National Aeronautics and Space Administration

FY23 Innovative Spontaneous Concepts Research and Technology Development (ISC)

Superconducting nanowire single-photon detectors for infrared wavelengths up to ~~25~~ 29 µm

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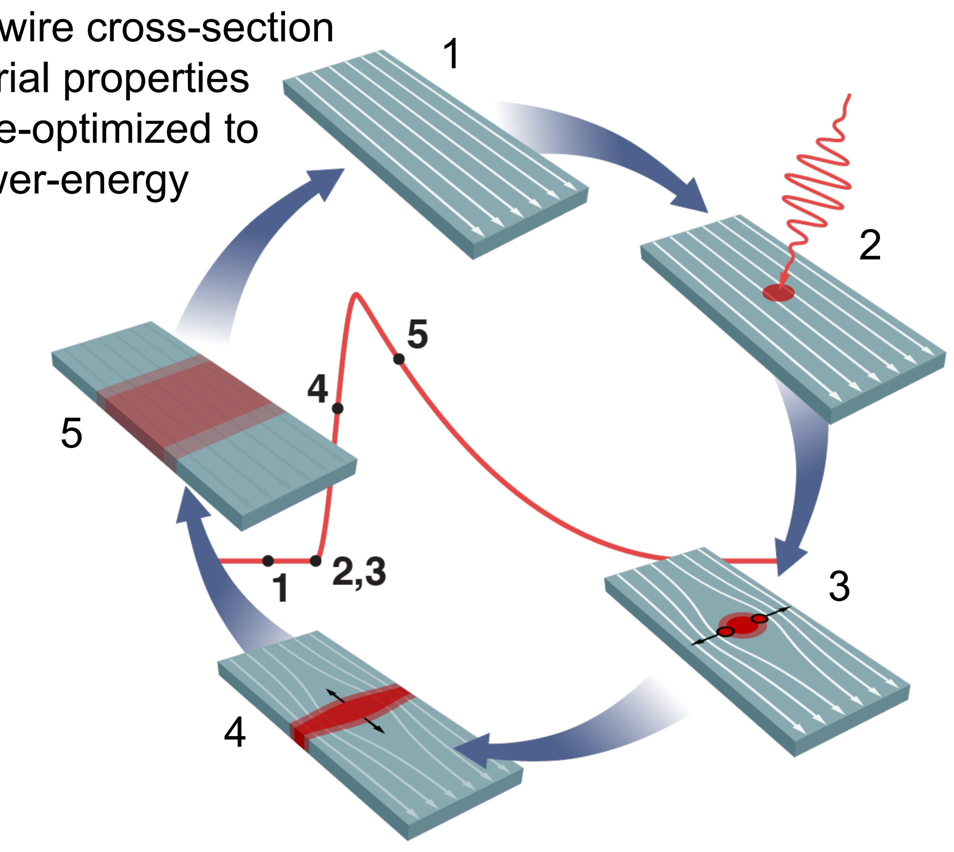
Objectives:

1) Demonstrate superconducting nanowire single-photon detectors (SNSPDs) with high internal detection efficiency to single photons from 15 to 30 µm.
2) Design and simulate optical coupling schemes to enhance the coupling efficiency for this spectral range.

