

Quantum Cascade Lasers

Field Guide to Lasers Rüdiger Paschotta.2008 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.

Transport in Quantum Cascade Lasers Romain Terazzi.2012-07 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.

Widely Tunable and High Power Mid-Infrared Quantum Cascade Lasers .2001 Single mode cw and pulsed distributed feedback (DFB) QC lasers with wide current tuning and high single mode power, have been realized at $\lambda_{app.} = 4.6 \text{ nm}; 5.2 \text{ nm}, 8 \text{ nm}$ and $9.5\text{-}10 \text{ nm}$ and their trace gas sensing ability (parts per billion in volume or less) has been demonstrated by a variety of spectroscopic techniques. These devices, free-running and stabilized, had cw linewidths of 1 MHz and 10 KHz, respectively. Optical powers in excess of 0.5W (1W) at 300K (200K) was obtained in 75-stage structures; the cw operating temperature was increased to 175K using epitaxial-side heat sinking. New chirped superlattice active region designs yielded greater optical power per stage and allowed extension of the operating wavelength to 19 nm. These longwavelength QCLs use metal semiconductor waveguides supporting a surface plasmon mode, which allows greater optical confinement, and hence lower thresholds than conventional semiconductor waveguides of nearly double thickness. A QCL lasing simultaneously at two or more widely spaced wavelengths and a bidirectional QCL emitting different wavelengths for opposite bias polarity were demonstrated. Gain switching and active modelocking of QC lasers at 5 and 8 nm gave pulse widths of 90 ps and a few ps, respectively.

Semiconductor Lasers Junji Ohtsubo.2017-05-03 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.

Quantum Cascade Lasers Jérôme Faist.2013-03-14 This book provides an introduction to quantum cascade lasers, including the basic underlying models used to describe the device. It aims at giving a synthetic view of the topic including the aspects of the physics, the technology, and the use of the device. It should also provide a guide for the application engineer to use this device in systems. The book is based on lecture notes of a class given for Masters and beginning PhD students. The idea is to provide an introduction to the new and exciting developments that intersubband transitions have brought to the use of the mid-infrared and terahertz region of the electromagnetic spectrum. The book provides an introductory part to each topic so that it can be used in a self-contained way, while references to the literature will allow deeper studies for further research.

Nonlinear Photonics in Mid-infrared Quantum Cascade Lasers Louise Jumpertz.2017-08-31 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.

Global Markets for Quantum Cascade Lasers BCC Research.2017-06

Mid-Infrared Quantum Cascade Lasers Alfredo Bismuto.2012-02 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 transport 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.

Mid-infrared-emitting Quantum Cascade Lasers on Metamorphic Buffer Layers Ayushi Rajeev.2019 When using conventional substrates, such as InP and GaAs, the materials constituting the superlattice (SL) core region of the quantum cascade laser (QCL) are constrained by strain-induced critical-thickness limitations. Metamorphic buffer layers (MBLs) can serve as virtual substrates with a designer-chosen surface lattice constant, thus expanding the compositional-design space for a variety of device structures, including short-wavelength QCLs. An optimized short-wavelength (3.4 μm) single-phonon-resonant (SPR)+ miniband extraction QCL design, grown on an $[\text{In}_x\text{Ga}_{1-x}\text{As}]$ MBL, is presented along with the optical and thermal device considerations in play. MBLs can be grown with a variety of graded regions such as linear composition

grade from GaAs to [In_xGa_{1-x}As] or by employing dislocation filters between Si substrate and InP. QCL and test superlattices' regrowth on these MBLs with the corresponding materials and device analysis, is presented in this work. In addition to the materials limitation for the design of QCL devices, the requirement to have the constituent layers (1-5 nm) to be precisely controlled in the various compositions and thicknesses, is a challenge. Interfacial grading in strained SLs is studied via atom probe tomography for SLs with various layer thicknesses and relative lattice strains. The tip reconstructions are analyzed by fitting the interfaces to diffusion profiles. Mechanisms possible for the observed interdiffusion profile, such as surface segregation and/or bulk diffusion, are discussed. With an understanding of the compositional gradient at the interfaces, together with optimized QCL designs and regrowth on the MBLs, short-wavelength QCLs with high performances can be achieved

From Quantum Cascade Lasers to Flat Optics for the Twenty-first Century Federico Capasso.2019

Spectroscopic Applications of Terahertz Quantum-Cascade Lasers Tasmim Alam.2020-10-29 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 effect 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.

