Optimizing charge qubit oscillations in double dot systems to unitary amplitude

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Solid state devices are attractive candidates for implementing quantum computation because of their high integrability in current industrial production lines as well as their cheap processing costs. Quantum dots gained an increasing interest due to higher scalability and the observation of long coherence times reaching tens of ms [1]. They offer an ideal system for implementing charge qubits, with the qubit states determined by the spatial location of an electron in one of the dots of a double well potential. Coherent oscillations between the states are then obtained by applying specific gate voltages across the region and inducing electron tunnelling across the tunnel barrier. The use of geometrically isolated structures (with the detectors coupled capacitively) improves the electrical isolation of the dots, however, it makes the detection more challenging [2].

It is theorised that pulses generated by the gates can produce a perfect control of the electron. However, although quantum gates error rates up to 3 % could be theoretically tolerated [3], this fidelity threshold for the application of error correction codes is difficult to attain in practice in quantum dots or more complex qubit systems. This is due both to technical reasons as well as physical processes and has a drastic impact on the oscillations' visibility by reducing gate fidelities down to 60 % [4]. These effects could be limited either by obtaining higher quality material and improving device processing or by implementing new pulsing schemes which will provide higher quality oscillations under realistic experimental conditions.

We computationally model the dynamical behaviour of an electron in 2D quantum dots using the time-dependent Schrödinger equation and the finite-difference method [Fig. 1]. It can be proven that the method is convergent, stable and accurate. In particular, total electron probability is conserved and finite accuracy errors do not accumulate with time [5]. To increase efficiency of the algorithm, we parallelise it and accelerate with graphics processing units (GPUs) [6].

Using this solver, any type of gate with varying position, strength and pulse raise (fall) time can be modelled. For the standard scheme which places a gate along the longitudinal (x) direction, we investigated how the oscillation amplitude depends on the pulse strength and raise time and with the aim of improving it [Fig. 2]. We have also applied a pulse along the transverse (y) direction, centred at the middle barrier and performed similar measurement [Fig. 3]. As a result, we present a method which makes it possible to obtain nearly unitary oscillations between the qubit basis states even in case of imperfect pulses.

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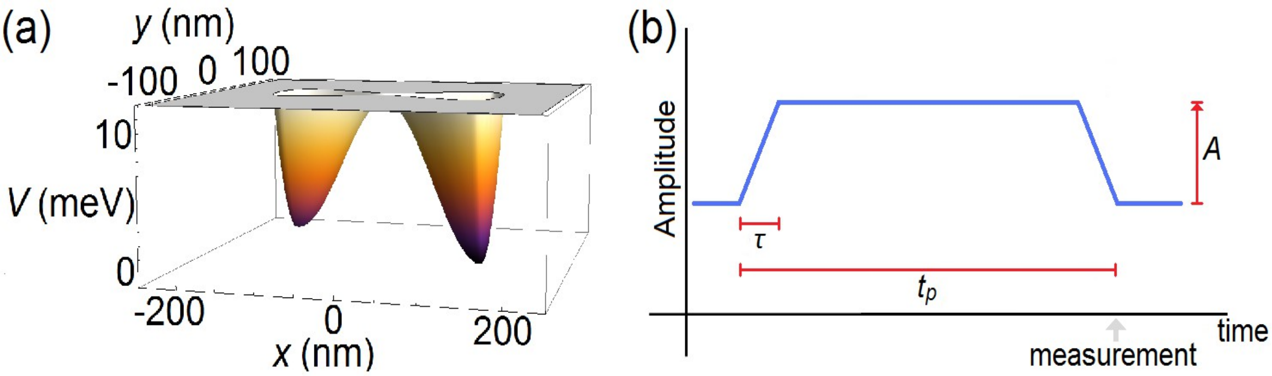

Fig. 1. Theoretical model of (a) the double dots and (b) the pulse.

