
Contents

Preface.....	v
1 Advanced Processing of Gallium Nitride for Electronic Devices.....	1
1.1 Abstract	1
1.2 Introduction	2
1.3 Results and Discussion	16
1.3.1 Ultra-High-Temperature Activation of Implant Doping in Gallium Nitride	16
1.3.1.1 High-Temperature Annealing and Aluminum Nitride Encapsulation	17
1.3.1.2 n-Type Implant Doping.....	22
1.3.1.3 p-Type Implant Doping.....	25
1.3.1.4 Dopant Redistribution	26
1.3.1.5 Residual Damage	31
1.4 Implant Isolation.....	32
1.4.1 Oxygen Implantation for Selective Area Isolation	34
1.4.2 Creation of High-Resistivity Gallium Nitride by Ti, Iron, and Chromium Implantation	38
1.5 Electrical Contacts to Gallium Nitride	41
1.5.1 Effects of Interfacial Oxides on Schottky Contact	44
1.5.2 Interfacial Insulator Model	49
1.5.3 Thermally Stable Tungsten-Based Ohmic Contact.....	51
1.5.4 Behavior of Tungsten and Tungsten Silicide Contacts on p-Gallium Nitride	54
1.6 Dry Etch Damage in Gallium Nitride.....	60
1.6.1 Plasma Damage in n-Gallium Nitride.....	61
1.6.2 Effect of Etching Chemistries on Damage	66
1.6.3 Thermal Stability of Damage.....	71
1.6.4 Plasma Damage in p-Gallium Nitride.....	75
1.6.5 Thermal Stability of Damage.....	80
1.6.6 Determination of Damage Profile in Gallium Nitride	82
1.7 Conclusions and Future Trends	86
References	89

2 Dry Etching of Gallium Nitride and Related Materials	97
2.1 Abstract.....	97
2.2 Introduction	97
2.3 Plasma Reactors.....	97
2.3.1 Reactive Ion Etching.....	98
2.3.2 High-Density Plasmas.....	100
2.3.3 Chemically Assisted Ion Beam Etching	101
2.3.4 Reactive Ion Beam Etching	102
2.3.5 Low-Energy Electron Enhanced Etching.....	103
2.4 Plasma Chemistries.....	104
2.4.1 Chlorine-Based Plasmas	104
2.4.2 Iodine- and Bromine-Based Plasmas	116
2.4.3 Methane–Hydrogen–Argon Plasmas	121
2.5 Etch Profile and Etched Surface Morphology	122
2.6 Plasma-Induced Damage	124
2.6.1 n-Gallium Nitride.....	126
2.6.2 p-Gallium Nitride.....	133
2.6.3 Schottky Diodes.....	141
2.6.4 p-n Junctions.....	148
2.7 Device Processing.....	152
2.7.1 Microdisk Lasers.....	152
2.7.2 Ridge Waveguide Lasers	153
2.7.3 Heterojunction Bipolar Transistors.....	157
2.7.4 Field Effect Transistors.....	161
2.7.5 Ultraviolet Detectors.....	166
References	169
 3 Design and Fabrication of Gallium Nitride High-Power Rectifiers.....	179
3.1 Abstract.....	179
3.2 Introduction	179
3.3 Background.....	180
3.3.1 Temperature Dependence of Bandgap.....	180
3.3.1.1 Gallium Nitride	180
3.3.1.2 6H-SiC	181
3.3.2 Effective Density of States	182
3.3.3 Intrinsic Carrier Concentration	182
3.3.4 Incomplete Ionization of Impurity Atoms	183
3.3.5 Mobility Models	184
3.3.5.1 Analytical Mobility Model.....	184
3.3.5.2 Field-Dependent Mobility Model	185
3.3.6 Generation and Recombination	186
3.3.6.1 Shockley–Read–Hall Lifetime.....	186

