Large-Area 64-pixel Array of WSi Superconducting Nanowire Single Photon Detectors

Conference on Lasers and Electro-Optics

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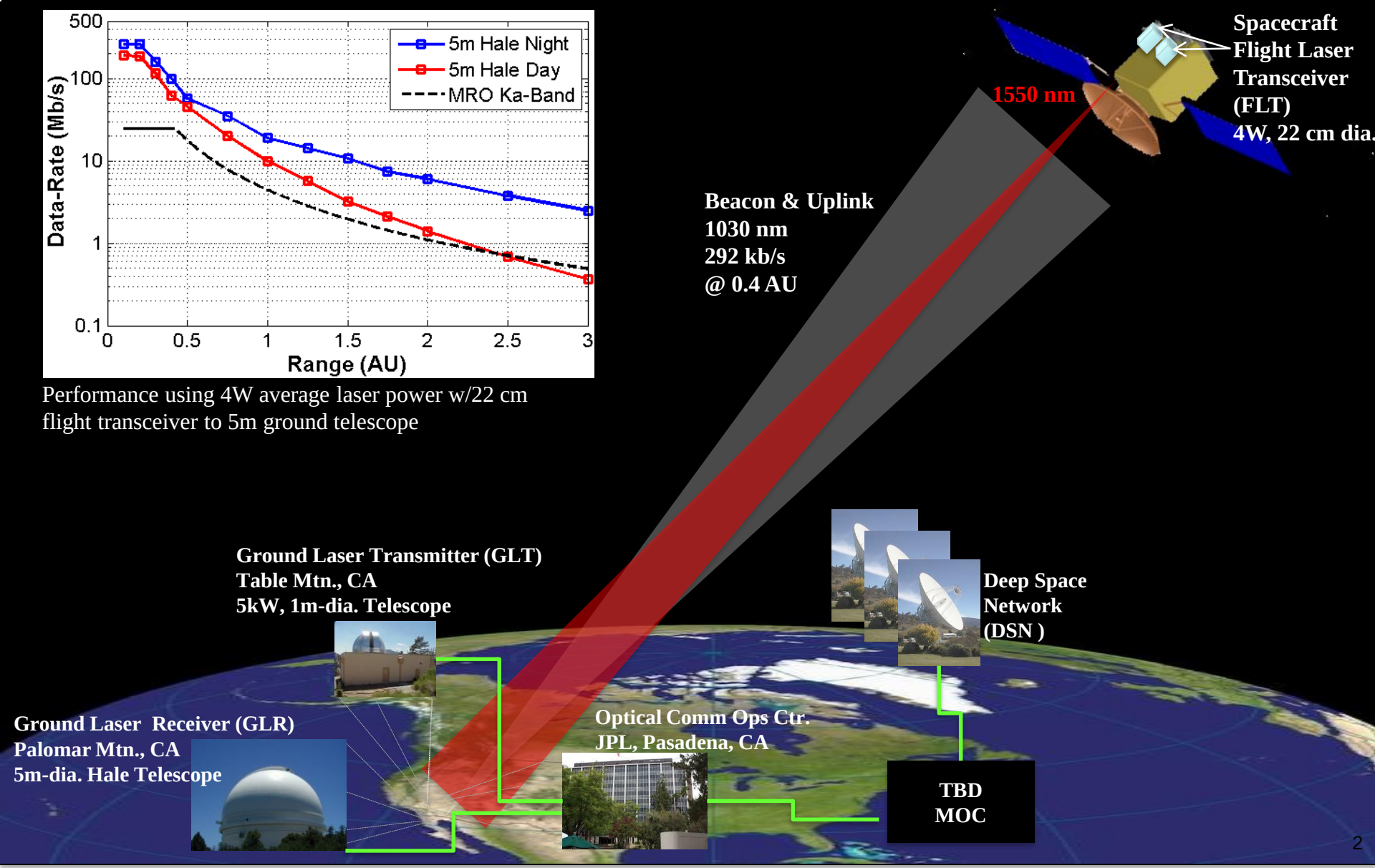
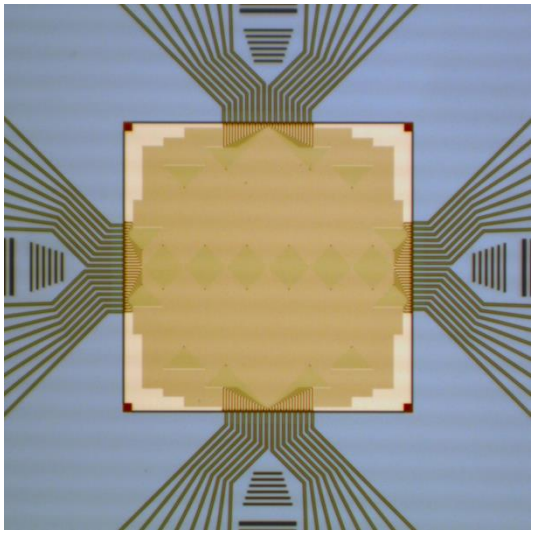
DSOC Project Overview

