The Temperature Dependence of Superconducting Single Photon Detectors is a Vortex Effect

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Abstract — We report an experimental result solving the long-standing question of the temperature dependence of nanowire superconducting single photon detectors (SSPDs). SSPDs are single photon detectors consisting of a thin wire of superconductor carrying a strong bias current. They operate by converting absorbed photons into a cloud of quasiparticles. This process reduces the ability for the superconductor to carry current, resulting in a transition to the normal state. Such detectors have great potential for fundamental science and technological applications.
The temperature dependence of the SSPD action is poorly understood. From the simple picture given above, one would expect that the overall efficiency increases when the number of quasiparticles produced per unit energy is increased. This happens when the temperature is increased and the energy gap of the superconductor decreases. However, the opposite effect is observed across many experiments.

We report on an experimental solution to this puzzle. We perform detector tomography, which enables us to separate the detector response into three parts: a linear optical efficiency, which represents absorption into the active layer, a term describing the energy conversion from the photon into quasiparticles, and a current scale intrinsic to the detector which governs the overall response, which we term the reference current I_0.

We find that both the absorption into the detector and the quasiparticle conversion term are independent of temperature, but that the reference current is not. In particular, we find cases where the reference current is larger than the critical current, and cases where the reference current is smaller. The crossover occurs around 5.5 K. Moreover, we find that the reference current follows a theoretical prediction by Bulaevskii et al for the temperature dependence of the unbinding of a vortex from the side of the detector.

This brings us to the following interpretation of our results: in the temperature regime where SSPDs are typically operated (2-6 K), the main effect in the temperature dependence is not due to the behavior of the quasiparticles but due to the behavior of vortices.

Keywords (Index Terms) — SSPD, vortex physics, quantum tomography, edge barriers.