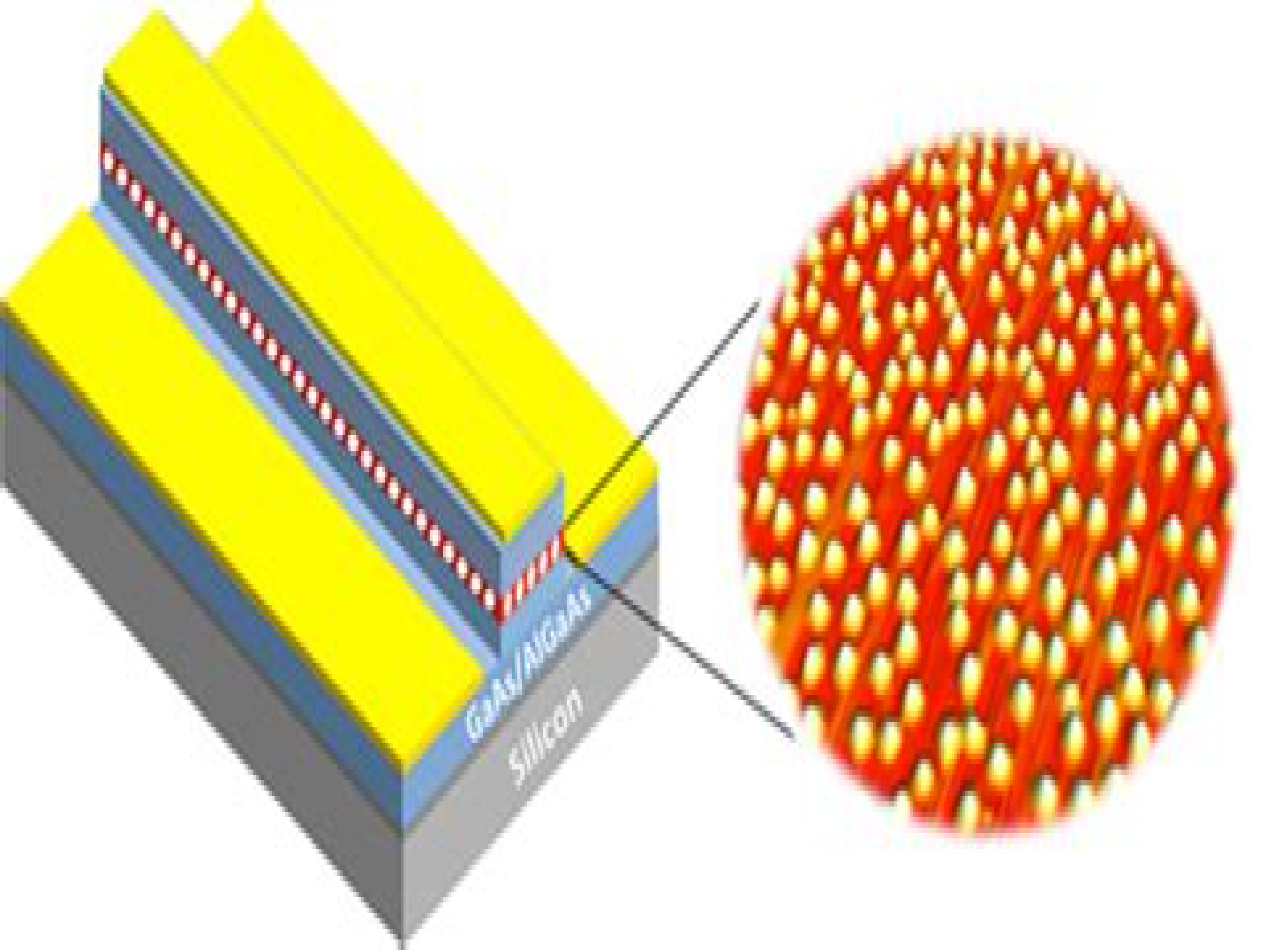
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# Quantum Dot Lasers

