A simple quantum circuit using ESR with the scanning tunnelling microscope

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Abstract

A scanning tunnelling microscope (STM) can drive the spin evolution of a single atom, molecule or nanostructure on a solid surface [1]. A tunnelling electron current is localized on a single atom, while the bias is modulated at microwave frequencies. The measured current shows excitations attributed to a spin resonance (ESR). We have developed software to simulate virtually any instance of ESR-STM under realistic conditions of temperature, external fields, and electron conductance [2,3].
Here, we suggest the realization of a quantum circuit that converts a product state to a maximally entangled state (the GHZ state), Figure 1. To do this, the first step of the sequence (a Hadamard gate) is implemented to act on the first spin. Figure 1 shows the evolution of the first spin of our simulation when initialized in the '0' state, transformed into a rotating frame, and then represented on the Bloch sphere. The evolution onto the final state (a Bloch vector pointing on the 'x' direction) demonstrates the realization of the Hadamard gate, plus current-induced decoherence if a longer evolution time is used as shown in the Figure. The right-hand graph shows the time-resolved tunnelling current of the simulated STM, with the interruption of the driving pulse and the fast Larmor oscillation. A similar rotation from the '1' state to the negative 'x' direction on the Bloch sphere is also demonstrated. The CNOT operation is performed on pairs of qubit driving one single frequency as shown in [1]. To characterize our circuit, we evaluate its fidelity on the desired GHZ state. This allows us to discuss the performance of the simulated gate using tunnelling currents and solid state-hosted spins.

References

[1] K. Yang et al., Science 366 (2019) 509
[2] J. Reina et al., Phys. Rev. B 104 (2021) 24535
[3] https://github.com/qphensurf/TimeESR

Figures

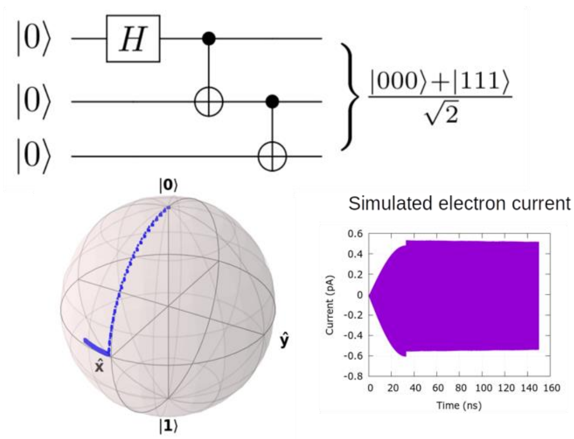

Figure 1: Scheme of the simple quantum circuit converting a product state to a maximally entangled state. The Bloch sphere shows the evolution of the first qubit in the ESR-STM implementation that we proposed, where the electronic current plotted on the right graph is the physical observable of this technique.