Multimode Surface Acoustic Wave Interactions Mediated by a Nonlinear SQUID Array

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Due to the intrinsically slow velocity of sound, Surface Acoustic Wave (SAW) resonators can confine a dense spectrum of mechanical modes in a compact space while maintaining long lifetimes. Our work leverages these unique properties to realize two key developments.

In the first part, we achieve a multimode (or superstrong) coupling regime by interfacing a high-impedance SQUID array with the SAW resonator [1]. In this configuration, the SAW–SQUID coupling is comparable to (or even exceeds) the free spectral range of the SAW resonator. As a consequence, the nonlinearity of the SQUID is effectively transferred onto multiple SAW modes simultaneously. To quantitatively capture this behavior, we introduce the SQUID participation ratio as a metric for the multimode coupling regime. Our innovative measurement technique shows excellent agreement with detailed system modeling, and complementary cross-Kerr experiments confirm that several SAW modes acquire nonlinear characteristics directly as a result of this coupling.

In the second part, we demonstrate tunable SAW–SAW strong interactions by applying parametric drives to the SQUID flux line [2]. This engineered interaction enables the creation of synthetic lattices in the frequency dimension, which facilitate non-reciprocal interactions and the realization of topological lattices [3,4]—each offering promising avenues for quantum simulations of interacting bosonic modes.

Looking ahead, simply replacing our weakly nonlinear SQUID array with a transmon is expected to yield a scalable platform hosting up to ten mechanical qubits [5], opening new routes for advanced quantum information processing and bosonic quantum simulations.

References

[1] Moores et al., PRL **120** 227701 (2018)
[2] Von Lüpke et al., Nat. Phys. **20**, 564–570 (2024)
[3] Hung et al., PRL **127**, 100503 (2021)
[4] Slim et al., arXiv: 2501.18882 (2025)
[5] Yang et al., Science **386**, 6723 (2024)

Figures

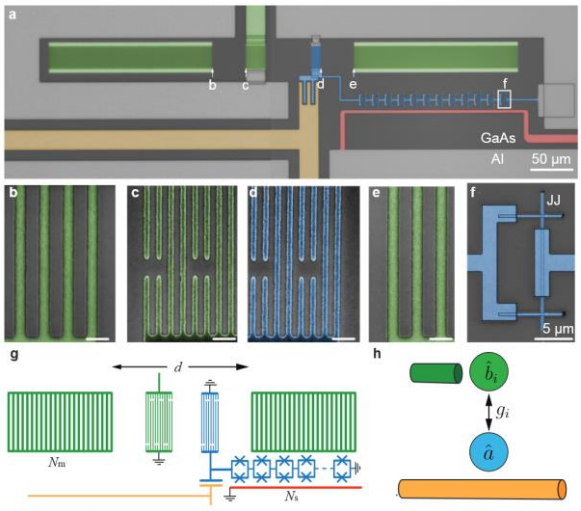

Figure 1: Surface acoustic wave resonator coupled to a SQUID array resonator.

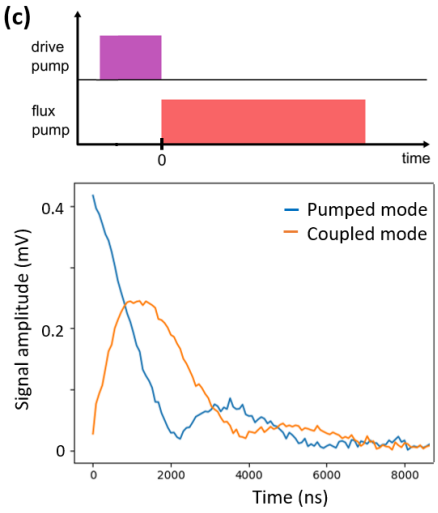

Figure 2: After populating one SAW mode, we activate the parametric coupling via the flux line and observe coherent exchange between different SAW modes.