National Aeronautics and Space Administration

Postdoc Research

Thermally-coupled imagers for time-resolved single-photon detection

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Background and scientific goals

Single-photon imager for a future IR/O/UV (0.2…2 μm) space telescope with:

- near-unity efficiency
- megapixel resolution
- $< 10\ \mu\mathrm{m}$ spatial resolution
- $< 10^{-2}$ dark counts/hr/px
- $> 10\ \mathrm{kHz}$ count rate/px
- few $10\mathrm{s\ of\ ps}$ timing jitter
- radiation tolerance

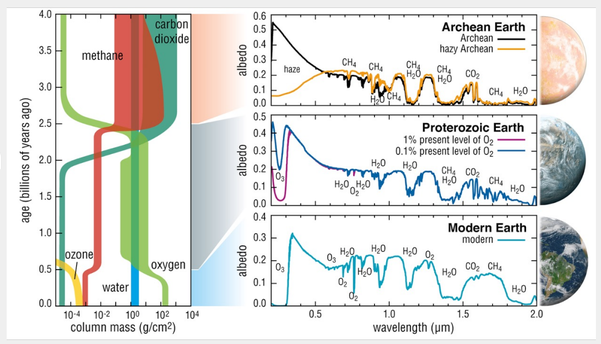
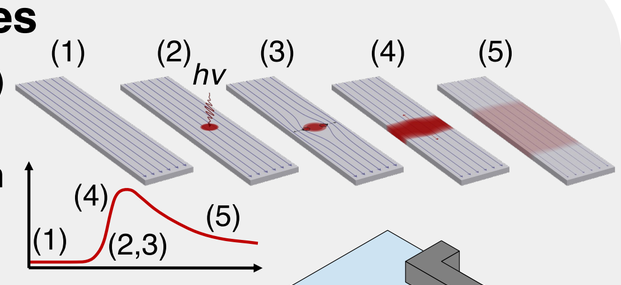


Fig. 1.1, Astro2020 report [1]

SNSPD and multiplexing principles

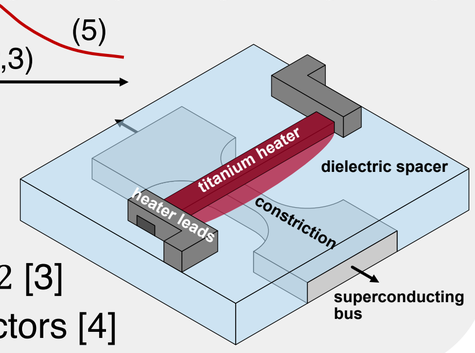
SNSPD (nanowire single-photon detector)

- current-biased superconducting nanowire
- photon absorption induces resistive region
- bias current is shunted to readout



Multiplexing

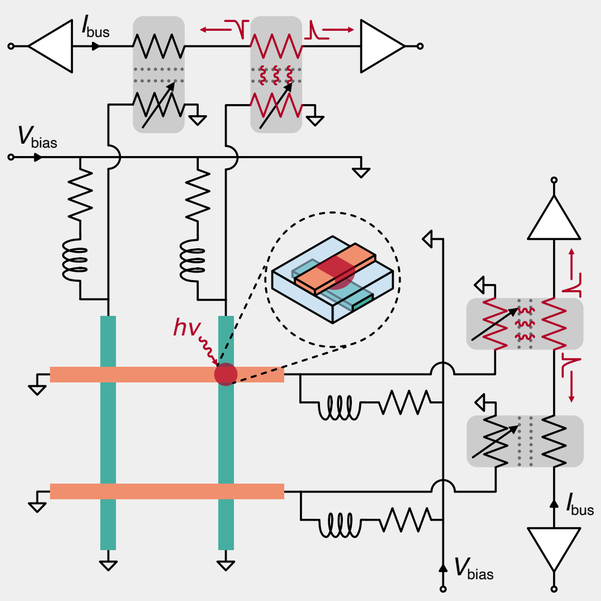
- unidirectional thermal coupling of detector signal via heater to a common superconducting bus [2]
- time-of-flight measurement: $x_\mathrm{p} = [(\tau_2 - \tau_1)v + L]/2$ [3]
- pulse coincidences between row and column detectors [4]



Detector architectures

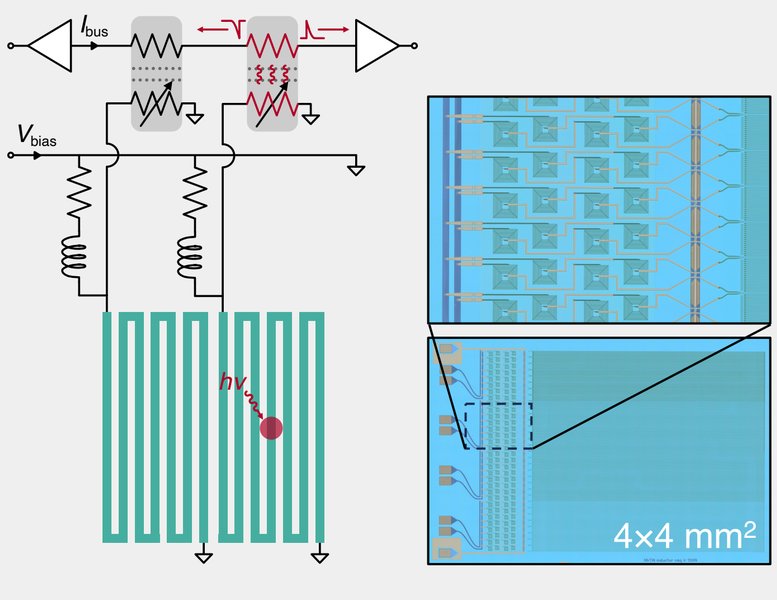
Megapixel array

- scale to megapixel array with high fill factor
- thermal coupling between stacked nanowires
- only 4 microwave lines for array readout



