2.3	Metathesis Routes	299
10.2.4	Sol–Gel and Related Routes	300
10.3	Photocatalysis	302
10.4	Electrocatalysis	308
10.5	Conclusion	316
	References	316
11	<b>Conclusion</b>	321
	<i>Alexander A. Gromov and Liudmila N. Chukhlomina</i>	
	Reference	323
	<b>Index</b>	325