Abstract

The topic of the thesis is modelling the phonon-induced kinetics of charge and spin carriers in coupled semiconductor nanostructures. I have paid special attention to systems of different spatial dimensions. Such systems have a wide range of applications but are also demanding in terms of theoretical and numerical analysis.

The growing interest in semiconductor nanosystems has necessitated a full theoretical description of carrier dynamics, which is determined by the structural characteristics of the system and by the carrier-phonon interactions. The main goal of my thesis is to develop tools and describe the problem of carrier dynamics in coupled structures of different dimensionality. An example of such a system is a quantum-dot laser enriched with layers of quantum wells increasing the efficiency of carriers injection into the active region. The prepared research workshop was used to determine and characterize the relaxation processes of the charge in the well-dot system and spin-flip processes in quantum dots.

In my research, I have sought to combine advanced methods of calculating quantum states in coupled structures with the description of dynamics by full quantum kinetics in order to create a complete method of modelling phonon relaxation processes in semiconductor nanostructures. The difficulty lying in the different nature of structures of distinct dimensionalities results in numerical complexity of the problem. Therefore, during my research I have developed efficient methods for calculating wave functions within the $\boldsymbol{k}\cdot\boldsymbol{p}$ model and in the effective model for axially-symmetric systems. Then MPI parallel codes were developed. I also determined the time evolution given by the system of differential equations using the PETSc numerical library in my original program.

The main results of the thesis are: investigation of the influence of strain distribution on the conductive band carriers in the well-dot system; development of efficient methods of calculating electron-phonon coupling at dense discretization of the continuum; creation and detailed analysis of a complex model of quantum kinetics; finding the time of the carriers injection into the dot, which is compatible with experimental results; derivation of the spin effective mass equation; and investigation of the main channels of phonon-related spin decoherence in self-assembled quantum dots.