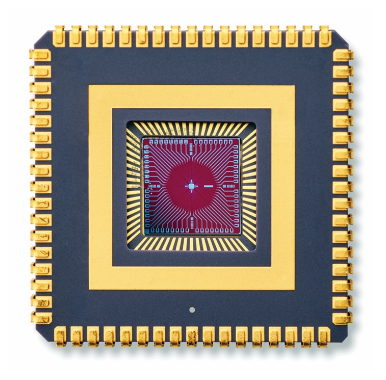
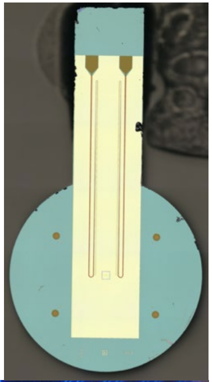
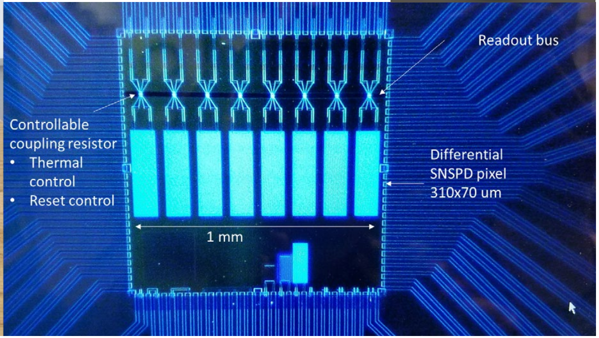






Virtual Research Presentation Conference

Next-Generation Deep Space Optical Communication Ground Terminals

Principal Investigator: Matt Shaw (389)
Co-Is: Ryan Rogalin (332), Abi Biswas (337), Andrew Beyer (389), Bruce Bumble (389) Boris Korzh (389)
Program: Strategic Initiative

Assigned Presentation # RPC-181

Jet Propulsion Laboratory
California Institute of Technology

Tutorial Introduction

Deep space optical communication is a critical new technology which can enable **order of magnitude improvement in data volumes** from deep space

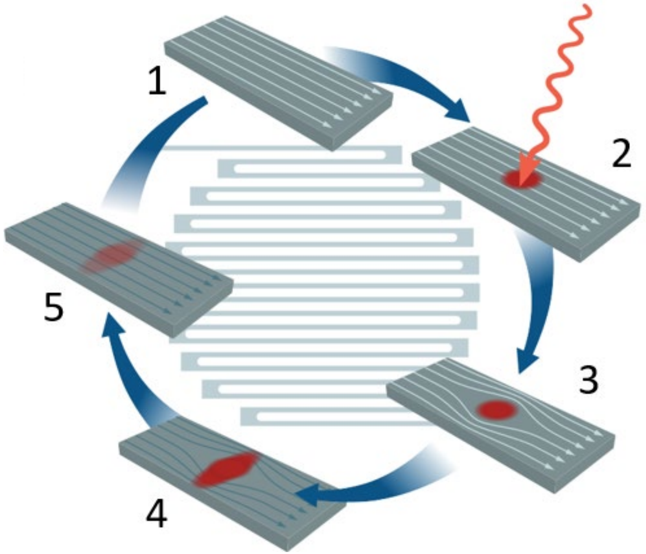
New technologies are necessary on the ground to implement a future **optical Deep Space Network** in the coming decade

This task seeks to develop **larger, faster detectors** to accommodate larger telescope apertures than have been used in previous demonstrations

Performed basic development of new nanofabrication processes for the next generation of **superconducting nanowire single photon detectors**, which are the highest performing detectors for time-resolved single photon counting available in the near infrared

Also received **fast readout electronics** to handle larger signal fluxes

Work in future years will also focus on **advanced filters** to reject background, **novel architectures** for signal processing, and **mitigation of atmospheric effects** in uplink systems.