Marcel A. Müller

**Quantum Dot Lasers:**

**Quantum Dot Lasers** Victor Mikhailovich Ustinov,2003 The book addresses issues associated with physics and technology of injection lasers based on self organized quantum dots Fundamental and technological aspects of quantum dot edge emitting lasers and VCSELs their current status and future prospects are summarized and reviewed Basic principles of QD formation using self organization phenomena are reviewed Structural and optical properties of self organized QDs are considered with a number of examples in different material systems Recent achievements in controlling the QD properties including the effects of vertical stacking changing the matrix bandgap and the surface density of QDs are reviewed The authors focus on the use of self organized quantum dots in laser structures fabrication and characterization of edge and surface emitting diode lasers their properties and optimization with special attention paid to the relationship between structural and electronic properties of QDs and laser characteristics The threshold and power characteristics of the state of the art QD lasers are demonstrated Issues related to the long wavelength 1 3 mm lasers on a GaAs substrate are also addressed and recent results on InGaAsN based diode lasers presented for the purpose of comparison Ultrafast Lasers Based on Quantum Dot Structures Edik U. Rafailov,Maria Ana Cataluna,Eugene A. Avrutin,2011-04-08 In this monograph the authors address the physics and engineering together with the latest achievements of efficient and compact ultrafast lasers based on novel quantum dot structures and devices Their approach encompasses a broad range of laser systems while taking into consideration not only the physical and experimental aspects but also the much needed modeling tools thus providing a holistic understanding of this hot topic **Quantum Dot Lasers** ,2003 **Quantum Dot Lasers on Silicon** Bozhang Dong,2023-02-04 This book provides guidelines and design rules for developing high performance low cost and energy efficient quantum dot QD lasers for silicon photonic integrated circuits PIC optical frequency comb generation and quantum information systems To this end the nonlinear properties and dynamics of QD lasers on silicon are investigated in depth by both theoretical analysis and experiment This book aims at addressing four issues encountered in developing silicon PIC 1 The instability of laser emission caused by the chip scale back reflection During photonic integration the chip scale back reflection is usually responsible for the generation of severe instability i e coherence collapse from the on chip source As a consequence the transmission performance of the chip could be largely degraded To overcome this issue we investigate the nonlinear properties and dynamics of QD laser on Si in this book to understand how can it be applied to isolator free photonic integration in which the expensive optical isolator can be avoided Results show that the QD laser exhibits a high degree of tolerance for chip scale back reflections in absence of any instability which is a promising solution for isolator free applications 2 The degradation of laser performance at a high operating temperature In this era of Internet of Thing IoT about 40% of energy is consumed for cooling in the data center In this context it is important to develop a high temperature continuous wave CW emitted laser source In this book we introduce a single mode distributed feedback DFB QD laser with a

design of optical wavelength detuning OWD By taking advantage of the OWD technique and the high performance QD with high thermal stability all the static and dynamical performances of the QD device are improved when the operating temperature is high This study paves the way for developing uncooled and isolator free PIC 3 The limited phase noise level and optical bandwidth of the laser are the bottlenecks for further increasing the transmission capacity To improve the transmission capacity and meet the requirement of the next generation of high speed optical communication we introduce the QD based optical frequency comb OFC laser in this book Benefiting from the gain broadening effect and the low noise properties of QD the OFC laser is realized with high optical bandwidth and low phase noise We also provide approaches to further improve the laser performance including the external optical feedback and the optical injection 4 Platform with rich optical nonlinearities is highly desired by future integrated quantum technologies In this book we investigate the nonlinear properties and four wave mixing FWM of QD laser on Si This study reveals that the FWM efficiency of QD laser is more than ten times higher than that of quantum well laser which gives insight into developing a QD based silicon platform for quantum states of light generation Based on the results in this book scientists researchers and engineers can come up with an informed judgment in utilizing the QD laser for applications ranging from classical silicon PIC to integrated quantum technologies **Dynamics of Quantum Dot Lasers** Christian Otto,2014-01-21 This thesis deals with the dynamics of state of the art nanophotonic semiconductor structures providing essential information on fundamental aspects of nonlinear dynamical systems on the one hand and technological applications in modern telecommunication on the other Three different complex laser structures are considered in detail i a quantum dot based semiconductor laser under optical injection from a master laser ii a quantum dot laser with optical feedback from an external resonator and iii a passively mode locked quantum well semiconductor laser with saturable absorber under optical feedback from an external resonator Using a broad spectrum of methods both numerical and analytical this work achieves new fundamental insights into the interplay of microscopically based nonlinear laser dynamics and optical perturbations by delayed feedback and injection Quantum Dot Devices Zhiming M. Wang,2012-05-24 Quantum dots as nanomaterials have been extensively investigated in the past several decades from growth to characterization to applications As the basis of future developments in the field this book collects a series of state of the art chapters on the current status of quantum dot devices and how these devices take advantage of quantum features Written by 56 leading experts from 14 countries the chapters cover numerous quantum dot applications including lasers LEDs detectors amplifiers switches transistors and solar cells Quantum Dot Devices is appropriate for researchers of all levels of experience with an interest in epitaxial and or colloidal quantum dots It provides the beginner with the necessary overview of this exciting field and those more experienced with a comprehensive reference source *The Physics and Engineering of Compact Quantum Dot-based Lasers for Biophotonics* Edik U. Rafailov,2013-12-30 Written by a team of European experts in the field this book addresses the physics the principles the engineering methods and the latest

