FY24 R&TD Innovative Spontaneous Concepts (ISC)

High-efficiency thermally coupled imager for high-contrast coronagraphs

Principal Investigator: Jason Allmaras (337); **Co-Investigators:** Emanuel Knehr (389), Crystal Kim (UCSB), Andrew Beyer (389), Boris Korzh (389), Benjamin Mazin (UCSB), Matthew Shaw (389)

Strategic Focus Area: Innovative Spontaneous Concepts

Objectives

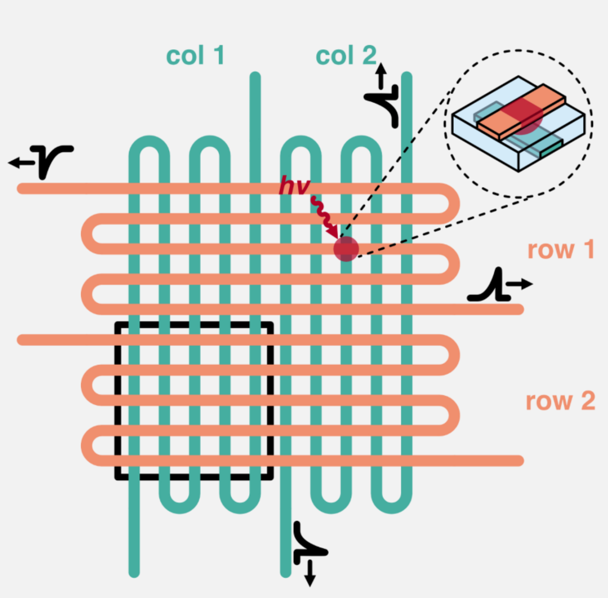
- Develop a high-efficiency SNSPD array with
  - an optical stack for efficient photon absorption in the 250 nm – 1.0 µm spectral range
  - increase the fill factor to >85%
  - increase the pixel size to 6.5 × 6.5 µm^2
- Assemble a measurement setup including a monochromator as the optical source and the RF detector readout
- Characterize the fabricated array at a relevant wavelength

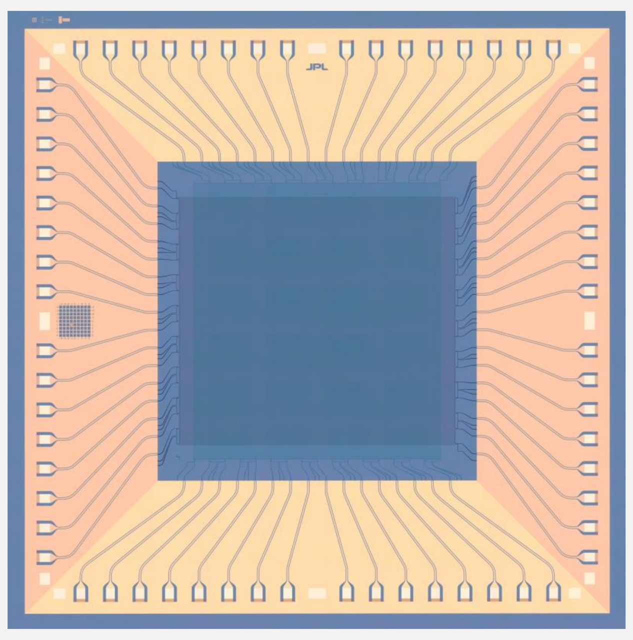
Background

The coronagraph instrument for the Habitable Worlds Observatory (HWO) will require a science camera with high detection efficiency across the UV to NIR band, near-zero read noise, and moderately large 512x512 pixel formats. Superconducting nanowire single-photon detector (SNSPDs) arrays are photon-counting sensors promising to meet these strict demands. Recently, a new time-domain multiplexing scheme has allowed to scale these arrays to 400,000 pixels with zero read noise and low dark count rates, but it was still limited in terms of efficiency across the targeted spectral range [1].

Approach and Results

Detector Architecture and Design





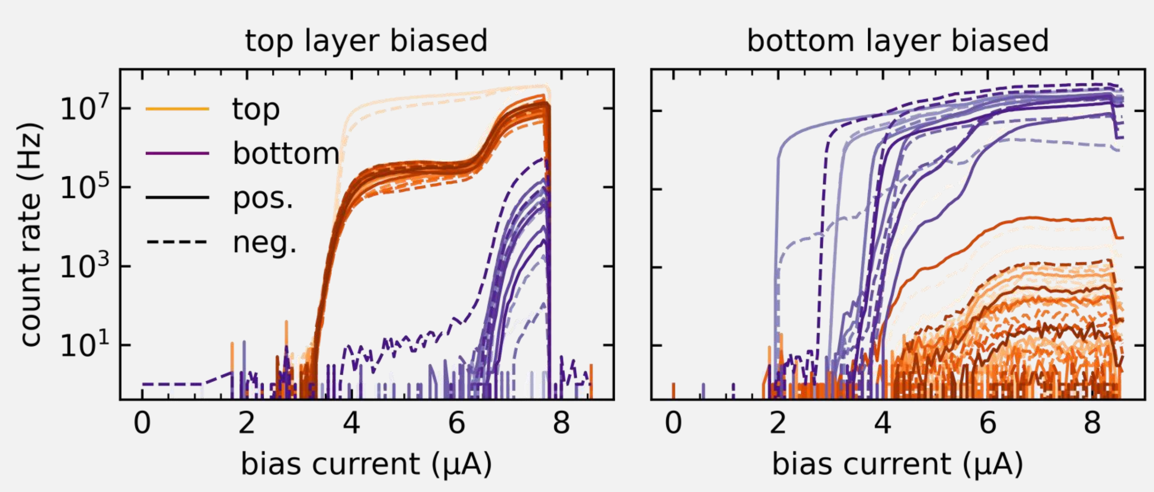
The detector array consists of a two-layer nanowire stack with rows and columns, which are thermally coupled to each other. A single absorbed photon generates four electrical pulses travelling to opposite ends of one row and one column. Time-of-flight measurement and row-column coincidences are used to map each photon event.

