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Editors

Semiconductor Research

Experimental Techniques

With 192 Figures

Springer

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Preface

This book intends to provide its readers with the fundamentals and applications of experimental techniques commonly used in semiconductor research. Each chapter describes the physics concepts underlying a specific technique and its latest developments in the investigation of novel semiconductor materials and heterostructures, including InN, dilute nitride III-N-V alloys, InAs/GaSb heterostructures and self-assembled quantum dots.

Chapter 1 focuses on the investigation of semiconductor surfaces by reflection high-energy electron diffraction (RHEED) and low-energy electron diffraction (LEED). These diffraction-based techniques give access to the structural properties of crystalline layers and junctions, which represent the core of modern devices. Several examples of LEED and RHEED patterns are described and provide the reader with the basic tools for interpreting RHEED and LEED data. *Chapter 2* describes transmission electron microscopy (TEM) and high resolution electron microscopy techniques. These are based on the analysis of a transmitted electron beam through an electron-transparent sample. Operation principles of TEM and examples of spatial mapping of composition and strain at the nanoscale and atomic resolution are the focus of this chapter. *Chapter 3* reviews common techniques used to investigate the energy and momentum relaxation rates of hot carriers in semiconductors where the carrier heating is achieved by either the application of an electrical field or by an optical excitation. This condition is frequently met in optical and electronic device. Also, this chapter reviews steady-state spectral and transient measurement techniques. *Chapter 4* describes the principles, experimental setups, and theoretical approaches used in optical modulation spectroscopy studies. Particular attention is dedicated to contactless electroreflectance (CER) and photoreflectance (PR). These are non-destructive techniques, which are widely applied to study the band structure properties of semiconductor materials and devices. The complementary technique of photoluminescence (PL) and its relation to absorption and photoluminescence excitation (PLE) spectroscopy are described in *Chap. 5*. Typical experimental setups for optical studies, with and without an applied magnetic field, are discussed and examples of their application to study electronic properties, disorder effects and carrier thermalization in III–V semiconductor alloys and heterostructures are provided. High pressure is one of the most valuable characterization tools available in semiconductor research. *Chapter 6* describes how it can be used to investigate several important physical phenomena in semiconductor materials and devices such as the Gunn effect and avalanche breakdown. It also considers laser devices and the interesting changes that take place when a semiconductor material is subject to high pressures. *Chapter 7* describes the principles and instrumentation of techniques used in spatially resolved spectroscopy, including micro-photoluminescence (μ-PL), scanning near-field optical microscopy (SNOM), and spatially resolved cathodoluminescence (CL). Since the spatial resolution is often limited not only by instrumental capabilities but also by the spreading of the photoexcited carriers outside the photoexcited volume, the mechanisms of diffusion, photon recycling, phonon wind, and Fermi pressure are reviewed. The availability of ultrashort laser pulses has offered a new investigation tool to the optical spectroscopy field, giving access not only to the spectral features of luminous phenomena, but also directly to their dynamics. *Chapter 8* presents an overview of the most popular ultra-fast time resolved optical spectroscopy techniques used in semiconductor physics in the picosecond and sub-picosecond time range. For each of these techniques, which include time resolved PL (TRPL), pump and probe time resolved spectroscopy, and time-correlated single photon counting (TCSPC), the operating principles and the fundamental concepts are introduced together with typical experimental setups and applications. The development of a new generation of Raman spectroscopy systems in recent years has contributed to the widespread of Raman spectroscopy in materials science. The aim of *Chap. 9* is to offer an up-to-date overview of the fundamentals and use of Raman spectroscopy. The chapter is restricted to standard spontaneous Raman spectroscopy. It discusses the basic concepts of inelastic light scattering and its application to study phonon and impurity modes, crystal quality, and strain effects in semiconductors. High magnetic fields have played a key role in elucidating the electronic properties of semiconductors. The cyclotron resonance (CR) and the Hall effects are perhaps the most celebrated examples of the use of magnetic fields in semiconductor physics. Cyclotron resonance is the focus of *Chap. 10*, which describes the basic theory of CR and discusses experimental setups and applications of CR to unravel the determination of the electron mass in various materials. *Chapter 11* examines instead the physics of electron motion in the presence of a magnetic field, with particular reference to recent applications in which high magnetic fields have been used to elucidate the electronic and quantum properties of novel heterostructures and nanostructures. Also, it describes how magneto-tunnelling spectroscopy (MTS) can be used to measure the band structure of semiconductors and to investigate and manipulate the energy eigenvalues and eigenfunctions of electrons confined in low-dimensional systems. Finally, photoconductivity (PC), photo-induced transient spectroscopy (PITS), and deep level transient spectroscopy (DLTS) are presented in *Chap. 12*. These techniques provide powerful tools to investigate the intrinsic and extrinsic energy levels of a semiconductor, time constants associated with carrier recombination, activation energies, carrier capture cross-section and densities of energy traps.

Several colleagues have contributed to this book by kindly making available their expertise and knowledge. We are very grateful for their help in completing this book, which we hope will assist students and researchers in their work, thus contributing to novel and exciting research in semiconductor physics.

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