developments of efficient and compact ultrafast lasers based on novel quantum dot structures and devices as well as their applications in biophotonics Recommended reading for physicists engineers students and lecturers in the fields of photonics optics laser physics optoelectronics and biophotonics *High Power Ultra-short Pulse Quantum-dot Lasers* Daniil Nikitichev,2012-08-12 In this thesis novel multi section laser diodes based on quantum dot material are designed and investigated which exhibit a number of advantages such as low threshold current density temperature insensitivity and suppress carrier diffusion due to discrete nature of density of state of quantum dots The spectral versatility in the range of 1 1 m 1 3 m wavelengths is demonstrated through novel mode locking regimes such as dual wavelength mode locking wavelength bistability and broad tunability Moreover broad pulse repetition rate tuning using an external cavity configuration is presented A high peak power of 17 7 W was generated from the quantum dot laser as a result of the tapered geometry of the gain section of the laser has led to successful application of such device for two photon imaging Dual wavelength mode locking is demonstrated via ground 1180 nm and excited 1263 nm spectral bands with optical pulses from both states simultaneously in the 5 layer quantum dot two section diode laser The widest spectral separation of 83 nm between the modes was achieved in a dual wavelength mode locked non vibronic laser Power and wavelength bistability are achieved in a mode locked multi section laser which active region incorporates non identical QD layers grown by molecular beam epitaxy As a result the wavelength can be electronically controlled between 1245 nm and 1290 nm by applying different voltages to the saturable absorber Mode locked or continuous wave regimes are observed for both wavelengths over a 260 mA 330 mA current ranges with average power up to 28 mW and 31 mW respectively In mode locked regime a repetition rate of 10 GHz of optical pulses as short as 4 ps is observed Noticeable hysteresis of average power for different bias conditions is also demonstrated The wavelength and power bistability in QD lasers are potentially suitable for flip flop memory application In addition a unique mode locked regime at expense of the reverse bias with 50 nm wavelength tuning range from 1245 nm to 1290 nm is also presented Broad repetition rate tunability is shown from quantum dot external cavity mode locked 1 27 m laser The repetition rate from record low of 191 MHz to 1 GHz from fundamental mode locking was achieved Harmonic mode locking allows further to increase tuning up to 6 8 GHz 34th order harmonic from 200 MHz fundamental mode locking High peak power of 1 5 W can be generated directly from two section 4 mm long laser with bent waveguide at angle of 7 at 1 14 GHz repetition rate without the use of any pulse compression and optical amplifier Stable mode locking with an average power up to 60 mW corresponding to 25 pJ pulse energy is also obtained at a repetition frequency of 2 4 GHz The minimum time bandwidth product of 1 01 is obtained with the pulse duration of 8 4 ps Novel tapered quantum dot lasers with a gain guided geometry operating in a passively mode locked regime have been investigated using structures that incorporated either 5 or 10 quantum dot layers The peak power of 3 6 W is achieved with pulse duration of 3 2 ps Furthermore the record peak power of 17 7 W and transform limited pulses of 672 fs were achieved with

