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Quantum Cascade Lasers Mid-infrared Quantum Cascade Lasers for Chaos Secure Communications Nonlinear Photonics in Mid-infrared Quantum Cascade Lasers Spectroscopic Applications of Terahertz Quantum-Cascade Lasers From Quantum Cascade Lasers to Flat Optics for the Twenty-first Century Mid-Infrared and Terahertz Quantum Cascade Lasers Quantum Cascade Lasers (QCLs) Quantum Cascade Lasers on AlGaAs-GaAs for the Mid-infrared Regime Broadly Tunable Mid-infrared Quantum Cascade Lasers for Spectroscopic Applications Quantum Cascade Lasers Quantum Interband and Cascade Lasers Low Frequency and Circuit Based Quantum Cascade Lasers Quantum Cascade Lasers Design and Fabrication of Quantum Cascade Lasers Field Guide to Lasers Transport in Quantum Cascade Lasers Deep-well GaAs- and InP-based Quantum Cascade Lasers for Mid-infared Emission High Average Brightness Broad Area Quantum Cascade Lasers Mid-Infrared Quantum Cascade Lasers Quantum Cascade Lasers and Optical Metamaterials Ultrafast Mid-Infrared Dynamics in Quantum Cascade Lasers Highly Efficient Long-wavelength Infrared, Step-taper Active-region Quantum Cascade Lasers Low-Noise Operation of Mid-Infrared Quantum Cascade Lasers Using Injection Locking Modeling of Quantum Cascade Lasers Epi-Side-Down Mounting of Interband Cascade Lasers for Army Applications From High Power Terahertz Quantum Cascade Lasers to Terahertz Light Amplifiers Materials and Designs for Realizing Short-wavelength Quantum Cascade Lasers High Spectral Brightness, Broad Area Quantum Cascade Lasers Quantum Cascade Lasers Based on Intra-cavity Frequency Mixing Quantum Cascade Lasers Grown by Gas-source Molecular Beam Epitaxy Quantum Cascade Lasers Designed Toward Shorter Wavelengths Long-wave Infrared Frequency Combs Based on Quantum Cascade Lasers Continuous-wave Operation of Far-infrared Quantum Cascade Lasers Monolithic Tuneable Quantum Cascade Lasers Bipolar Cascade Lasers Long Wavelength Quantum Cascade Lasers Short Wavelength Quantum Cascade Lasers Semiconductor Lasers Far-infrared Quantum Cascade Lasers Global Markets for Quantum Cascade Lasers

This book describes the fascinating recent advances made concerning the chaos, stability and instability of semiconductor lasers, and discusses their applications and future prospects in detail. It emphasizes the dynamics in semiconductor lasers by optical and electronic feedback, optical injection, and injection current modulation. Applications of semiconductor laser chaos, control and noise, and semiconductor lasers are also demonstrated. Semiconductor lasers with new structures, such as vertical-cavity surface-emitting lasers and broad-area semiconductor lasers, are intriguing and promising devices. Current topics include fast physical number generation using chaotic semiconductor lasers for secure communication, development of chaos, quantum-dot semiconductor lasers and quantum-cascade semiconductor lasers, and vertical-cavity surface-emitting lasers. This fourth edition has been significantly expanded to reflect the latest developments. The fundamental theory of laser chaos and the chaotic dynamics in semiconductor lasers are discussed, but also for example the method of self-mixing interferometry in quantum-cascade lasers, which is indispensable in practical applications. Further, this edition covers chaos synchronization between two lasers and the application to secure optical communications. Another new topic is the consistency and synchronization property of many coupled semiconductor lasers in connection with the analogy of the dynamics between synaptic neurons and chaotic semiconductor lasers, which are compatible nonlinear dynamic elements. In particular, zero-lag synchronization between distant neurons plays a crucial role for information processing in the brain. Lastly, the book presents an application of the consistency and synchronization property in chaotic semiconductor lasers, namely a type of neuro-inspired information processing referred to as reservoir computing. The quantum cascade laser is a new type of mid- and far-infrared semiconductor laser. Through quantum mechanical "bandgap engineering", an intersubband laser can be designed within the conduction band of an arbitrary semiconductor heterostructure. The goal of this work is to develop a compact infrared laser that is clearly superior to its' competitors, and is capable of deployment in a variety of advanced infrared systems. Inside this thesis, this topic will be explored in detail. Continuous-wave operation of a terahertz quantum cascade laser is reported. Optical output powers ranging from 410 μW at 10 K to 124 μW at 35 K, at an emission wavelength of 66 μm are obtained. This report summarizes the entire research period. In this program, we performed experiments using a femtosecond mid-infrared pump-probe system implemented for QCL samples operating at 4.6 and 5.3 m. We employed femtosecond time-resolved pump-probe measurements to probe the nature of the transport through the laser structure via the dynamics of the gain. The gain recovery was determined by the time-dependent transport of electrons through the cascade heterostructure; as the laser approaches