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Enhancing quasiparticle lifetime in a superconductor with a phononic crystal

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When quasiparticles in a BCS superconductor recombine into Cooper pairs, phonons are emitted within a narrow band of energies above the pairing energy at 2Δ . These phonons either further Cooper break pairs after some time, or escape to the thermal bath of the system. We show that the quasiparticle lifetime in a superconductor can be increased by more than an order of magnitude by restricting the escape of recombination phonons out of the superconductor with a phonon bandgap. The phonon bandgap can be realized and matched to the recombination phonon energy of the superconductor with a phononic crystal. The results have important implications for superconducting detectors such as the Kinetic Inductance Detector (KID), where the sensitivity is proportional to the square-root of the quasiparticle lifetime. We present the details of the nonequilibrium quasiparticle and phonon distributions that arise in a superconductor due to a phonon bandgap and a pair-breaking photon signal. Although intrinsically a non-equilibrium effect, the small-signal lifetime enhancement in a superconductor due to a phonon bandgap is remarkably similar to an estimate from an equilibrium formulation. The equilibrium estimate closely follows $\exp(\Omega_{bg}/k_BT_b)$, where Ω_{bg} is the phonon bandgap energy bandwidth above 2Δ , and T_b is the phonon bath temperature of the coupled electron-phonon system. We describe the impact of a phononic bandgap on the performance of a superconducting circuit element, and propose a microwave resonator to measure the enhancement in the quasiparticle lifetime. We refer to work in these proceedings for a detailed discussion on the phononic crystal geometries suitable for the application described here (Puurtinen et al.), and a status of the fabrication effort currently under way at Goddard Space Flight Center to realize phononic-isolated KIDs (Denis et al.).

Less than 5 years of experience since completion of Ph.D

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