optimized structure The generation of picosecond pulses with high average power of up to 209 mW was demonstrated corresponding to 14 2 pJ pulse energy The improved optical parameters of the tapered laser enable to achieve nonlinear images of fluorescent beads Thus it is for the first time that QD based compact monolithic device enables to image biological samples using two photon microscopy imaging technique Quantum Dot Lasers ,2003 Addressing issues associated with the physics and technology of injection lasers this book examines self organized quantum dots Fundamental and technological aspects of quantum dot edge emitting lasers and VCSELs their current status and future prospects are summarized and reviewed **Numerical Modeling of Narrow-linewidth Quantum Dot Lasers** Bjelica, Marko,2017-01-01 The quantization of the active laser medium has enabled numerous advances in fiber optic communications e g higher efficiency of laser diodes higher modulation bandwidth lower spectral linewidth of the emitted signal In recent years the quantum dot lasers have demonstrated a strong potential to continue this trend therefore by progressing from standard quantum well to quantum dot designs it can be expected that the quantum dot lasers will play an increasingly important role in future fiber optic communications The research work presented in this dissertation seeks to further develop the quantum dot laser designs and improve the understanding of complex operating conditions affecting the laser linewidth This is achieved by developing a comprehensive laser simulator that was applied to design and simulation of edge emitting lasers and laser arrays As a result the optimized laser diodes have demonstrated a significantly lower linewidth compared to equivalent quantum well designs Due to their narrow linewidth the realized photonic devices can be a viable solution for high bit rate fiber optic networks *Design and Fabrication of Quantum-dot Lasers* Sheila P. Nabanja,2008 Semiconductor lasers using quantum dots in their active regions have been reported to exhibit significant performance advantages over their bulk semiconductor and quantum well counterparts namely low threshold current high differential gain and highly temperature stable light current characteristics This thesis investigates the lasing characteristics of a ridge waveguide laser containing seven layers of quantum dots as the active region A summary of the electrical and optical performance data of the heterostructure quantum dot lasers as well as previously fabricated quantum well lasers is presented The motivation of using InAs quantum dots in the active region is to produce near infrared emission for telecommunication applications High Power High Efficiency Electron-hole and Unipolar Quantum Dot Lasers Sonia Quadery,2007 The goal of this research work is to develop and analyze Quantum Dot QD lasers aimed at improving high power performance which is crucial for numerous scientific military and industrial applications Fundamentally two dissimilar types of lasers are investigated namely bipolar electron hole laser and unipolar quantum cascade laser Planar quantum well QW laser diodes are already well established as commercially available high power semiconductor lasers However these lasers are unable to deliver power greater few 10 s of watts due to reduction in efficiency at longer cavity lengths This limitation arises from inherent optical losses tied to the two dimensional density of available states in QWs A novel approach

