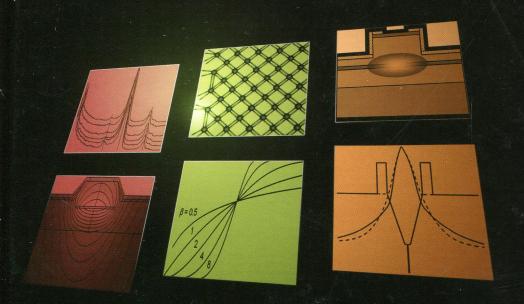
Semiconductor Laser Engineering, Reliability and Diagnostics



A Practical Approach to High Power and Single Mode Devices

Peter W. Epperlein



Semiconductor Laser Engineering, Reliability and Diagnostics

A Practical Approach to High Power and Single Mode Devices

Peter W. Epperlein



This edition first published 2013 © 2013, John Wiley & Sons Ltd

Registered office

John Wiley & Sons Ltd, The Atrium, Southern Gate, Chichester, West Sussex, PO19 8SQ, United Kingdom

For details of our global editorial offices, for customer services and for information about how to apply for permission to reuse the copyright material in this book please see our website at www.wiley.com.

The right of the author to be identified as the author of this work has been asserted in accordance with the Copyright, Designs and Patents Act 1988.

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system, or transmitted, in any form or by any means, electronic, mechanical, photocopying, recording or otherwise, except as permitted by the UK Copyright, Designs and Patents Act 1988, without the prior permission of the publisher.

Wiley also publishes its books in a variety of electronic formats. Some content that appears in print may not be available in electronic books.

Disclaimer: All reasonable endeavours have been used to develop, research and test the information presented in this publication, however the publisher and the author make no representations or warranties with respect to the accuracy or completeness of the contents of this work and specifically disclaim all warranties, including without limitation warranties of fitness for a particular purpose. No warranty may be created or extended by sales or promotional materials. The advice and strategies contained herein may not be suitable for every situation. This work is sold with the understanding that the publisher is not engaged in rendering legal, accounting, or other professional services. If professional assistance is required, the services of a competent professional person should be sought. Neither the publisher nor the author shall be liable for damages arising herefrom. The fact that an organization or Website is referred to in this work as a citation and/or a potential source of further information does not mean that the author or the publisher endorses the information the organization or Website may provide or recommendations it may make. Further, readers should be aware that Internet Websites listed in this work may have changed or disappeared between when this work was written and when it is read.

Library of Congress Cataloging-in-Publication Data

Epperlein, Peter W.

Semiconductor laser engineering, reliability, and diagnostics: a practical approach to high power and single mode devices / Peter W. Epperlein.

pages cm

Includes bibliographical references and index.

ISBN 978-1-119-99033-8 (hardback)

1. Semiconductor lasers. I. Title.

TA1700.E67 2013

621.36'61-dc23

2012025789

A catalogue record for this book is available from the British Library.

Print ISBN: 978-1-119-99033-8

Typeset in 10/12pt Times by Aptara Inc., New Delhi, India Printed and bound in Singapore by Markono Print Media Pte Ltd

Contents

	Pref	ace			xix		
	About the author						
PA	RT 1	DIC	DE LAS	SER ENGINEERING	1		
	Over	view			1		
1	Basi	c diode	laser en	gineering principles	3		
		duction			4		
	1.1	Brief 1	recapitula	tion	4		
		1.1.1	Key feat	tures of a diode laser	4		
			1.1.1.1	Carrier population inversion	4		
			1.1.1.2	Net gain mechanism	6		
			1.1.1.3	Optical resonator	9		
			1.1.1.4	Transverse vertical confinement	11		
			1.1.1.5	Transverse lateral confinement	12		
		1.1.2	Homoju	nction diode laser	13		
		1.1.3	Double-	heterostructure diode laser	15		
		1.1.4	Quantur	n well diode laser	17		
			1.1.4.1	Advantages of quantum well heterostructures for			
				diode lasers	22		
				Wavelength adjustment and tunability	22		
				Strained quantum well lasers	23		
				Optical power supply	25		
				Temperature characteristics	26		
		1.1.5	Commo	n compounds for semiconductor lasers	26		
	1.2	Optica	ıl output j	power – diverse aspects	31		
		1.2.1	Approac	ches to high-power diode lasers	31		
			1.2.1.1	Edge-emitters	31		
			1.2.1.2	Surface-emitters	33		
		1.2.2	High op	otical power considerations	35		
			1.2.2.1	Laser brightness	36		
			1.2.2.2	Laser beam quality factor M^2	36		

