

Junji Ohtsubo

# Semiconductor Lasers

Stability, Instability and Chaos

*3rd Edition*



Springer

# Semiconductor Lasers Stability Instability And Chaos

**Marek Wartak**



## **Semiconductor Lasers Stability Instability And Chaos:**

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.

**Semiconductor Lasers** Junji Ohtsubo, 2010-11-16 This monograph describes fascinating recent progress in the field of chaos stability and instability of semiconductor lasers. Applications and future prospects are discussed in detail. The book emphasizes the various dynamics induced in semiconductor lasers by optical and electronic feedback, optical injection, and injection current modulation. Recent results of both theoretical and experimental investigations are presented. Demonstrating applications of semiconductor laser chaos control and noise, *Semiconductor Lasers* describes suppression and chaotic secure communications. For those who are interested in optics but not familiar with nonlinear systems, a brief introduction to chaos analysis is presented.

Semiconductor Lasers Junji Ohtsubo, 2012-10-06 This third edition of *Semiconductor Lasers Stability Instability and Chaos* was significantly extended. In the previous edition, the dynamics and characteristics of chaos in semiconductor lasers after the introduction of the fundamental theory of laser chaos and chaotic dynamics induced by self-optical feedback and optical injection were discussed. Semiconductor lasers with new device structures such as vertical cavity surface emitting lasers and broad area semiconductor lasers are interesting devices from the viewpoint of chaotic dynamics since they essentially involve chaotic dynamics even in their free-running oscillations. These topics are also treated with respect to the new developments in the

current edition Also the control of such instabilities and chaos control are critical issues for applications Another interesting and important issue of semiconductor laser chaos in this third edition is chaos synchronization between two lasers and the application to optical secure communication One of the new topics in this edition is fast physical number generation using chaotic semiconductor lasers for secure communication and development of chaos chips and their application As other new important topics the recent advance of new semiconductor laser structures is presented such as quantum dot semiconductor lasers quantum cascade semiconductor lasers vertical cavity surface emitting lasers and physical random number generation with application to quantum key distribution Stabilities instabilities and control of quantum dot semiconductor lasers and quantum cascade lasers are important topics in this field

*Semiconductor Lasers* Junji Ohtsubo, 2008 This monograph describes fascinating recent progress in the field of chaos stability and instability of semiconductor lasers Applications and future prospects are discussed in detail The book emphasizes the various dynamics induced in semiconductor lasers by optical and electronic feedback optical injection and injection current modulation Recent results of both theoretical and experimental investigations are presented Demonstrating applications of semiconductor laser chaos control and noise

*Semiconductor Lasers* describes suppression and chaotic secure communications For those who are interested in optics but not familiar with nonlinear systems a brief introduction to chaos analysis is presented

**Theory of Semiconductor Lasers** Minoru Yamada, 2014-04-10 This book provides a unified and complete theory for semiconductor lasers covering topics ranging from the principles of classical and quantum mechanics to highly advanced levels for readers who need to analyze the complicated operating characteristics generated in the real application of semiconductor lasers The author conducts a theoretical analysis especially on the instabilities involved in the operation of semiconductor lasers A density matrix into the theory for semiconductor lasers is introduced and the formulation of an improved rate equation to help understand the mode competition phenomena which cause the optical external feedback noise is thoroughly described from the basic quantum mechanics The derivation of the improved rate equation will allow readers to extend the analysis for the different types of semiconductor materials and laser structures they deal with This book is intended not only for students and academic researchers but also for engineers who develop lasers for the market as the advanced topics covered are dedicated to real problems in implementing semiconductor lasers for practical use

Optical Communication with Chaotic Lasers Atsushi Uchida, 2012-02-13 Starting with an introduction to the fundamental physics in chaotic instabilities in laser systems this comprehensive and unified reference goes on to present the techniques and technology of synchronization of chaos in coupled lasers as well as the many applications to lasers and optics communications security and information technology Throughout it presents the current state of knowledge including encoding decoding techniques performance of chaotic communication systems random number generation and novel communication technologies

Introduction to Simulations of Semiconductor Lasers Marek Wartak, 2024-03-21 Simulations play an increasingly important role not only in scientific

research but also in engineering developments Introduction to Simulations of Semiconductor Lasers introduces senior undergraduates to the design of semiconductor lasers and their simulations The book begins with explaining the physics and fundamental characteristics behind semiconductor lasers and their applications It presumes little prior knowledge such that only a familiarity with the basics of electromagnetism and quantum mechanics is required The book transitions from textbook explanations equations and formulas to ready to run numeric codes that enable the visualization of concepts and simulation studies Multiple chapters are supported by MATLAB code which can be accessed by the students These are ready to run but they can be modified to simulate other structures if desired Providing a unified treatment of the fundamental principles and physics of semiconductors and semiconductor lasers Introduction to Simulations of Semiconductor Lasers is an accessible practical guide for advanced undergraduate students of Physics particularly for courses in laser physics