is proposed here to circumvent this limitation by introducing self assembled QDs into the laser cavity which due to their delta like discrete density of states promise to reduce the optical losses by at least an order of magnitude hence allowing cavity length to increase proportionally Detailed analysis based on harmonic oscillator model and solution at quasi equilibrium condition reveal that total internal losses as low as 0 05 per cm 1 can be achieved in a QD laser enabling it to deliver 50 watts of power from each bar while maintaining efficiency close to 90% In order to take full advantage of the discrete atom like behavior it is also of utmost importance to reduce the inhomogeneous broadening of the dot distribution originating from size fluctuation Experimental data of ultra narrow linewidth InAs quantum dots having linewidth of only 22 meV is presented Research attempt has been taken to integrate these narrowly distributed dots into a workable structure Preliminary data shows that these dots are extremely sensitive to the laser material which calls for careful optimization of the entire structure As for the unipolar QCL it is shown that internal absorption caused by phonon emission of electrons in a planar quantum cascade laser represents a possible limitation to the maximum operating efficiency Possibility of reducing this absorption is explored and it is optimistically asserted that introducing QDs into the gain stage of a QCL can eliminate this internal loss mechanism thus greatly improving high power operating characteristics **Nonlinear Laser Dynamics** Kathy Lüdge,2012-04-09 A distinctive discussion of the nonlinear dynamical phenomena of semiconductor lasers The book combines recent results of quantum dot laser modeling with mathematical details and an analytic understanding of nonlinear phenomena in semiconductor lasers and points out possible applications of lasers in cryptography and chaos control This interdisciplinary approach makes it a unique and powerful source of knowledge for anyone intending to contribute to this field of research By presenting both experimental and theoretical results the distinguished authors consider solitary lasers with nano structured material as well as integrated devices with complex feedback sections In so doing they address such topics as the bifurcation theory of systems with time delay analysis of chaotic dynamics and the modeling of quantum transport They also address chaos based cryptography as an example of the technical application of highly nonlinear laser systems **Dynamic Scenarios in Two-State Quantum Dot Lasers** André Röhm,2015-03-25 Andr R hm investigates the dynamic properties of two state lasing quantum dot lasers with a focus on ground state quenching With a novel semi analytical approach different quenching mechanisms are discussed in an unified framework and verified with numerical simulations The known results and experimental findings are reproduced and parameter dependencies are systematically studied Additionally the turn on dynamics and modulation response curves of two state lasing devices are presented

**Quantum Dots** Elena Borovitskaya,Michael S Shur,2002-07-08 In this book leading experts on quantum dot theory and technology provide comprehensive reviews of all aspects of quantum dot systems The following topics are covered 1 energy states in quantum dots including the effects of strain and many body effects 2 self assembly and self ordering of quantum dots in semiconductor systems 3 growth structures and optical properties of III nitride quantum dots 4 quantum dot lasers

**Sensitivity of Quantum Dot Lasers to External Optical Feedback** David Vincent O'Brien,2004 Quantum dots are man made nanostructures that typically vary from 10 s to 100 s of nonometers in size These dimensions are of the order of the De Broglie wavelength of the electron and so electrons confined in these structures exhibit electronic and optical characteristics that are similar to those in atoms These low dimensional semiconductor structures have attracted considerable interest both for their fundamental properties and for their potential applications in micro and optoelectronics Possible applications that have been suggested include single electron transistors various photonic devices and as components for quantum computing systems In particular laser diodes incorporating quantum dot active regions have been studied extensively in the last few years Many theoretical studies have shown the potential benefits of these devices over more conventional semiconductor laser diodes From the atom like density of states a symmetric gain spectrum is predicted which eliminates some problems inherent in other semiconductor lasers such as self focusing and filamentation in broad area devices antiguiding in narrow stripe devices and chirp under high speed modulation These and other effects in semiconductor lasers have been characterized in terms of the a factor This parameter has been predicted to approach zero for quantum dot devices lasing in the ground state Lasers incorporating quantum dot active regions have the potential for the improved performance of gas lasers and some other laser systems while maintaining the advantage of smaller size and ease of manufacture that have made semiconductor lasers so widespread Recent advances in the fabrication of quantum dot materials have made the manufacture of high quality quantum dot material more feasible bringing the potential applications that much closer With improved fabrication techniques dots of similar size shape strain and consistency can be achieved with device performance improving alongside these developments As the quality of the material improves it is possible to study more closely the difference between real life devices and the theoretical abstractions that predict their enhanced performance Inhomogeneous broadening of the gain region Coulomb effects relaxation mechanisms and rates involved all give rise to a more complex system than the sum of a series of two level systems that was originally visualized as the active region arising from a quantum dot ensemble *Quantum Confined Laser Devices* Peter Blood,2015 This book is intended to take students final year undergraduates and graduates and researchers along the path to understand quantum processes in semiconductors and to enable them as researchers to contribute to further advances and inventions **Investigation of Quantum Dot Lasers** ,2004 Since the first demonstration of room temperature operation of self assembled quantum dot QD lasers about a decade ago there have been great strides in improving the characteristics and performance of these lasers They currently match or surpass the performance of quantum well lasers However there are unique problems that limit the performance of conventional separate confinement heterostructure SCH QD lasers compared to what is expected from ideal lasers with near singular density of states In the study reported here unique insights and solutions to these problems are demonstrated and reliable quantum dot lasers that surpass quantum well lasers in performance characteristics are developed