Specifications of the fabricated arrays:
- 2 × 2 mm^2 total active area
- 65k to 1M pixel formats
- readout with 64 RF lines

Fabrication Process Development

To fabricate efficient nanowire layers on top of each other, a 40 nm thick spin-on glass process was developed to decrease the step height of the bottom layer topography from 10 nm to 1 nm. This solved the problem of poor top layer yield experienced during previous attempts to fabricate multilayer nanowire devices.

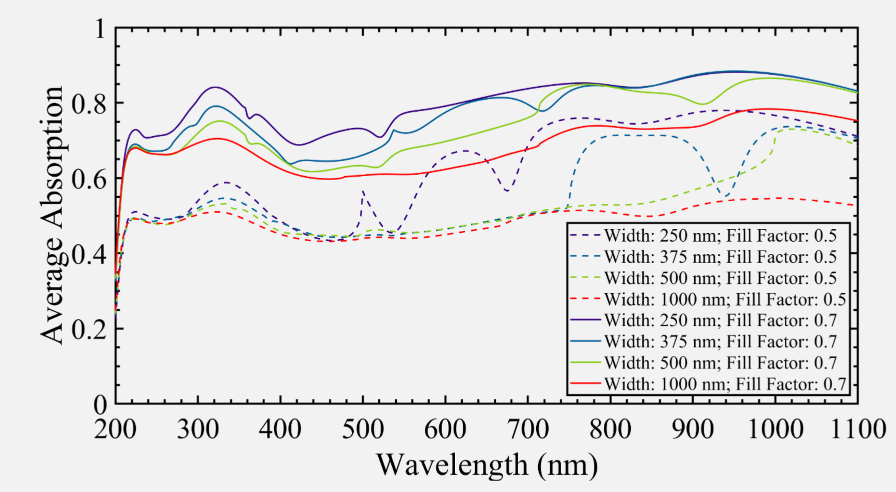
Array Characterization



The large saturated regime for the top layer devices signifies near-unity quantum efficiency at 1550 nm and below (UV/VIS/NIR). Preemptive relaxation oscillations on the bottom layer prevented operating this layer at an efficient bias point.

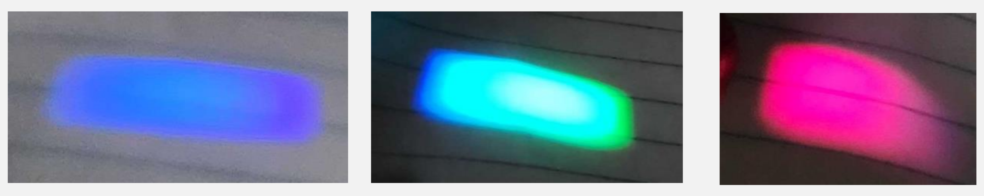
Optical Stack Modeling

To achieve high efficiency, SNSPDs are embedded in an optimized optical cavity. Optical stack designs were modeled using an Al mirror with SiO2 dielectric layers for broadband absorption. For a given nanowire fill factor, narrower wires lead to greater absorption.



Measurement Setup

Monochromator functionality was tested for detector characterization in the 250 nm – 1.0 µm spectral range.



400 nm 500 nm 700 nm

Significance/Benefits to JPL and NASA

Large format, low noise imaging arrays are one of the driving elements which will dictate the performance of next generation space telescopes. The fabrication process development and infrastructure improvements made during this program are beneficial to NASA as they better position JPL to be able to produce and test the SNSPD focal plane arrays needed for these missions. While camera for the coronagraph instrument for the HWO mission was focus of this work, the process development from this program is directly transferrable to larger format SNSPD arrays which could be optimized for wavelength ranges from the deep UV through the near-infrared, and potentially into the mid-infrared. Accurately measuring device performance through laboratory experiments is crucial for modeling the science yield of planned missions.

National Aeronautics and Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

www.nasa.gov

RPD-062 Clearance Number: CL#24-5047

References

[1] Bakhrom Oripov, Dana Rampini, Jason Allmaras, Matthew Shaw, Sae Woo Nam, Boris Korzh, and Adam McCaughan, “A superconducting nanowire single-photon camera with 400,000 pixels,” *Nature* **622** (Oct 25, 2023): pp. 730-4.

PI/Task Mgr. Contact Information:

Jason Allmaras: *(818) 393-7384*
jason.p.allmaras@jpl.nasa.gov