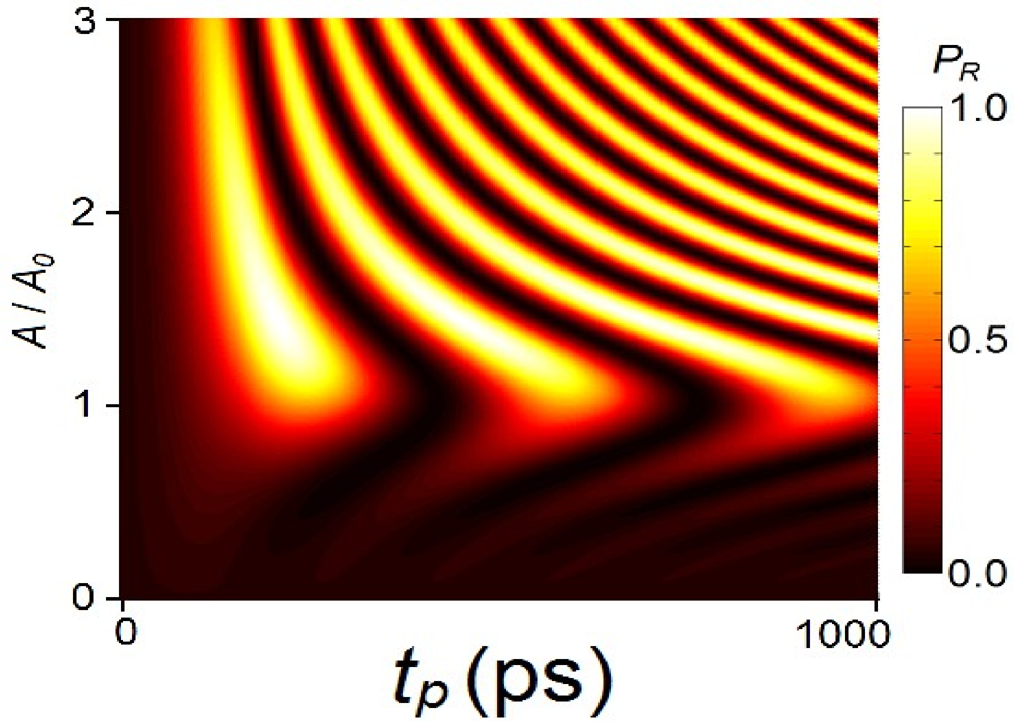

Fig. 2. Longitudinal (x) pulse amplitude measurement as a function of pulse length and detuning (with a finite raise time of 90 ps).

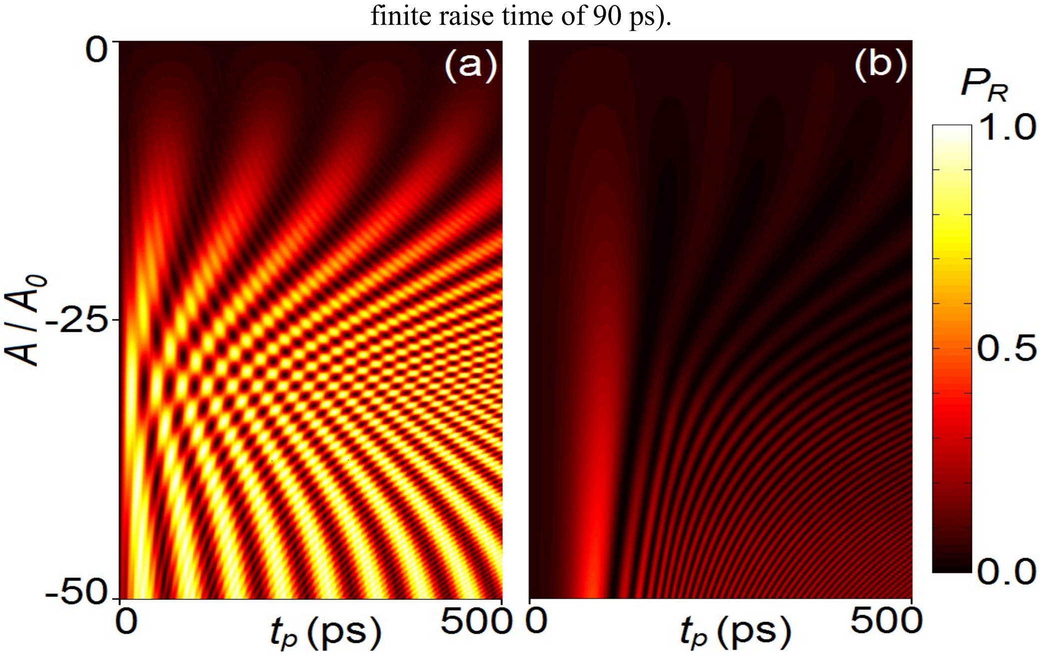

Fig. 3. y-pulse amplitude measurement for (a) 0 and (b) 90 ps raise time.