

# Contents

<b>1</b>	<b>Heteroepitaxy of Nonpolar and Semipolar GaN .....</b>	<b>1</b>
	Qian Sun and Jung Han	
1.1	Introduction .....	1
1.2	Kinetic Wulff Plot ( <i>V</i> -Plot) of GaN .....	3
1.3	Heteroepitaxy of Nonpolar GaN on Planar Substrates .....	6
1.4	Heteroepitaxy of Semipolar GaN on Planar Substrates .....	15
1.5	OCE of Semipolar GaN on Nonplanar Substrates .....	22
1.6	Summary and Outlook .....	23
	References .....	25
<b>2</b>	<b>High-Quality Al-Rich AlGa<sub>N</sub> Alloys .....</b>	<b>29</b>
	B.N. Pantha, J.Y. Lin, and H.X. Jiang	
2.1	Introduction .....	29
2.2	Growth of AlGa <sub>N</sub> .....	31
2.2.1	Typical Growth Condition of AlGa <sub>N</sub> .....	31
2.2.2	Effect of In as Surfactant in Al-Rich AlGa <sub>N</sub> Alloys .....	32
2.2.3	AlN/Al <sub>x</sub> Ga <sub>1-x</sub> N Quantum Well Structures Grown on Substrates with Different Orientations .....	35
2.3	Fundamental Properties of Al <sub>x</sub> Ga <sub>1-x</sub> N Alloys .....	43
2.3.1	Band Structures of Al <sub>x</sub> Ga <sub>1-x</sub> N Alloys .....	43
2.3.2	Bandgap Bowing in Al <sub>x</sub> Ga <sub>1-x</sub> N Alloys .....	44
2.3.3	Unique Optical Properties of AlGa <sub>N</sub> Alloys .....	46
2.3.4	Exciton Localization in AlGa <sub>N</sub> Alloys .....	49
2.4	Optical Properties of Al <sub>x</sub> Ga <sub>1-x</sub> N .....	57
2.4.1	Impurity Transitions in Al <sub>x</sub> Ga <sub>1-x</sub> N Alloys .....	57
2.4.2	Impurity Transition in Mg-Doped AlGa <sub>N</sub> Alloys .....	62
2.4.3	Energy Level of Various Acceptors in AlN .....	64
2.5	Electrical Properties of AlGa <sub>N</sub> .....	66
2.5.1	n-Type Al <sub>x</sub> Ga <sub>1-x</sub> N Alloys .....	66
2.5.2	p-Type Al <sub>x</sub> Ga <sub>1-x</sub> N .....	71

2.6	Concluding Remarks .....	76
	References .....	77
<b>3</b>	<b>Deep Ultraviolet Light-Emitting Diodes .....</b>	<b>83</b>
	Michael Shur, Max Shatalov, Alex Dobrinsky, and Remis Gaska	
3.1	Introduction .....	83
3.2	Materials Properties .....	91
3.3	Materials Growth .....	92
3.4	Design of Deep UV LEDs .....	96
3.4.1	DUV LED Fabrication .....	102
3.4.2	DUV LED Performance .....	103
3.4.3	Conclusion .....	112
A.1	Band Structure Parameters for AlN, InN, and GaN (STR 2011) .....	114
A.2	Mechanical and Polarization Properties of AlN, InN, and GaN (STR 2011) .....	114
A.3	Ionization Energies and Nonradiative Recombination Constants for AlN, InN, and GaN (STR 2011) .....	115
A.4	Optical Constants for Materials Used for LED Design .....	115
A.5	Definition of Efficiencies of Ultra-Violet Light Emitting Diode (UV LED) .....	115
	References .....	116
<b>4</b>	<b>Green Nitride LEDs .....</b>	<b>121</b>
	Xian-An Cao	
4.1	The “Green Gap” .....	121
4.2	Advances in Growth of c-Plane Green LEDs .....	123
4.2.1	Green LEDs on (0001) sapphire .....	123
4.2.2	Green LEDs on Free-Standing (0001) GaN .....	128
4.3	Piezoelectric Polarization in c-Plane Green LEDs .....	133
4.4	Green LEDs on Nonpolar and Semipolar Substrates .....	136
4.5	Carrier Localization in Green LEDs .....	139
4.6	Efficiency Droop in Green LEDs .....	144
4.7	Conclusions .....	148
	References .....	149
<b>5</b>	<b>Improved Light Extraction Efficiency in GaN-Based Light Emitting Diodes .....</b>	<b>153</b>
	Jihyun Kim	
5.1	PEC Etch: c-Plane vs. a-Plane .....	154
5.2	Natural Lithography .....	156
5.3	Photonic Crystal .....	161
5.4	Plasmonics .....	161
5.5	Chip Shaping .....	162
5.6	Patterned Sapphire Substrate .....	163
	References .....	163