and exceeds threshold, the gain recovery shows a dramatic reduction due to the onset of quantum stimulated emission. Since the electron transport through each state in the cascade is determined by the state lifetime, the transport in a cascade laser is driven by the photon density in the cavity. The gain recovery is qualitatively different from that in conventional atomic, molecular and interband semiconductor lasers due to the superlattice transport in the cascade. We also studied the effects of pulse propagation in the laser, including group velocity dispersion and coherent pulse reshaping due to ultrafast Rabi flopping of the gain medium. This Guide provides an overview on the essential types of lasers and their key properties as well as an introduction into the most important physical and technological aspects of lasers. Apart from describing the basic principles (such as stimulated emission and the properties of optical resonators), this Guide discusses the numerous important properties of laser crystals, the impact of thermal effects on laser performance, methods of wavelength tuning and pulse generation, and laser noise. Practitioners will also gain valuable insight from remarks on laser safety and obtain new ideas about how to make the laser development process more efficient. The mid-infrared domain is a promising optical domain because it holds two transparency atmospheric windows, as well as the fingerprint of many chemical compounds. Quantum cascade lasers (QCLs) are one of the available sources in this domain and have already been proven useful for spectroscopic applications and free-space communications. This thesis demonstrates how to implement a private free-space communication relying on mid-infrared optical chaos and this requires an accurate cartography of non-linear phenomena in quantum cascade lasers. This private transmission is made possible by the chaos synchronization of two twin QCLs. Chaos in QCLs can be generated under optical injection or external optical feedback. Depending on the parameters of the optical feedback, QCLs can exhibit several non-linear phenomena in addition to chaos. Similarities exist between QCLs and laser diodes when the chaotic dropouts are synchronized with an external modulation, and this effect is known as the entrainment phenomenon. With a cross-polarization reinjection technique, QCLs can generate all-optical square-waves. Eventually, it is possible to trigger optical extreme events in QCLs with tilted optical feedback. All these experimental results allow a better understanding of the non-linear dynamics of QCLs and will extend the potential applications of this kind of semiconductor lasers. This thesis presents the first comprehensive analysis of quantum cascade laser nonlinear dynamics and includes the first observation of a temporal chaotic behavior in quantum cascade lasers. It also provides the first analysis of optical instabilities in the mid-infrared range. Mid-infrared quantum cascade lasers are unipolar semiconductor lasers, which have become widely used in applications such as gas spectroscopy, free-space communications or optical countermeasures. Applying external perturbations such as optical feedback or optical injection leads to a strong modification of the quantum cascade laser properties. Optical feedback impacts the static properties of mid-infrared Fabry–Perot and distributed feedback quantum cascade lasers, inducing power increase; threshold reduction; modification of the optical spectrum, which can become either single- or multimode; and enhanced beam quality in broad-area transverse multimode lasers. It also leads to a different dynamical behavior, and a quantum cascade laser subject to optical feedback can oscillate periodically or even become chaotic. A quantum cascade laser under external control could therefore be a source with enhanced properties for the usual mid-infrared applications, but could also address new applications such as tunable photonic oscillators, extreme events generators, chaotic Light Detection and Ranging (LIDAR), chaos-based secured communications or unpredictable countermeasures. Quantum Cascade Lasers (QCLs) are unipolar lasers based on intersubband transitions that have emission wavelengths in the mid- to far-infrared. Mid-infrared QCLs have recently reached a high level of technological maturity with watt level continuous wave output powers being demonstrated at room temperature. However, the performance of these conventional QCLs falls away very rapidly below -4 urn where a number of important applications exist. This thesis details the design, fabrication and characterisation of high performance 'short wavelength' QCLs that operate in the 3-4 urn region. The high conduction band offset of the InGaAs/ AIAsSb material system and its compatibility with InP based waveguides and fabrication technology has made it the most attractive solution to achieving high performance QCLs in the 3-4 urn region. This thesis covers the development of InGaAs/AIAsSb based QCLs and covers the demonstration of a number of record high output powers and maximum operating temperatures. Watt level peak powers at room temperature and operation up to at least 400 K have