Monolithic Tuneable Quantum Cascade Lasers Devnath Dhirhe.2013

Terahertz (THz), Mid Infrared (MIR) and Near Infrared (NIR) Technologies for Protection of Critical Infrastructures Against Explosives and CBRN Mauro Fernandes Pereira, Apostolos Apostolakis.2022-05-02 Critical infrastructures are targets for terrorism and deliver a valuable vector through which the proliferation of CBRN and explosive precursors can be detected. Recent technological breakthroughs, notably in the field of near infrared (NIR), mid infrared (MIR), Terahertz (THz) and Gigahertz (GHz) sources and detectors, have led to rugged commercial devices, capable of standoff sensing a range of these dangerous substances. However, at the same time criminal and terrorist organizations have also benefited from the availability of technologies to increase the threat they pose to the security of citizens and a concerted effort is needed to improve early detection measures to identify activities, such as the production of homemade explosives or CBRN that can be potentially dangerous to society. The key global technological bottleneck to be overcome is the current lack of integration and networking of mature detection technology into early warning systems for critical infrastructures. Thus, this book brings together complementary information connecting the research of leading teams working on critical infrastructure protection with academic developers and industrial producers of state of the art sensors.

Semiconductor Laser for the 2-5 Micrometers and 7-9 Micrometers Region/Quantum Cascade Lasers .2002 The quantum cascade laser is one of the strong candidates for a portable mid-infrared light source for a variety of DoD applications We have seen dramatic improvements in high temperature performance at long wavelengths, including threshold current densities as low as 1.4 kA/cm² and peak power outputs greater than 7 W for a single 20 mm aperture. Along with the significant design improvements, we have also demonstrated laser operation at 9 and 11 mm up to 425 K. Single mode operation has been accomplished with the use of surface distributed feedback gratings. An important parallel development to these performance improvements is the integration of discrete lasers into a compact, durable laser pointer system. A compact, battery-driven power supply has been designed and tested, as well as a simple, laboratory optical system for pointer evaluation.

Highly Efficient Long-wavelength Infrared, Step-taper Active-region Quantum Cascade Lasers Kevin Michael Oresick.2021 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 [η_{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 $\sim 8 \mu\text{m}$ -emitting QCL, so-called step-tapered active-region (STA), to a conventional $\sim 8 \mu\text{m}$ -emitting QCL. We find that the internal efficiency reaches a high value of $\sim 73.6\%$, due to record-high injection- and laser-transition efficiencies. Experimentally we obtain a single-facet [η_{wp}] value of 10.6%, a record-high value for 8-11 μm -emitting QCLs grown by MOCVD. Then, by using both band- and interface-roughness (IFR)-scattering - engineering we designed an optimized 8.2 μm -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 $\sim 8 \mu\text{m}$ -emitting QCLs as well as a projected [η_{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 [η_{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 $\sim 8 \mu\text{m}$ -emitting QCLs that holds the world record [η_{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 [η_{wp}] values if high-quality interfaces are employed. We then derive ultimate limits for the [η_{wp}] value in the 7-11 μm wavelength range.

Quantum Cascade Lasers .19??