<b>6</b>	<b>GaN-Based Sensors</b> .....	165
	F. Ren, B.H. Chu, K.H. Chen, C.Y. Chang, Victor Chen, and S.J. Pearton	
6.1	Introduction.....	165
6.2	Gas Sensing.....	167
6.2.1	$H_2$ Sensing.....	167
6.2.2	$O_2$ Sensing.....	169
6.2.3	$CO_2$ Sensing.....	171
6.2.4	$CH_4$ Sensing.....	173
6.3	Sensor Functionalization.....	174
6.4	pH Measurement.....	175
6.5	Exhaled Breath Condensate.....	177
6.6	Heavy Metal Detection.....	179
6.7	Biotoxin Sensors.....	182
6.7.1	Botulinum.....	182
6.8	Biomedical Applications.....	184
6.8.1	Prostate Cancer Detection.....	186
6.8.2	Kidney Injury Molecule Detection.....	187
6.8.3	Breast Cancer.....	189
6.8.4	Lactic Acid.....	191
6.8.5	Chloride Ion Detection.....	193
6.8.6	Pressure Sensing.....	194
6.8.7	Traumatic Brain Injury.....	196
6.9	Nerve Cell Monitoring.....	197
6.10	InN Sensors.....	199
6.11	Summary and Conclusions.....	202
	References.....	203
<b>7</b>	<b>GaN HEMT Technology</b> .....	209
	Wayne Johnson and Edwin L. Piner	
7.1	Introduction.....	209
7.2	Substrate Considerations.....	210
7.2.1	Silicon.....	211
7.2.2	SiC.....	212
7.2.3	Sapphire.....	212
7.2.4	GaN.....	213
7.3	Epitaxy and Device Structures.....	213
7.3.1	GaN Epitaxy.....	213
7.3.2	Nucleation.....	214
7.3.3	Buffer Layer Structure.....	216
7.4	Device Layer Structure.....	218
7.4.1	GaN Cap.....	219
7.4.2	AlN Interlayer.....	220
7.4.3	Back Barrier Structures.....	220

7.5	HEMT Device Processing .....	221
7.5.1	Metalization.....	222
7.5.2	Isolation .....	223
7.5.3	Passivation and Field Plating.....	224
7.6	HEMT Packaging and Products .....	226
7.6.1	Air Cavity Packaging.....	226
7.6.2	Plastic Overmold .....	227
7.6.3	GaN HEMT Products.....	228
7.7	Future Directions for GaN HEMTs .....	229
7.7.1	GaN-on-Diamond.....	229
7.7.2	Heterointegration .....	230
7.7.3	InAlN HEMTs .....	231
	References.....	234
<b>8</b>	<b>Recent Advances in High-Voltage GaN MOS-Gated Transistors for Power Electronics Applications .....</b>	<b>239</b>
	T. Paul Chow and Z. Li	
8.1	Introduction.....	239
8.2	Device Structures and Design .....	240
8.3	Device Design .....	241
8.4	Experimental Results.....	244
8.5	Technical Challenges and Reliability.....	248
8.6	Summary.....	249
	References.....	249
<b>9</b>	<b>Radiation Effects in GaN .....</b>	<b>251</b>
	Alexander Y. Polyakov	
9.1	Introduction.....	251
9.2	Fundamental Studies of Radiation Defects in GaN and Related Materials .....	252
9.2.1	Threshold Displacement Energy: Theory and Experiment .....	252
9.2.2	Radiation Defects in GaN: Defects Levels, Effects on Charge Carriers Concentration, Mobility, Lifetime of Charge Carriers, Thermal Stability of Defects .....	253
9.3	Radiation Effects in Other III-Nitrides .....	274
9.4	Radiation Effects in GaN Schottky Diodes, in AlGaIn/GaN and GaN/InGaIn Heterojunctions and Quantum Wells .....	276
9.5	Radiation Effects in GaN-Based Devices .....	282
9.6	Prospects of Radiation Technology for GaN.....	285
9.7	Summary and Conclusions .....	287
	References.....	289

