Self-Assembled Quantum Dots

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Self-Assembled Quantum Dots

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Preface

Self-Assembled Quantum Dots, commonly referred to as self-organized quantum dots, form spontaneously under certain growth conditions during molecular-beam epitaxy or metal organic chemical vapor deposition, as a consequence of lattice-mismatch between the deposited material (generally semiconductors) and underlying substrate. The resulting semiconductor nanostructures consist of three-dimensional islands standing on a two-dimensional wetting layer. Such islands can be subsequently buried to realize quantum confinement. In the past 15 years, self-assembled quantum dots have provided vast opportunities for physical research and technological applications, including quantum cryptography, quantum computing, optics and optoelectronics. The present book is devoted to some of these fascinating aspects, including growth, properties and applications of quantum dots, both in theory and experiment.

The main body of the chapter comprises of contributions that focuses on InGaAs quantum dots, since this material has been intensively investigated as a model system. Specifically, chapters 1–3 offer a comprehensive perspective from a growth point of view. Chapter 1 reviews the recent advances on understanding the basic microscopic mechanisms driving the nucleation and evolution of quantum dots under the role of composition, coverage, and intermixing. On the other hand, the authors of Chapter 2 and Chapter 3 summarize their recent efforts to address two challenging issues of the quantum dot growth; these include random distribution on surface and non-uniformity in size and shape. Chapter 2 demonstrates the capability to control the position of InGaAs quantum dots arrays at the nanometer scale on (110) crystal surface. Chapter 3 reports the achievement of a particular kind of quantum dot ensemble, equally-shaped with a well-defined multimodal size distribution.

In Chapter 4–7, great emphasis is placed on systematic studies of optical properties of InGaAs quantum dots. Chapter 4 deals with the carrier transfer among quantum dots. Chapter 5 reviews the dynamics of carrier transfer into InGaAs quantum dots. Chapter 6 presents spin phenomena in quantum dots, showing a great potential for the field of spintronics. Chapter 7 is a theoretical contribution in nature and addresses the optical properties of quantum dots coupled with a continuum of extended states, which will challenge experimental physicists to study quantum dots more as a complete system including the wetting layer, barrier and contact.

The progress made towards quantum information processing is discussed in chapters 8 and 9. Chapter 8 offers an extensive investigation on coupling in quantum dot molecules for their potential application to scale up in quantum computation. Chapter 9 describes the site-control and electronic access of quantum dots as well as the achievement of single photon emitters in telecommunication bands.

Chapter 10 reports on experimental and theoretical investigations of mechanical stress relaxation in heterostructures with buried quantum dots. Chapter 11 presents capacitance-voltage spectroscopy as a powerful method to gain information on the energy level structure and the Coulomb interaction in InGaAs quantum dots.

Both Chapter 12 and 13 give overviews of epitaxial growth, device design and fabrication for particular applications. Chapter 12 starts with a description of metal organic chemical vapor deposition, followed by a detailed discussion of various growth parameters and their impacts on formation of quantum dots. Finally, the authors characterize the associated quantum dot lasers and present their efforts towards quantum dot based photonic integrated circuits. Chapter 13 reports on new site-control techniques for photonic crystal based all-optical devices, including selective area growth by a metal-mask method, and lateral position control using lithography patterned substrates and Nano-Jet probes.

While the above chapters focus on InGaAs quantum dots, two different material systems are the subjects of the last two chapters. Chapter 14 is devoted to detailed analysis of the shape-dependent deformation field in Ge islands on Si (001). Investigations on such a relative simple heteroepitaxial system with respect to InGaAs quantum dots provide more fundamental perspective that determines the behavior and growth mode of compound nanostructures. On the other hand, the authors of Chapter 15 deal with nitride semiconductor quantum dots, which is a more complicated material system. This chapter covers the growth and characterization of III-Nitride quantum dots and their application to light emitting diodes emitting in the visible part of the electromagnetic spectrum.

Last but not least, the editor is honored and greatly indebted to Gregory J. Salamo for his support in many ways, without which this book would be impossible. With his enthusiasm, diligence, and intelligence, Salamo is always able to create a congenial atmosphere for friends and colleagues to explore the seemingly impossible. May he be an example followed by many!

Fayetteville, September 2007 Zhiming M. Wang

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