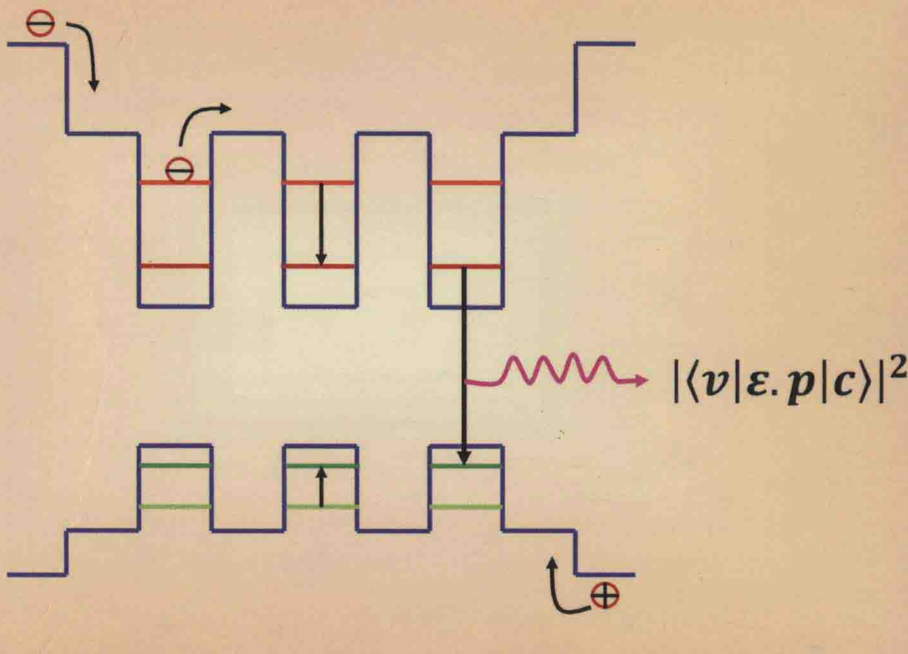
Semiconductor Laser Theory



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Semiconductor Laser Theory

To

Dilip, Pradip, Chhabi, Baby, Karabi, Kaberi,
Chittaranjan, Arundhati, Goutam, Uttam and Rupam (by Prasanta)

To

Late Jiban Ratan Mukhopadhyay (father)
and
Smt. Nilima Mukhopadhyay (mother)
(by Bratati)

To

Chitrani (by Rikmantra)

Preface

The concept of stimulated emission was introduced by Einstein in 1917. The real use of this process came in 1954 with the announcement of the ammonia laser. The race to obtain light amplification by the stimulated emission of radiation (LASER) action then started. It took another 7–8 years to realize laser action in semiconductors, when four groups announced the p-n junction laser almost simultaneously; their discoveries were published in September and October 1962 issues of different journals.

Since its first announcement, research and development on the semiconductor laser has never stopped. After some periods of uncertainty, the first room temperature double heterostructure laser working in continuous wave mode was developed. After that, there was no looking back. The double heterostructure laser has now been replaced by the quantum well laser. Intensive research is being conducted to utilize the benefits of quantum wire and quantum dot lasers. Today, quantum dot lasers are considered to be a serious competitor for quantum wire lasers.

The manufacture of semiconductor lasers is a very big industry. The all-pervading nature of laser diodes in day-to-day life is manifested in the use of bar-code readers, printers, optical mouses in computers, laser torches and pointers, optical disc readers, and many other gadgets. Semiconductor lasers also find use in medicine, military, environment, surveillance, and lighting; their most important application is long- and short-haul fiber-optic communications and networks.

