Building a Platform for Beyond Near - Infrared Detection with Superconducting Nanowire Single Photon Detectors

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Superconducting nanowire single-photon detectors (SNSPDs) are digital photon counters featuring high timing resolution [1], low dark counts [2], large-format arrays [3], and a broad dynamic range spanning the UV [4] to the far-infrared up to 29 mm [5]. Although SNSPDs demonstrate single-photon sensitivity in the far-infrared, their development remains nascent, with most commercial detectors centered around near-infrared telecom wavelengths. Advancing SNSPDs to these longer wavelengths unlocks their potential for applications in spectroscopy, quantum sensing, quantum networking, physical chemistry, and dark matter searches. To achieve this, we tune parameters at both the material and device levels. From a materials perspective, we have developed a process for low-critical-temperature (Tc) WSi thin films with higher resistivity, effectively lowering the SNSPD's detection energy density for single-photon detection beyond 29 mm. However, lowering the film's Tc also reduces the operational bias currents, leading to poor signal-to-noise ratio (SNR) performance. To combat these lower operating currents, we discuss our work on superconducting nanowire avalanche photodetectors (SNAPs) combined with impedance-matching tapers, which improve both output pulse amplitude and slew rate [6]. Additionally, we illustrate adapting this materials platform for microwire arrays using superconducting microwire single-photon detectors (SMSPDs). Their increased width compared to typical SNSPDs intrinsically provides improved optical coupling and ease of fabrication. Ultimately, this talk discusses the success of sub-1K WSi detectors and elucidates pathways toward bringing the advantageous properties of near-infrared SNSPDs to longer wavelengths.

References

[1] B. Korzh et. al. “Demonstration of sub-3 ps temporal resolution with a superconducting nanowire single-photon detector,” Nature Photonics 14, 250–255 (2020).
[2] J. Chiles et. al. “New constraints on dark photon dark matter with super- conducting nanowire detectors in an optical haloscope,” Physical Review Letters 128, 231802 (2022).
[3] B. G. Oripov et. al. “A superconducting nanowire single-photon camera with 400,000 pixels,” Nature 622, 730–734 (2023).
[4] E. E. et. al. "UV superconducting nanowire single-photon detectors with high efficiency, low noise, and 4 K operating temperature," Opt. Express 25, 26792-26801 (2017)
[5] G. G. Taylor et. al. “Low- noise single-photon counting superconducting nanowire detectors at infrared wavelengths up to 29 µm,” Optica 10, 1672–1678 (2023).
[6] S. R. Patel et. al. Improvements of readout signal integrity in mid-infrared superconducting nanowire single-photon detectors. *Appl. Phys. Lett.* 15 April 2024; 124 (16): 162604.