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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 non-equilibrium 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 $\exp(\Omega_{bg}/k_B T_b)$, 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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