2 Fundamentals of Semiconductors and Nanostructures

The majority of experiments of inelastic light scattering on semiconductor nanostructures has been performed on III–V semiconductors, like GaAs, as the most prominent example. In this chapter, an introduction into the basic properties of these materials is given. The first section gives a summary of the crystal and electronic band structure of the bulk material. After a short survey into the properties of electrons in different dimensions in the second section, growth methods for so called vertical nanostructures, i.e., layered heterostructures consisting of two different materials, are described in the third section. In these vertical nanostructures, quasi two–dimensional (Q2D) electron systems can be realized. This section is finalized by the description of commonly used concepts for theoretical calculations of the ground state of such systems. The second last section introduces the most important methods for the preparation of lateral micro and nanostructures. In those structures, the dimensionality of charge carriers or of quasi particles is reduced further by lithography and etching processes, or by self–organized growth methods, resulting in quasi one–dimensional (Q1D) or quasi zero–dimensional (Q0D) quantum structures. The section is finalized by an overview over methods for the calculation of the electronic ground state of lateral nanostructures. Readers who are already familiar with semiconductors and the fabrication and physics of nanostructures may skip this tutorial chapter and directly continue with Chap. 3.

2.1 III-V Semiconductors: Crystal and Band Structure

2.1.1 Phenomenology

Most III–V compound semiconductors, like GaAs, grow in Zincblende structure. The symmetry of this cubic lattice structure is described by the space group T_d^2. The corresponding point group, T_d, of the lattice sites is the symmetry group of the regular tetrahedron. It consists of 24 symmetry operations [1]. The Zincblende lattice is formed by two intersecting face–centered cubic (fcc) lattices, which are shifted by one quarter of the cubic space diagonal against each others. In Fig. 2.1, the spatial arrangement of Ga and As atoms in the Zincblende lattice is shown and compared to the diamond lattice (e.g.,

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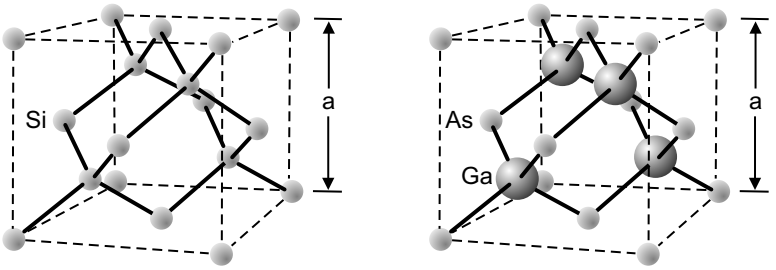

Fig. 2.1. Crystal structure of Silicon (*left*) and Galliumarsenide (*right*)

Si). The Zincblende lattice is no Bravais lattice, since its elementary cell contains two atoms, one at the origin and one at $(\frac{a}{4}, \frac{a}{4}, \frac{a}{4})$, where a is the lattice parameter. The reciprocal lattice of the fcc lattice, which is the underlaying lattice of the Zincblende structure, is a body–centered cubic (bcc) lattice. The Wigner–Seitz cell of the bcc lattice, which is the first Brillouin zone corresponding to the real space fcc lattice, is shown in Fig. 2.2. Some high–symmetry points, like the Γ– or the X–point, are indicated. Lattices of the point group T_d have no inversion symmetry, in contrast to semiconductors as, e.g., Si, which grow in the diamond structure (see Fig. 2.1).

The ternary alloy semiconductor $Al_xGa_{1-x}As$ is realized by replacing the fraction x of Ga atoms by Al atoms in the crystal lattice. Because of the statistical distribution of the atoms on the lattice sites of the Zincblende structure, the lattices of such ternary alloy semiconductors have no translational invariance. In principle, this has strong impact on the theoretical description of these structures, since electronic band structures, effective masses of electrons, etc., are no longer defined quantities. One usually circumvents these complications by introducing the so called virtual crystal approximation, which means that the real stochastic potential is replaced by an averaged potential which restores translational invariance. This guarantees that Bloch states, energy band gaps, and effective masses are defined. Usually with this

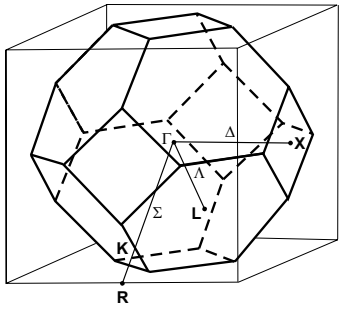

Fig. 2.2. First Brillouin zone of a face–centered cubic lattice