Photon-Counting with KID Resonators for THz/Submillimeter Space Spectroscopy

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Abstract— Photon-counting direct detectors are highly desirable for reaching the ~ 10^{-20} W/Hz$^{1/2}$ power sensitivity permitted by the Origins Space Telescope (OST), a notional cryogenic facility inspired by NASA's Astrophysics Roadmap. We are developing Kinetic Inductance Detectors (KIDs) with photon counting capability in the far-infrared/THz combined with integrated spectrometers suitable for the OST facility. To reach the required sensitivity we are experimenting with single-layer superconducting resonators made from aluminum films (10 – 25 nm thick) on single-crystal Si substrates. Small-volume inductors made from such thin Al films have the potential to become ultra-sensitive to single pair-braking far-IR photons (>90 GHz) under the right conditions. Understanding the physics of these superconducting films and superconducting-dielectric systems is critical to achieving detector performance with ultra low-loss and low-noise substrates.

In our measurements of these resonators, we have achieved very high internal quality factors (Q_i ~ 7 x 10^6 for 25 nm Al, and 1.1 x 10^6 for 10 nm Al) at ~10^6 microwave photon drive power. At single-photon drive powers both films remarkably maintain a very high Q_i ~ 0.5 x 10^6, by far the highest value for such thin films reported in literature to the best of our knowledge. In addition we have obtained quasi-particle (QP) lifetimes of ~ 1.0 ms for 100 nm Al on Si resonators, another critical material parameter for reaching photon-counting sensitivity. Our cryogenic testbed was optimized for ultra low stray radiation, which was confirmed by measurement cross comparisons. To realize a practical device, we are integrating these films with our Silicon-on-Insulator (SOI) process to form parallel-plate capacitors on single-crystal dielectric to minimize two-level system frequency noise and loss. We have designed KID geometries with small-volume inductors that allow us to probe the quasi-particle dynamics at these never before explored volume limits, and to measure quality factor and QP lifetime as a function of microwave readout power. Based on a detailed physical model, we simulated the detector output time stream for a given design when illuminated with random photon events, and using an optimal linear filter were able to show that photon counting with >95% efficiency at 0.5 and 1.0 THz is possible.

We report on these developments and discuss our plans to implement these devices into optically coupled ultrasensitive KIDs suitable for photon counting in space.