been achieved across the -3.3-3.7 urn range. These high performance InGaAs/ AIAsSb lasers are well suited for the realization of single-mode devices that can be used to create compact, ultra-sensitive trace-gas sensors based on absorption spectroscopy. To this effect, single-mode distributed feedback (DFB) QCLs where developed at -3.35-3.45 urn with side mode suppression ratios of up to 30 dB. The lasers employed buried third order DFB gratings and operated at room temperature. Finally, the development of strain compensated InGaAs/AlInAs QCLs grown by metal- organic vapour phase epitaxy (MOVPE) is detailed. This growth technique presents significant advantages for commercial device production when compared to the more typically employed molecular beam epitaxy growth technique. MOVPE grown InGaAs/ AlInAs QCLs with 70% indium composition in the wells operating at -4 urn are reported. The simulation of transport in semiconductor heterostructures like quantum cascade lasers is of central interest as it enables the knowledge of the electrons dynamics inside such structures, allowing the determination of electrical and optical properties of the latter. These human-designed structures have an atomic resolution and therefore require a quantum mechanical description. The latter can be performed at different levels. The basic description gives the band-structure that represents where electrons can exist in the structure. However this description does not provide information about the transport properties, as the latter require the knowledge of the interaction of electrons with various sources of scattering inside the structure. In this work we present an effective transport model that relies both on coherent and incoherent transport processes. Quantum cascade lasers are unipolar semiconductor lasers based on intersubband transitions in heterostructures. These lasers, which have demonstrated continuous wave operation at room temperature in the mid-infrared spectral range, are well suited for the realization of compact, ultra-sensitive, trace-gas sensors based on absorption spectroscopy. Up to now, only distributed feedback (DFB) single-mode devices have been used for such applications. DFB quantum cascade lasers have proven to be effective for gas sensing, but their relatively narrow tuning range, smaller or equal to about 1% of the wavelength, makes them not very versatile and limits their usefulness for spectroscopic investigations. In this thesis we developed broadly tunable external cavity quantum cascade lasers. The main advantage of these sources compared with DFBs is their broader tuning range, which is limited only by the spectral bandwidth of the gain element. We particularly studied broad gain bandwidth active regions based on bound-to-continuum designs. With that kind of active region, we have demonstrated a tuning range equal to 15% of the center wavelength at l ~ 10 mm, which was three times broader than the best values reported in the literature at that time, as well as good performance in pulsed mode at room temperature. Using a strain-compensated bound-to-continuum design emitting near 5.2 mm, we have demonstrated for the first time continuous-wave operation of an external cavity quantum cascade laser on a thermoelectric cooler. The tuning range was comparable to that of pulsed devices, but with a much better side-mode suppression ratio and a much narrower linewidth. This continuous-wave device has successfully been applied to the spectroscopy of nitric oxide in collaboration with Prof. Tittel's Laser Science Group at Rice University. High resolution absorption spectra of that gas could be acquired over a large wavelength range. We also studied heterogeneous cascade structures, that is quan. Ever since the invention of quantum cascade laser (QCL), the performance and the flexibility in design has made it a desirable source for a wide range of applications, such as trace-chemical sensing, health monitoring, frequency metrology, noninvasive imgaing and infrared countermeasures. The LWIR region (or mid-infrared region), roughly ranging from 2-20 [mu]m, is of particular importance to spectroscopy applications, since many molecular species have their strongest rotational-vibrational absorption bands in that area. Infrared laser spectroscopy began about 40 years ago and has been using a variety of different tunable laser-based sources, particularly lead salt diodes, color center lasers, difference frequency generation and optical parametric oscillators. The large tunabilitiy in the design (lasing frequency, tunability, power, material system, etc.) and the compactness in fabrication and packaging has made QCL an ideal source for laser-based spectroscopy. Traditional spectroscopy systems suffer from problems like large physical dimensions, long data-processing times and spectral resolution restrictions. Therefore the development of a simple, robust, compact and inexpensive optical source/system like QCL frequency combs can largely benefit spectroscopy systems. In the past few years, QCLs have proven to be able to form comb radiation in both LWIR and THz regions. And dual comb spectroscopy has been demonstrated using QCL frequency combs with very short