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Dynamics of hotspots in superconducting nanowires

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The detection mechanism of a superconducting nanowire single-photon detector (SNSPD) relies on the local photon-induced suppression of superconductivity [1]. This region of suppressed superconductivity is usually referred to as a hotspot. Hotspot dynamics are crucially important for the operation of SNSPDs because they determine the spectral sensitivity [2] and limit the reset time of the detectors [3]. The formation and subsequent dynamics of hotspots play central roles in the detection mechanism.

Despite significant progress in the development of SNSPDs, many fundamental questions remain open. These relate both to formation and evolution of a hotspot following the absorption of a photon and to the detection mechanism. Here we introduce a model that describes relaxation of strongly non-equilibrium distributions of interacting quasiparticles (QPs) and phonons inside a generated hotspot. We show that this model provides interpretation of recent two-photon experiments [4] describing in detail the evolution of relaxing hotspots. The model quantitatively reproduces the measured current, wavelength and temperature dependences of the hotspot relaxation time.

Our theoretical model explains our experimental data completely ignoring QP diffusion. In fact, the model was developed under the evidence drawn from the data that diffusion effects are not important, at least over time scales of the order of one nanosecond. This behaviour represents an enigma, which deserves special discussion. The linear diffusion model based on the assumption of nearly constant thermal diffusivity of quasiparticles predicts much faster relaxation of hotspots because of the rapid expansion of the hotspot. Not only does this contradict the measured (significantly slower) relaxation times, but it also predicts no significant dependence on bath temperature, which is in contrast with the significant temperature dependence seen in the experiments.

We show that the linear thermal diffusion model cannot be justified because of a strong variation of QP temperature across the hotspot. We derive the appropriate non-linear heat balance equation from the simplified Ovchinnikov and Larkin kinetic equation [5]. We numerically solve the heat balance equation and prove that non-linearity significantly slows down the hotspot expansion relative to linear diffusion theory, providing the support for the kinetic theory of hotspots developed in [6].

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