NanoScience and Technology

M. Grundmann (Ed.)

Nano-Optoelectronics

Concepts, Physics and Devices

Springer

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Springer

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Preface

The conquest of the nano-cosmos is occurring simultaneously in almost every field with a strong interdisciplinary and an increasing transdisciplinary character. The mechanical, electronic, optical, magnetic, and (bio)chemical properties of materials are beginning to be mastered on a nano-scale. This enables the fabrication of devices that rely on effects on the nano-scale.

For the creation of nanostructures self-assembly and self-ordering have become very important pathways. The interactions leading to the formation of nanostructures ordered with regard to size and shape, but also with regard to absolute and relative position, are typically weaker than the interactions leading to the formation of the underlying materials themselves. In the present volume self-ordered nanostructures and optoelectronic devices on the basis of crystalline, semiconducting solids are discussed, where mostly mesoscopic strain effects are responsible for nanostructure formation. Thus the ordering is not perfect and presently inhomogeneous broadening in ensembles of nanostructures is inevitable.

Of great importance is the development and routine use of a new generation of nano-tools for characterizing and manipulating nanostructures. Using scanning probe techniques, atomic precision can be achieved for surfaces and cross-sectional surfaces. Such information, as feedback for nano-fabrication, is crucial. However, current technology has not realized its ultimate goal – the determination of the three-dimensional position and character of each atom making up a nanostructure.

Of equal importance is the understanding of the quantum physics governing the physical properties of nanostructures. Although quantum mechanics textbook examples give good guidance to the general behavior, 'real life' nanostructures typically exhibit complex geometries, complicated underlying material properties, and interaction with the environment. In ensembles homogeneous and inhomogeneous broadening effects impact the physical properties. Thus detailed theoretical modeling is required.

Eventually, new functionality and novel and/or improved devices will be demonstrated using nanostructures, requiring the development of controllable and reproducible fabrication technologies suitable for mass production. Self-ordered nanostructures prepared with epitaxial methods turn out to be highly compatible with 'conventional' optoelectronic device design and fabrication involving wave-guides and optical cavities based on multilayer structures. Quantum dots can be incorporated even into the most advanced designs such as vertical cavity surface emitting lasers.

The field of optoelectronics is one of the main driving forces for the exploration of nanostructures because of the promise of superior devices, in particular lasers, based on quantum confinement effects. After the successful fabrication of self-ordered quantum dots in a variety of semiconductor systems, nanostructures of high optical quality are now available to realize nano-optoelectronic devices. Much progress has been made in recent years towards realizing several of the initially predicted nanotechnological advantages, among them ultralow threshold, low chirp, reduced degradation, and enhanced radiation hardness.

In Part I of this book the underlying *concepts* of nano-optoelectronics, namely semiconductor heterostructures (Chap. 1) and stress-engineering of semiconductors (Chap. 2), are covered.

In Part II the new *physics* in nanostructures is discussed. The first contributions focus on the structural properties investigated by transmission electron microscopy, planar and cross-sectional scanning tunneling microscopy and X-ray diffraction (Chaps. 3–6). In Chap. 7 the theory of electronic and optical properties of quantum dots is discussed. In Chap. 8 the electronic properties of quantum dots are investigated using magnetotunneling spectroscopy. In Chaps. 9–11 optical properties are discussed with focus on the dielectric function, interband transitions and condensation phenomena, respectively.

The application of these novel properties in nano-optoelectronic *devices* is the focal point of Part III. In Chap. 12 the theory of quantum dot lasers is presented. The following contributions focus on experimental results on active devices, i.e., lasers (Chaps. 13–17) with focus on long-wavelength, red, blue/UV, high power, and mid-infrared (inter-sublevel) emission as well as amplifiers (Chap. 18).

This volume is dedicated to Professor Dr. phil. nat. Dieter Bimberg on the occasion of his 60th birthday. Prof. Bimberg has been very actively involved in the field of size-quantized semiconductor structures and nano-optoelectronics for several decades. His enthusiasm and expertise paired with perseverance, the challenging guidance of his students and the fruitful, stimulating cooperation with many colleagues, among them the authors of this book, has allowed many scientific breakthroughs. On behalf of the authors of this book I express gratitude for time and thoughts shared.

Leipzig, January 2002 *Marius Grundmann*

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Contents

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