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# III-Nitride Semiconductors and their Modern Devices

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*Edited by*  
Bernard Gil



# III-Nitride Semiconductors and their Modern Devices

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**Bernard Gil**

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17. S. Maekawa, S. O. Valenzuela, E. Saitoh, T. Kimura: *Spin current*
18. B. Gil: *III-nitride semiconductors and their modern devices*

## Preface

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When I met Sönke Adlung, of Oxford University Press, during the annual meeting of the European Materials Research Society in Strasbourg in June 1996, he was taking care of the exhibition booth in his editorial role, while I was co-organizing a symposium dedicated to visible-light emitters.

Nitrides were booming world-wide at that time. During the preceding three years, many researchers, including myself, had reoriented their research activities to nitrides after several Japanese researchers, including Prof Isamu Akasaki and Drs Hiroshi Amano and Shuji Nakamura, had made significant breakthroughs in various scientific areas such as materials science and device physics. These breakthroughs had led to the realization and commercialization of blue light-emitting diodes based on nitride semiconductors. More recently, in January 2006, a blue laser was demonstrated in Japan. Most of the attendees at the visible-light symposium had come to Strasbourg to hear, in a very crowded conference room, the talk by Shuji Nakamura, planned for Friday the 7th, so that they could see with their own eyes the coherent blue light-ray of a nitride-based laser exciting the fluorescence of a paper screen.

During the afternoon of that Friday, Sönke, with whom I was chatting in front of the OUP booth, suggested that I edit a book dedicated to nitrides. *Group III Nitride Semiconductor Compounds: Physics and Applications* was edited one and-a-half years later in 1998, and it was followed by *Low-Dimensional Nitride Semiconductors* in 2002. Today you are holding *III-Nitride Semiconductors and their Modern Devices*.

Ten years have passed since the second volume of this series was published. We believed a few months ago, in light of recent new developments in the field, that it was time to offer a modernized compilation of today's research activities. We kept the initial format: a book accessible to the larger community, including PhD students at the beginning of their studies and not yet familiar with the world of semiconductor physics. Light emission/detection is a newly developing area. Therefore, I asked Professor Amano of Nagoya University, one of the fathers of nitrides, to write a general introductory chapter to provide an overview of the needs and realizations in that area. His chapter combines a review of economic issues and societal needs, together with growth aspects, physics characterization, and device realizations. All other chapters were written by leading researchers in specific fields. Dr Izabella Grzegory has been growing bulk gallium nitride since the beginning of her career. I had in my hands some very tiny pieces of her transparent gallium nitride bulk crystal as early as January 1986! I found it natural to

ask her to take care of the chapter dedicated to the homoepitaxial challenge, and she wrote it in collaboration with her colleagues at Warsaw: Michal Bockowski, Piotr Perlin, Czeslaw Skierbiszewski, Tadeusz Suski, Marcin Sarzynski, Stanislaw Krukowski, and Sylwester Porowski. They share it with us here, and they indicate how far they have advanced since their early studies in Poland at the end of the 1970s. Nitrides being often deposited by using modern epitaxial growth techniques (see for instance, the first book of this series), to review the status of the research at the nitride–silicon interface is of value. I asked Professor Alois Krost and Dr Armin Dadgar, of the Otto-von-Guericke-University at Magdeburg, to address this message at the dawn 2013. This constitutes the third chapter, which precedes the chapter dedicated to the growth of bulk aluminium nitride (a very promising substrate for the years to come), written by Zlatko Sitar and Ronny Kirste of the North Carolina State University at Raleigh. Since the beginning of the 1980s, semiconductor quantum dots have been known to be, beyond the scope of promising concepts, efficient adimensional localization centers for electrons and holes, offering the possibility of realizing low-threshold lasing. We now know that quantum dots are useful for realizing single-photon sources and entangled-photon pair-emitters. Andre Strittmatter, of the Technical University of Berlin, agreed to write the fifth chapter, dedicated to the growth of such light-emitters. Band-gap engineering issues are particularly important regarding the growth of heterostructures on lattice mismatched substrates. Chapters 6 and 7 were written by researchers at the Ecole Polytechnique Fédérale de Lausanne and Mie University, respectively. Aluminum indium nitride was initially proposed by Professor Marc Illegems (now retired) and Dr Jean François Carlin. I thus naturally asked the colleagues that are currently holding Marc's stick to accept the burden of reviewing the status and importance of the AlInN alloy at the composition lattice-matched to GaN. Drs Raphaël Butté, Gatien Cosendey, Lorenzo Lugani, Marlene Glauser, Antonino Castiglia, Guillaume Perillat-Merceroz, Jean-François Carlin, and Professor Nicolas Grandjean did this very nicely. Aluminum-rich AlGaIn alloys are also very important for targeting deep-ultraviolet applications. These alloys are treated by an internationally recognized expert in the area of crystal growth of chalcopyrites and nitrides: Professor Hideto Miyake, of Mie University. There are tremendous developments these days regarding the properties of light-emitters grown on non-polar or semipolar orientations. Writing such a chapter, while retaining clarity and a reasonable length, required considerable effort by Professor Michael Kneissl and Dr Tim Wernicke of the Technical University and Ferdinand-Braun-Institute at Berlin. The result is impressive. In Chapter 9, Drs Rudeesun Songmuang and Eva Monroy address the single-nanowire devices, which was quite challenging from the beginning. Dr Jean-Yves Duboz, of the Centre of Research on Hetero-Epitaxy and its Applications, in Valbonne, agreed to write on advanced photonic and nanophotonic devices, the topic of Chapter 10. Dr Yvon Cordier, of the Centre of Research on Hetero-Epitaxy and Applications, Valbonne, and Drs Tatsuya Fujishima, Bin Lu, Elison Matioli, and Professor Tomás Palacios,