viii CONTENTS

	1.2.3	Power 1	imitations	37
		1.2.3.1	Kinks	37
		1.2.3.2	Rollover	38
		1.2.3.3	Catastrophic optical damage	38
		1.2.3.4	Aging	39
	1.2.4	High po	ower versus reliability tradeoffs	39
	1.2.5	Typical	and record-high cw optical output powers	40
		1.2.5.1	Narrow-stripe, single spatial mode lasers	40
		1.2.5.2	Standard 100 µm wide aperture single emitters	42
		1.2.5.3	Tapered amplifier lasers	43
			Standard 1 cm diode laser bar arrays	44
1.3			nt basic diode laser characteristics	45
	1.3.1			45
	1.3.2		l gain spectra	46
		1.3.2.1	Bulk double-heterostructure laser	46
			Quantum well laser	47
	1.3.3	-	confinement	49
	1.3.4		old current	52
			Double-heterostructure laser	52
			Quantum well laser	54
			Cavity length dependence	54
		1.3.4.4		56
	1.3.5		rse vertical and transverse lateral modes	58
		1.3.5.1	Vertical confinement structures – summary	58
			Double-heterostructure	58
			Single quantum well	58
			Strained quantum well	59
			Separate confinement heterostructure SCH and	
			graded-index SCH (GRIN-SCH)	59
			Multiple quantum well (MQW)	59
		1.3.5.2	Lateral confinement structures	60
			Gain-guiding concept and key features	60
			Weakly index-guiding concept and key features	62
			Strongly index-guiding concept and key features	63
		1.3.5.3	Near-field and far-field pattern	64
	1.3.6		Pérot longitudinal modes	67
	1.3.7	-	ng characteristics	69
			Optical output power and efficiency	72
		1.3.7.2	Internal efficiency and optical loss	
			measurements	74
		1.3.7.3	Temperature dependence of laser characteristics	74
	1.3.8		reflectivity modifications	77
1.4			on technology	81
	1.4.1		afer growth	82
		1.4.1.1	Substrate specifications and preparation	82

				CONTENTS	ix
			1.4.1.2	Substrate loading	82
			1.4.1.3		83
		1.4.2		afer processing	84
				Ridge waveguide etching and embedding	84
			1.4.2.2		84
			1.4.2.3	Ridge waveguide protection	85
			1.4.2.4	Wafer thinning and the n-type electrode	85
			1.4.2.5	Wafer cleaving; facet passivation and coating;	
			11	laser optical inspection; and electrical testing	86
		1.4.3	Laser pa	ackaging	86
		2		Package formats	87
				Device bonding	87
				Optical power coupling	89
				Device operating temperature control	95
			1.4:3.5		95
	Refe	rences	1.1.0.0	Tiermene seming	96
					, ,
2	Desi	gn cons	sideratio	ns for high-power single spatial mode operation	101
	Intro	duction	ì		102
	2.1	Basic	high-pow	er design approaches	103
		2.1.1	Key asp	ects	103
	2.1.2		Output	power scaling	104
		2.1.3	Transve	rse vertical waveguides	105
			2.1.3.1	Substrate	105
			2.1.3.2	Layer sequence	107
			2.1.3.3	Materials; layer doping; graded-index layer	
				doping	108
				Materials	108
				Layer doping	113
				Layer doping – n-type doping	113
				Layer doping – p-type doping	113
				Graded-index layer doping	114
			2.1.3.4	Active layer	114
				Integrity – spacer layers	114
				Integrity – prelayers	115
				Integrity – deep levels	115
				Quantum wells versus quantum dots	116
				Number of quantum wells	119
			2.1.3.5	Fast-axis beam divergence engineering	121
				Thin waveguides	122
				Broad waveguides and decoupled confinement	
				heterostructures	122
				Low refractive index mode puller layers	124
				Optical traps and asymmetric waveguide	
				structures	126