Performance using 4W average laser power w/22 cm flight transceiver to 5m ground telescope

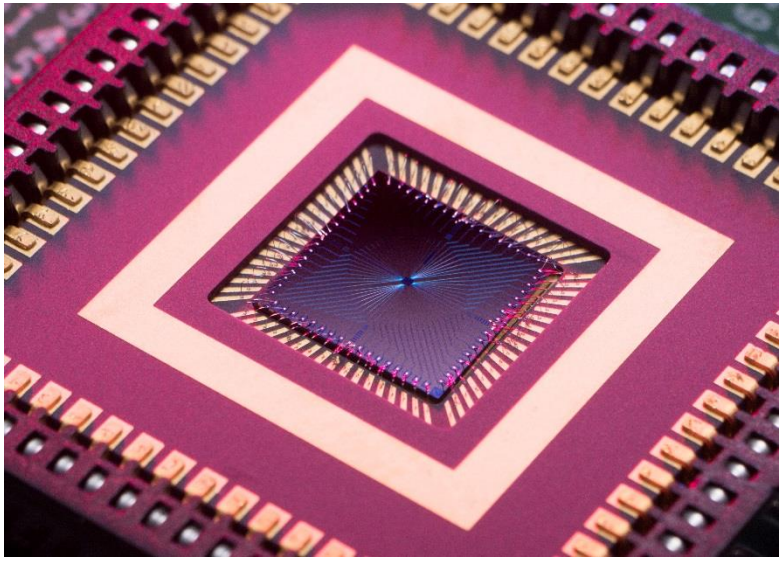


Superconducting Nanowire Single Photon Detectors (SNSPDs)

- SNSPDs are the **highest performing** single photon detectors available in the infrared (efficiency, count rate, timing jitter, dark counts)
- They operate at deep cryogenic temperatures (~1 K) and are being developed for use on the **ground** for deep space optical communication
- SNSPD arrays with **sufficient active area** to couple to a 5-meter telescope and support **gigacount-per-second** count rates are a **completely new technology.**

