Genetic Algorithms in the control and design of charge one qubit quantum gates in circular graphene quantum dots

Gibrán Amparán(1)(2) ***F. Rojas***(1)(2) *and Antonio Pérez-Garrido*(1)

(1)*Departamento de Física Aplicada, Antiguo Hospital de la Marina, Campo Muralla del Mar, UPCT, Cartagena 30202, Murcia Spain*
(2)*Departamento de Física Teórica, Centro de Nanociencias y Nanotecnologías, Universidad Nacional Autónoma de México, UNAM. Apdo. Postal 356, Ensenada Baja California 22830 México frojas@cnyn.unam.mx*

Abstract

The design of quantum logic gates have been implemented in several physical systems, where the qubit is represented as charge states using trapped ions, nuclear magnetic resonance using the magnetic spin of ions and with light using light polarization or spin in solid state nanostructures. In graphene spin-qubits in graphene nano-ribbons has been also proposed.
In this work we propose the control and design for the one charge qubit quantum logic gates σ_x, σ_y y σ_z using the bound states of circular graphene quantum dots [1]. The nanostructure studied consists of graphene circular quantum dot (QD) grown over a semiconductor material which introduces a constant mass term which allow us to make a confinement that is made with a circular electric potential with constant radio (R) where homogeneous magnetic field (B) is applied in order to break the degeneracy between Dirac's points K and K'. We consider two independent Hilbert spaces where the orthonormal states $|\psi_j\rangle$ have spinor form and are described by the Kummer functions identified by the half-odd integer j, this integer is eigenvalue of the total angular momentum operator.

The control for the three quantum gate implementation is made with an oscillating electric field [2] and a onsite (inside the quantum dot) pulse with amplitude and time width modulation which introduce relative phase and transitions between states respectively. This introduce a dipolar matrix between the states and the onsite energy in the dot. We solve and control the evolution of the time dependent Schrodinger equation to describe the evolution of the expansion coefficients, i.e. $C_j(t)$ of being in the bound states in the dot Two bound states in QD are chosen to be the computational basis for the qubit subspace[3]: $|0\rangle \equiv |\psi_{1/2}\rangle$ and $|1\rangle \equiv |\psi_{-1/2}\rangle$ states with j=1/2,-1/2 of the quantum dot . We study the general n states problem with all dipolar and onsite interactions included so that, our objective is optimize the time dependent physical interactions as control parameters in order to minimize the probability leaking out of the qubit subspace and achieve the desired one qubit gates successfully.

The control parameters optimization is solved as a maximization problem using a genetic algorithm [4] which find efficiently the optimal parameters for the gate implementation where the genes are: magnitude (ε_0) and direction (ρ) of electric field, magnitude of gate voltage (V_{g0}) and pulse width (τ_v). The fitness F is defined as the gate fidelity an one desire to obtain the best fitness (F=1) that allows us to produce the desired quantum logic gate and obtain the best combination of parameters[5]
The results for example for the gate σ_x are shown in Fig. 1, for a QD of radius where the probability of the state and one achieve a fitness of F=.977, in our calculation n=7 states where considered, the optimal parameter obtained with the Genetic algorithm are shown in the figure caption. In Fig 2, we show how the control is achieved the time density probability in the QD, leading to the transformation of the wave function from $|0\rangle$ to $|1\rangle$. So we were able to implement the three gates, and for the z gate we only use the pulse control.
Thanks to DGAPA an project PAPPIT IN112012 for financial support and sabbatical scholarship for F. Rojas and G.Amparan to Conacyt, Mexico for graduate scholarship.

References

1. Patrik Recher, Johan Nilsson, Guido Burkard, Björn Trauzettel, Phys. Rev. B 79, **Issue 8**, Bound states and magnetic field induced valley splitting in gate-tunable graphene quantum (2009) 085407.
2. *Mark Fox,* Optical Properties of Solids, Oxford University Press (2001), Quantum Theory of radiative absorption and emission.
3. Charles H. Bennett & David P. DiVincenzo, Nature Vol. 404, Quantum Information and Quantum Computation (2000) 247-255
4. Shuford, Kevin L, Krause, Jeffrey L, International Journal of Quantum Chemistry vol. 77, **Issue 1** (200) 393-200
5. Edwin K. P. Chong and Stanislaw H. Zak, An introduction to optimization 2nd Edition Editorial WILEY (2001), Chapter 14: Genetic Algorithms.