of the Massachusetts Institute of Technology, Cambridge, next address nitride-based electron devices, widely investigated for the next generation of high-power and high-frequency applications.

The potentialities of having large conduction-band offsets in nitride heterostructures enables targeting of intersubband transitions in low-dimensional nitrides, which are in particular investigated at the Institute of Fundamental Electronics by Drs Maria Tchernycheva and François Julien. They both accepted my invitation to write the chapter dedicated to applications of nitride heterostructures in the mid-infrared. The large oscillator strength of nitrides paves the way to fascinating optical properties, among which is the slow-light propagation phenomenon. Drs Tatiana Shubina and Mikhail Glazov, of the IOFFE Institute in St Petersburg, together with Dr Nikolay Gippius of the General Physics Institute of the Russian Academy of Sciences, in Moscow, placed aside the Cyrillic alphabet in order to write the thirteenth chapter, and I share the responsibility with them. Then follow three chapters dedicated to very prospective issues. Nitride devices and their biofunctionalization for biosensing applications are treated in a fourteenth chapter by my office neighbor Professor Csilla Gergely at Montpellier, and Walter R. L. Lambrecht and Atchara Punya, of the Department of Physics at Case Western Reserve University, Cleveland, address, in a very didactical way, the physics of heterovalent ternary II-IV-N<sub>2</sub> compounds and perspectives for a new class of materials that are, *mutatis mutandis*, the analogs of the chalcopyrites. Finally, it has been proposed recently by Professor Alexey Kavokin to produce a radiative relaxation process between a forbidden excitonic transition populated by non-linear two-photon spectroscopy and an allowed one. Two photons are successively emitted—the first by cascading at an energy in the terahertz frequency region, and the second occurring at the host material band-gap energy. This process arm-twists the black-body radiation law, and may lead to a new class of THz emitters. I have asked Drs Oleksandr Kyriienko and Ivan Shelykh, of the University of Iceland, in Reykjavik, and the Division of Physics and Applied Physics, Anyang Technological University of Singapore, and Professor Alexey Kavokin, of the University of Southampton, to provide readers with sufficient elements for them to eventually handle this kind of research. The cover picture represents a photonic billiard designed by Didier Felbacq, realized and shined with a blue laser by Emmanuel Rousseau.

This book obviously departs from perfection, and is not exhaustive. I deeply hope, however, that it fulfils most of the needs of people in academic laboratories and most of the companies. To conclude, I would like to acknowledge all the contributors, and in addition, Jessica White, Sönke Adlung, Gandhimathi Ganesan, and Victoria Mortimer at Oxford University Press.