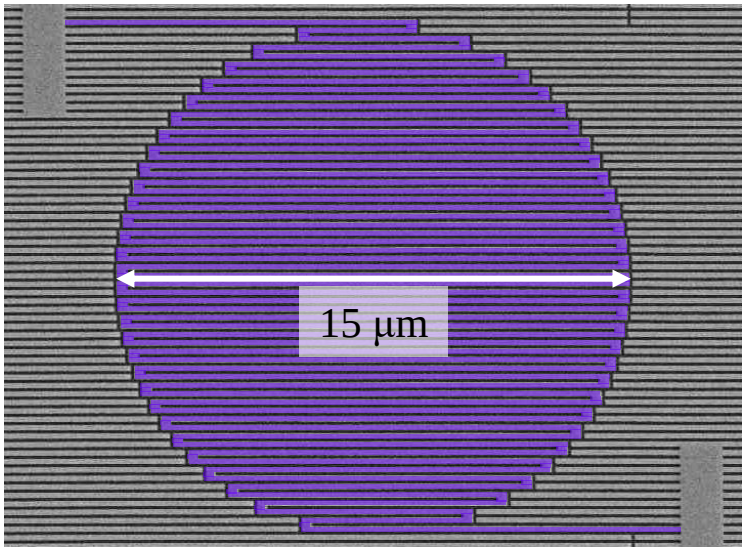


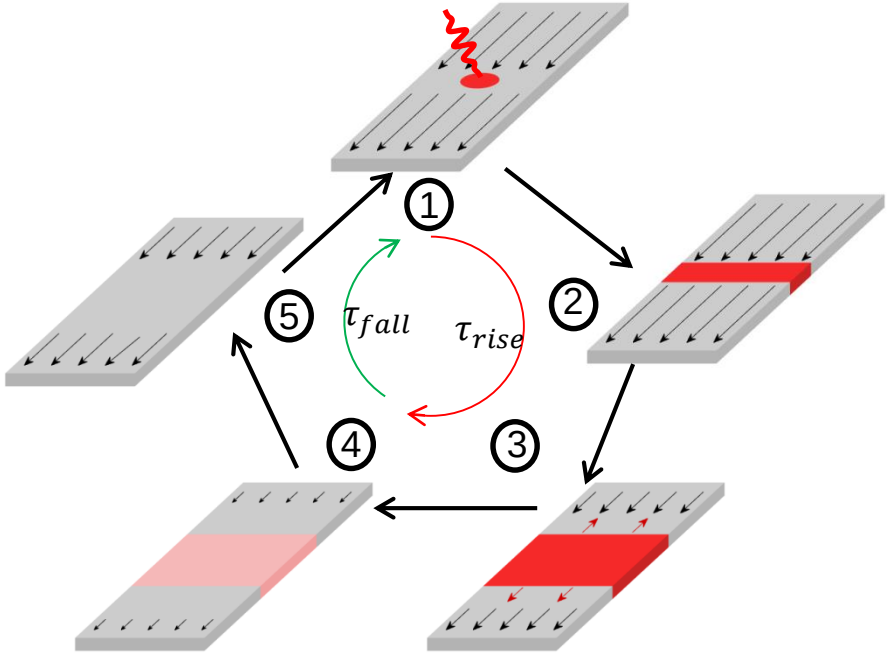
64-pixel WSi SNSPD array with 320-µm diameter active area