All undergraduate and graduate courses in electrical engineering, physics, and materials science include in brief the basic properties, structures, and applications of semiconductor lasers. There are a number of advanced texts solely on semiconductor lasers, which form part of graduate- and PhD-level course work. The available texts are divided into two categories. The first type deals with sophisticated theories of lasers: quantum mechanical treatment of electron–photon interactions, density matrix formalism, and the like. The other type employs the semiclassical theory of radiation and its interaction with electrons, rate equation models, and the like. The second approach is simpler and caters better to the needs of students in electrical engineering. However, the texts in this category, except one or two, deal more on principles; the structure, applications, and the like are given somewhat less emphasis.

In a rapidly changing scenario, there is a need to constantly upgrade the textbooks covering recent developments in the field. Some of the earlier texts, though useful for a clear understanding, do not include recent progress, such as diode lasers using quantum wells, dots, quantum cascade lasers, nitride lasers, and so on.

The present text has been developed by considering the recent advances. It belongs to the second category, that is, it uses a semiclassical approach. The target audience comprises graduate students and recently graduated post-doctorate workers.

The book is divided into two parts. After giving a brief overall introduction including the historical development of semiconductor lasers in Chapter 1, the basic concepts are developed in Chapters 2 through 6. Chapter 2 discusses the basic semiconductor physics that is needed to understand the operation of lasers. It also includes p-n junction theory. Chapter 3 considers alloys, heterostructures, and quantum nanostructures. Chapter 4 develops **k.p** theory. Chapter 5 covers waveguides, resonators, and filters. Chapter 6 discusses optical processes.

The actual lasers are covered from Chapter 7 to Chapter 15. The double heterostructure laser is treated in Chapter 7. Though it is hardly used, the theory forms the basis for a discussion of all modern lasers. Chapter 8 discusses quantum wire lasers. Without discussing quantum wire lasers, Chapter 9 deals with quantum dot lasers. Quantum cascade lasers are introduced in Chapter 10, followed by vertical-cavity surface-emitting lasers in Chapter 11. Chapter 12 treats single-mode and tunable lasers. The next three chapters attempt to introduce the readers to the latest developments. Chapters 13 through 15 cover nitride lasers, Group IV lasers, and transistor lasers, respectively. However, these three chapters are by no means self-sufficient. There is rapid progress in all these areas. The intention is to acquaint the readers with the developments in these important fields.

It is difficult to cover all the important aspects of lasers in a volume like this. A noteworthy omission is the noise properties of lasers. To do justice to this topic, a detailed introduction to the theory, Langevin's equation, and so on would be needed. It was felt that such an inclusion would excessively increase the volume of the text.

The text grew out of a lecture on materials given by the authors to undergraduate and graduate students and the knowledge gathered through the research topics set for PhD students. Existing textbooks with similar titles to this book, invited reviews and tutorials, and special issues on semiconductor lasers published by professional societies served as invaluable sources for the present text. These sources are duly acknowledged in the reading lists and references. Numerous examples have been included in each chapter to illustrate the theory. A Problems section is also included in most of the chapters.

Despite the efforts of the authors, there may be errors and omissions, which may be more serious in the treatment of more recent topics. The authors offer their sincerest regrets.

The authors are indebted to a numbers of people and agencies for both financial and moral support, encouragement, and active help. They are duly acknowledged in the proper place.

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Rikmantra Basu obtained his academic degrees from the University of Calcutta. He started working on this book at the end of his doctoral study in 2012. For the last year, he has been attached as a faculty member to the Electrical and Electronics Engineering Department of the Birla Institute of Technology and Science Pilani. He is thankful to his thesis supervisor (Bratati) and Vedatrayee at the Institute of Radio Physics and Electronics, University of Calcutta, for their constant support. Rikmantra acknowledges the cooperation received from all his colleagues at the Birla Institute of Technology and Science Pilani, especially the head of department, Dr. Anu Gupta, and the authorities of the Birla Institute of Technology and Science Pilani, for providing all kinds of support, and also for giving him the OPERA research award. Partial support from the Council of Scientific & Industrial Research, India, is also acknowledged. He is thankful to Professor Ajay Sharma, Director of NIT Delhi, where he is currently employed, for his encouragement.

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