Electron Shuttling by Surface Acoustic Waves

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One pathway toward a scalable quantum computing architecture based on spin qubits in semiconductor heterostructures is via electron shuttling. Among the variety of ways an electron can be transported, such as the bucket brigade approach and the conveyor belt approach, surface acoustic waves (SAW) is a more radical approach. Experimentally, it has been shown that SAW can indeed transport a single or multiple electrons from one quantum dot to another with high fidelity in terms of charge motion. Electron beam splitting and other coherent manipulations have also been demonstrated.

Here we present a comprehensive study of SAW and its utility in electron shuttling. After clarifying the different SAW modes in a piezoelectric material, we focus specifically on how an electron is picked up by an SAW from a fixed quantum dot. To maintain the integrity of the spin sector, it is imperative that this pick-up process is adiabatic, so that the mixing between spin and orbital degrees of freedom is minimized. In this work we study the electron transfer process by first setting up the problem in a reference frame that moves with the SAW dot, and numerically calculate the time-dependent electron wave function through the transfer process. Most importantly, we find the process to be decidedly nonadiabatic: during the SAW pick-up process the electron ends up in a superposition state that consists of many highly excited orbital states. We vary system parameters such as relative dot sizes, bias potential, and speed of the moving dot, and find that the electron can indeed be picked up with high fidelity, albeit in a highly excited wave packet. Keeping this high degree of excitation in mind, we examined the electron spin decoherence, especially relaxation, and show that they are negatively impacted by the orbital excitation.

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