Mid-infrared Spectroscopic Studies of Quantum Cascade Lasers Michael Richard Soulby.2010

2-d Coherent Power Scaling of Mid-infrared Quantum Cascade Lasers Christopher Andrew Sigler.2018 Scaling the continuous-wave (CW) power of quantum cascade lasers (QCLs) beyond ~ 5 W has proven difficult, and beam-quality degradation is common when scaling the device volume for high power. The primary objective of this work was to develop methods for spatially-coherent power scaling of mid-infrared-emitting QCLs to high CW powers. Two approaches were investigated: 1) resonant leaky-wave-coupled antiguided phase-locked laser arrays; and 2) grating-coupled surface-emitting lasers (GCSELs). These two approaches can be combined to realize high surface-emitted powers in a spatially and temporally coherent beam pattern. Optical and thermal models of planarized leaky-wave-coupled phase-locked QCL arrays were coupled together to investigate the influence of thermal lensing on modal behavior. Self-focusing under thermally-induced index variations across the array were found to impact the field profile and promote multi-moding due to gain spatial hole burning. Two techniques were found to mitigate this effect: 1) employing anti-resonant reflective-optical waveguide terminations outside the array; and 2) chirping the element width across the array to obtain identical optically-equivalent widths under CW operation, eliminating thermal lensing at a particular operating condition. Five-element phase-locked arrays of 4.7 μm -emitting QCLs were demonstrated which operate in a near-diffraction-limited beam (primarily in the in-phase array mode) to 5.1 W peak pulsed power, in agreement with simulations. Spectrally resolved near- and far-field measurements indicate that the wide spectral bandwidth of the QCL core promotes multi-mode operation at high drive levels. An optimized array design was identified to allow sole in-phase mode operation to high drive levels above threshold, indicating

that full spatial coherence to high output powers does not require full temporal coherence for phase-locked laser arrays. Lastly, a novel method for obtaining a single-lobed beam pattern from transverse magnetic (TM)-polarized GCSELS is proposed: resonant coupling of the optical mode of a QCL to the antisymmetric surface plasmon mode of a 2nd-order distributed feedback metal/semiconductor grating results in strong antisymmetric-mode absorption. Lasing in the symmetric mode, resulting in a single-lobed far-field beam pattern from the substrate emission, is strongly favored around resonance. For infinite-length devices, the symmetric mode has negligible absorption loss while still being efficiently outcoupled by the grating.

External Cavity Quantum Cascade Lasers Jan-Ferenc Kischkat.2015

Quantum Interband and Cascade Lasers Jerry Meyer,Igor Vurgaftman.2011-04-20 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.

Mode Locking of Quantum Cascade Lasers .2007 A theoretical and experimental study of multimode operation regimes in quantum cascade lasers (QCLs) is presented. It is shown that the fast gain recovery of QCLs promotes two multimode regimes in QCLs: One is spatial hole burning (SHB), and the other one is related to the Risken-Nummedal-Graham-Haken (RNGH) instability predicted in the sixties. A model that can account for coherent phenomena, a saturable absorber and SHB is developed and studied in detail both analytically and numerically. A wide variety of experimental data on multimode regimes is presented. Lasers with narrow active region and/or with metal coating on the sides tend to develop a splitting in the spectrum, approximately equal to twice the Rabi frequency. It is proposed that this behavior stems from the presence of a saturable absorber, which can result from a Kerr lensing effect in the cavity. Lasers with a wide active region, which have weaker saturable absorber, do not exhibit a Rabi splitting, and their multimode regime is governed by SHB. This experimental phenomenology is well explained by our theoretical model.

Quantum Photonics Thomas P. Pearsall.2021-01-04 Photonics is the discipline of electrons and photons working in tandem to create new physics, new devices and new applications. This textbook employs a pedagogical approach that facilitates access to the fundamentals of quantum photonics. Beginning with a review of the quantum properties of photons and electrons, the book then introduces the concept of their non-locality at the quantum level. It presents a determination of electronic band structure using the pseudopotential method, enabling the student to directly compute the band structures of most group IV, group III-V, and group II-VI semiconductors. The book devotes further in-depth discussion of second quantization of the electromagnetic field that describes spontaneous and stimulated emission of photons, quantum entanglement and introduces the topic of quantum cascade lasers, showing how electrons and photons interact in a quantum environment to create a practical photonic device. This extended second edition includes a detailed description of the link between quantum photon states and the macroscopic electric field. It describes the particle qualities of quantum electrons via their unique operator algebra and distinguishable behavior from photons, and employs these fundamentals to describe the quantum point contact, which is the quantum analogue of a transistor and the basic building block of all nanoscopic circuits, such as electron interferometers. Pearsall's Quantum Photonics is supported by numerous numerical calculations that can be repeated by the reader, and every chapter features a reference list of state-of-the-art research and a set of exercises. This textbook is an essential part of any graduate-level course dealing with the theory of nanophotonic devices or computational physics of solid-state quantum devices based on nanoscopic structures.