acquisition time ([mu]s). The development of a broadband, high power, narrow linewidth and stable LWIR frequency comb based on quantum cascade laser is the key to realizing such broadband ultrafast spectrometer in the mid-infrared range. This thesis explores the design, fabrication and characterization techniques towards the development of LWIR QCL frequency comb devices for spectroscopic purposes. A complete wet etch epi-up fabrication process is reported, with preliminary results on the dry-etch technique to incorporate dispersion compensation strucutre and epi-down fabricaiton for high power CW mode QCL device. Formation of comb(-like) regime has been observed in two devices, with the Gires-Tournois Interferometer (GTI) mirror providing dispersion from the rear facet. In order to improve the comb performance of these devices, dispersion of the device is measured to provide essential information for the design of chirped top cladding for dispersion compensation. This thesis provides an important step towards the realization of a room temperature, broadband, CW mode LWIR QCL frequency comb device for spectroscopic purposes. A state-of-the-art overview of this rapidly expanding field, featuring fundamental theory, practical applications, and real-life examples. Quantum cascade lasers (QCLs) are semiconductor lasers that emit in the mid- to far-infrared and employ intersubband transitions in multiple quantum-well structures. Conventionally, the active region of QCLs has consisted of quantum wells and barriers of fixed-alloy composition. That has led to severe carrier leakage from the upper-laser level and injector states, evidenced by strong temperature dependences of the device characteristics, which resulted in low values for wall-plug efficiency [eta]wp of CW-operating devices. We have devised in the past means for carrier-leakage suppression, and have recently derived a comprehensive carrier-leakage formalism that bridges the gap between theoretical and experimental values for the internal efficiency. Here we present a refinement of the comprehensive carrier-leakage formalism and employ it for comparing our band-engineered ~ 8 [mu]m-emitting QCL, so-called step-tapered active-region (STA), to a conventional ~ 8 [mu]m-emitting QCL. We find that the internal efficiency reaches a high value of ~ 73.6%, due to record-high injection- and laser-transition efficiencies. Experimentally we obtain a single-facet [eta]wp value of 10.6%, a record-high value for 8-11 Îơm-emitting QCLs grown by MOCVD. Then, by using both band- and interface-roughness (IFR)-scattering -engineering we designed an optimized 8.2 [mu]m-emitting STA-QCL that reaches a record-high injection efficiency of 89.5%. By minimizing the waveguide loss and raising the doping level the device reaches a record-high internal efficiency (80%) for ~ 8 [mu]m-emitting QCLs as well as a projected [eta]wp value of 11.2%. The studies are extended to devices of higher layer-interface quality, grown by two different techniques. As a result, we obtain [eta]wp values as high as 15.6 %. In addition, the optimized STA-QCL has a lower-level lifetime dominated by IFR scattering, which makes it amenable to further optimization via IFR engineering. Finally, we analyze an ~ 8 [mu]m-emitting QCLs that holds the world record [eta]wp value, primarily due to low voltages via the realization of photon-induced carrier transport. We find that the device has significant carrier leakage, and show that our optimized STA QCL can reach comparable [eta]wp values if high-quality interfaces are employed. We then derive ultimate limits for the [eta]wp value in the 7-11 [mu]m wavelength range. The interband cascade laser, based on the type II energy band alignment in the InAs/GaSb material system, has great potential to meet the power and the wall plug efficiency requirements of many Army applications. However, the development of interband cascade lasers has lagged the development of InP-based quantum cascade lasers. These latter devices have recently exhibited high power, room temperature, cw operation at 3.8 m and at longer wavelengths. Only a few groups are working on the interband cascade lasers, and relatively modest progress has been made in advancing their high-temperature performance. In this paper, we describe our efforts to improve the high temperature performance of these sources using epi-sidedown mounting. Quantum cascade lasers are unipolar semiconductor lasers based on intersubband transitions in quantum wells. They have shown laser operation from above 100 THz down to the terahertz region and are promising sources for the terahertz region (0.3-10 THz) which is lacking of efficient narrowband radiation sources. A low frequency quantum cascade laser design is developed that faces the emerging challenges when the photon energy approaches the broadening of the energy levels. A record lowest operation frequency of 1.2 THz is demonstrated. A hybrid laser-oscillator for the terahertz is developed in the second part of this work, consisting of an optical gain medium and an electronic resonator. The resonator is an inductor-capacitor resonant circuit. The so called circuit based laser has the property of being a deep