



Agnieszka Pietrzak (Autor)

# Realization of High Power Diode Lasers with Extremely Narrow Vertical Divergence



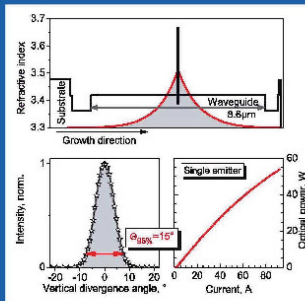
Leibniz  
Ferdinand-Braun-Institut

21

Forschungsberichte aus dem  
Ferdinand-Braun-Institut  
Leibniz-Institut  
für Höchstfrequenztechnik

Innovationen mit Mikrowellen & Licht

Realization of High Power Diode  
Lasers with Extremely Narrow  
Vertical Divergence



Agnieszka Pietrzak

<https://cuvillier.de/de/shop/publications/39>

Copyright:

Cuvillier Verlag, Inhaberin Annette Jentsch-Cuvillier, Nonnenstieg 8, 37075 Göttingen, Germany  
Telefon: +49 (0)551 54724-0, E-Mail: [info@cuvillier.de](mailto:info@cuvillier.de), Website: <https://cuvillier.de>



# Contents

<b>1. Introduction and motivation</b>	<b>1</b>
1.1. Overview of chapter contents .....	4
<b>2. The overview of general concepts for vertical mode expansion</b>	<b>6</b>
2.1. Thin Active Layer (TAL) lasers .....	6
2.2. Separate Confinement Heterostructure (SCH) .....	7
2.3. Photonic Band Crystals lasers (PBC) .....	9
2.4. Tilted Wave Laser (TWL) .....	10
2.5. Super Large Optical Cavity (SLOC) .....	11
<b>3. Semiconductor laser model with Fabry-Perot resonator</b>	<b>13</b>
3.1. Basic diode laser concept .....	13
3.2. Simulation of an optical mode in a layered media .....	17
3.2.1 The Quasi-2Dimensional Semiconductor Laser Simulator .....	17
3.2.2. Calculation of the index of refraction .....	17
3.2.3. The one-dimensional (vertical) optical waveguide model .....	19
3.2.4. Vertical divergence angle .....	21
3.3. Phenomenological laser model .....	21
3.3.1. Carrier injection and photon generation .....	21
3.3.2. Optical loss, gain and threshold conditions .....	22
3.3.3. Optical power-current characteristic .....	24
3.3.4. Thermal parameters influencing the semiconductor laser performance .....	26
<b>4. Process technology and packaging of high power diode lasers</b>	<b>30</b>
4.1. Epitaxy of high power 1050 – 1150 nm diode laser structures based on GaAs substrates .....	30
4.2. Processing of edge emitting broad area diode lasers .....	32
4.2.1. Technology of diode laser for ‘Pre-test’ .....	32



4.2.2. Technology of high power broad area single emitters .....	33
4.3. Mounting of high power diode lasers .....	33
<b>5. Measurement techniques and experimental setups for diode laser characterization</b>	<b>35</b>
5.1. Characterization of uncoated and unmounted laser chip.....	35
5.1.1. Length-dependence measurement – ‘Pre-test’ .....	35
5.2. Characterization of mounted laser devices.....	37
5.2.1. Power-Voltage-Current characteristics and optical spectrum.....	37
5.2.2. Measurement of the spontaneous emission from the waveguide.....	42
5.3. Characterization of the laser beam .....	43
5.3.1. Measurement techniques .....	45
5.3.2. Experimental setup for laser beam characterization in the vertical plane .....	45
5.3.3. Experimental setup for laser beam characterization in the lateral plane .....	46
<b>6. Basic features of the SLOC design – simulation results</b>	<b>48</b>
6.1. Introduction .....	48
6.2. The optical cavity size and the optical mode distribution.....	48
6.3. Confinement factor $\Gamma$ and equivalent vertical spot-size .....	53
6.4. The optical cavity size and the number of vertical modes .....	55
6.5. Discrimination of higher order modes.....	56
<b>7. Assessment of the limits to the maximum optical power of the 1100 nm SLOC design</b>	<b>59</b>
7.1. Introduction .....	59
7.2. Investigated SLOC designs .....	59
7.3. Assessment of the limiting factor to the maximum optical power.....	60
7.4. Higher number of quantum wells for vertical carrier leakage reduction.....	62
7.4.1. Analytical description of the problem.....	62
7.4.2. Experimental results.....	64
7.5. Conclusions .....	66
<b>8. 1130 nm-diode laser with a reduced vertical divergence angle to 13° and maintained high optical power</b>	<b>67</b>
8.1. Introduction .....	67



8.2. Investigated SLOC designs .....	67
8.3. Parameters of laser structures – ‘Pre-test’ results.....	68
8.4. Characterization of mounted devices .....	69
8.4.1. Laser based on 3.4 $\mu\text{m}$ thick GaAs-waveguide.....	70
8.4.2. Laser based on 5.0 $\mu\text{m}$ thick GaAs-waveguide.....	71
8.5. Conclusion.....	73
<b>9. 1060 nm laser design based on extremely large waveguides for small divergence angle of <math>10^\circ</math></b> .....	<b>74</b>
9.1. Introduction .....	74
9.2. Investigated SLOC designs .....	74
9.3. Low effective barrier in GaAs-waveguide based design resulting in inefficient laser operation.....	77
9.4. AlGaAs-waveguides for good carrier confinement and improved laser operation .....	79
9.5. Conclusions .....	84
<b>10. SLOC with low index quantum barriers for small vertical far-fields</b> .....	<b>86</b>
10.1. Introduction .....	86
10.2. Investigated SLOC designs .....	86
10.3. Optical mode expansion for narrow vertical far-field.....	88
10.4. Internal parameters of the laser design.....	89
10.5. Power-current characteristics of mounted lasers.....	89
10.5.1. Experimental results.....	89
10.5.2. Device simulations .....	91
10.5.3. Thermal stability and the resonator length.....	93
10.5.4. High-power laser devices with long resonators .....	94
10.6. Lateral far-field of laser based on the SLOC-LIQB design .....	95
10.7. Conclusions .....	96
<b>11. Summary and outlook</b> .....	<b>98</b>
<b>Appendix 1: List of grown epitaxial structures</b> .....	<b>103</b>
<b>Appendix 2: Stimulated emission recombination rate and the power of the guided mode</b> .....	<b>106</b>
<b>Appendix 3: Mirror losses and threshold conditions</b> .....	<b>108</b>



<b>Appendix 4: The WIAS-TeSCA Software .....</b>	<b>110</b>
<b>Appendix 5: Simulations of temperature distribution in the transverse cross section of the laser diode .....</b>	<b>114</b>
<b>Bibliography.....</b>	<b>117</b>