Modeling of Quantum Cascade Lasers Mihai Ursu.2001

Low Frequency and Circuit Based Quantum Cascade Lasers Christoph Walther.2011 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.

High Performance Mid-infrared-emitting Quantum Cascade Lasers Jeremy Daniel Kirch.2017 The active region of conventional Quantum Cascade Lasers (QCLs) is composed of quantum wells and barriers of fixed alloy composition. As a consequence, they suffer severe carrier leakage from the upper laser level, as evidenced by low characteristic-temperature values for both the threshold current density and the slope efficiency, over a wide range of heatsink temperatures above room temperature. Here, we describe three methods by which the performance of these devices can be substantially increased. First, to suppress carrier leakage, the energy separation between the upper laser level and the next-higher energy state in the active region, E₅₄ (or E₄₃), needs to be increased; to this end, we propose 4.8 μ m-emitting, step-tapered active-region (STA) QCLs for nearly complete suppression of carrier leakage. Secondly, we introduce an 8-9 μ m-emitting STA-QCL design, which also employs a miniband-like carrier extraction scheme to ensures rapid depopulation of the lower laser level. We call the fast, carrier-extraction scheme resonant extraction (RE) since it involves resonant-(tunneling)-extraction not only from lower active-region levels but also from the lower laser level. When both the STA concept and miniband-like carrier extraction scheme are applied, in so-called STA-RE QCLs, it is shown that record-high internal differential efficiency hid values of $\sim 86\%$ can be achieved, by comparison to the prior state-of-the-art values of 57 to 67%. Furthermore, the fundamental upper limit for hid is shown be $\sim 90\%$. With this improvement to internal differential efficiency, the wall-plug efficiency, hwp of mid-infrared-emitting QCLs should be $\sim 34\%$ higher than previously predicted, with hwp reaching values in excess of 40% for 4.6 μ m-emitting QCLs. Preliminary results from 5.0 μ m-emitting STA-RE QCLs are shown. Lastly, we show how single QCL emitters can be monolithically beam-combined to create High-Index-Contrast Photonic-Crystal (HC-PC) lasers as a means to coherently scale a QCL's output power while maintaining high beam quality, even under continuous-wave (CW) operating conditions. We present one such structure, which provided an output power of 5.5 W in a far-field beam pattern with lobewidths ~ 1.65 times the diffraction limit, and 82% energy contained in the central lobe. Methods to further improve on this result are also discussed.

Quantum Cascade Lasers .2005 The overall goal of DARPA PWASSP is the development of innovative Quantum Cascade (QC) lasers that are spectrally, spatially and temporal agile, and to deliver them for applications in sensing and signal processing. Significant advances in several fields closely aligned with these goals have been made, namely in the development of faster, more spectrally agile, and generally novel QC lasers, as outlined in the following in more detail.

Design and Fabrication of Quantum Cascade Lasers Giuseppe Scarpa.2003

Mid-Infrared and Terahertz Quantum Cascade Lasers Dan Botez,Mikhail A. Belkin.2023-09-14 Learn how the rapidly expanding area of mid-infrared and terahertz photonics has been revolutionized in this comprehensive overview. State-of-the-art practical applications are supported by real-life examples and expert guidance. Also featuring fundamental theory enabling you to improve performance of both existing and future devices.