sub-wavelength sized microcavity laser. The effective mode volume is among the smallest for electrically pumped lasers. The circuit based resonator in combination with an active region could lead to a class of new devices to generate and manipulate terahertz radiation that exploit cavity quantum electrodynamic effects. The terahertz (THz) frequency range (300 GHz to 10 THz, wavelength 30-1000 [mu]m), despite having many potential applications, is technologically relatively underdeveloped mainly because of the lack of suitable coherent radiation sources when compared with nearby electromagnetic radiation spectrum. The invention of the THz quantum cascade laser, a electronically-pumped semiconductor heterostructure which emits photons from electronic intersubband transitions, provides the first solidstate fundamental oscillator at the frequency range from 1.2 to 5.1 THz. Due to the subwavelength confinement nature of the metal-metal waveguide used in most of the THz QC lasers, far-field beam patterns from lasers with simple Fabry-Perot waveguides are divergent and far from ideal Gaussian beams. The first part of this thesis describes the development of single-mode THz QC lasers on metal-metal waveguides. Starting with the corrugated third-order DFB laser-a clever laser structure which utilizes end-fire array effect to achieve low divergence beam patterns-several applications using densely-packed third-order DFB laser arrays, such as frequency agile sources for THz swept-source optical tomography and local oscillators for THz heterodyne receivers with precise frequency control, have been investigated. With the improved design rules and fabrication techniques, 830 GHz single-mode frequency coverage on a monolithic multicolor DFB laser array has been achieved. The origin of the deterioration in far-field beam patterns and power outputs in long third-order DFB lasers is then identified. This finding leads to a modified third-order DFB laser structure which can achieve perfect phase-matching (PM) condition, resulting in scalable power output and even lower beam divergence when compared with that of a conventional third-order DFB laser. Radiations from up to 151 laser sectors are phase-locked to form a single-lobe beam pattern with divergence ~ 6 x 11° and ~13 mW pulsed power at the end-fire direction. This approach substantially increases the usable length of a third-order DFB laser while keeping a high slope efficiency (140 mW/A). Later development applies the concept of microstrip antenna-a structure commonly used in microwave engineering-to THz photonics devices. By coupling the microstrip antenna to each grating aperture of a perfectly phase-matched DFB laser, the radiation impedance of the laser can now be tuned to enhance the overall emission efficiency. This novel genre of DFB laser achieves > 8 mW pulsed power (10% duty-cycle) at 12 K with beam divergence as low as 12.5 x 12.5' and maximum lasing temperature Tmax = 109 K (pulsed) and 77 K (c.w.) with the highest slope efficiency (~450 mW/A) and wall-plug efficiency (0.57%) of all THz DFB laser sources. The second part of the thesis then focuses on the development of the first light amplifier in THz frequency under Fabry-Perot amplifier (FPA) scheme. Although amplification at terahertz frequency in quantum cascade structures has been demonstrated under the transient state or in a integrated platform, none of them is suitable for amplifying continuous-wave free-space THz radiations. The proposed amplifier is consisted of an array of short-cavity surface-emitting second-order distributed feedback lasers arranged in a two-dimensional grid which are operated marginally beneath their lasing thresholds. A overall system power gain of ~5.6x = 7.5 dB at ~3 THz is obtained with ~1 GHz bandwidth. The free-space THz light amplifier can be used as the pre-amplifier for a THz heterodyne receiver system to reduce the receiver system noise, or be placed on the focal plane of a THz imaging system to enhance the signal-to-noise ratio of the image and reduce the acquisition time. A new locking mechanism for two-dimensional phase-locked laser arrays based on antenna mutual-coupling is also proposed and then successfully demonstrated in the THz frequency using short-cavity DFB THz lasers. Up to 37 lasers are phase-locked to deliver 6.5 mW single-mode pulsed power (4% duty-cycle) at 3 THz with symmetric beam pattern (10 x 10°). This new coupling scheme can be extended to other electromagnetic systems with sub-wavelength confined elements such as plasmonic lasers and nanolasers. This thesis also reports the development of fabrication techniques required to bring the aforementioned novel THz cavity designs from concepts to reality which include a high aspect ratio (1:10) anisotropic reactive-ion etch on GaAs which is compatible with the metal-metal waveguide platform and the procedure to create airbridge structures by selectively removing the dielectric materials beneath the metal contacts. Quantum cascade (QC) lasers have application in areas such as medical diagnostics and homeland security. Optical metamaterials have novel interactions with light and potential application for sub-wavelength imaging and optical cloaking. This