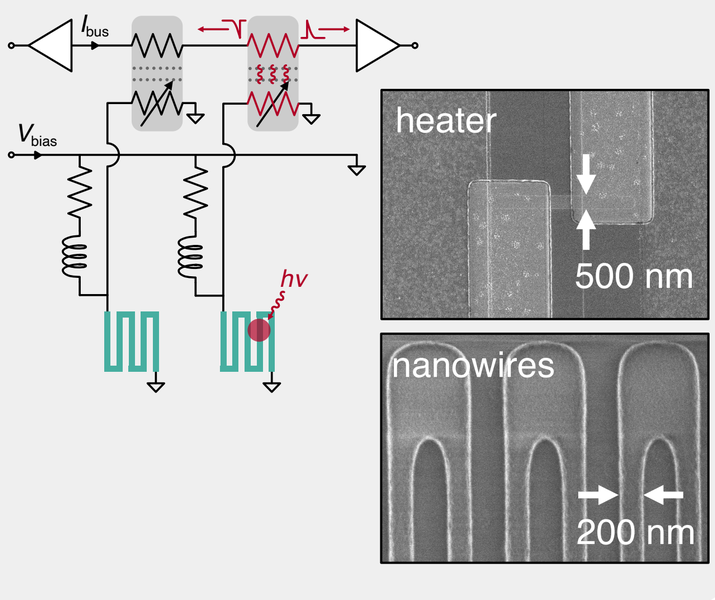
Superconducting photomultiplier

- large active area up to 10×10 mm²
- no imaging, fast bus integrates pulses, height proportional to photon number across array



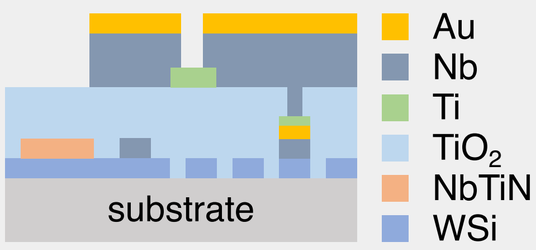
High-speed array

- 64 differential buses with 64 short nanowires each, for 4096 pixel array over ~5×5 mm²
- several GHz count rate across array

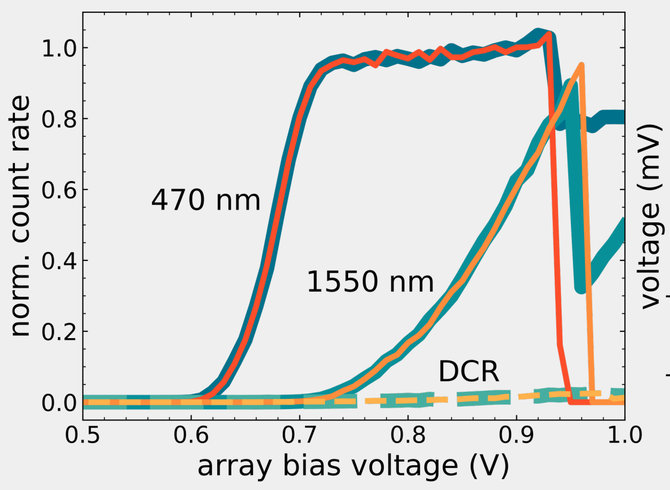


Technology development and results

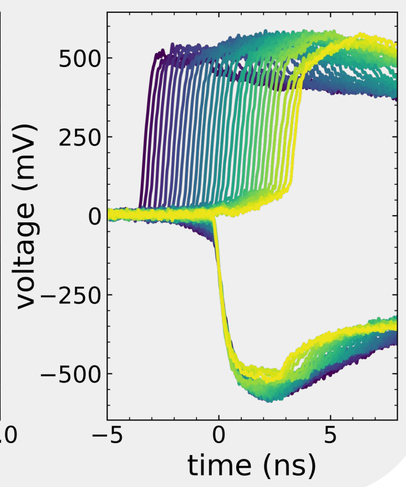
- dielectric spacer for heat transfer
- resistive thermal coupler
- superconducting vias and wires
- high-yield nanowire patterning



Comparison: **bus** vs. **direct** readout



Differential bus readout



Outlook

- ✔ reliable fabrication process
- ✔ thermal coupling to superconducting bus
- ✔ proof-of-principle readout of detector array
- ●●● minimum energy to trigger the bus
- ●●● timing characteristics of thermal coupling
- ●●● planarization process for stacked nanowires
- ●●● scaling to megapixel single-photon imager

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References

[1] National Academies of Sci., Eng., and Med., *Pathways to Discovery in Astronomy and Astrophysics for the 2020s* (2021)
[2] McCaughan *et al.*, Appl. Phys. Lett. 121, 102602 (2022)
[3] Zhao *et al.*, Nature Photonics 11, 247 (2017)
[4] Allmaras *et al.*, Nano Letters 20., 2163 (2020)

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