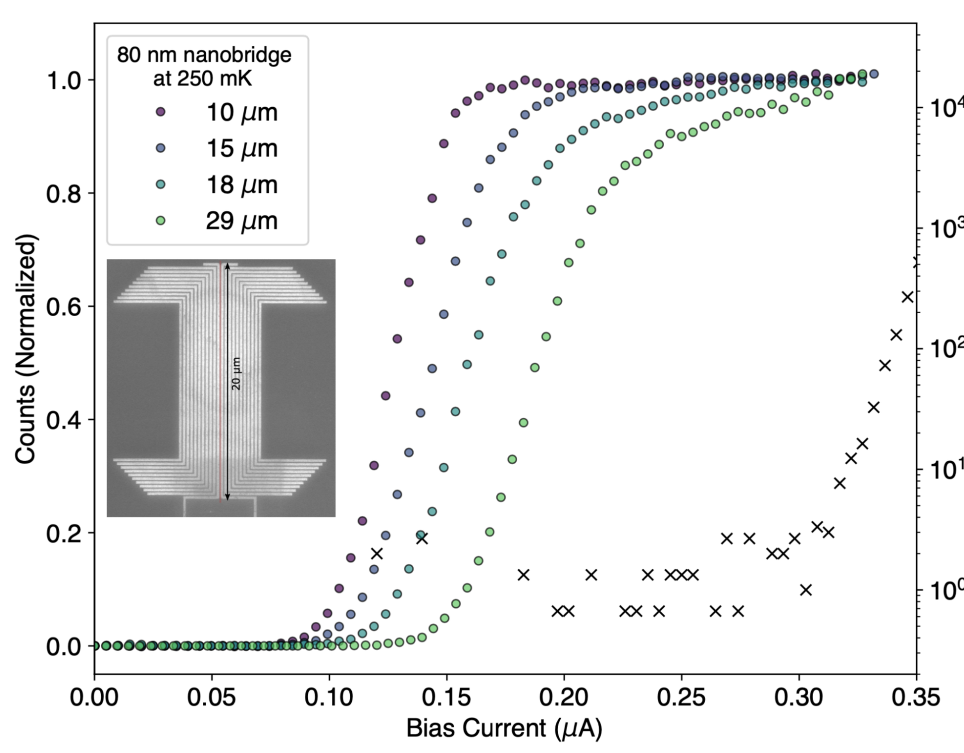
SNSPD operating principle. The nanowire cross-section and material properties must be re-optimized to detect lower-energy photons.



Background: The mid-IR is of particular interest for exoplanet science, but there is currently a lack of high-performing detectors in the wavelength range from 15 to 30 µm. SNSPDs are true single-photon detectors with zero read noise, low dark-count rates, and the ability to reach high efficiencies due to their compatibility with several different optical coupling schemes. Detecting longer-wavelength photons is challenging due to the smaller energies involved, and optical coupling at longer wavelengths is difficult, because the schemes used for near-IR SNSPDs do not work well beyond ~ 10 µm.

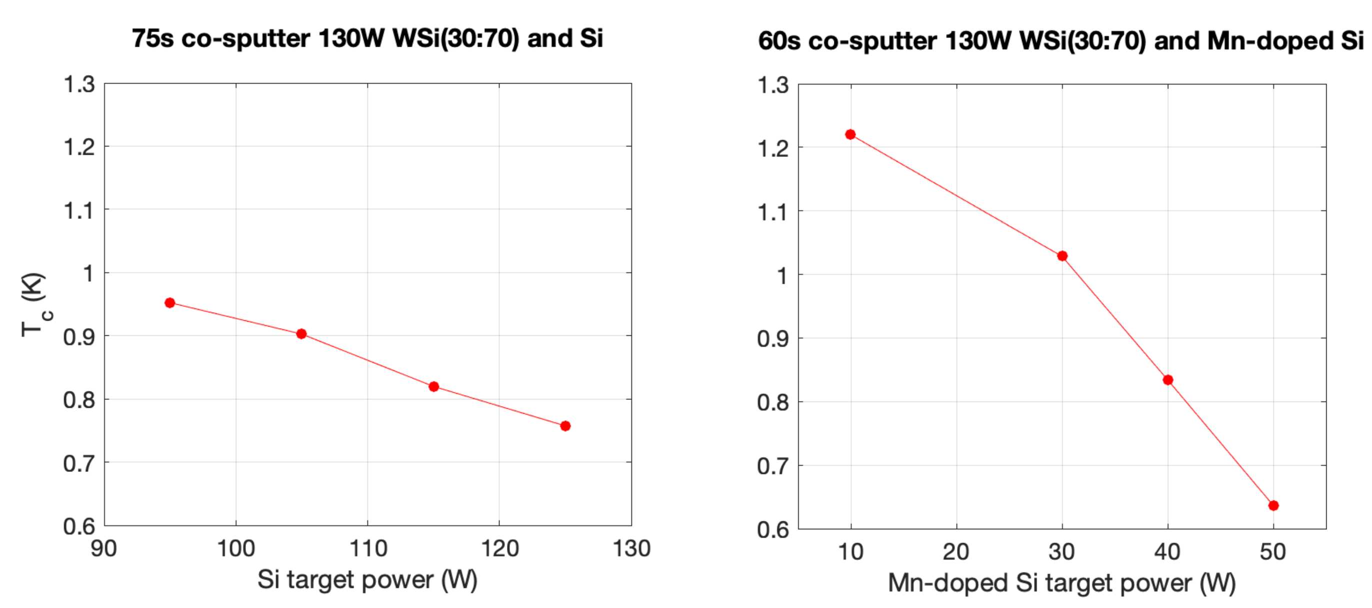
Approach and Results:

Testing at 29 µm:



80nm-wide nanowire device measured with a filtered blackbody source at wavelengths from 10 to 29 µm. The detector exhibits saturated internal detection efficiency (IDE) vs. bias current, indicating that every absorbed photon produces an output pulse.

Material development:



Critical temperature vs. sputtering power for Si-rich-WSi (left) and Mn-WSi (right) thin films. The films are produced by co-sputtering with a W30Si70 target at a fixed power of 130 W. T_c decreases with increasing Si and Mn-doped Si content, signifying a smaller energy gap and higher sensitivity to low-energy photons.

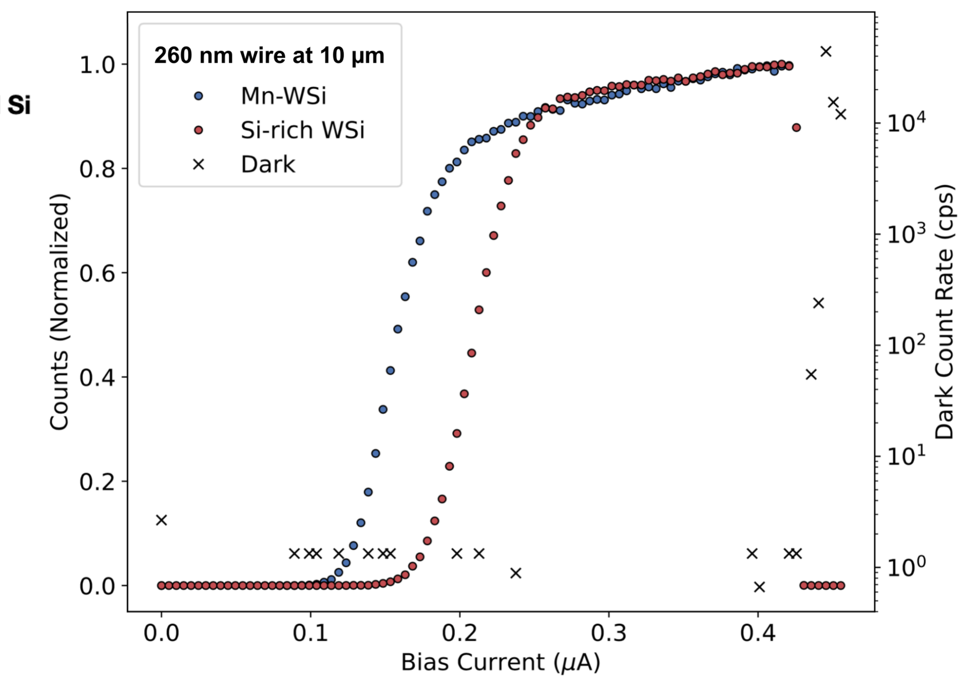


Photo-counts vs. bias current for 260nm-wide nanowires fabricated from the Si-rich WSi and Mn-doped WSi films. The detectors show saturated IDE despite their wider width. The Mn-doped detector has an enhanced IDE plateau.