x CONTENTS

			Spread index or passive waveguides	127
			Leaky waveguides	128
			Spot-size converters	128
			Photonic bandgap crystal	130
		2.1.3.6	Stability of the fundamental transverse vertical	
			mode	133
	2.1.4	Narrow-	-stripe weakly index-guided transverse	
			vaveguides	134
		2.1.4.1	Ridge waveguide	134
		2.1.4.2		135
		2.1.4.3		137
		2.1.4.4		138
		2.1.4.5		140
		2.1.4.6	Stability of the fundamental transverse	
			lateral mode	141
	2.1.5	Therma	l management	144
	2.1.6		ophic optical damage elimination	146
2.2			node and kink control	146
	2.2.1	Key asp		146
		2.2.1.1	Single spatial mode conditions	147
		2.2.1.2		150
			Waveguide geometry; internal physical	100
			mechanisms	150
			Figures of merit	152
			Transverse vertical mode expansion; mirror	152
			reflectivity; laser length	153
		2.2.1.3	Higher order lateral mode suppression by	155
		2.2.1.3	selective losses	154
			Absorptive metal layers	154
			Highly resistive regions	156
		2.2.1.4	Higher order lateral mode filtering schemes	157
		2.2.1.7	Curved waveguides	157
			Tilted mirrors	158
		2.2.1.5	Beam steering and cavity length dependence	150
		2.2.1.3	of kinks	158
			Beam-steering kinks	158
			Kink versus cavity length dependence	159
		2.2.1.6	Suppression of the filamentation effect	160
2.3	High-		ngle spatial mode, narrow ridge waveguide lasers	162
2.3	2.3.1	Introduc		162
	2.3.2		l calculated parameter dependencies	163
	4.3.4	2.3.2.1	Fundamental spatial mode stability regime	163
		2.3.2.1	Slow-axis mode losses	163
		2.3.2.2		164
		2.3.2.4	Slow-axis far-field angle	166
			Transverse lateral index step	167
		4.1.4.1	TIANS VELSE TALETAL TRUEX SIED	107

				CONTENTS	хi
			2.3.2.6	Fast-axis near-field spot size	167
			2.3.2.7	Fast-axis far-field angle	168
			2.3.2.8	Internal optical loss	170
		2.3.3		experimental parameter dependencies	171
		2.5.5	2.3.3.1	Threshold current density versus cladding layer	
			2.5.5.1	composition	171
			2.3.3.2	Slope efficiency versus cladding layer	- / -
			2.3.3.2	composition	172
			2.3.3.3	Slope efficiency versus threshold current density	172
			2.3.3.4	Threshold current versus slow-axis far-field angle	172
			2.3.3.5	Slope efficiency versus slow-axis far-field angle	174
			2.3.3.6	Kink-free power versus residual thickness	174
	2.4	Selecte		rea laser concepts and techniques	176
		2.4.1	Introduc	•	176
		2.4.2		rea (BA) lasers	178
				Introduction	178
				BA lasers with tailored gain profiles	179
				BA lasers with Gaussian reflectivity facets	180
			2.4.2.4	BA lasers with lateral grating-confined angled	
				waveguides	182
		2.4.3	Unstable	e resonator (UR) lasers	183
			2.4.3.1	Introduction	183
			2.4.3.2	Curved-mirror UR lasers	184
			2.4.3.3	UR lasers with continuous lateral index variation	187
			2.4.3.4	Quasi-continuous unstable regrown-lens-train	
				resonator lasers	188
		2.4.4	•	amplifier lasers	189
				Introduction	189
			2.4.4.2	Tapered lasers	189
			2.4.4.3	Monolithic master oscillator power amplifiers	192
		2.4.5		aser array structures	194
				Introduction	194
				Phase-locked coherent linear laser arrays	194
			2.4.5.3	High-power incoherent standard 1 cm laser bars	197
	Refe	rences			201
PA	RT 2	DIO	DE LAS	SER RELIABILITY	211
	Over				211
3	Basi	c diode	laser dec	gradation modes	213
_		Basic diode laser degradation modes Introduction			
	3.1			d stability criteria of critical diode laser	213
		_	teristics		214
		3.1.1		power; threshold; efficiency; and transverse modes	214
		AND WOOD (1995)	3.1.1.1	Active region degradation	214
			3.1.1.2	Mirror facet degradation	215

