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Semiconductor Lasers:
Stability, Instability and Chaos
2nd Edition

半导体激光器
——稳定性、失稳与混沌
第二版

（影印版）

〔日〕大坪顺次（J. Ohtsubo） 著

北京大学出版社
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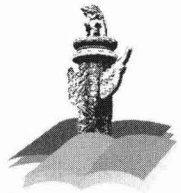

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序　言

物理学是研究物质、能量以及它们之间相互作用的科学。她不仅是化学、生命、材料、信息、能源和环境等相关学科的基础，同时还是许多新兴学科和交叉学科的前沿。在科技发展日新月异和国际竞争日趋激烈的今天，物理学不仅囿于基础科学和技术应用研究的范畴，而且在社会发展与人类进步的历史进程中发挥着越来越关键的作用。

我们欣喜地看到，改革开放三十多年来，随着中国政治、经济、教育、文化等领域各项事业的持续稳定发展，我国物理学取得了跨越式的进步，做出了很多为世界瞩目的研究成果。今日的中国物理正在经历一个历史上少有的黄金时代。

在我国物理学科快速发展的背景下，近年来物理学相关书籍也呈现百花齐放的良好态势，在知识传承、学术交流、人才培养等方面发挥着无可替代的作用。从另一方面看，尽管国内各出版社相继推出了一些质量很高的物理教材和图书，但系统总结物理学各门类知识和发展，深入浅出地介绍其与现代科学技术之间的渊源，并针对不同层次的读者提供有价值的教材和研究参考，仍是我国科学传播与出版界面临的一个极富挑战性的课题。

为有力推动我国物理学研究、加快相关学科的建设与发展，特别是展现近年来中国物理学者的研究水平和成果，北京大学出版社在国家出版基金的支持下推出了“中外物理学精品书系”，试图对以上难题进行大胆的尝试和探索。该书系编委会集结了数十位来自内地和香港顶尖高校及科研院所的知名专家学者。他们都是目前该领域十分活跃的专家，确保了整套丛书的权威性和前瞻性。

这套书系内容丰富，涵盖面广，可读性强，其中既有对我国传统物理学发展的梳理和总结，也有对正在蓬勃发展的物理学前沿的全面展示；既引进和介绍了世界物理学研究的发展动态，也面向国际主流领域传播中国物理的优秀专著。可以说，“中外物理学精品书系”力图完整呈现近现代世界和中国物理

科学发展的全貌，是一部目前国内为数不多的兼具学术价值和阅读乐趣的经典物理丛书。

“中外物理学精品书系”另一个突出特点是，在把西方物理的精华要义“请进来”的同时，也将我国近现代物理的优秀成果“送出去”。物理学科在世界范围内的重要性不言而喻，引进和翻译世界物理的经典著作和前沿动态，可以满足当前国内物理教学和科研工作的迫切需求。另一方面，改革开放几十年来，我国的物理学研究取得了长足发展，一大批具有较高学术价值的著作相继问世。这套丛书首次将一些中国物理学者的优秀论著以英文版的形式直接推向国际相关研究的主流领域，使世界对中国物理学的过去和现状有更多的深入了解，不仅充分展示出中国物理学研究和积累的“硬实力”，也向世界主动传播我国科技文化领域不断创新的“软实力”，对全面提升中国科学、教育和文化领域的国际形象起到重要的促进作用。

值得一提的是，“中外物理学精品书系”还对中国近现代物理学科的经典著作进行了全面收录。20 世纪以来，中国物理界诞生了很多经典作品，但当时大都分散出版，如今很多代表性的作品已经淹没在浩瀚的图书海洋中，读者们对这些论著也都是“只闻其声，未见其真”。该书系的编者们在这方面下了很大工夫，对中国物理学科不同时期、不同分支的经典著作进行了系统的整理和收录。这项工作具有非常重要的学术意义和社会价值，不仅可以很好地保护和传承我国物理学的经典文献，充分发挥其应有的传世育人的作用，更能使广大物理学人和青年学子切身体会我国物理学研究的发展脉络和优良传统，真正领悟到老一辈科学家严谨求实、追求卓越、博大精深的治学之美。

温家宝总理在 2006 年中国科学技术大会上指出，“加强基础研究是提升国家创新能力、积累智力资本的重要途径，是我国跻身世界科技强国的必要条件”。中国的发展在于创新，而基础研究正是一切创新的根本和源泉。我相信，这套“中外物理学精品书系”的出版，不仅可以使所有热爱和研究物理学的人们从中获取思维的启迪、智力的挑战和阅读的乐趣，也将进一步推动其他相关基础科学更好更快地发展，为我国今后的科技创新和社会进步做出应有的贡献。

