Theoretical study of the electric dipole spin resonance in $LaAlO_3/SrTiO_3$ quantum dots

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Oxide-based two-dimensional electron gases (2DEGs), such as those formed at the $SrTiO_3/LaAlO_3$ (STO/LAO) interface, have emerged as promising platforms for quantum dot-based spin qubits [1]. This interest is driven by their high mobility, strong spin-orbit coupling, gate-tunable superconductivity, magnetic ordering, and ferroelectricity, as well as the expected suppression of decoherence due to reduced hyperfine interactions stemming from the $3d$ character of the electronic states [2].
Here, we present a theoretical analysis of quantum dots embedded in the 2DEG formed at the LAO/STO interface, using the $k \cdot p$ theory. We consider various confinement potentials and determine the electronic spectrum of QDs in the external electric and magnetic fields. We demonstrate that for QDs in the regime of a strong confinement, the contribution of the d_{yz} and d_{xz} bands starts to become significant which strongly influences quantum dot properties.
Considering the potential application of quantum dots as spin-qubits we further investigate the system in an oscillating electric field realizing the switching between spin states in the framework of the electric-dipole spin resonance (EDSR) [3]. The analysis of the system dynamics shows that the transitions of spin states have the character of Rabi oscillations, and that both one- and multi-photon transitions are present. To assess qubit performance, we calculate figures of merit such as fidelity, which quantifies leakage to other states, and the switching time. Our results demonstrate that the external parameters of the quantum dot strongly affect these quantities and they can be tuned to achieve fast switching while maintaining high fidelity. For optimized parameters, we find switching times on the order of 10 ps with fidelities exceeding 90%.

References:

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