work first explores new approaches to designing QC lasers. High performance QC lasers are described with a voltage defect of only 19 meV, resulting in record voltage efficiency. Lasers with ultra-strong coupling attain 50% wall-plug efficiency. The thermoelectric effect is measured for the first time within QC lasers, informing further performance enhancements. This work then describes two efforts to improve mid-IR metamaterials. Negative refraction bandwidth and dispersion properties are improved through the use of multiple-metamaterial stacks. QC gain regions are added to these metamaterials to reduce their absorption loss. Finally, QC lasers are developed for trace gas sensing of CO2 isotopes, and a techno-economic model is used to value improved CO2 isotope-based sequestration leakage monitoring. QC laser applications in non-invasive tissue measurements, inter-planetary sensors, C60 spectroscopy, and IR countermeasures are also examined. This title provides an introduction to quantum cascade lasers including the basic underlying models used to describe the device. It gives a synthetic view of the topic including the aspects of the physics, the technology, and the use of the device. It also provides a guide for the application engineer to use this device in systems. Quantum Cascade Lasers are a novel semiconductor light source with the unique property of wavelength tunability over the mid-infrared and terahertz range of frequencies. Advances since their first demonstration in 1994 have led to highly efficient designs capable of continuous room temperature operation. In lieu of increased advances in laser core efficiency, power scaling with broad area quantum cascade lasers has demonstrated enhanced continuous power. This initial work is used as a starting point for continuing advances in average brightness of quantum cascade lasers. A figure of merit calculation reliably predicts to within parts in thousands the qualitative beam profile of continuously driven and high duty cycle devices. Further, a model is developed to project performance not only in continuously driven conditions, but also in variable duty cycles. This is combined with the figure of merit calculation to guide designs for optimized average brightness. This book describes the physics, fabrication technology, and applications of the quantum cascade laser. Quantum cascade lasers are unipolar semiconductor lasers that offer a unique combination of compact size, high efficiency, high optical power, and flexibility to achieve a targeted emission wavelength with the same laser core material composition, employing so-called bandgap engineering. Since their invention in 1994, watt-level CW power with 5 to 20 % wallplug efficiency was demonstrated for QCLs throughout the entire 4 to 12 [micrometer] range, which makes QCLs very attractive for a number of practical applications. Our earlier work on broad-area QCLs emitting in the 4.6 [micrometer] to 5.7 [micrometer] spectral range demonstrated that CW power scaling with lateral device dimensions is an effective approach to increasing QCL power. First experimental and numerical data for short-wavelength (This work describes the work performed by the author at the ETH Zurich, under the supervision of Prof. Jerome Faist on the optimization of high performance quantum cascade lasers (QCLs) in the Mid-IR spectral region. The main factors influencing laser performance have therefore been analyzed. In particular the optimization of the laser design in order to improve the electron tranport and the optical gain. In addition a detailed analysis of the fabrication process is performed and a novel process scheme is presented for buried heterostructure lasers. Quantum cascade lasers are the most promising optical source for emission in the mid-infrared and THz region, and they are already used in a large number of applications such as free-space communications, absorption spectroscopy, sensing and so on. In all these applications, the noise properties of the optical sources are critical for the system performance. In this work, the authors present a theoretical study on the intensity noise characteristics of quantum cascade lasers (QCLs) under external non-coherent optical injection. The injection locking has been proven in the past beneficial for noise properties of bipolar lasers, and thus this technique is utilized here in quantum cascade lasers. With the help of various analytical and numerical models, it is shown that intensity noise reduction can be achieved in the operation of the so-called locked slave laser compared to its free-running values. The detailed analysis reveals the contribution of the various noise sources to the intensity noise of the laser and how they affect the injection locking process. Using different numerical models, two distinct schemes are investigated, analysed and discussed, injection on the lasing mode or on non-lasing residual modes of the slave laser cavity. Quantum cascade lasers (QCLs) are attractive for high-resolution spectroscopy because they can provide high power and a narrow linewidth. They are particularly promising in the terahertz (THz) range since they can be used as local oscillators for heterodyne detection