By utilizing the concepts of tunnel injection and p doping 1 0 micrometer and 1 3 micrometer quantum dot lasers with high differential gain modulation bandwidth 25GHz a factor less than unity and zero chirp have been achieved This final report summarizes the successful design fabrication and characterization of high performance 1 0 micrometer QD Distributed Feedback DFB lasers 1 0 micrometer QD Tunnel Injection lasers undoped and p doped and 1 3 micrometer p doped QD lasers The authors have demonstrated record performance of these unique devices in terms of differential gain modulation bandwidth temperature dependence chirp and linewidth enhancement factor 16 figures 14 refs **Investigations of Quantum Dot Lasers** ,2000 A detailed theoretical and experimental study of the application of quantum dot active regions to edge emitting lasers and electro optic modulators was undertaken The theoretical work included calculation of the bandstructure and electronic properties of self assembled quantum dots carrier scattering rates and the oscillator strength and gain of interband and intersubband transitions Experimental work included growth of self organized dots and active devices their fabrication and characterization Very narrow PL linewidths in the dots were achieved approx 19 meV by the incorporation of buried stressor dots The dynamics of hot carriers and carrier relaxation rates were characterized by differential transmission spectroscopy It was established from a variety of measurements and calculations that electron hole scattering is the dominant carrier relaxation mechanism in quantum dots Modulation bandwidth measurements on QD lasers at cryogenic temperatures f 3dB approx 30 GHz at T 100K confirmed the role of electron hole scattering The electron optic coefficients of quantum dots was measured for the first time and a QD modulator has been demonstrated Bistability and gain switching has also been observed and characterized The unique carrier dynamics in quantum dots is favorable for the realization of intersubband emitters and detectors and these have been investigated Quantum Dot Based Mode-locked Semiconductor Lasers and Applications Jimyung Kim,2010 In this dissertation self assembled InAs InGaAs quantum dot Fabry P rot lasers and mode locked lasers are investigated The mode locked lasers investigated include monolithic and curved two section devices and colliding pulse mode locked diode lasers Ridge waveguide semiconductor lasers have been designed and fabricated by wet etching processes Electroluminescence of the quantum dot lasers is studied Cavity length dependent lasing via ground state and or excited state transitions is observed from quantum dot lasers and the optical gain from both transitions is measured Stable optical pulse trains via ground and excited state transitions are generated using a grating coupled external cavity with a curved two section device Large differences in the applied reverse bias voltage on the saturable absorber are observed for stable mode locking from the excited and ground state mode locking regimes The optical pulses from quantum dot mode locked lasers are investigated in terms of chirp sign and linear chirp magnitude Upchirped pulses with large linear chirp magnitude are observed from both ground and excited states Externally compressed pulse widths from the ground and excited states are 1 2 ps and 970 fs respectively Ground state optical pulses from monolithic mode locked lasers e g two section devices and colliding pulse mode locked lasers are also studied Transformed limited

optical pulses 4 5 ps are generated from a colliding pulse mode locked semiconductor laser The above threshold linewidth enhancement factor of quantum dot Fabry P rot lasers is measured using the continuous wave injection locking method A strong spectral dependence of the linewidth enhancement factor is observed around the gain peak The measured linewidth enhancement factor is highest at the gain peak but becomes lower 10 nm away from the gain peak The lowest linewidth enhancement factor is observed on the anti Stokes side The spectral dependence of the pulse duration from quantum dot based mode locked lasers is also observed Shorter pulses and reduced linear chirp are observed on the anti Stokes side and externally compressed 660 fs pulses are achieved in this spectral regime A novel clock recovery technique using passively mode locked quantum dot lasers is investigated The clock signal 4 GHz is recovered by injecting an interband optical pulse train to the saturable absorber section The excited state clock signal is recovered through the ground state transition and vice versa Asymmetry in the locking bandwidth is observed The measured locking bandwidth is 10 times wider when the excited state clock signal is recovered from the ground state injection as compared to recovering a ground state clock signal from excited state injection

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