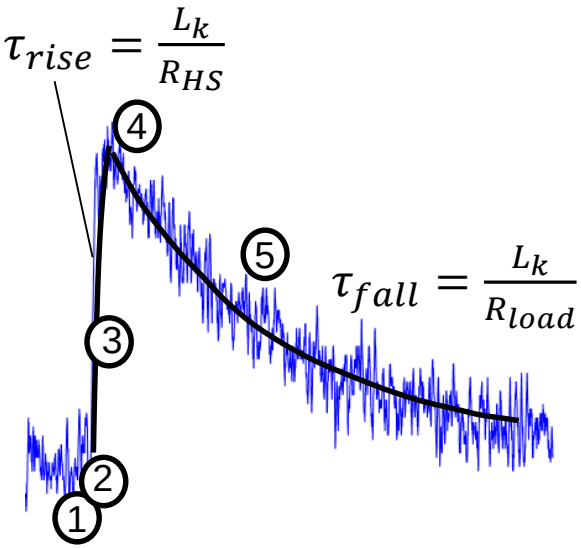


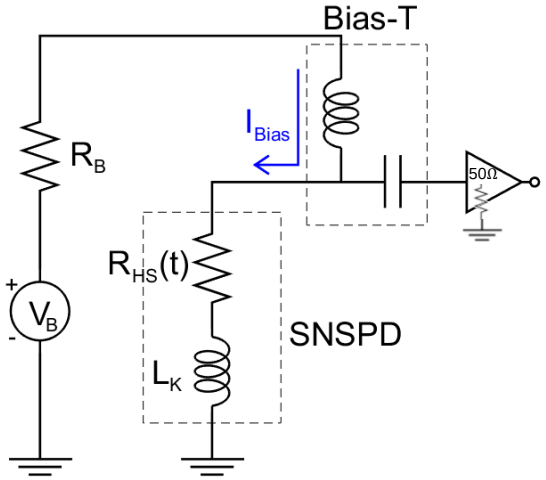
64-pixel SNSPD array bonded in chip carrier package

