Preface

The electronic properties of semiconductors form the basis of the latest and current technological revolution, the development of ever smaller and more powerful computing devices, which affect not only the potential of modern science but practically all aspects of our daily life. This dramatic development is based on the ability to engineer the electronic properties of semiconductors and to miniaturize devices down to the limits set by quantum mechanics, thereby allowing a large scale integration of many devices on a single semiconductor chip.

Parallel to the development of electronic semiconductor devices, and no less spectacular, has been the technological use of the optical properties of semiconductors. The fluorescent screens of television tubes are based on the optical properties of semiconductor powders. The red light of GaAs light emitting diodes is known to all of us from the displays of domestic appliances, and semiconductor lasers are used to read optical discs and to write in laser printers. Furthermore, fiber-optic communications, whose light sources, amplifiers and detectors are again semiconductor electro-optical devices, are expanding the capacity of the communication networks dramatically.

Semiconductors are very sensitive to the addition of carriers, which can be introduced into the system by doping the crystal with atoms from another group in the periodic system, electronic injection, or optical excitation. The electronic properties of a semiconductor are primarily determined by transitions within one energy band, i.e., by *intraband transitions*, which describe the transport of carriers in real space. Optical properties, on the other hand, are connected with transitions between the valence and conduction bands, i.e., with *interband transitions*. However, a strict separation is impossible. Electronic devices such as a *p*-*n* diode can only be under-

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stood if one considers also interband transitions, and many optical devices cannot be understood if one does not take into account the effects of intraband scattering, carrier transport and diffusion. Hence, the optical and electronic semiconductor properties are intimately related and should be discussed jointly.

Modern crystal growth techniques make it possible to grow layers of semiconductor material which are narrow enough to confine the electron motion in one dimension. In such *quantum-well* structures, the electron wave functions are quantized like the standing waves of a particle in a square well potential. Since the electron motion perpendicular to the quantum-well layer is suppressed, the semiconductor is *quasi-two-dimensional*. In this sense, it is possible to talk about low-dimensional systems such as quantum wells, quantum wires, and quantum dots which are effectively two, one and zero dimensional.

These few examples suffice to illustrate the need for a modern textbook on the electronic and optical properties of semiconductors and semiconductor devices. There is a growing demand for solid-state physicists, electrical and optical engineers who understand enough of the basic microscopic theory of semiconductors to be able to use effectively the possibilities to engineer, design and optimize optical and electronic devices with certain desired characteristics.

Many results in the different chapters are developed in parallel first for bulk material, and then for quasi-two-dimensional quantum wells and for quasi-one-dimensional quantum wires, respectively. Semiconductor quantum dots are treated in a separate chapter. The semiconductor Bloch equations have a central position. They are formulated not only for free particles in various dimensions, but also in the Landau basis for low-dimensional electrons in strong magnetic fields or in the basis of quantum dot eigenfunctions. Correlation and scattering effects are introduced at different levels of approximation. Particularly, the relaxation and the dephasing in the Bloch equations are treated not only within the semi-classical Boltzmann kinetics, but also within quantum kinetics, which is needed for ultrafast semiconductor spectroscopy. The applications of these equations to time-dependent and coherent phenomena in semiconductors are presented in the chapters dealing with the excitonic optical Stark effect and various nonlinear wave-mixing configurations. The discussion of the nonequilibrium Green's function theory contains both introductory material as well as applications to Coulomb carrier scattering and time-dependent screening. The final chapter in this book deals with quantum optical effects in semiconductors. A cluster-expansion scheme is used to treat the Coulombic and quantum optical correlations consistently. The semiconductor luminescence equations are derived and solved for several examples.

This book is written for graduate-level students or researchers with general background in quantum mechanics as an introduction to the quantum theory of semiconductors. The necessary many-particle techniques, such as field quantization and Green's functions are developed explicitly. Wherever possible, we emphasize the motivation of a certain derivation and the physical meaning of the results, avoiding the discussion of formal mathematical aspects of the theory. The book, or parts of it, can serve as textbook for use in solid state physics courses, or for more specialized courses on electronic and optical properties of semiconductors and semiconductor devices. Especially the later chapters establish a direct link to current research in semiconductor physics.

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