

Preface to the Fourth Edition

In the fourth edition, I include further progress of the recent study of fundamental dynamics and applications in chaotic semiconductor lasers. Semiconductor lasers with extra device structures are essentially unstable lasers that exhibit chaos even without external perturbations as discussed in the previous editions. The new results for the stability and instability in such devices, e.g., vertical-cavity surface-emitting lasers, broad-area semiconductor lasers, quantum-dot semiconductor lasers, and quantum-cascade lasers, are treated. New developments are also achieved in the control and applications of instability and chaos in semiconductor lasers. For example, the method of self-mixing interferometry in quantum-cascade lasers treated in the current edition is indispensable in practical applications, since fast external photodetector is not available in those THz optical wavelength regions. One of the new topics in this edition is the consistency and synchronization property of many coupled semiconductor lasers in connection with the analogy of the dynamics in synaptic neurons. In particular, zero-lag synchronization is very important in nonlinear networks, since zero-lag synchronization between distant neurons plays a crucial role for the information processing in the human brain. The consistency and synchronization properties in chaotic networks consisting of many coupled semiconductor lasers are discussed as a new chapter in this edition. Also, as an application of the consistency and synchronization in chaotic semiconductor lasers, neuro-inspired information processing, which is called reservoir computing, is presented.

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Preface to the Third Edition

After the publication of the second edition of this book in 2008, further significant advance has been made in chaos research in semiconductor lasers. One of the topics that is worth treating in this book is the method of ultrafast physical random number generations using chaotic semiconductor lasers, which is suitable for random key distributions in modern cryptographic applications. Based on the method, we can generate true physical random numbers that are hundred times or even thousand times faster than those in existing methods. In conjunction with the method, photonic integrated circuits for chaotic light generators have recently been developed. Thus, chaos, especially chaos in semiconductor lasers, is now not only an interesting issue from the viewpoint of fundamental research, but also an important tool for engineering applications. These topics are treated as a new chapter in this book. In parallel with these topics, great advance has been made for the study of the dynamics in various types of semiconductor lasers with new device structures. I have already treated the dynamics in vertical-cavity surface-emitting lasers and broad-area semiconductor lasers in the first and second editions. Further advance has been brought in the dynamics of these lasers and they have been added in the third edition. Other examples of newly developed lasers are quantum-dot and quantum-cascade semiconductor lasers and they show interesting dynamics. I also discuss these new topics in Chap. 8. At the same time, several subjects are appropriately revised and a number of misprints in the second edition have been corrected. For the second edition, I have received several advices and comments for the improvements of the book, although I would not mention each of them. I have taken some of them into account for the new edition. I would like to thank those persons.

Junji Ohtsubo

Preface to 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
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Preface to the First Edition

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, 2, 3 and 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, 6, 7, 8, 9, 10, 11 and 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. They are Prof. Wolfgang Elsässer, 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. Atsuhiko 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.

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