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Fabrication and investigation of the optical properties of type II heterostructures in nanowires and quantum dots composed of II-VI semiconductors

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Abstract

Semiconductor heterostructures can be classified as type I or type II due to relative alignment of conduction and valence band edges. Type II heterostructures are characterized by spatial separation of electrons and holes. This provides an additional degree of freedom that significantly influences the transport and optical properties of low-dimensional structures. It particularly enables the control of carrier lifetimes in nanostructures and facilitates efficient manipulation of optical emission energy.

The aim of this PhD thesis is to produce by using molecular beam epitaxy both: self-assembled quantum dots and quantum dots in nanowires, composed of II-VI semiconductors, which are characterized by type II band alignment between the dot semiconductor and the barrier semiconductor, and to investigate the effect of spontaneous spatial separation of electrons and holes on the optical properties of the fabricated structures.

At the beginning, I introduce selected topics that will be subsequently used within this PhD thesis, such as the crystal and band structure of II-VI semiconductors used for the growth of the structures studied in this thesis. I provide a brief description of selected properties of low-dimensional structures, type II heterostructures including, in particular, their optical properties and potential applications. I also discuss the influence of spatial separation of electrons and holes on the optical properties of quantum dots, including exciton lifetime, biexciton binding energy, reduction of fine structure splitting, optical Aharonov-Bohm effect, as well as the piezoelectric effect, which might be an additional effect beside the type II character of the heterojunction leading to the spatial separation of electrons and holes.

The next chapter contains a brief description of the setups and measurement techniques used in this research. In particular, the molecular beam epitaxy technique is described, along with a detailed explanation of technological processes leading to the formation of self-assembled quantum dots and nanowires, which are the main focus of this thesis. Additionally, measurement techniques used to investigate the optical properties and morphology of the fabricated structures are described, such as photoluminescence, micro-photoluminescence, time-resolved photoluminescence, scanning electron microscopy and cathodoluminescence.

The subsequent section presents the key research findings included in this doctoral thesis, divided into three subsections. The first subsection presents the results of experimental studies performed on type II Cd(Se,Te) quantum dots embedded in

ZnTe matrix. It describes the growth process of self-assembled Cd(Se,Te) dots, allowing the precise control of the Se content within the dots. The influence of increasing Se concentration on their optical properties such as the energy shift of about 500 meV, increase of the exciton lifetime by two orders of magnitude, and change from binding to antibinding character of biexciton complexes are demonstrated. The results are interpreted in terms of the increasing spontaneous electron-hole separation.

Next subsection is devoted to the results of investigations performed on (Zn,Mg)Te nanowires containing axial ZnTe quantum dots. It is found that the biexciton binding energy depends strongly on the size of the dot. The results are interpreted in terms of the impact of spontaneous electron-hole separation given by the quantum dot size, likely induced by the piezoelectric effect.

Finally, the results regarding the fabrication of type II quantum dots in nanowires are described. The proposed and fabricated structures consist of an axial ZnTe quantum dot within a (Zn,Mg)Te nanowire, surrounded by a radial ZnSe shell. First of all, optical studies are conducted to identify the optical emission from the type II quantum dots. Then, the impact of spatial electron-hole separation on the exciton lifetime and biexciton binding energy is investigated demonstrating the presence of type II heterojunction between the quantum dot and the radial ZnSe shell. At last, an attempt to observe the optical Aharonov-Bohm effect is performed by applying an external magnetic field along the nanowire axis. Only weak oscillations of emission energy originating probably from this effect are observed.

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