

Contents

| | | |
|----------|---|------------|
| 1 | Introduction and Motivation | 1 |
| 2 | Polarization Properties and Polarization Control | 3 |
| 2.1 | Fundamentals of VCSELs | 3 |
| 2.2 | Polarization of VCSELs: Experimental Findings | 11 |
| 2.3 | Polarization of VCSELs: Theoretical Explanations | 17 |
| 2.4 | Demand for and Previous Attempts on Polarization Control | 25 |
| 3 | Concept and Design of Surface Gratings | 31 |
| 3.1 | Concept of Surface Gratings for Polarization Control | 32 |
| 3.2 | Fully Vectorial, Three-Dimensional VCSEL Model | 34 |
| 3.3 | Simulation of VCSELs With a Surface Grating | 41 |
| 3.4 | Design of Surface Gratings | 45 |
| 4 | Processing of Surface Grating VCSELs | 55 |
| 4.1 | Integration Into Fabrication Process | 55 |
| 4.2 | Definition of the Grating | 57 |
| 4.3 | Etching Process of the Grating | 60 |
| 5 | Investigation of Grating Parameters | 65 |
| 5.1 | Measurement Setup | 65 |
| 5.2 | Polarization-Stable Single-Mode VCSELs | 68 |
| 5.3 | Polarization-Stable Multimode VCSELs | 73 |
| 5.4 | Grating Depth and Grating Period | 77 |
| 5.5 | Yield of Polarization-Stable VCSELs | 84 |
| 5.6 | Performance of First Generation Grating VCSELs | 88 |
| 5.7 | Diffraction Induced by a Surface Grating | 89 |
| 5.8 | VCSELs With Small Grating Depth and Large Duty-Cycle | 101 |
| 6 | Polarization Control Under Demanding Conditions | 105 |
| 6.1 | Polarization Control Under Variation of the Substrate Temperature | 105 |
| 6.2 | Polarization Control Under Optical Feedback | 107 |
| 6.3 | Polarization Control Under External Stress | 113 |

CONTENTS

| | | |
|-----------|--|------------|
| 6.4 | Polarization Control Under High-Frequency Modulation | 116 |
| 6.5 | Polarization Division Multiplexing | 123 |
| 7 | Direct Measurement of the Dichroism | 129 |
| 7.1 | Underlying Theory | 130 |
| 7.2 | Spectral Measurements at Laser Threshold | 132 |
| 7.3 | Determination of the Modal Dichroism | 133 |
| 7.4 | Comparison of Measurements and Simulations | 138 |
| 7.5 | Modal Dichroism and OPSR | 140 |
| 8 | Inverted Grating VCSELs | 143 |
| 8.1 | Concept of Inverted Gratings | 143 |
| 8.2 | Polarization Control Induced by an Inverted Grating | 146 |
| 8.3 | Performance of Inverted Grating VCSELs | 149 |
| 8.4 | Diffraction Induced by an Inverted Grating | 151 |
| 8.5 | Layer Structures Other Than Normal and Inverted | 156 |
| 9 | Grating Relief VCSELs | 159 |
| 9.1 | Single-Mode VCSELs | 159 |
| 9.2 | Concept of Surface Reliefs and Surface Grating Reliefs | 160 |
| 9.3 | Processing of Grating Relief VCSELs | 164 |
| 9.4 | Polarization Control Induced by a Grating Relief | 165 |
| 9.5 | Performance of Grating Relief VCSELs | 167 |
| 9.6 | Diffraction Induced by a Grating Relief | 169 |
| 9.7 | Grating Relief VCSELs for Oxygen Sensing | 170 |
| 10 | Summary and Conclusion | 177 |
| A | Layer Structure and Expansion Modes | 183 |
| B | Optical Contact Lithography of Gratings | 185 |
| C | Details of Technological Processes | 189 |
| D | Investigated Wafers | 191 |
| E | Index of Mathematical Symbols | 197 |
| F | Index of Abbreviations | 201 |
| | Publications | 203 |
| | Bibliography | 208 |