Time-limitations for fast control of charge and spin in quantum dots due to decoherence

L. Jacak[(a)], P. Machnikowski[(a)], J. Krasnyj[(b)] , A. Radosz[(a)]

[(a)]Institute of Physics, Wrocław University of Technology, Wrocław, Poland
[(b)]Institute of Mathematics. University of Opole, Opole, Poland (on the leve from Institute of Physics, Odessa University, Odessa, Ukraine)

Abstract

The kinetics of relaxation and dephasing (decoherence) processes for orbital and spin degrees of freedom of carriers confined in various quantum dots (QDs) under fast switching are considered. Understanding the mechanisms of these effects is related to applications to a quantum information processing and to a new generation of opto-electronic and spintronic devices based on coherent control of individual quantum states. Due to the nanometer scale of confinement of the carrier dynamics in QDs, their energy characteristics fall in the range of a few to a few tens of meV, which overlaps with the energy scales of phonons (typical bandwidths of acoustical phonons and energy of optical phonons) and magnons (in semi-magnetic semiconductors). The proximity of resonances precludes treating the phonon (magnon) interaction as a weak perturbation (as it was the case in atomic physics and as it was initially expected for QDs, in view of the so-called *bottle-neck* effect), but rather leads to many non-perturbative effects resulting from radical modification of the spectrum [1]. Electrons and excitons are replaced by new quasiparticles, the electronic polarons and excitonic polarons with new properties resulting from the coupling with longitudinal optical phonons. The coresponding energy shift is in typical QDs surprisigly big – of several meV order, both for electronic and excitonic polarons. It is due to a relatively high value of coupling of QD charge with longitudinal optical phonons in a weakly polar medium (e.g. in GaAs), additionally enhanced by QD confinement effects [2]. Coupling to longitudinal acoustical phonons – of lower orders – not inducing essential energy modification, plays a dominating role in dephasing. It is caused by the relatively high value of a sound velocity in the crystal medium, which determines the time needed for transfer to the rest of the crystal of an excess energy of forming polaron in the region of QD. Similarly, interaction with magnons in magnetic QDs results in magnetic dressing phenomena. The kinetics of the dressing of the charge and spin excitation in QDs with clouds of phonons (magnons) is analysed in detail in order to explain the recent high resolution time-resolved experiments with QD excitations [3,4]. The role of anharmonic effects is also considered. The limitations for coherent control of orbital and spin degrees of freedom of carriers confined in QDs are predicted [5,6] with relevance to application in QD-based implementations of quantum gates controlled by light and magnetic field (including spin-charge conversion, e.g. phonon-dressing-induced time limitation for spin Pauli blocking) and in opto-electronic devices [7]. While decresing the dressing-related error requires slowing down the system dynamics, other types of error, increasing uniformly with time, favor fast gates. The trade-off between these opposite needs has been studied and the optimal gating time and minimal error level for a QD qubit have been found [8]. The impact of the lattice dynamics on Rabi oscillations in a QD under various conditions of external driving has been investigated [9]: it has been shown that only in the limit of slow excitation the system may be controlled fully coherently.

Pulse-shape dependence of the decoherence level is also studied, leading to the optimization of driving conditions [8,9].

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