SNSPD Physics and Operation

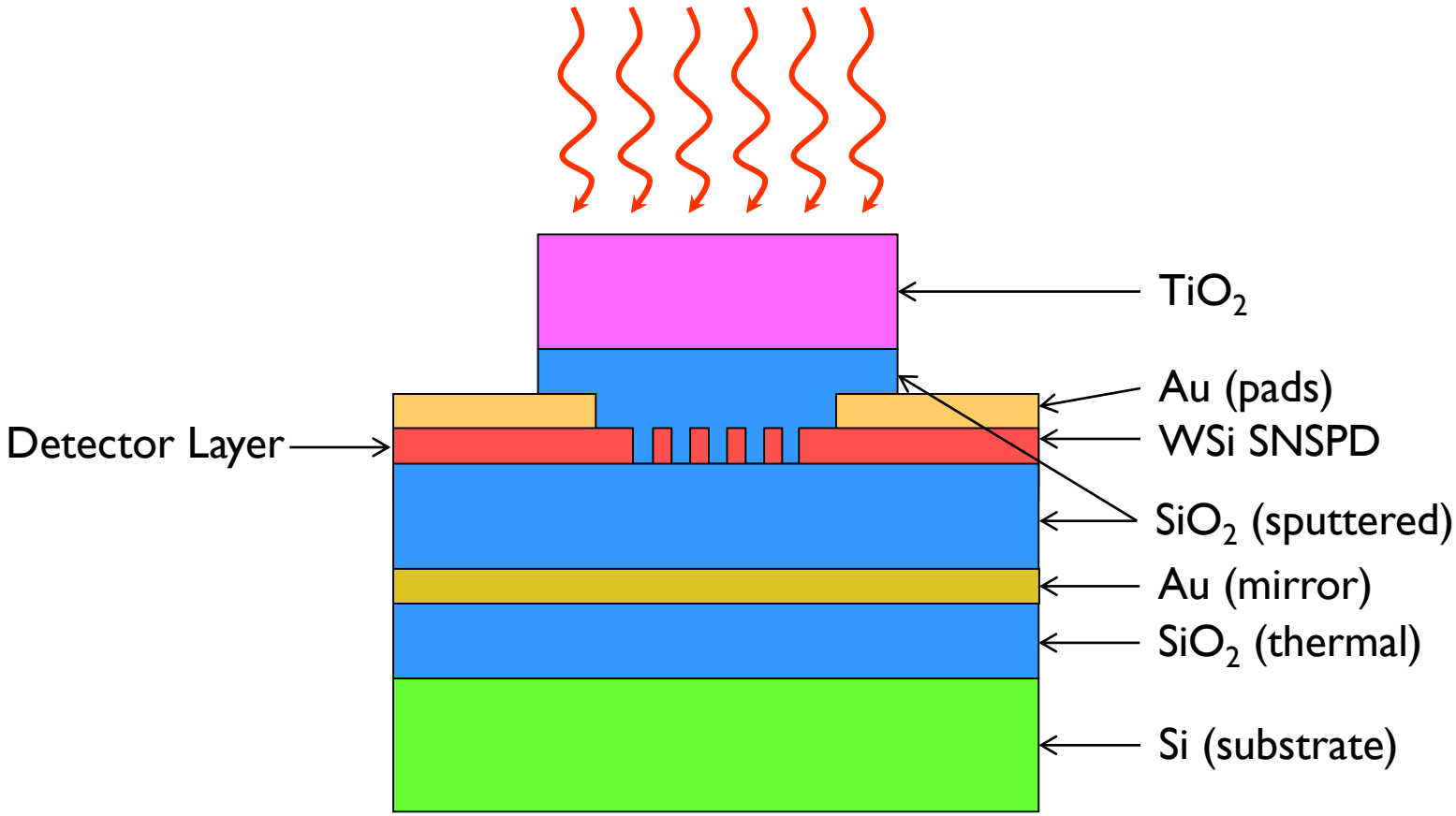








Optical Cavity to Enhance Absorption



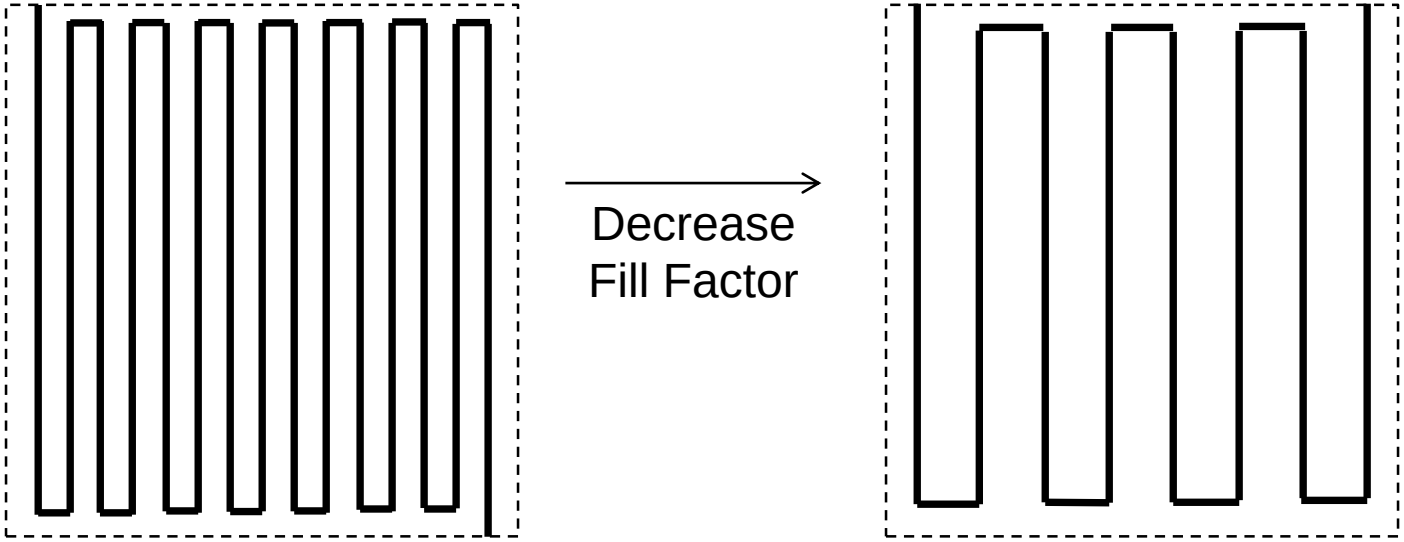
- Photosensitive nanowire element is embedded in a vertical quarter-wave cavity
- Enhances detection efficiency from 20% to >90%