xii CONTENTS

			3.1.1.3	Lateral confinement degradation	215	
			3.1.1.4	Ohmic contact degradation	216	
		3.1.2	Lasing	wavelength and longitudinal modes	220	
	3.2	Classi	Classification of degradation modes			
		3.2.1	Classific	cation of degradation phenomena by location	222	
			3.2.1.1	External degradation	222	
				Mirror degradation	222	
				Contact degradation	223	
				Solder degradation	224	
			3.2.1.2	Internal degradation	224	
				Active region degradation and junction		
				degradation	224	
		3.2.2	Basic de	egradation mechanisms	225	
			3.2.2.1	Rapid degradation	226	
				Features and causes of rapid degradation	226	
				Elimination of rapid degradation	229	
			3.2.2.2	Gradual degradation	229	
				Features and causes of gradual degradation	229	
				Elimination of gradual degradation	230	
			3.2.2.3	Sudden degradation	231	
				Features and causes of sudden degradation	231	
				Elimination of sudden degradation	233	
	3.3	-	aser robus	tness factors	234	
	Refe	erences			241	
4	Opt	Optical strength engineering				
	Intro	oduction	n		245	
	4.1	Mirro	r facet pro	operties – physical origins of failure	246	
	4.2	Mirror facet passivation and protection			249	
		4.2.1	Scope and effects		249	
		4.2.2	Facet pa	assivation techniques	250	
			4.2.2.1	E2 process	250	
			4.2.2.2	Sulfide passivation	251	
			4.2.2.3		252	
			4.2.2.4	N ² IBE process	252	
			4.2.2.5	I-3 process	254	
			4.2.2.6	Pulsed UV laser-assisted techniques	255	
			4.2.2.7	Hydrogenation and silicon hydride barrier layer		
				process	256	
		4.2.3		rotection techniques	258	
	4.3		_	nirror technologies	259	
		4.3.1	Concept		259	
		4.3.2		grown on facet	260	
			4.3.2.1	ZnSe window layer	260	
			4.3.2.2	AlGaInP window layer	260	

			CONTENTS	xiii
		4.3.2.3	AlGaAs window layer	261
			EMOF process	261
		4.3.2.5	Disordering ordered InGaP	262
	4.3.3		n well intermixing processes	262
	4.3.3		Concept	262
		4.3.3.2	Impurity-induced disordering	263
		4.3.3.2	Ion implantation and annealing	263
			Selective diffusion techniques	265
			Ion beam intermixing	266
		4.3.3.3	Impurity-free vacancy disordering	267
			Laser-induced disordering	268
	4.3.4	Bent wa		269
4.4			strength enhancement approaches	270
7.7	4.4.1		blocking mirrors and material optimization	270
	4.4.1	4.4.1.1	Current blocking mirrors	270
		4.4.1.2	Material optimization	272
	4.4.2		reader layer; device mounting; and number	212
	4.4.2		um wells	273
		4.4.2.1	Heat spreader and device mounting	273
		4.4.2.1	Number of quantum wells	273
	4.4.3		oot widening techniques	274
Dafa	rences	wiode sp	oot widening techniques	276
Keie	iences			210
Basi	c reliab	ility engi	ineering concepts	281
	duction			282
5.1			ability statistics	283
			ity density function	283
			tive distribution function	283
			ity function	284
	5.1.4		neous failure rate or hazard rate	285
			tive hazard function	285
			failure rate	286
		Failure 1		286
	5.1.8		failure rate curve	287
5.2			tion functions – statistical models for nonrepairable	
	popula		1	288
	5.2.1	Introduc	etion	288
	5.2.2		nal distribution	289
		5.2.2.1	Introduction	289
		5.2.2.2	Properties	289
		5.2.2.3	Areas of application	291
	5.2.3		distribution	291
	2.3.0	5.2.3.1	Introduction	291
		5.2.3.2	Properties	292
		5.2.3.3	Areas of application	294
		J J. J		0.00