3.3.6.2 Auger Recombination	186
3.3.7 Reverse Breakdown Voltage	186
3.3.8 On-State Resistance	191
3.4 Edge Termination Design	195
3.4.1 Field Plate Termination	195
3.4.2 Junction Termination	198
3.5 Comparison of Schottky and p-n Junction Diodes	201
3.5.1 Reverse Bias	201
3.5.2 Forward Bias.....	201
3.6 High Breakdown Lateral Diodes	204
3.7 Bulk Diode Arrays.....	207
3.8 Conclusions	210
References	211
4 Chemical, Gas, Biological, and Pressure Sensing.....	213
4.1 Abstract.....	213
4.2 Introduction	214
4.3 Sensors Based on AlGaN–GaN Heterostructures.....	219
4.3.1 Gateless AlGaN–GaN High Electron Mobility Transistor Response to Block Co-Polymers	219
4.3.2 Hydrogen Gas Sensors Based on AlGaN–GaN-Based Metal-Oxide Semiconductor Diodes.....	222
4.3.3 Hydrogen-Induced Reversible Changes in Sc_2O_3- AlGaN–GaN High Electron Mobility Transistors	226
4.3.4 Effect of External Strain on Conductivity of AlGaN– GaN High Electron Mobility Transistors.....	230
4.3.5 Pressure Sensor Fabrication.....	236
4.3.6 Selective-Area Substrate Removal	239
4.3.7 Biosensors Using AlGaN–GaN Heterostructures	240
4.3.8 Surface Acoustic Wave-Based Biosensors	245
4.4 Surface Acoustic Wave Device Fabrication	247
4.5 Surface Acoustic Wave Device for Gas Sensing.....	250
4.6 Flexural Plate Wave Device for Liquid Sensing	251
4.7 Surface Acoustic Wave Array	251
4.8 Wireless Sensor Network and Wireless Sensor Array Using Radio Frequency Identification Technology	252
4.9 Summary.....	255
References	255
5 Nitride-Based Spintronics	261
5.1 Abstract.....	261
5.2 Introduction	261

5.3	Potential Semiconductor Materials for Spintronics.....	262
5.4	Mechanisms of Ferromagnetism	263
5.5	(Ga,Mn)N	266
5.6	Role of Second Phases	269
5.7	Electrical and Optical Properties.....	273
5.8	Transport Properties	281
5.9	Contacts to (Ga,Mn)N	285
5.10	Aluminum Nitride-Based Ferromagnetic Semiconductors	287
5.11	Implanted Aluminum Nitride Films	291
5.12	Implanted AlGaN Films	294
5.13	Potential Device Applications	299
5.14	Issues to Be Resolved.....	307
	References.....	307
 6 Novel Insulators for Gallium Nitride Metal-Oxide Semiconductor Field Effect Transistors and AlGaN–GaN Metal-Oxide Semiconductor High Electron Mobility Transistors		313
6.1	Abstract	313
6.2	Introduction	314
6.3	Insulators for Gallium Nitride Metal-Oxide Semiconductor and Metal–Insulator–Semiconductor Field Effect Transistors.....	317
6.4	Approach for Gallium Nitride	320
6.4.1	Bixbyite Oxides	321
6.4.2	Scandium Oxide	326
6.4.3	MgO–CaO	327
6.4.4	Amorphous Aluminum Nitride.....	327
6.5	Gate-Controlled Metal-Oxide Semiconductor Diodes	329
6.5.1	Surface Passivation.....	334
6.5.2	Radiation-Damage Experiments.....	348
6.6	Metal-Oxide Semiconductor Field Effect Transistors.....	349
6.6.1	n-Channel Depletion Mode Gallium Nitride Metal-Oxide Semiconductor Field Effect Transistors Using Stacked Gate Dielectric of SiO ₂ –Gd ₂ O ₃	349
6.6.2	MgO–p-GaN Enhancement Mode Metal-Oxide Semiconductor Field Effect Transistors	352
6.7	Conclusions	355
	References.....	355
	Index	361