Enhanced electrical signal:

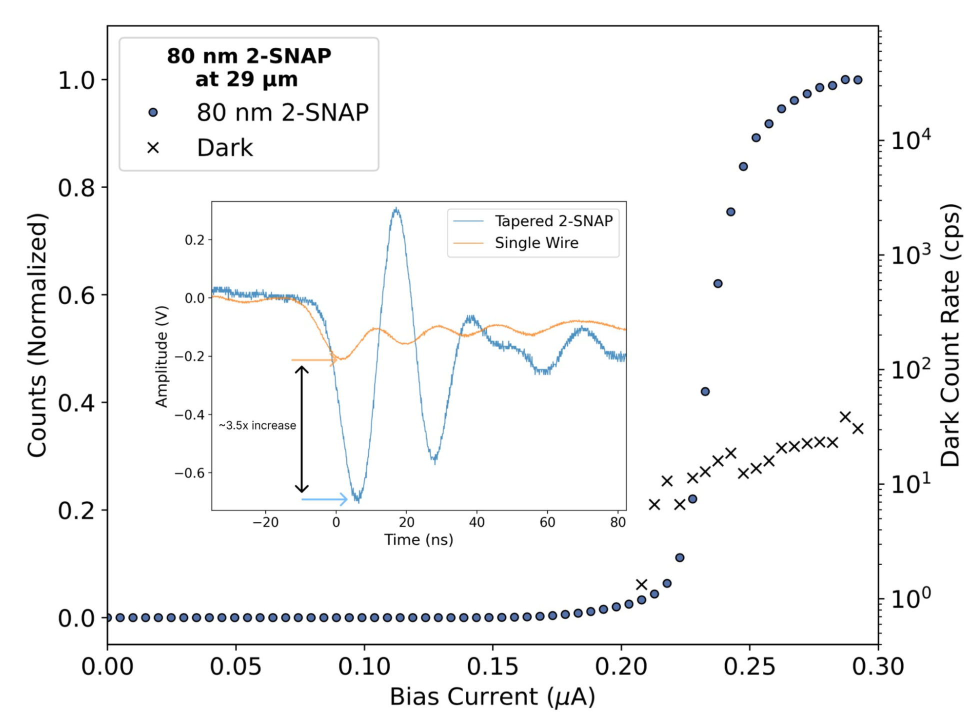
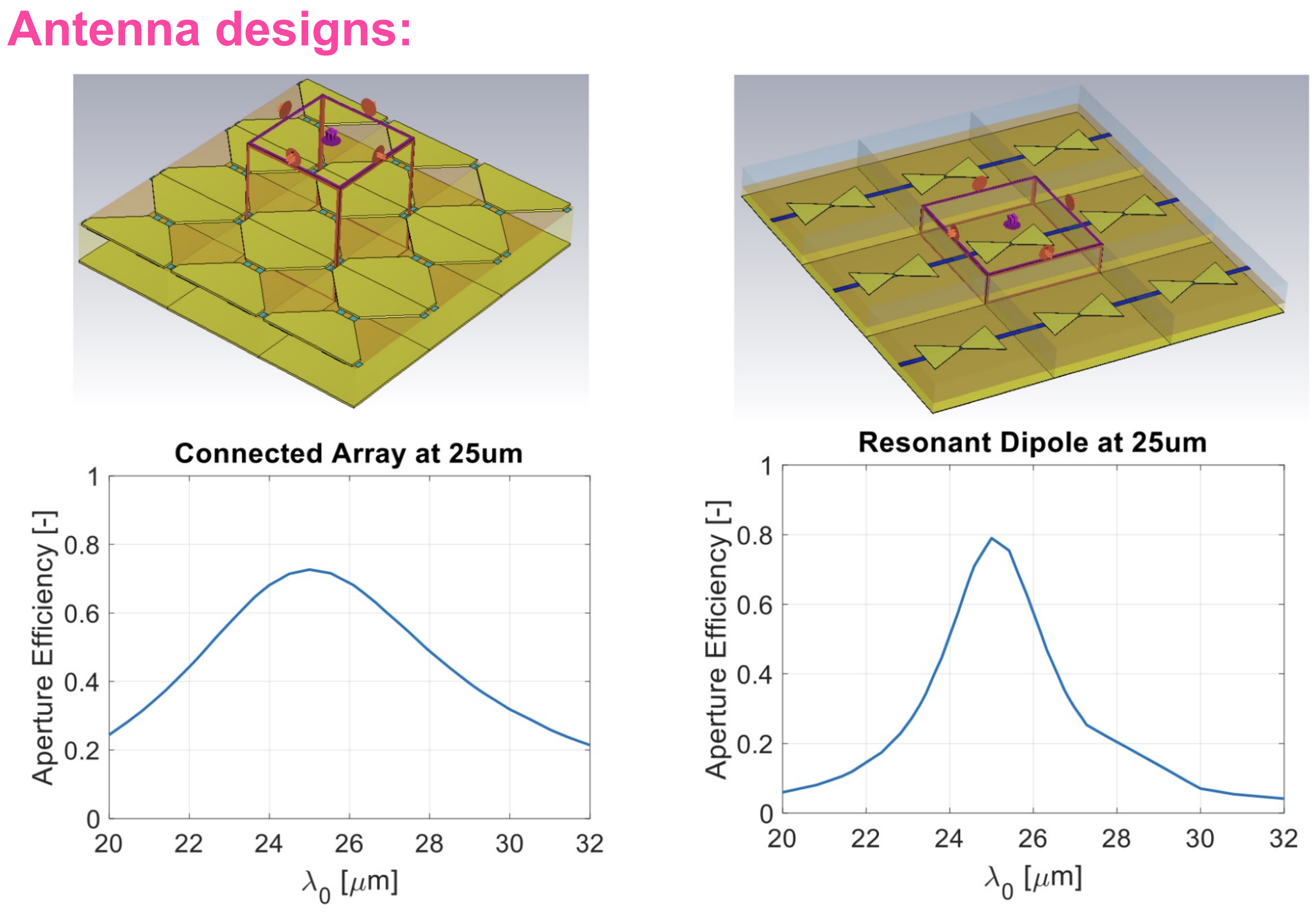