Quantum Cascade Lasers (QCLs) Joseph D. Bennett.2016 Quantum cascade lasers (QCLs) are unipolar devices with lasing occurring through transitions between quantised 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.

Mid-infrared Quantum Cascade Lasers Modeling, Fabrication and Characterization Luyao Xu.2013 In the past 20 years, mid-infrared Quantum Cascade Lasers (mid-IR QCLs) have been experiencing rapid development and have become practical mid-IR sources for a variety of applications. There is particular technological interest in high efficiency lasers designed for the midwave infrared (MWIR) atmospheric window (3-5 [μm]) and longwave infrared (LWIR) atmospheric window (8-13 [μm]). This work presents a systematic study over mid-IR QCLs, including theoretical modeling, device fabrication and characterization. An effective bandstructure calculation method is implemented in this work for active region modeling. A standard process for fabricating mid-IR QCLs has been developed, based on which both LWIR (~ 9 [μm]) and MWIR (~ 4 [μm]) QCLs have been successfully demonstrated. Comprehensive testing results are analyzed and discussed, yielding valuable information about the current device design.

Highly Efficient and Reliable Quantum Cascade Lasers Benjamin Knipfer.2021 Mid-infrared (mid-IR) quantum cascade lasers (QCLs) have been commercially available for low power applications, however, while the desire for higher power devices is present, the efficiency and reliability are severe limitations. This work takes a multi-faceted approach to improving the reliability and efficiency of QCLs including: the identification and mitigation of failure mechanisms under high power continuous wave (CW) and quasi-continuous wave (QCW) operation, optical and thermal modeling of devices to further reduce active region heating, verification of these models using charge-coupled device (CCD) based thermoreflectance, and the introduction of interface roughness (IFR) engineered devices to reduce IFR scattering and leakage. Atom probe tomography (APT) is also employed to investigate the amount of aluminum and gallium incorporation in thin InAlAs barriers and InGaAs wells. It was found that thin layers with thicknesses less than 2 nm require an intentional aluminum or gallium overshoot in the gas phase during growth to grow the targeted compositions. This was verified when the overshoot in thin barriers resulted in the convergence of modeled and experimental emitting wavelengths. APT was also used to interrogate a few key interfaces within a 40 stage strain-compensated QCL emitting near 4.6 [μm]. This interrogation yielded both in-plane and axial IFR parameters for barriers of high and low aluminum incorporation, and in turn high and low strain, respectively. It was found that the barrier with the highest aluminum target had a nearly 50% larger root mean square (RMS) roughness when compared to the shorter barriers. As the IFR scattering is proportional to the square of both the RMS roughness and in-plane correlation length, this finding has a significant impact on the IFR scattering and leakage. The variable IFR parameters, axial correlation length, graded interfaces, graded lattice constants, graded conduction band edge, and quaternary alloy disorder (AD) scattering have been incorporated into a scattering model. Results from this model suggest lower global lifetimes and significantly reduced transition efficiencies which results in lower IFR leakage, however, if electronic temperatures from software using non-equilibrium Green's function (NGEF) is incorporated, leakage currents remain high.

Strain-free Ge/GeSiSn Quantum Cascade Lasers Based on L-Valley Intersubband Transitions .2007 The authors propose a Ge/Ge_{0.76}Si_{0.19}Sn_{0.05} quantum cascade laser using intersubband transitions at L valleys of the conduction band which has a clean offset of 150 meV situated below other energy valleys Gamma and X. The entire structure is strain-free because the lattice-matched Ge and Ge_{0.76}Si_{0.19}Sn_{0.05} layers are to be grown on a relaxed Ge buffer layer on a Si substrate. Longer lifetimes due to the weaker scattering of nonpolar optical phonons reduce the threshold current and potentially lead to room temperature operation.

Mid-infrared Quantum Cascade Lasers for Chaos Secure Communications Olivier Spitz.2021-05-15 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.

Modeling of Quantum Cascade Lasers by Ensemble Monte-Carlo Methods Alpár István Mátyás.2011

Quantum Cascade Lasers Jérôme Faist.2013-03-14 This book describes the physics, fabrication technology, and applications of the quantum cascade laser.

