Surface acoustic wave phonons: Quantum control and quantum state transfer

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I will report on a recent experiment [1] using a superconducting qubit to probe the 4 GHz fundamental mode of a surface acoustic wave (SAW) resonator. This experiment builds on prior work coupling superconducting qubits to mechanical devices, here achieving full quantum control over the SAW resonant phonon mode and exceeding the control achieved over earlier bulk acoustic resonator-qubit experiments. The SAW device, fabricated on a lithium niobate substrate, was designed to have a single SAW mode centered at 4 GHz, with higher order modes outside the stop band of the SAW resonator mirrors. A superconducting qubit, coupled to the SAW resonator through an electrically controlled coupler element, was fabricated on a separate sapphire substrate, with the SAW device flip-chip bonded to the qubit chip. We used the qubit to characterize the SAW resonator admittance; measure the mode occupation with no excitation, in other words a quantum thermometry measurement; and generate one- and two-phonon Fock states, as well as measure the Wigner tomograms of the resonator in its ground state; with one phonon; and with a superposition state of zero and one phonons.

In more recent work, we have coupled two superconducting qubits to a long SAW resonator with a 500 ns phonon bounce time. We used this device to release and recapture individual itinerant phonons using one of the two qubits, as well as transfer quantum states between the two qubits. By sharing half a phonon between the two qubits (in other words, generating the qubit-phonon-qubit entangled state |e0g>+|g1g>, that on catching the itinerant phonon with the second qubit, transitions to the Bell state |e0g>+|g0e>), we were able to acoustically generate a high-fidelity Bell state between the two qubits [2].

[1] K. J. Satzinger et al., “Quantum control of surface acoustic wave phonons”, Nature 563, 661–665 (2018).

[2] A. Bienfait et al., “Phonon-mediated quantum state transfer and remote qubit entanglement”, submitted (2019).