Quasiparticle Conversion in SN-N-NS Josephson Junctions

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The miniaturization of superconducting electronics demands precise control over quasiparticle dynamics at the nanoscale. Understanding and controlling quasiparticle dynamics is essential for advancing superconducting electronics, particularly as device dimensions approach the nanoscale. Here we present direct experimental evidence for the quasiparticle-to-supercurrent conversion in planar SN–N–NS Josephson nanobridges with submicron electrodes. By employing a versatile measurement platform, we demonstrate that the injection geometry—through either superconducting or normal-metal leads—dramatically alters the critical current and resistance of the junction. Using a tunable measurement setup that allows current injection through either superconducting or normal-metal leads, we uncover marked changes in critical current and resistance depending on the injection geometry—effects that become significant when electrode widths fall below the characteristic conversion length of ~400 nm. These observations are quantitatively explained by a phenomenological model that accounts for nonequilibrium transport and incomplete quasiparticle conversion in narrow electrodes. These results point to the emergence of non-equilibrium transport governed by an intrinsic conversion length. We develop and apply a method for extracting this length from standard transport measurements, offering a practical diagnostic for nanoscale superconducting circuits. Our findings enable optimized design of compact Josephson junctions and support the integration of proximity-based weak links into scalable superconducting logic and sensing architectures.

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