Figures

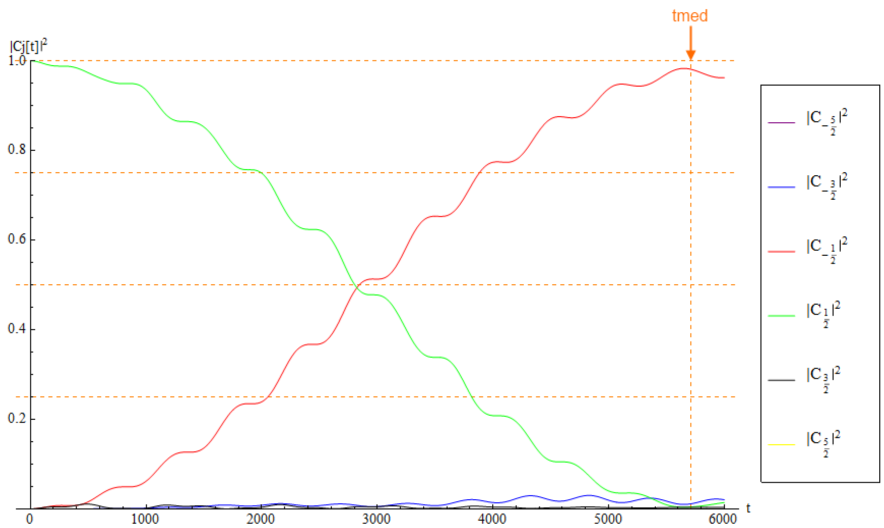

Fig. 1. Optimal time Evolution of probabilities $|c_j|^2$ under σ_x quantum gate for each QD state. It shows the transition made from the initial state $|0\rangle \equiv |\psi_{1/2}\rangle$ to $|1\rangle \equiv |\psi_{-1/2}\rangle$ and a small leakage to the state $|\psi_{-3/5}\rangle$. The quantum dot has a radius R=25nm and the perpendicular magnetic field is B=3.043 Teslas. The quantum gate σ_x is obtained with the following control parameters: ε_0=.0000924, ρ=.993π, V_{g0} = .0003685 and τ_v=4215.957 .

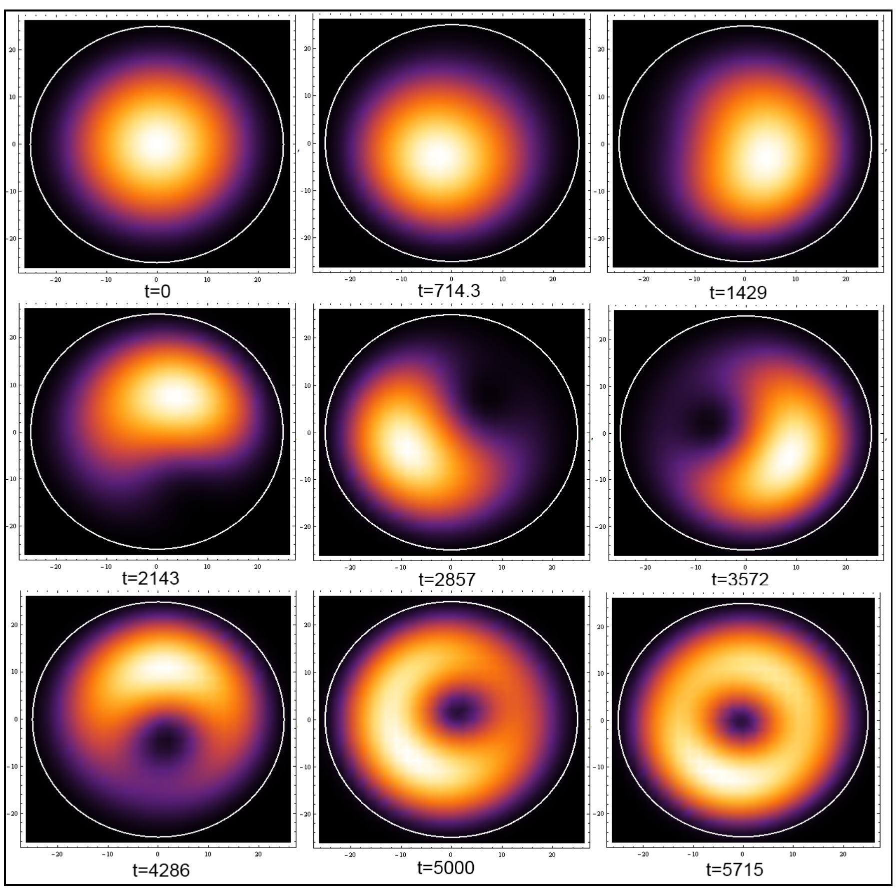

Fig. 2: Evolution under σ_x quantum gate of the probability density in the quantum dot and pseudospin's direction. At t=0 the wave function is in the initial state $|0\rangle$ and it evolves until at t_{med} it reaches the state $|1\rangle$.