**Key Features** A unified treatment of fundamental principles Explanations of the fundamental physics of semiconductor Explanations of the operation of semiconductor lasers An historical overview of the subject     *Oscillations, Waves and Interactions* Thomas Kurz,2007     Microcavity Semiconductor Lasers Yong-zhen Huang,Yue-de Yang,2021-06-28 Microcavity Semiconductor Lasers Explore this thorough overview of integrable microcavity semiconductor lasers and their applications from two leading voices in the field Attracting a great deal of attention over the last decades for their promising applications in photonic integration and optical interconnects microcavity semiconductor lasers continue to develop via advances in fundamental physics theoretical analysis and numerical simulations In a new work that will be of interest to researchers and practitioners alike Microcavity Semiconductor Lasers Principles Design and Applications delivers an application oriented and highly relevant exploration of the theory fabrication and applications of these practical devices The book focuses on unidirectional emission microcavity lasers for photonic integrated circuits including polygonal microresonators microdisk and microring lasers After an introductory overview of optical microcavities for microlasers and detailed information of the lasers themselves including mode structure control and characteristics and lasing properties the distinguished authors discuss fabrication and applications of different microcavity lasers Prospects for future research and potential new applications round out the book Readers will also benefit from the inclusion of A thorough introduction to multilayer optical waveguides the FDTD Method and Pad Approximation and deformed chaos and unidirectional emission microdisk lasers An exploration of mode analysis for triangle and square microresonators similar as FP Cavity Practical discussions of mode analysis and control for deformed square microlasers An examination of hexagonal microcavity lasers and polygonal microcavities along with vertical radiation loss for 3D microcavities Perfect for laser specialists semiconductor physicists and solid state physicists Microcavity Semiconductor Lasers Principles Design and Applications will also earn a place in the libraries of materials scientists and professionals working in the semiconductor and optical industries seeking a one stop reference for integrable microcavity semiconductor lasers     Chaotic Signal Processing Henry Leung,2013-12-05 Chaos is a deterministic random

phenomenon Many signal processes e g radar and sonar have a random appearance and chaos provides an alternative approach to processing these signals This book presents up to date research results on chaotic signal processing including the application of nonlinear dynamics to radar target recognition an exactly solvable chaos approach for communications a chaotic approach for reconfigurable computing system identification using chaos design of a high resolution LADAR system based on chaos and the use of chaos in compressive sensing

**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

*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

Nonlinear and Nonequilibrium Dynamics of Quantum-Dot Optoelectronic Devices Benjamin

Lingnau,2015-12-14 This thesis sheds light on the unique dynamics of optoelectronic devices based on semiconductor quantum dots The complex scattering processes involved in filling the optically active quantum dot states and the presence of charge carrier nonequilibrium conditions are identified as sources for the distinct dynamical behavior of quantum dot based devices Comprehensive theoretical models which allow for an accurate description of such devices are presented and applied to recent experimental observations The low sensitivity of quantum dot lasers to optical perturbations is directly attributed to their unique charge carrier dynamics and amplitude phase coupling which is found not to be accurately described by conventional approaches The potential of quantum dot semiconductor optical amplifiers for novel applications such as simultaneous multi state amplification ultra wide wavelength conversion and coherent pulse shaping is investigated The scattering mechanisms and the unique electronic structure of semiconductor quantum dots are found to make such devices prime candidates for the implementation of next generation optoelectronic applications which could significantly simplify optical telecommunication networks and open up novel high speed data transmission schemes

*Single Frequency*

*Semiconductor Lasers* Zujie Fang,Haiwen Cai,Gaoting Chen,Ronghui Qu,2017-07-29 This book systematically introduces the single frequency semiconductor laser which is widely used in many vital advanced technologies such as the laser cooling of atoms and atomic clock high precision measurements and spectroscopy coherent optical communications and advanced optical sensors It presents both the fundamentals and characteristics of semiconductor lasers including basic F P structure and monolithic integrated structures interprets laser noises and their measurements and explains mechanisms and

technologies relating to the main aspects of single frequency lasers including external cavity lasers frequency stabilization technologies frequency sweeping optical phase locked loops and so on It paints a clear physical picture of related technologies and reviews new developments in the field as well It will be a useful reference to graduate students researchers and engineers in the field

