Preface

The experience of the past shows that throughout constant technology improvement electronics (*optoelectronics*) has become more reliable, faster, more powerful, and less expensive by reducing the dimensions of integrated circuits. These advantages will lead to the development of modern microelectronics. The long-term goal of this development will lead to *nanoelectronics*. Advancing to the nanoscale is not just a step toward miniaturization, but requires the introduction and consideration of many additional phenomena. At the *nanoscale*, most phenomena and processes are dominated by quantum physics and they exhibit unique behavior. *Nanotechnology* includes the integration of man-made nanostructures into larger material components and systems (see, e.g. [1–4]). Importantly, within these larger scale systems, the active elements of the system will remain at nanoscale.

Low-dimensional structures have become one of the most active research not only in nanoscience and nanotechnology but also isotopetronics. Quantum wells, quantum wires, and quantum dots structures produced in the main by epitaxial growth techniques (mainly molecular beam epitaxy (MBE) and metal-organic chemical vapor deposition (MOCVD) and their various variations such as chemical beam epitaxy (CBE), atomic layer epitaxy (ALE), etc. (see, e.g. [5–10]). MBE and MOCVD are of considerable technological interest since they are used as active components in modern devices. These devices are high-electron-mobility transistors, diodes and lasers, as well as quantum dots from quantum computations and communications perspectives.

The seminal works of Esaki and Tsu [11] and others on the semiconductor superlattice stimulated a vast international research effort to understand the fabrication and electronic properties of superlattice, quantum wells, quantum wires, and quantum dots (see, for example, [1–4]). The dimensional scale of such samples between 10 and 100 nm which are the subject of *nanoscience*—is a broad and interdisciplinary field of emerging research and development. Nanoscience and nanotechnology are concerned with materials, structures, and systems whose components exhibit novel and significantly modified physical, chemical properties due to their nanoscale sizes. The new direction of nanoscience is isotope-engineered materials, which is studied the more low-dimensional in size, as a rule the sizes of the sample of isotope-engineered materials compare with the atomic size. *Nuclear* technology—neutron irradiation [12]—is a very useful method for preparing low-dimensional structure: quantum wells, quantum wires, and quantum dots [13]. A principal goal of isotope-engineered materials as new directions of the nanotechnology is to control and exploit their new properties in structures and devices at atomic, three molecular, and supramolecular levels. The minituarization required by modern electronics is one of the driving forces for isotope-engineered materials (*isotopetronics*)—new direction of nanotechnology (see, also [14]).

Modern *nanoscience* and *nanotechnology* is a fertile ground for teaching, as it brings together the quantum theory of materials, novel physics in the electronic and optical properties of solids, the engineering of small structures, and the design of high performance electronic, photonic, and optoelectronic systems. The treatments attempt to be introductory, comprehensive, and phenomenological in the main. The new physics described in this book comes from one important consideration—length scale (see, also [1, 2, 15, 16]) especially in *mesoscopic* physics. As we all know, mesoscopic physics deals with structures which have a size between the macroscopic and the microscopic or atomic one. These structures are also called mesoscopic systems, or nanostructures [3] in a more colloquial way since their size usually ranges from a few nanometers to about 100 nm. The electrons in such mesoscopic systems show their wavelike properties [15, 16] and therefore their behavior is markedly dependent on the geometry of the samples. In this case, the states of the electrons are wave-like and somewhat similar to electromagnetic waves (see, e.g. [16]).

As mentioned above for the description of the behavior of electrons in solids, it is very convenient to define a series of characteristic lengths. If the dimension of the solids in which the electron embedded is of the order of, or smaller than these characteristic lengths (λ_B de Broglie wavelength, or a_{ex}—exciton radius, etc.) the material might show new properties, which in general are more interesting than the corresponding ones in macroscopic materials. On the contrary, a mesoscopic system approaches its macroscopic limit if its size is several times its characteristic length.

As mentioned above, when the dimensions of the solid get reduced to a size comparable with, or smaller λ_B, then the particles behave wavelike and quantum mechanics should be used. Let us suppose that we have an electron confined within a box of dimensions L_x, L_y, L_z. If the characteristic length is l, we can have the following situations:

1. $l \langle L_x, L_y, L_z$. In this case the electron behaves as in regular 3D bulk *semiconductor* (*insulator*).
2. $l \rangle L_x$ and $L_x \langle\langle L_y, L_z$. In this situation we have a 2D semiconductor perpendicular to the x-axis. This mesoscopic system is also called a quantum well (for details see Chap. 3).

3. $l \rangle L_x, L_y$ and $L_x, L_y \langle\langle L_z$. This case corresponds to a 1D semiconductor or quantum wire, located along the z-axis.
4. $l \rangle\rangle L_x, L_y, L_z$. In this case it is said that we have a 0D or a quantum dot [1, 2].

In general, we say in mesoscopic physics that a solid, very often a crystal, is of reduced dimensionality if at least one of its dimensions L_i is smaller than the characteristic length. For instance, if L_x and L_y are smaller than l we have a crystal of dimensionality equal to one. We could also have the case that l is comparable, or a little larger, than one of the dimensions of the solid but much smaller than the other two. Then we have a quasi 2D system, which in practice is a very thin film, but not thin enough to show quantum size effect (for details see Chap. 3).

This review is organized into four chapters. In Chap. 1, I review the present status of elementary excitations in solids. Preparation methods of low-dimensional structures are described in Chap. 2. Chapter 3 deals with physics of low-dimensional structure. In this chapter of the most frequently structures—quantum dots are revised. The applications of low-dimensional structures is done in Chap. 4.

Tallinn Vladimir G. Plekhanov

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