SNSPD Operating Principle

Problem Description

Context

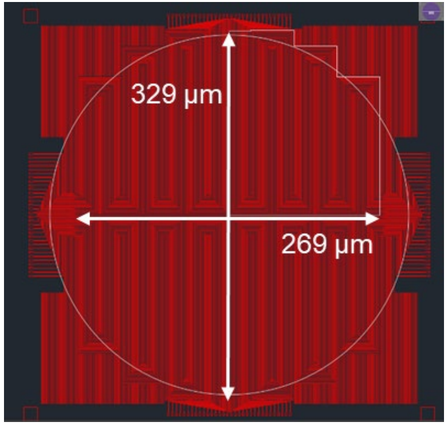
Future deep space optical communication systems will rely on cutting-edge technology in both the flight and ground systems. The goal of this task is to develop the most advanced possible technology for **ground systems** in order to take maximum advantage of costly space assets. Specifically, this task seeks to develop detectors with an active area as large as 2 mm in diameter, with maximum count rates of 6 Gcps, as well as signal processing electronics and algorithms capable of handling such large data streams.

Comparison with State of the Art

The JPL-led DSOC project is the first demonstration of free-space optical communication from deep space, operating at ~1000x the range of any previous demonstration. The DSOC downlink receiver at Palomar Observatory features an 0.3 mm diameter detector with a ~1 Gcps maximum count rate, and comparable FPGA-based readout electronics.

Relevance

Optical communication represents the future of the Deep Space Network in the coming decades. The technology developed under this task has multiple opportunities for infusion in the coming years, including in the RF/Optical Hybrid project and potential DSOC follow-ons.



64-pixel JPL SNSPD Array for DSOC

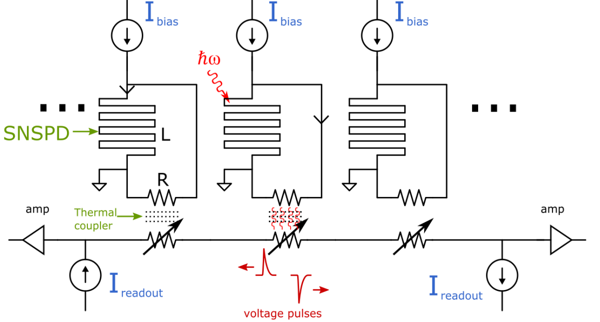
Future infusion opportunities in DSN

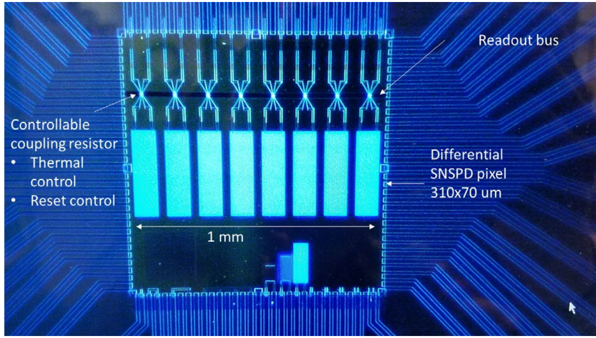
Methodology

Several basic strategies have been employed to make detectors which are both larger and faster at the same time:

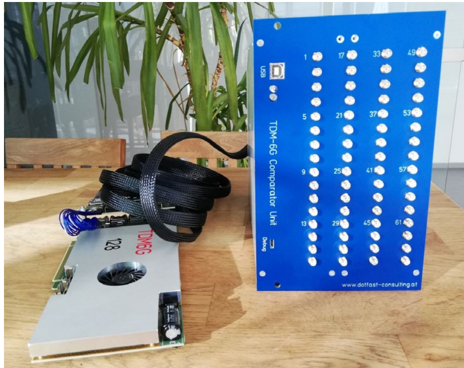
- Exploration of **new materials** such as Si-rich WSi, small-crystal NbN, and small-crystal NbTiN to reduce reset time and enhance detector yield, and **new geometries** such as ultra-thin micron-width wires
- Investigation of a new **multiplexing scheme** (the “thermally coupled imager”) which allows cryogenic fanout of many nanowires onto a single readout line, making the best use of the available readout bandwidth
- Exploration of **advanced lithography techniques** such as atomic layer etching and self-aligned double patterning to create robust dielectric hardmasks, improving nanowire uniformity and yield compared to conventional techniques with organic resists

In addition, we have worked with an outside contractor to develop an FPGA-based time-to-digital converter (TDC) capable of time-tagging 6.5 billion events per second with 25 picosecond accuracy, over a 100 Gbps data pipeline. This represents a 7-fold increase in event rate compared to the state-of-the-art readout electronics used in DSOC.