Quantum Cascade Lasers and Optical Metamaterials Matthew Escarra.2013-01 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.

Photonics for THz Quantum Cascade Lasers Maria Ines Amanti.2010

Transport in Quantum Cascade Lasers Romain Léon Terazzi.2012

Modern Techniques of Spectroscopy Dheeraj Kumar Singh,Manik Pradhan,Arnulf Materny.2021-04-01 The book highlights recent developments in the field of spectroscopy by providing the readers with an updated and high-level of overview. The focus of this book is on the introduction to concepts of modern spectroscopic techniques, recent technological innovations in this field, and current examples of applications to molecules and materials relevant for academia and industry. The book will be beneficial to researchers from various branches of science and technology, and is intended to point them to modern techniques, which might be useful for their specific problems. Spectroscopic techniques, that are discussed include, UV-Visible absorption spectroscopy, XPS, Raman spectroscopy, SERS, TERS, CARS, IR absorption spectroscopy, SFG, LIBS, Quantum cascade laser (QCL) spectroscopy, fluorescence spectroscopy, ellipsometry, cavity-enhanced absorption spectroscopy, such as cavity ring-down spectroscopy (CRDS) and evanescent wave-CRDS both in gas and condensed phases, time-resolved spectroscopy etc. Applications introduced in the different chapters demonstrates the usefulness of the spectroscopic techniques for the characterization of fundamental properties of molecules, e.g. in connection with environmental impact, bio-activity, or usefulness for pharmaceutical drugs, and materials important e.g. for nano-science, nuclear chemistry, or bio-applications. The book presents how spectroscopic techniques can help to better understand substances, which have also great impact on questions of social and economic relevance (environment, alternative energy, etc.).

High Power, High Beam Quality Mid-infrared Quantum Cascade Lasers Jae Ha Ryu.2022 Coherent power scaling of quantum cascade lasers (QCLs) for high-power, single-mode continuous-wave (CW) operation has proven to be quite a difficult task - while the device volume could be scaled for higher output power, many other factors such as beam quality and thermal resistance are negatively impacted if the device design is not

carefully considered. The main objective of this work has been to develop methods for realizing high continuous-wave (CW) output power QCLs with high beam quality and minimal beam steering. One attractive approach for tackling this problem is the use of resonant leaky-wave-coupled antiguided phase-locked laser arrays. This dissertation focusses on two approaches to achieve high coherent power: 1) one alternate to the resonant leaky-wave-coupled antiguided phase-locked array concept, so called 'reverse-taper' laser; and 2) one combining grating-coupled surface-emitting lasers (GCSELS) with resonant leaky-wave-coupled antiguided phase-locked arrays, where each array element is coupled in both the lateral and longitudinal direction; thus, has a potential for multi-watt -CW surface-emitted output powers with good beam quality and narrow spectral linewidth. The novel geometry reverse-taper QCL device can scale the output power while maintaining good beam quality and beam stability - the tapered region scales the output power, while the emitting facet is located at the narrow-end taper section, which provides mode filtering by suppressing high-order spatial modes. A small degree of collimated-beam centroid movement (

Whispering the Techniques of Language: An Psychological Quest through **Quantum Cascade Lasers**

In a digitally-driven world where monitors reign great and instant interaction drowns out the subtleties of language, the profound secrets and psychological nuances concealed within phrases often move unheard. Yet, located within the pages of **Quantum Cascade Lasers** an interesting fictional treasure blinking with organic feelings, lies an exceptional journey waiting to be undertaken. Written by an experienced wordsmith, that enchanting opus attracts viewers on an introspective journey, delicately unraveling the veiled truths and profound affect resonating within the very cloth of every word. Within the psychological depths with this poignant evaluation, we can embark upon a genuine exploration of the book's key subjects, dissect its interesting writing design, and succumb to the effective resonance it evokes heavy within the recesses of readers' hearts.

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