<b>10 Recent Advances in GaN Nanowires: Surface-Controlled Conduction and Sensing Applications</b>	295
Ruei-San Chen, Abhijit Ganguly, Li-Chyong Chen, and Kuei-Hsien Chen	
10.1 Introduction	295
10.2 Surface-Controlled Transport	296
10.2.1 Surface Photoconduction	296
10.2.2 Size-Dependent Transport Properties	300
10.2.3 Persistent Photoconductivity	303
10.3 Molecular Sensing	305
10.3.1 Gain Amplified and Selective Gas Sensing	305
10.3.2 Biomolecular Sensing	306
10.4 Summary	312
References	312
<b>11 Minority Carrier Transport in ZnO and Related Materials</b>	317
Elena Flitsyian, Zinovy Dashevsky, and Leonid Chernyak	
11.1 Introduction	317
11.2 Role of Minority Carrier Diffusion Length in Bipolar Device Performance	319
11.3 Methods for Determination of Minority Carrier Lifetime and Diffusion Length	320
11.3.1 EBIC Technique	321
11.3.2 SPV Technique	322
11.3.3 TRPL Technique	322
11.4 Temperature Dependence of Minority Carrier Diffusion Length and Lifetime	323
11.4.1 Studies in n-Type ZnO	323
11.4.2 Studies in p-Type ZnO Doped with Antimony	326
11.5 Studies of Minority Carrier Recombination	331
11.5.1 Influence of Electron Trapping on Minority Carrier Diffusion Length	332
11.5.2 Optical Studies of the Effects of Electron Trapping on Minority Carrier Lifetime	335
11.5.3 Mechanism of Electron Injection Effect	341
11.5.4 Device Applications	342
11.6 Summary	345
References	345
<b>12 Conduction in Degenerately Doped <math>\text{Zn}_{1-x}\text{Al}_x\text{O}</math> Thin Films</b>	349
Michael Snure, David Toledo, Paul Slusser and Ashutosh Tiwari	
12.1 Introduction	349
12.2 Experimental Procedure	350
12.3 Results	351

12.4	Discussion .....	356
12.5	Summary.....	358
	References.....	359
<b>13</b>	<b>Multifunctional ZnO Nanostructure-Based Devices.....</b>	<b>361</b>
	Yicheng Lu, Pavel I. Reyes, Jian Zhong, and Hannhong Chen	
13.1	Introduction.....	361
13.2	Multifunctional ZnO Nanostructures for Biosensing.....	362
13.2.1	Wettability Control on ZnO Nanostructures.....	363
13.2.2	Biofunctionalization of ZnO Nanostructures.....	367
13.2.3	Morphology Effects of ZnO Nanostructures on Adhesion of Biospecies .....	369
13.2.4	ZnO Nanostructure-Based Acoustic Biosensors .....	371
13.3	The 3D Electrodes Consisting of ZnO TCO Films and Nanostructures for Optoelectronic Devices .....	381
13.3.1	Integration of ZnO TCO Films and ZnO Nanotip Arrays.....	381
13.3.2	ZnO 3D Photoelectrodes for Dye-Sensitized Solar Cells .....	387
13.3.3	ZnO 3D Electrodes for Enhanced Emission Efficiency in GaN LED.....	398
13.4	Conclusion.....	407
	References.....	408
<b>14</b>	<b>ZnO/MgZnO Quantum Wells .....</b>	<b>413</b>
	Jeffrey Davis and Chennupati Jagadish	
14.1	Properties of Conventional ZnO/ZnMgO Quantum Wells .....	414
14.2	Unconventional QW Structures.....	423
14.2.1	Non-Polar ZnO .....	423
14.2.2	Effects of Varying the Potential Profile.....	424
14.2.3	Coupled Quantum Wells .....	429
14.3	Progress Towards ZnO/ZnMgO QW Devices .....	430
14.4	Summary.....	432
	References.....	432
<b>15</b>	<b>N-Type Oxide Semiconductor Thin-Film Transistors .....</b>	<b>435</b>
	Pedro Barquinha, Rodrigo Martins, and Elvira Fortunato	
15.1	Device Structure and Operation .....	435
15.2	Semiconductor Materials for TFTs.....	440
15.2.1	The Era of Oxide Semiconductors .....	440
15.2.2	Comparison of n-Type Oxide TFTs with Existing TFT Semiconductor Material Technologies .....	443
15.3	Multicomponent Oxide TFTs @ CENIMAT .....	446
15.3.1	Role of Oxygen During GIZO Sputtering .....	446
15.3.2	Role of Deposition Pressure and rf Power Density During GIZO Sputtering .....	449

15.3.3	Role of GIZO Target Composition .....	451
15.3.4	Role of GIZO Thickness .....	453
15.3.5	Role of TFT's Annealing Temperature .....	459
15.3.6	Role of Passivation Layer .....	462
15.3.7	Constant Drain Current and Constant Gate Bias Stress Measurements.....	466
15.4	Conclusions and Outlook .....	471
	References.....	473
<b>Index</b>	.....	<b>477</b>

GaN and ZnO-based Materials and Devices

Pearson, S. (Ed.)

2012, XVIII, 486 p., Hardcover

ISBN: 978-3-642-23520-7