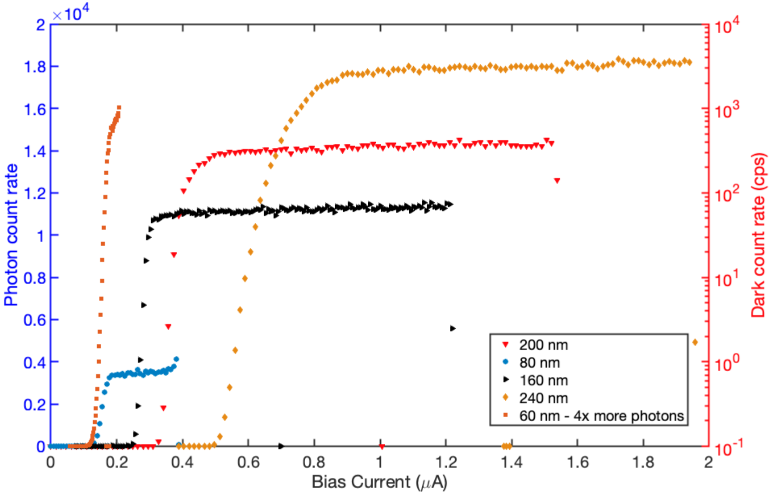
Thermally coupled imager concept and test structure



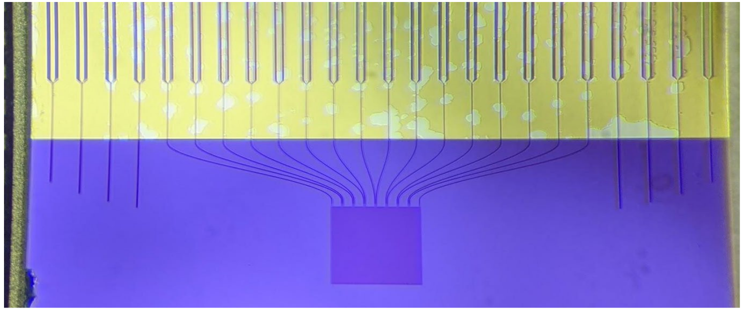
6.5 Gtps TDC
(Dotfast Consulting)

Results

- Performed studies of ultra-wide nanowires (up to 4 microns in width) fabricated from 3-nm WSi (in collaboration with NIST), enabling larger device active area
- Fabricated mm-square test structures using wide WSi wires to demonstrate device yield over large areas
- Developed deposition processes for small-crystal NbN and NbTiN, and Si-rich WSi with two different stoichiometries. Fabricated test structures and evaluated suitability of new materials for SNSPD fabrication.
- Designed, fabricated, and tested TCI test structures for on-chip thermal multiplexing. Developed detailed microscopic theory for TCI operation, the results of which were fed directly back into design
- Performed process development for hardmask lithography, including atomic layer etching and self-aligned double patterning
- Obtained experimental 6.5 Gtps time-to-digital converter hardware at JPL



Test results from low-gap WSi devices at various widths



mm-square area test structures to demonstrate device yield

Publications and References

Publications based directly on RTD research

Chiles, J., et al. "Superconducting microwire detectors based on WSi with single-photon sensitivity in the near-infrared." *Applied Physics Letters* 116.24 (2020): 242602.

Other related publications on JPL SNSPD technology in FY20

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Allmaras, Jason P., et al. "Demonstration of a Thermally Coupled Row-Column SNSPD Imaging Array." *Nano letters* 20.3 (2020): 2163-2168.

Zhu, Di, et al. "Resolving Photon Numbers Using a Superconducting Nanowire with Impedance-Matching Taper." *Nano Letters* 20.5 (2020): 3858-3863.

Wang, Xiaoxi, et al. "Oscilloscopic Capture of Greater-Than-100 GHz, Ultra-Low Power Optical Waveforms Enabled by Integrated Electrooptic Devices." *Journal of Lightwave Technology* 38.1 (2020): 166-173.

Caloz, Misael, et al. "Intrinsically-limited timing jitter in molybdenum silicide superconducting nanowire single-photon detectors." *Journal of Applied Physics* 126.16 (2019): 164501.