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Nonlinear Properties of Supercurrent-Carrying Single and Multi-Layer Thin-Film Superconductors

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Superconducting thin-films are central to the operation of many kinds of quantum sensors and quantum computing devices: Kinetic Inductance Detectors (KIDs), Travelling-Wave Parametric Amplifiers (TWPAs), Qubits, and Spin-based Quantum Memory devices. In all cases, the nonlinearity resulting from the supercurrent is a critical aspect of behaviour, either because it is central to the operation of the device (TWPA), or because it results in non-ideal second-order effects (KID).

Here we present an analysis of supercurrent carrying superconducting thin-films that is based on the generalized Usadel equation. Our analysis framework is suitable for both homogeneous and multilayer thin-films, and can be used to calculate the resulting density of states, superconducting transition temperature, superconducting critical current, complex conductivities, complex surface impedances, transmission line propagation constants, and non-linear kinetic inductances in the presence of a supercurrent. Our analysis gives the scale of kinetic inductance non-linearity (I*) for a given material combination and geometry, and is important in optimizing the design of detectors and amplifiers in terms of materials, geometries, and dimensions.

To investigate the validity of our analysis across a wide range of supercurrent, we have measured the transition temperatures of superconducting thin-films as a function of DC supercurrent. These measurements show good agreement with our theoretical predictions.

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Y

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