Proof-of-concept atomic-scale visualization of 'poisoning' quasiparticles in superconductors

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Abstract

Superconducting qubit states are protected from decaying by the energy gap, but pair-breaking excitations, known as Bogoliubov quasiparticles, always exist when the real superconductor departs from an ideal one. The quasiparticle concentration in superconducting qubits is suggested to exceed the expectation of thermal excitation by orders of magnitudes [1]. Even though the absolute value of quasiparticle concentration is small, decoherence of individual qubits may occur due to nearby quasiparticle states allowing additional channels for single-charge relaxation [2].

Quasiparticle poisoning poses a fundamental challenge in error mitigation when using superconducting qubits. Despite that quasiparticle concentration has been characterized on mesoscopic devices via the relaxation rate or the frequency shift measurements, the spatial information of quasiparticles remains unexplored. A direct, nanoscale quantification of the quasiparticle concentration, particularly desired for evaluating the performance of quasiparticle traps, is absent. In this work [3], we locally determine quasiparticle concentration by measuring shot noise in a scanning tunneling microscope. Using the vortex lattice as a model system, we directly visualize the spatial variation of the quasiparticle concentration around superconducting vortices (Fig. 1), which can be described within the Ginzburg–Landau framework. This shows a direct, non-invasive approach for the atomic-scale detection of relative quasiparticle concentration as small as 10^{-4} in various superconducting qubit systems. Our results alert of a quick increase in quasiparticle concentration with decreasing intervortex distance in vortex-based Majorana qubits.

References

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Figures

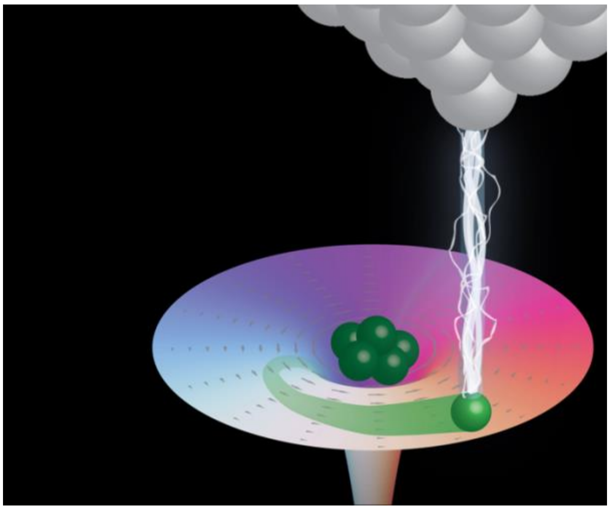

Figure 1: Visualizing quasiparticles by scanning tunneling noise spectroscopy. The order parameter of a superconducting vortex is denoted by a winding phase (color wheel) and a decreasing amplitude (vertical height) inside the vortex core. Tunnel current (thick curves) with its noise (thin curves) passes between the tip (silver balls) and quasiparticles (green balls), with the quasiparticle concentration schematically illustrated.