

---

## Contents

---

<b>Introduction . . . . .</b>	ix
<b>Chapter 1. Light-emitting Diodes: State-of-the-Art GaN Technologies . . . . .</b>	
1.1. Current economic context . . . . .	2
1.1.1. Global LED market . . . . .	2
1.1.2. Societal and market issues of GaN LEDs for public lighting . . . . .	5
1.2. State-of-the-art GaN-based LEDs . . . . .	11
1.2.1. Nitrides: from the wurtzite structure to band engineering . . . . .	11
1.2.2. Electroluminescent GaN-based diodes . . . . .	18
1.3. Positioning, justification and objectives of the study . . . . .	34
1.3.1. Positioning and justification of the study . . . . .	35
1.3.2. Objectives of the study . . . . .	38
1.4. Conclusion . . . . .	42
<b>Chapter 2. Tools and Analysis Methods of Encapsulated LEDs . . . . .</b>	
2.1. Junction temperature measurement methodologies . . . . .	44
2.1.1. Electrical methods . . . . .	46
2.1.2. Optical methods . . . . .	50
2.1.3. Methodology synthesis and thermal parameters . . . . .	51
2.2. Mechanisms and electrical models of an LED . . . . .	53
2.2.1. Current–voltage measurement bench I(V) . . . . .	54
2.2.2. Electronic transport phenomena . . . . .	55

2.3. Mechanisms and optical models of LED . . . . .	61
2.3.1. Bench optical power measurements . . . . .	61
2.3.2. Model of optical power . . . . .	63
2.3.3. Bench spectral measurements . . . . .	69
2.3.4. Phenomena of electronic transitions of a DH LED . . . . .	71
2.3.5. Optical parameters of a DH LED . . . . .	76
2.3.6. Phenomena of electronic transitions of a MQW LED . . . . .	78
2.3.7. Optical parameters of a MQW LED . . . . .	81
2.4. Physicochemical characterizations of an LED . . . . .	82
2.4.1. Sample preparation techniques . . . . .	83
2.4.2. Nuclear analyses . . . . .	85
2.4.3. Electronic analyses . . . . .	93
2.4.4. Optical analyses . . . . .	97
2.4.5. Temperature analysis: differential scanning calorimetry . . . . .	102
2.4.6. Summary of physicochemical analyses . . . . .	104
2.5. Conclusion . . . . .	105
<b>Chapter 3. Failure Analysis Methodology of Blue LEDs . . . . .</b>	<b>107</b>
3.1. Mission and aging profile . . . . .	108
3.1.1. Component definition . . . . .	108
3.1.2. Environmental stresses and acceleration factor . . . . .	109
3.2. Aging campaigns . . . . .	110
3.2.1. Specifications of accelerated aging . . . . .	110
3.2.2. Aging campaign . . . . .	111
3.3. Initial characterization of LEDs: electrical and optical aspects . . . . .	115
3.3.1. LEDs' technological description . . . . .	116
3.3.2. Extraction of LEDs' electro-optical parameters . . . . .	119
3.4. Application of the methodology on low-power LEDs . . . . .	131
3.4.1. Impact of aging on the optical power . . . . .	131
3.4.2. Electrical failure signatures . . . . .	132
3.4.3. Optical failure signatures . . . . .	134
3.4.4. Confirmation of failure mechanisms: physicochemical analyses . . . . .	135
3.5. Summary of results and conclusions . . . . .	142

<b>Chapter 4. Integration of the Methodology Starting from Component Design</b>	147
4.1. Mission profile for public lighting . . . . .	148
4.1.1. Context and project objectives . . . . .	149
4.1.2. Environmental requirements and constraints in public lighting . . . . .	150
4.1.3. Studied technologies . . . . .	152
4.2. Aging campaign and component description . . . . .	153
4.2.1. Aging campaign specifications . . . . .	153
4.2.2. Technological description of LEDs . . . . .	154
4.3. Physical failure analysis . . . . .	156
4.3.1. Location of degraded areas: electro-optical and thermal failure signature . . . . .	157
4.3.2. Validation of failure mechanisms by using physicochemical analyses . . . . .	171
4.3.3. Technological solutions . . . . .	184
4.4. Summary of results and conclusions . . . . .	185
<b>Conclusion</b> . . . . .	187
<b>Bibliography</b> . . . . .	195
<b>Index</b> . . . . .	209