Semiconductor Optics and Transport Phenomena

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Wilfried Schäfer   Martin Wegener

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With 151 Figures, 10 Tables,
114 Problems and Hints for Solutions

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Preface

Whenever a physicist visits the physics faculty in Dortmund, he/she is bound to hear the success story of the so-called integrated course, a four-semester introduction to physics. These lectures are given by two professors simultaneously, one experimentalist and one theorist. After having asked the common question, "How many professors have killed each other?", the visitor usually realizes that this is an excellent way of presenting a coherent introduction to both experimental and theoretical physics. We decided to try this concept in an advanced course on semiconductor physics. At that point the typical student has already had an introductory course in solid-state physics and solid-state theory. The aim of the lectures was to repeat some of the most important, well-known classics of semiconductor optics and transport and eventually guide the students to topics of current interest in research. When preparing the lectures, we did not find a textbook addressing all these aspects: experiment *and* theory in semiconductor optics *and* transport – which made us write this book. This book presents the phenomenology and a simple, intuitive understanding of many effects and, in addition, attempts to explain the underlying physics on a consistent theoretical footing. Calculations are presented such that a student should be able to follow them with a pencil and a piece of paper. It is our hope that this synthesis of experiment and theory will help to prepare young scientists to contribute something new at the current frontiers of semiconductor physics. After all, the optical and transport properties of semiconductors are among the most important aspects of this particular class of solids for the purposes of their applications – and there are many such applications in everyday life.

This book is organized as follows. A brief introduction to the material systems, we are concerned with in this book is given in Chap. 1. A reader familiar with the general aspects of semiconductor physics and with a basic knowledge of solid-state theory may easily skip Chaps. 2 and 3 without problems. These chapters are merely intended as a reminder of our basic knowledge of electrodynamics, quantum mechanics, statistical physics, and solid-state physics. In addition, they define our nomenclature. We then start discussing the optical properties of semiconductors in Chap. 4, where the important Coulomb correlations are neglected. Nevertheless, this allows us to understand basic experimental techniques, semiconductor photodetectors, and lasers. In Chaps. 5 and 6, Coulomb correlations are treated to first order, such that two-particle correlations are taken into account. This treatment constitutes the semiconductor Bloch equations and modifies the physics of Chap. 4. The dependence on static external fields is discussed in Chaps. 7 and 8, which enables us to understand most types of electro-optic modulators.

A method to include higher order correlations, in particular the formation of four-particle bound states, is introduced in Chap. 9. In order to take care also of other important many-particle interaction processes, such as scattering or screening, we head towards the quantum kinetic equations. The necessary mathematical background is derived in Chap. 10 and extended in Chap. 11 to include scattering from phonons. On a first reading, Chap. 10 (which contains some fairly spicy mathematics) might be skipped. A survey of basic experimental facts and of applications of the theory is presented in Chap. 12. The physics of semiconductor lasers is a nice example where semiconductor optics and transport merge. The physics of these technologically important devices is discussed in Chap. 13.

Classical transport (Chap. 14) is nothing but the strong-scattering limit of the Boltzmann equation. This limit is contrasted with the weak-scattering limit of transport, which is realized in mesoscopic systems. An introduction to this issue is given in Chaps. 15 and 16. Current topics, such as for example, single-electron charging effects, the fractional quantum Hall effect, and magnetotransport through dot and antidot lattices, are dealt with.

We use SI units consistently throughout this book. Nevertheless, a few reminders of fundamental constants in SI units are included in Chaps. 2 and 3 for those using other systems.

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