Bernard Gil  
Montpellier, November 2012



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# Contents

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## List of Contributors

xviii

<b>1 Development of the nitride-based UV/DUV LEDs</b>	<b>1</b>
<b>Hiroshi Amano</b>	
1.1 Introduction	1
1.2 Efficiency limiting process	4
1.2.1 Internal quantum efficiency	4
1.2.2 Current injection efficiency	10
1.2.3 Light extraction efficiency	14
1.3 Summary	14
Acknowledgments	14
References	15
<b>2 The homoepitaxial challenge: GaN crystals grown at high pressure for laser diodes and laser diode arrays</b>	<b>18</b>
<b>Izabella Grzegory, Michal Bockowski, Piotr Perlin, Czeslaw Skierbiszewski, Tadeusz Suski, Marcin Sarzynski, Stanislaw Krukowski, and Sylwester Porowski</b>	
2.1 Introduction	18
2.2 Thermodynamics of GaN	20
2.2.1 Melting conditions of GaN	20
2.2.2 High-pressure thermodynamics of GaN: phase diagrams	24
2.3 Crystal growth of GaN	29
2.3.1 GaN by HVPE	30
2.3.2 High-nitrogen-pressure solution growth of GaN	32
2.3.3 Ammonothermal growth of GaN	38
2.4 Epitaxy of nitrides on single-crystalline HNPS GaN: early results	41
2.5 Development of nitrides epitaxy by PA MBE	44
2.5.1 Growth conditions for PAMBE	44
2.5.2 The role of threading dislocations and miscut angle on surface morphology in low-temperature PAMBE	46
2.5.3 The growth of high-In-content InGa <sub>N</sub> layers by PAMBE	47

2.5.4	The influence of the growth conditions on the optical properties of InGaN QWs	49
2.5.5	Optical lasing from InGaN QWs	52
2.5.6	Laser diodes	54
2.6	“Plasmonic” GaN substrates and their use for lasers	58
2.7	Laser diode arrays on laterally patterned substrates	61
2.7.1	Background	61
2.7.2	Laser diode arrays on laterally patterned HNPS GaN substrates	64
2.8	High-power lasers and arrays on Ammono and HNPS GaN substrates	67
2.9	Summary and conclusions	71
	Acknowledgments	72
	References	72
<b>3</b>	<b>Epitaxial growth and benefits of GaN on silicon</b>	<b>78</b>
	<b>Armin Dadgar and Alois Krost</b>	
3.1	Introduction	78
3.2	The GaN-on-silicon challenges	78
3.2.1	Lattice mismatch	79
3.2.2	Thermal mismatch	81
3.2.3	Meltback etching	82
3.2.4	Plastic substrate deformation	83
3.2.5	Vertical conductivity	85
3.3	Seed layer growth	87
3.4	Stress management	89
3.4.1	Stress management by Al(Ga)N layers	90
3.4.2	Selective growth	95
3.5	Dislocation reduction	95
3.6	Light-emitting diodes	98
3.7	Electronics	102
3.7.1	RF transistors	103
3.7.2	HV transistors	103
3.8	Limits of GaN-on-Si MOVPE technology and new developments	106
3.8.1	Limits of GaN-on-Si MOVPE technology	107
3.8.2	New developments	107
	Acknowledgments	112
	References	112
<b>4</b>	<b>The growth of bulk aluminum nitride</b>	<b>121</b>
	<b>Ronny Kirste and Zlatko Sitar</b>	
4.1	Introduction	121
4.2	Bulk AlN: a pathway to high-quality AlGaIn	121

4.3	Growth of AlN crystals	123
4.3.1	Physical vapor transport	124
4.3.2	Hydrid vapor phase epitaxy	126
4.3.3	Solution growth	128
4.3.4	Seeding of AlN crystal growth	129
4.4	Properties of state-of-the-art bulk AlN	130
4.4.1	Structural properties	131
4.4.2	Optical properties and impurities	133
4.5	Applications and devices	137
4.5.1	Properties of AlN and AlGa <sub>N</sub> epitaxial layers on AlN	137
4.5.2	Devices on bulk AlN substrates	139
4.6	Outlook	141
	References	142
<b>5</b>	<b>Epitaxial growth of nitride quantum dots</b>	<b>147</b>
	<b>André Strittmatter</b>	
5.1	Introduction	147
5.2	GaN quantum dots	148
5.2.1	Molecular beam epitaxy	148
5.2.2	Metalorganic vapor phase epitaxy	151
5.2.3	Growth on non-polar and semipolar planes	152
5.3	In <sub>x</sub> Ga <sub>1-x</sub> N quantum dots	157
5.3.1	Phase separation and In segregation effects	157
5.3.2	Stranski-Krastanow growth mode	159
5.3.3	Spontaneous quantum dot formation in InGa <sub>N</sub> layers	162
5.3.4	Thermal annealing and surface pre-treatment methods	164
5.3.5	InN quantum dots	165
5.4	Site-selective growth	167
5.5	Summary	169
	References	170
<b>6</b>	<b>Properties of InAlN layers nearly lattice-matched to GaN and their use for photonics and electronics</b>	<b>177</b>
	<b>Raphaël Butté, Gatien Cosendey, Lorenzo Lugani, Marlene Glauser, Antonino Castiglia, Guillaume Perillat-Merceroz, Jean-François Carlin, and Nicolas Grandjean</b>	
6.1	Introduction	177
6.2	Growth and structural properties of bulk InAlN layers	178
6.2.1	Growth characteristics of InAlN films	178
6.2.2	Structural properties of bulk InAlN layers	181
6.3	Optical and electronic properties of bulk InAlN layers	188
6.4	Optical features of GaN/InAlN quantum wells	191