“中外物理学精品书系”编委会 主任

中国科学院院士，北京大学教授

王恩哥

2010 年 5 月于燕园

Junji Ohtsubo

Semiconductor Lasers

Stability, Instability and Chaos

Second, Enlarged Edition

With 169 Figures and 5 Tables

Springer

Preface

Preface for the second edition

Chaos research in laser physics, especially in semiconductor lasers, has developed further even after completion of the first edition of this book in the late summer of 2004, and it is still growing rapidly. For example, various forms of chaotic dynamics have been applied in newly developed semiconductor lasers, such as in vertical-cavity surface-emitting semiconductor lasers and broad-area semiconductor lasers. Chaotic dynamics plays an important role in these new lasers, even for their solitary oscillations, and control of the dynamics is currently an important issue for practical applications. Another significant advance has been made in the area of chaotic optical secure communications. Chaotic secure communications using existing public optical communications links have been tested, and successful results have been obtained. In this second edition, I have filled in the gaps in the explanation of chaotic laser dynamics in the previous edition, and I have also added several important topics that have been developed recently. In particular, a new chapter on laser stabilizations has been added, and a number of misprints in the first edition have been corrected. I believe this book will be of interest not only to researchers in the field of laser chaos, but also to those working in nonlinear science and technology.

Hamamatsu, Spring 2007 *Junji Ohtsubo*

Preface

The aim of this book is the description of the state of the art of chaos research in semiconductor lasers and their applications, and the future perspective of this field. However, for the beginner, including graduates who intend to participate newly in this field, the book starts with an introduction and explanation of chaos in laser systems and the derivation of semiconductor laser rate equations assuming two-level systems. I discuss stabilities, instabilities, and various chaotic dynamics in semiconductor lasers induced by optical and optoelectronic feedback, optical injection, and injection current modulation. As optical feedback, the effects of the conventional reflector, the grating feedback mirror, and the phase-conjugate mirror are considered. Recent results both for theoretical and experimental investigations are presented. Instabilities and chaotic dynamics for novel laser structures (self-pulsating semiconductor lasers, vertical-cavity surface-emitting semiconductor lasers (VCSELs), broad area semiconductor lasers, and semiconductor laser arrays) are also discussed not only for solitary operations but also in the presence of external perturbations.

As applications of semiconductor laser chaos, control and noise suppression of lasers based on chaos control algorithm are presented. Externally controlled lasers are also interesting for applications of new laser systems with high coherent light sources or tunable light sources. The self-mixing interferometer in semiconductor lasers is an attractive application based on dynamic properties using bistable states in optical feedback effects. I also discuss these subjects. As another application of chaos, several methods of data encryption into the chaotic carrier and its decryption are introduced for secure data transmissions and communications based on chaos synchronization in semiconductor laser systems. This book is focused on the dynamic characteristics of semiconductor lasers and their applications. Therefore, the detailed descriptions for materials and structures of semiconductor lasers are beyond the scope of this book. Of course, such characteristics are closely related to chaotic phenomena in semiconductor lasers. The interested reader is referred to the related books. For those who are interested in optics but not familiar with nonlinear systems and chaos, I have attached an appendix to describe the phenomena of chaotic dynamics and to accustom the reader to the common tools for chaos analyses in nonlinear systems. Chaos research,

especially in semiconductor laser systems, is still developing rapidly and is expected to produce fruitful results not only for the fundamental research of chaos but also for applications as dynamic engineering.

Chapters 1 to 4 are devoted to the basics and the introduction of laser chaos and chaotic dynamics in semiconductor lasers, so that readers who want to know what laser chaos is and how it behaves in semiconductor lasers can follow them. Chapters 5 to 12 discuss the topics of chaos in semiconductor lasers and readers may skip to each topic according to their interest. Expected readers of this book are as follows; first, I assume those researchers who have already been involved in this field to gain an overview of the state of the art of their research. The next group is the graduate students and researchers who intend to participate in this field. For them, I have derived and explained most equations in the text from first principles as far as possible. Those readers who are familiar with electromagnetic theory and have some fundamental knowledge of optics and lasers will be able to follow the book. Finally, this book is devoted to all other researchers and engineers who are interested in dynamics in nonlinear systems and laser instabilities and applications. Since the laser is a very excellent model of a nonlinear system that shows chaotic dynamics, I believe that this book will provide useful information for readers not only in the field of optics but also in other related areas. Moreover, I hope that the ideas and techniques discussed here will give rise to a new paradigm of nonlinear systems such as chaos engineering or dynamic engineering.

For the publication of this book, I am indebted to many people. Here, I will not be able to express thanks to all those people, but, at first, I would like to thank colleagues and some previous students in my laboratory, Drs. Yun Liu, Atsushi Murakami, Keizo Nakayama, Yoshiro Takiguchi, Shuying Ye, Hong Yu, for their many discussions and support. I also extend my thanks to many other researchers at various institutions and universities who gave me fruitful discussions and advice. Those are Prof. Wolfgang Eläßer, Dr. Peter Davis, Dr. Ingo Fischer, Prof. Jia-Ming Liu, Dr. Cristina Masoller, Dr. Claudio Mirasso, Prof. Rajarshi Roy, Prof. Kevin Alan Shore, and Dr. Atsuhi Uchida. I also owe thanks to many other people with whom I had useful discussions. Finally, I express sincere thanks to Prof. Toshimitsu Asakura who gave me the opportunity to write this book and also encouraged me in various stages of the research.

Hamamatsu, April 2005 *Junji Ohtsubo*

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