Photo-counts vs. bias current for a 80nm-wide parallel SNSPD (SNAP), showing saturated IDE at 29 µm. The SNAP geometry and impedance-matching tapers increase the SNR of the detector's output (inset).

Antenna designs:



The optical cavity structures used with near-IR SNSPDs are impractical at long wavelengths due to absorption in the dielectrics and thicknesses required. We simulated multiple antenna-coupling schemes with connected and resonant dipole antenna arrays at 18 and 25 µm wavelengths. Coupling efficiencies of 60-80% are possible with such schemes, depending on the desired bandwidth and polarization dependence

Significance of results: As a result of this project, we demonstrated the first SNSPDs operating at wavelengths as long as 29 µm, introducing a new class of photodetector for the mid and far-infrared. The new materials developed under this program will enhance the yield of these detectors, allowing for large-scale arrays of mid-IR SNSPDs in the future. The work performed under this task enhances SNSPDs as candidate technology for future large-scale space telescopes, such as the infrared flagship mission suggested by the 2020 Decadal Survey, the proposed LIFE nulling interferometry mission, or the proposed MIRECLE exoplanet mission. In addition, long-wavelength SNSPDs may have applications in other fields such as quantum or classical optical communications, where there are advantages to operating at mid-infrared wavelengths, or for direct dark matter detection or molecular spectroscopy.

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G. G. Taylor, A. B. Walter, B. Korzh, B. Bumble, S. Patel, J. P. Allmaras, A. D. Beyer, R. O'Brient, M. D. Shaw, & E. E. Wollman. "Low-noise single-photon counting superconducting nanowire detectors at infrared wavelengths up to 29 µm," *arXiv preprint* arXiv:2308.15631. (2023).

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