6.5	Nearly lattice-matched InAlN/(Al)GaN distributed Bragg reflectors	192
6.5.1	Growth properties	192
6.5.2	Optical properties	195
6.5.3	Applications	196
6.6	InAlN cladding layers for edge-emitting lasers	200
6.7	InAlN/GaN high electron mobility transistors	207
6.7.1	Growth of InAlN/GaN high electron mobility heterostructures	208
6.7.2	InAlN/GaN HEMTs for high-frequency applications	210
6.7.3	Power performance of InAlN/GaN HEMTs	212
6.7.4	Enhancement-mode InAlN/GaN HEMTs	214
6.8	Conclusion	216
	Acknowledgments	217
	References	217
<b>7</b>	<b>Growth and optical properties of aluminum-rich AlGaIn heterostructures</b>	<b>227</b>
	<b>Hideto Miyake</b>	
7.1	Introduction	227
7.2	Growth of Si-doped AlGaIn on AlN/sapphire templates	228
7.3	Growth of Si-doped AlGaIn/AlGaIn multiple-quantum wells	232
7.4	Fabrication of AlGaIn MQWs for electron-beam target for deep-ultraviolet light sources	240
7.5	Conclusions	241
	Acknowledgments	242
	References	242
<b>8</b>	<b>Optical and structural properties of InGaIn light-emitters on non-polar and semipolar GaIn</b>	<b>244</b>
	<b>Michael Kneissl and Tim Wernicke</b>	
8.1	Spontaneous and piezoelectric polarization in InGaIn/GaIn quantum wells on c-plane, semipolar, and non-polar crystal orientations	245
8.2	Performance characteristics of violet, blue, and green (0001) c-plane InGaIn quantum well LEDs and laser diodes	248
8.3	Growth of non-polar and semipolar GaIn buffer layers for device applications	253
8.3.1	Growth of GaIn on low-defect bulk GaIn substrates	253
8.3.2	Growth of GaIn on planar heteroepitaxial substrates	255
8.3.3	Strategies for defect reduction for heteroepitaxially grown GaIn	257



8.4	Growth of InGaN layers and quantum wells on m-plane and different semipolar surfaces, i.e. $(10\bar{1}2)$ , $(10\bar{1}1)$ , $(20\bar{2}1)$ , $(11\bar{2}2)$	261
8.4.1	Indium incorporation efficiency for different surface orientations	261
8.4.2	Optical properties of non-polar and semipolar InGaN QWs	263
8.5	Performance characteristics of non-polar and semipolar InGaN QW LEDs	266
8.5.1	External quantum efficiencies and emission wavelength	266
8.5.2	Polarization effects and efficiency droop	268
8.6	Performance characteristics of non-polar and semipolar InGaN QW lasers	269
8.6.1	Gain characteristics of InGaN quantum-well lasers on non-polar and semipolar GaN and effects of the excitation stripe orientation	269
8.6.2	Fabrication of laser cavities (e.g., etched, cleaved facets)	272
8.6.3	State-of-the-art of non-polar and semipolar InGaN laser diodes	276
8.7	Summary and outlook	279
	Acknowledgments	279
	References	279
<b>9</b>	<b>GaN-based single-nanowire devices</b>	<b>289</b>
	<b>Rudeesun Songmuang and Eva Monroy</b>	
9.1	Introduction	289
9.2	Nanowire synthesis	290
9.2.1	Catalyst-induced NW growth	290
9.2.2	Catalyst-free NW growth	293
9.3	Energy conversion	299
9.3.1	Photoconductive detection	299
9.3.2	Photovoltaics	305
9.3.3	Energy harvesting via piezoelectric effects	306
9.4	Nanoelectronics	308
9.4.1	GaN NW field-effect transistors	308
9.4.2	GaN NW single-electron transistors	310
9.4.3	GaN/AlN/AlGaIn core-shell NW high-electron-mobility transistors	312
9.4.4	GaN/AlN axial-heterostructure resonant tunneling devices	313
9.4.5	GaN/AlN axial-heterostructure single-electron transistors	315
9.5	Sensorics	317