

Contents

Preface	i
Abstract	iii
Zusammenfassung	v
List of Abbreviations	vii
Symbols	ix
1 Introduction	1
1.1 Terahertz radiation	1
1.2 Applications of THz radiation	3
1.2.1 Security screening	3
1.2.2 Biomedical research	3
1.2.3 Astrophysics and atmospheric sensing	4
1.2.4 Wireless communication	4
1.3 Organization of thesis	5
2 THz sources, detectors, and components	7
2.1 THz sources	7
2.1.1 Solid-state sources	7
2.1.2 Electron beam sources	8
2.1.3 THz gas laser	8
2.1.4 Difference frequency generation	9
2.2 THz detectors	10
2.2.1 Ge:Ga photoconductive detectors	10
2.2.2 Golay cell detectors	11
2.2.3 Microbolometers	12
2.2.4 Pyroelectric detectors	13

2.3	THz optical components	14
2.3.1	THz windows	14
2.3.2	THz optics	15
2.3.3	Polarizers	16
2.3.4	Waveplates	16
3	Fundamentals of terahertz quantum-cascade lasers and laser absorption spectroscopy	19
3.1	Historical overview of QCL	19
3.2	Active region of QCL	20
3.3	Active region designs	22
3.4	Waveguides	23
3.5	Temperature performance of THz QCLs	25
3.6	Spectroscopic techniques	25
3.6.1	Laser absorption spectroscopy	25
3.6.2	Heterodyne spectroscopy	30
3.6.3	Modulation spectroscopy	31
3.6.4	Saturation spectroscopy	32
4	Experimental techniques	35
4.1	Cooling system	35
4.1.1	Helium flow cryostat	35
4.1.2	Mechanical cryocooler	36
4.2	Power measurement of THz QCLs	37
4.3	Light-current-voltage characterization	38
4.4	Beam characterization	39
4.5	Fourier transform spectroscopy	41
4.6	High-resolution molecular spectroscopy with a THz QCL	42
4.6.1	Measurement setup	43
4.6.2	Data Acquisition	44
4.6.3	Frequency calibration	45
5	Doppler free spectroscopy with a THz QCL	47
5.1	Theoretical background	48
5.2	Experimental setup for QCL characterization and saturated absorption spectroscopy	49
5.3	Results	50
5.4	Experimental setup for Lamb-dip spectroscopy	52

5.5	Results	53
5.6	Doppler-free spectroscopy inside a mechanical cryocooler	55
5.7	Conclusion	57
6	Molecular spectroscopy by light-induced frequency tuning of THz QCLs	59
6.1	Theoretical background	60
6.2	Experimental setup	66
6.2.1	Setup for frequency tuning	67
6.2.2	Setup for molecular spectroscopy	68
6.3	Results	68
6.4	Illumination in different regions of the QCL	70
6.5	Comparison of light-induced, current and temperature tuning effects	71
6.6	Frequency tuning by continuously variable natural density filter	75
6.7	Future prospects	76
7	Frequency and output power stabilization of a THz QCL using near-infrared illumination	79
7.1	Experimental setup	80
7.2	Frequency tuning measurements	81
7.3	Frequency modulation spectroscopy	82
7.4	Frequency and output power stabilization	83
7.5	Frequency stabilization with NIR laser and power stabilization with QCL driving current	88
7.6	Longterm measurement	90
7.7	Conclusion	91
8	Summary and outlook	93
	Bibliography	95
	Acknowledgements	111