Modeling of CROT gates with Germanium hole spin qubits

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In double quantum dot systems, the difference in Zeeman splitting between the dots allows for the implementation of two-qubit gates [1]. Furthermore, the anisotropy of the exchange interaction makes their operation highly dependent on the orientation of the magnetic field, and is crucial to driving state transitions in singlet-triplet qubits [2]. To address this, we take our dressed basis method, derived from configuration interaction, which enables fast time-dependent calculations of the spectrum of two-particle problems in very realistic geometries [3]; and apply it to a double dot hole spin qubit in a Germanium heterostructure (Fig. 1), whose parameters are extracted from experimental data and microscopic models. By doing this, we efficiently explore arbitrary electrostatics and orientations of magnetic field. We analyze the Rabi oscillations between the ground state |↓↓> and the first excited state |↓↑>, relevant for the implementation of a CROT gate, as a function of the amplitude of the driving signal, driving time, and the orientation of the magnetic field (see Fig. 2). We also take into account the impact of the speed of the pulse between the initialization/read out and operation bias points. We highlight the importance of the couplings with the excited states for the computation of the CROT fidelities, and understand the regime of validity of the rotating wave approximation as a function of the pulse parameters when considering states out of the computational space. This study aids the understanding of the regimes of operation of two-qubit gates and the role of the exchange anisotropies [4].

References

[1] S. Geyer *et al.*, Nat. Phys., 20 (2024) 1152-1157.
[2] J. Saez-Mollejo *et al.*, Nat Commun, 16 (2025) 3862.
[3] M. J. Rodríguez *et al.*, Phys. Rev. B, 112 (2025) 115428.
[4] Chien-An Wang *et al.*, Science, 385 (2024) 447-452.

Figures

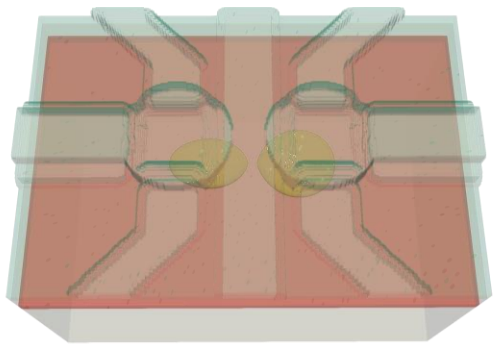

Figure 1: Double dot Ge heterostructure simulated in this work. The yellow volume corresponds to 85% of the charge density of the two-particle ground state of the system at zero detuning and zero magnetic field.

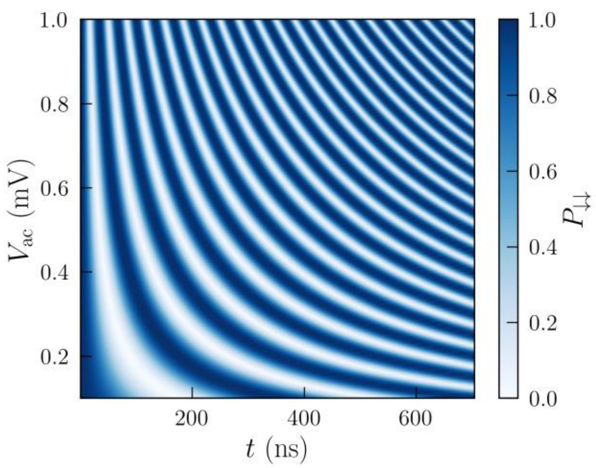

Figure 2: Probability of being in the |↓↓> as a function of the amplitude of the driving signal and the driving time for a fixed orientation of the magnetic field.