Carrier trapping and phonon-assisted relaxation in non-uniform quantum dashes

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We study theoretically phonon-assisted relaxation processes in highly elongated quantum dots, also referred to as quantum dashes (QDashes) [1]. Such a system is often characterized by the presence of shape irregularities, which can provide an additional confinement in the system [2]. This additional trapping within the QDash not only strongly influences its electronic and optical properties [3], but also phonon-induced carrier relaxation. We study the influence of the morphology of the widening of the structure on the phonon-mediated relaxation process and identify the possible relaxation bottlenecks in the system. The presence of the QDash widening strongly influences the phonon relaxation rates and can lead to both, their enhancement as well as decline, depending on the exact shape geometry of the widened section of a QDash. We show that a sufficiently large width fluctuation can even lead to the formation of a bottleneck for the relaxation to the exciton ground state. The appearance of this bottleneck is a direct result of the increase in the energy separation between the ground state and the excited states.

It has been shown that QDashes have several advantages over other nanostructures, especially in telecommunication applications, where InP structures are now commonly used in high performance lasers and optical amplifiers operating at 1.55 μm [1]. The morphology of some of the InAs QDash structures suggests that variations in their width may lead to the appearance of additional trapping within the volume of a QDash. The influence of the presence of such an additional trapping center on the optical properties of the system has already been studied [2, 3]. On the other hand the influence of such structure irregularities on phonon-mediated relaxation has not yet been investigated. The phonon relaxation of carrier confined in QDashes is important from the point of view of possible applications (eg. lasers, optical amplifiers). Understanding of the phonon-assisted relaxation and therefore carrier dynamics can be of particular interest for a broad range of optical devices.

We base our modeling of the electron-hole system on a single-band effective mass and envelope wave function description. For modeling of the carrier envelope wave functions we use a variational method and follow the adiabatic approximation [4]. Coulomb correlations are included within the configuration-interaction scheme. In our modeling we consider the case of a single exciton confined in a QDash. We take into account phonon couplings via deformation potential and piezoelectric interaction. The relaxation rates are calculated within the Fermi golden rule.

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