as well as transmitters for direct detection. However, THz QCL-based technologies are still under development and are limited by the lack of frequency tunability as well as the frequency and output power stability for free-running operation. In this dissertation, frequency tuning and linewidth of THz QCLs are studied in detail by using rotational spectroscopic features of molecular species. In molecular spectroscopy, the Doppler eff ect broadens the spectral lines of molecules in the gas phase at thermal equilibrium. Saturated absorption spectroscopy has been performed that allows for sub-Doppler resolution of the spectral features. One possible application is QCL frequency stabilization based on the Lamb dip. Since the tunability of the emission frequency is an essential requirement to use THz QCL for high-resolution spectroscopy, a new method has been developed that relies on near-infrared (NIR) optical excitation of the QCL rear-facet. A wide tuning range has been achieved by using this approach. The scheme is straightforward to implement, and the approach can be readily applied to a large class of THz QCLs. The frequency and output stability of the local oscillator has a direct impact on the performance and consistency of the heterodyne spectroscopy. A technique has been developed for a simultaneous stabilization of the frequency and output power by taking advantage of the frequency and power regulation by NIR excitation. The results presented in this thesis will enable the routine use of THz QCLs for spectroscopic applications in the near future. Over 16 years have passed since the Bell Labs group headed by Federico Capasso first demonstrated the quantum cascade laser (QCL). The intervening interval has seen the QCL evolve from a barely functional scientific curiosity into a powerful technology poised to offer new capabilities to a broad spectrum of real-world applications. In assembling this special section of Optical Engineering, the dual goals have been to provide a snapshot of the cascade laser field in its adolescence, and to familiarise a wider audience of optical engineers with the far-reaching practical potential of these unique IR sources. Quantum cascade lasers (QCLs) are unipolar devices with lasing occurring through transitions between quantized energy levels within the conduction band. When compared to conventional lasers (e.g. gas, liquid or solid state lasers), these new optoelectronic devices present a fundamental advantage that resides in their ability to tailor the wavelength of the emitted light via the layer thickness rather than the band gap. This book discusses different types and applications of quantum cascade lasers. Quantum cascade lasers (QCLs) operate due to population inversion on intersubband in unipolar mutiple-quantum-well (MQW) heterostructure. QCLs are considered one of the most flexible and powerful light semiconductor sources in the mid- and far-infrared (IR) wavelength range, covering most of the critical spectral regions relevant to IR applications. InGaAs/InAlAs/InP QCLs are the only semiconductor lasers capable of continuous wave (CW) operation at room temperature (RT) in the spectral range 3.4-12 micron. This dissertation details the development of RT QCLs based on passive nonlinear coupled-quantum-well structures monolithically integrated into mid-IR QCLs to provide a giant nonlinear response for the pumping frequency. The primary focus of short-wavelength approach in this dissertation is to develop of RT InGaAs/InAlAs/InP QCLs for lamda=2.5-3.7 micron region, based on quasi-phase-matched intracavity second harmonic generation (SHG) associated with intersubband transition. Intersubband optical transition can be engineered by the choice of quantum well and barrier thicknesses to provide the appropriate energy levels, optical dipole matrix elements, and electron scattering rates amongst other parameters. Thus, aside from their linear optical properties, resonant intersubband transitions in coupled QW's can also be designed to produce nonlinear optical medium with giant nonlinear optical susceptibilities. In long-wavelength region, at high temperature, the population inversion is reduced between the upper and lower laser levels due to the longitudinal optical (LO) phonon scattering of thermal carriers in the upper laser state and the thermal backfilling of carriers into the lower laser level from the injector state. This dissertation aims to improve an alternative approach for THz QCL sources based on intra-cavity difference frequency generation (DFG) in dual-wavelength mid-IR QCLs with a passive nonlinear structure, designed for giant optical nonlinearity. Further studies describe that Cerenkov DFG scheme allows for extraction of THz radiation along the whole length of the laser waveguide and provides directional THz emission in 1.2-4.5 THz range. An important requirement for many applications, like chemical sensing and molecular spectroscopy, is single-mode emission. We demonstrate single-mode RT DFG THz QCLs operation in 1-5 THz region by employing devices as integrated dual-period DFB lasers, where efficient solid state RT sources do not exist.

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