xiv CONTENTS

			and the second second	12 21 1
	5.2.4		ntial distribution	294
			Introduction	294
			Properties	295
			Areas of application	297
5.3	Reliat	oility data	* T	298
	5.3.1	Life-test	t data plotting	298
		5.3.1.1	Lognormal distribution	298
		5.3.1.2	Weibull distribution	300
		5.3.1.3	Exponential distribution	303
5.4	Furthe	er reliabili	ty concepts	306
	5.4.1	Data typ	oes	306
		5.4.1.1	Time-censored or time-terminated tests	306
		5.4.1.2	Failure-censored or failure-terminated tests	307
		5.4.1.3	Readout time data tests	307
	5.4.2	Confide	nce limits	307
	5.4.3	Mean tir	me to failure calculations	309
	5.4.4	Reliabili	ity estimations	310
5.5	Accel	erated reli	ability testing – physics–statistics models	310
	5.5.1	Accelera	ation relationships	310
		5.5.1.1	Exponential; Weibull; and lognormal distribution	
			acceleration	311
	5.5.2	Remarks	s on acceleration models	312
		5.5.2.1	Arrhenius model	313
		5.5.2.2	Inverse power law	315
			Eyring model	316
		5.5.2.4		318
		5.5.2.5	Selection of accelerated test conditions	319
5.6	Syster	n reliabili	ty calculations	320
		Introduc	•	320
	5.6.2	Indepen	dent elements connected in series	321
	5.6.3		system of independent components	322
Refe	erences			323
Dio	de laser	reliabilit	ty engineering program	325
Intro	duction	1		325
6.1	Reliab	ility test p	plan	326
	6.1.1	Main pu	rpose; motivation; and goals	326
	6.1.2	Up-fron	t requirements and activities	327
		6.1.2.1	Functional and reliability specifications	327
		6.1.2.2	Definition of product failures	328
		6.1.2.3	Failure modes, effects, and criticality analysis	328
	6.1.3		t parameters for long-term stability and	
		reliabilit		330
	6.1.4		parations and operation	330
		6.1.4.1	Samples; fixtures; and test equipment	330
		6.1.4.2		331

				CONTENTS	XV
		6.1.5	Overvie	w of reliability program building blocks	332
				Reliability tests and conditions	334
				Data collection and master database	334
			6.1.5.3	Data analysis and reporting	335
		6.1.6		oment tests	336
			6.1.6.1		336
				Reliability demonstration tests	336
				Step stress testing	337
			6.1.6.2	Accelerated life tests	339
				Laser chip	339
				Laser module	341
			6.1.6.3	Environmental stress testing – laser chip	342
				Temperature endurance	342
				Mechanical integrity	343
				Special tests	344
			6.1.6.4	Environmental stress testing – subcomponents	
				and module	344
				Temperature endurance	345
				Mechanical integrity	346
				Special tests	346
		6.1.7		cturing tests	348
				Functionality tests and burn-in	348
		D 11 1		Final reliability verification tests	349
	6.2			vth program	349
	6.3			efits and costs	350
		6.3.1	Types of		350
			6.3.1.1 6.3.1.2	1	350
			6.3.1.3		350 350
			6.3.1.4	Well-founded quality control	350
			6.3.1.5	Optimum warranty costs and period	351
			6.3.1.6	Improved life-cycle cost-effectiveness	351
			6.3.1.7		351
			6.3.1.8	Increase in customer satisfaction	351
				Promotion of sales and future business	351
		6.3.2		ity-cost tradeoffs	351
	Refe	rences	1101111011	ing cost made ons	353
PA	RT 3	DIO	DE LAS	SER DIAGNOSTICS	355
	Ove	view			355
					. somethir delic
7				er data for active layer material integrity;	
	_			ffects; and mirror temperatures	361
	Intro	duction			362
	7.1			y of laser wafer substrates	362
		7.1.1	Motivati	on	362