*Diode Lasers and Photonic Integrated Circuits* Larry A. Coldren, Scott W. Corzine, Milan L. Mashanovitch, 2012-03-02 Diode Lasers and Photonic Integrated Circuits Second Edition provides a comprehensive treatment of optical communication technology its principles and theory treating students as well as experienced engineers to an in depth exploration of this field Diode lasers are still of significant importance in the areas of optical communication storage and sensing Using the the same well received theoretical foundations of the first edition the Second Edition now introduces timely updates in the technology and in focus of the book After 15 years of development in the field this book will offer brand new and updated material on GaN based and quantum dot lasers photonic IC technology detectors modulators and SOAs DVDs and storage eye diagrams and BER concepts and DFB lasers Appendices will also be expanded to include quantum dot issues and more on the relation between spontaneous emission and gain

Delay-Coupled Complex Systems Valentin Flunkert, 2011-06-25 This work addresses time delay in complex nonlinear systems and in particular its applications in complex networks its role in control theory and nonlinear optics are also investigated Delays arise naturally in networks of coupled systems due to finite signal propagation speeds and are thus a key issue in many areas of physics biology medicine and technology Synchronization phenomena in these networks play an important role e g in the context of learning cognitive and pathological states in the brain for secure communication with chaotic lasers or for gene regulation The thesis includes both novel results on the control of complex dynamics by time delayed feedback and fundamental new insights into the interplay of delay and synchronization One of the most interesting results here is a solution to the problem of complete synchronization in general networks with large coupling delay i e large distances between the nodes by giving a universal classification of networks that has a wide range of interdisciplinary applications

**Semiconductor Laser Diode**

Dnyaneshwar Patil, 2012-04-25 This book represents a unique collection of the latest developments in the rapidly developing world of semiconductor laser diode technology and applications An international group of distinguished contributors have covered particular aspects and the book includes optimization of semiconductor laser diode parameters for fascinating applications This collection of chapters will be of considerable interest to engineers scientists technologists and physicists working in research and development in the field of semiconductor laser diode as well as to young researchers who are at the beginning of their career

Selected Topics in Nonlinear Dynamics and Theoretical Electrical Engineering Kyandoghere Kyamakya, Wolfgang A. Halang, Wolfgang Mathis, Jean Chamberlain Chedjou, Zhong Li, 2013-04-02 This book contains a collection of recent advanced contributions in the field of nonlinear dynamics and synchronization including selected applications in the area of theoretical electrical engineering The present book is divided into twenty one chapters grouped in



five parts The first part focuses on theoretical issues related to chaos and synchronization and their potential applications in mechanics transportation communication and security The second part handles dynamic systems modelling and simulation with special applications to real physical systems and phenomena The third part discusses some fundamentals of electromagnetics EM and addresses the modelling and simulation in some real physical electromagnetic scenarios The fourth part mainly addresses stability concerns Finally the last part assembles some sample applications in the area of optimization data mining pattern recognition and image processing

*Optical Nonlinearities in Chalcogenide Glasses and Their Applications* A. Zakery, S.R. Elliott, 2007-06-19 This book reviews techniques used to characterize non linear optical constants of chalcogenide glasses in bulk or thin films and presents the properties of many chalcogenide systems A range of applications of these glasses are surveyed including ultra fast switching optical limiting second harmonic generation and electro optic effects Also addressed are suitability of chalcogenide films in all optical integrated circuits fabrication of rib as well as ridge waveguides and of fiber gratings

*Transmission Electron Microscopy* Ludwig Reimer, Helmut Kohl, 2008-08-28 The aim of this monograph is to outline the physics of image formation electron specimen interactions and image interpretation in transmission electron microscopy Since the last edition transmission electron microscopy has undergone a rapid evolution The introduction of monochromators and proved energy filters has allowed electron energy loss spectra with an energy resolution down to about 0.1 eV to be obtained and aberration correctors are now available that push the point to point resolution limit down below 0.1 nm After the untimely death of Ludwig Reimer Dr Koelsch from Springer Verlag asked me if I would be willing to prepare a new edition of the book As it had served me as a reference for more than 20 years I agreed without hesitation Distinct from more specialized books on specific topics and from books intended for classroom teaching the Reimer book starts with the basic principles and gives a broad survey of the state of the art methods complemented by a list of references to allow the reader to find further details in the literature The main objective of this revised edition was therefore to include the new developments but leave the character of the book intact The presentation of the material follows the format of the previous edition as outlined in the preface to that volume which immediately follows A few derivations have been modified to correspond more closely to modern textbooks on quantum mechanics scattering theory or solid state physics

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