xvi CONTENTS

	7.1.2	Experimental details	363				
	7.1.3	Discussion of wafer photoluminescence (PL) maps	364				
7.2	Integr	Integrity of laser active layers					
	7.2.1	Motivation	366				
	7.2.2	Experimental details	367				
		7.2.2.1 Radiative transitions	367				
		7.2.2.2 The samples	369				
		7.2.2.3 Low-temperature PL spectroscopy setup	369				
	7.2.3	Discussion of quantum well PL spectra	371				
		7.2.3.1 Exciton and impurity-related recombinations	371				
		7.2.3.2 Dependence on thickness of well and barrier layer	373				
		7.2.3.3 Prelayers for improving active layer integrity	375				
7.3	-	level defects at interfaces of active regions	376				
	7.3.1		376				
	7.3.2	The state of the s	377				
	7.3.3	1 17	382				
7.4		-Raman spectroscopy for diode laser diagnostics	386				
	7.4.1		386				
	7.4.2		388				
	7.4.3	Experimental details	391				
	7.4.4	Raman on standard diode laser facets	394				
	7.4.5	Raman for facet temperature measurements	395				
		7.4.5.1 Typical examples of Stokes- and anti-Stokes					
		Raman spectra	396				
		7.4.5.2 First laser mirror temperatures by Raman	398				
	7.4.6	Various dependencies of diode laser mirror temperatures	401				
		7.4.6.1 Laser material	402				
		7.4.6.2 Mirror surface treatment	403				
		7.4.6.3 Cladding layers; mounting of laser die; heat					
		spreader; and number of active quantum wells	404				
Ref	erences		406				
Mar		andia langua data fara mirana fa antaliana dan effecta.					
		nostic laser data for mirror facet disorder effects; stress effects; and facet coating instability	409				
	oduction		410				
8.1		laser mirror facet studies by Raman	410				
0.1	8.1.1	Motivation	410				
		Raman microprobe spectra	410				
	8.1.3	Possible origins of the 193 cm ⁻¹ mode in (Al)GaAs	412				
	8.1.4	Facet disorder – facet temperature – catastrophic optical	714				
	5.1.7	mirror damage robustness correlations	413				
8.2	Local	mechanical stress in ridge waveguide diode lasers	416				
0.2	8.2.1	Motivation	416				
	8.2.2	Measurements – Raman shifts and stress profiles	417				
	8.2.3	Detection of "weak spots"	419				
	0.4.5	Detection of weak spots	-T17				

				CONTENTS	xvii
			8.2.3.1	Electron irradiation and electron beam induced	
				current (EBIC) images of diode lasers	419
			8.2.3.2	EBIC – basic concept	421
		8.2.4		nodel experiments	422
				Laser bar bending technique and results	422
	8.3			ror facet coating structural instability	424
			Motivati		424
				nental details	424
		8.3.3		recrystallization by internal power exposure	425
			8.3.3.1	•	425
			8.3.3.2	Temperature rises in ion beam- and plasma enhanced chemical vapor-deposited amorphous	
					427
		8.3.4	Ciliaan	silicon coatings recrystallization by external power exposure –	421
		6.3.4		experiments	428
			8.3.4.1	Effect on optical mode and <i>P/I</i> characteristics	429
	Refe	rences	0.5.4.1	Effect on optical mode and 177 characteristics	430
0	N	.1 35		to for discourse losses tomorporatives offected dynamics	
9				ta for diverse laser temperature effects; dynamic fects; and mirror temperature maps	433
		duction		iecis, and imitor temperature maps	434
	9.1			nce microscopy for diode laser diagnostics	435
	7.1	9.1.1			435
		9.1.2		and signal interpretation	437
		9.1.3		nce-temperature change relationship	439
		9.1.4		nental details	439
		9.1.5		l perturbation effects on reflectance	441
	9.2	Therm	oreflecta	nce versus optical spectroscopies	442
		9.2.1	General		442
		9.2.2	Compar	ison	442
	9.3			ple temperature rise	444
	9.4	Diode		ror temperatures by micro-thermoreflectance	445
		9.4.1			445
		9.4.2		ence on number of active quantum wells	445
				ence on heat spreader	446
		9.4.4	-	ence on mirror treatment and coating	447
		9.4.5		veguide nonabsorbing mirror	448
	9.5			ror studies by micro-thermoreflectance	451
		9.5.1	Motivat		451
		9.5.2		ne temperature-monitored laser degradation	451
			9.5.2.1	Critical temperature to catastrophic optical mirror	
			0.5.5	damage	451
			9.5.2.2	Development of facet temperature with operation	152
				time	453

xviii CONTENTS

Index

		9.3.2.3	reinperature associated with dark-spot defects in	
			mirror facets	454
	9.5.3	Local op	otical probe	455
		9.5.3.1	Threshold and heating distribution within	
			near-field spot	455
9.6	Diode	laser cavi	ity temperatures by micro-electroluminescence	456
	9.6.1	Motivati	on	456
	9.6.2	Experim	ental details – sample and setup	456
	9.6.3	Tempera	nture profiles along laser cavity	457
9.7	Diode	laser face	et temperature – two-dimensional mapping	460
	9.7.1	Motivati	on	460
	9.7.2	Experim	ental concept	460
	9.7.3	First tem	nperature maps ever	460
	9.7.4	Independ	dent temperature line scans perpendicular	
		to the ac	tive layer	461
	9.7.5	Tempera	ture modeling	462
		9.7.5.1	Modeling procedure	463
		9.7.5.2	Modeling results and discussion	465
Refe	rences			466