Low Nanowire Fill Factor Tradeoff

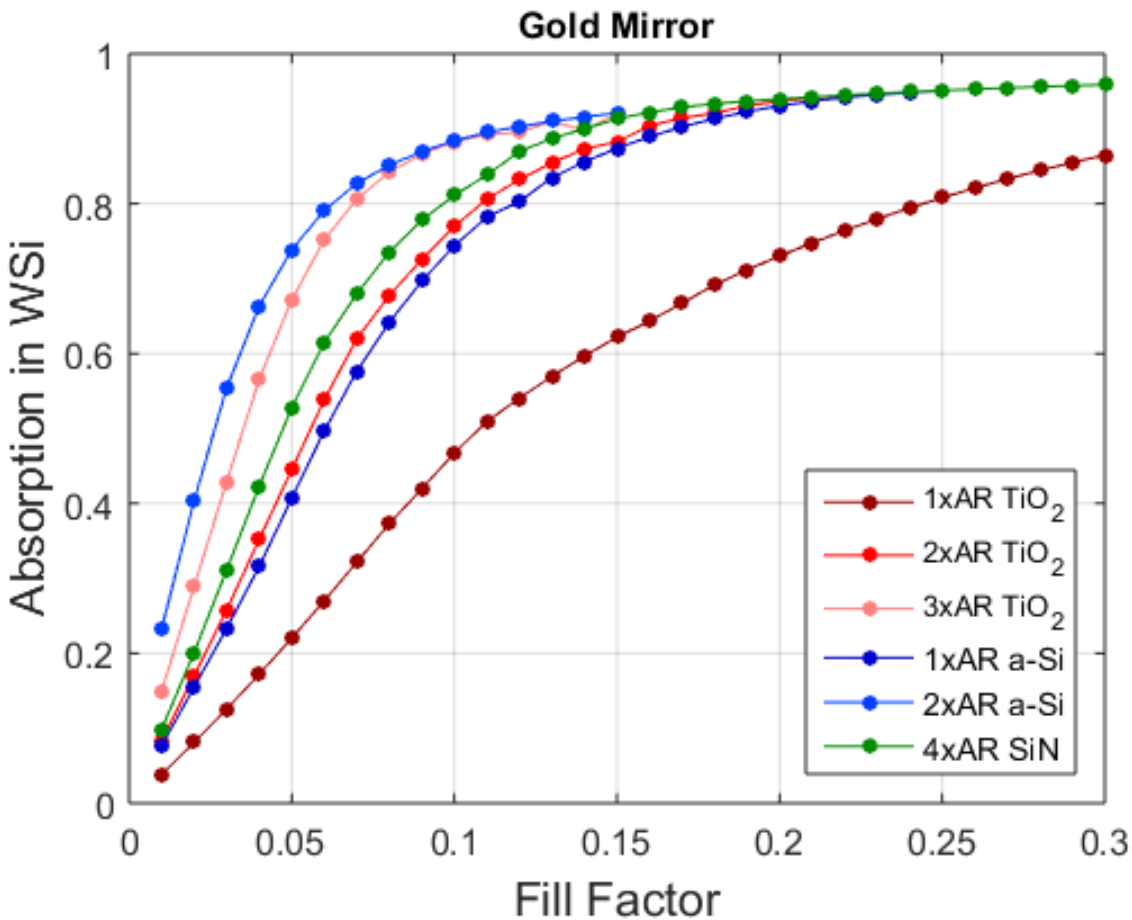
- For a given active area, decreased fill factor:
  - Decreases pixel number of squares
    - Increases maximum count rate
    - Decreases noise induced timing jitter
    - Improves device yield
  - Reduces pixel crosstalk
  - **Reduces optical coupling efficiency**

$$\mathrm{MCR} \sim \frac{1}{\tau_{dead}} \sim \frac{1}{\tau_{fall}} \sim \frac{R_{load}}{L_k}$$

$$Jitter_{rms} = \frac{V_{rms}}{\mathrm{SlewRate}} \sim \frac{V_{rms}}{1/\tau_{rise}} \sim \frac{L_k}{R_{HS}}$$

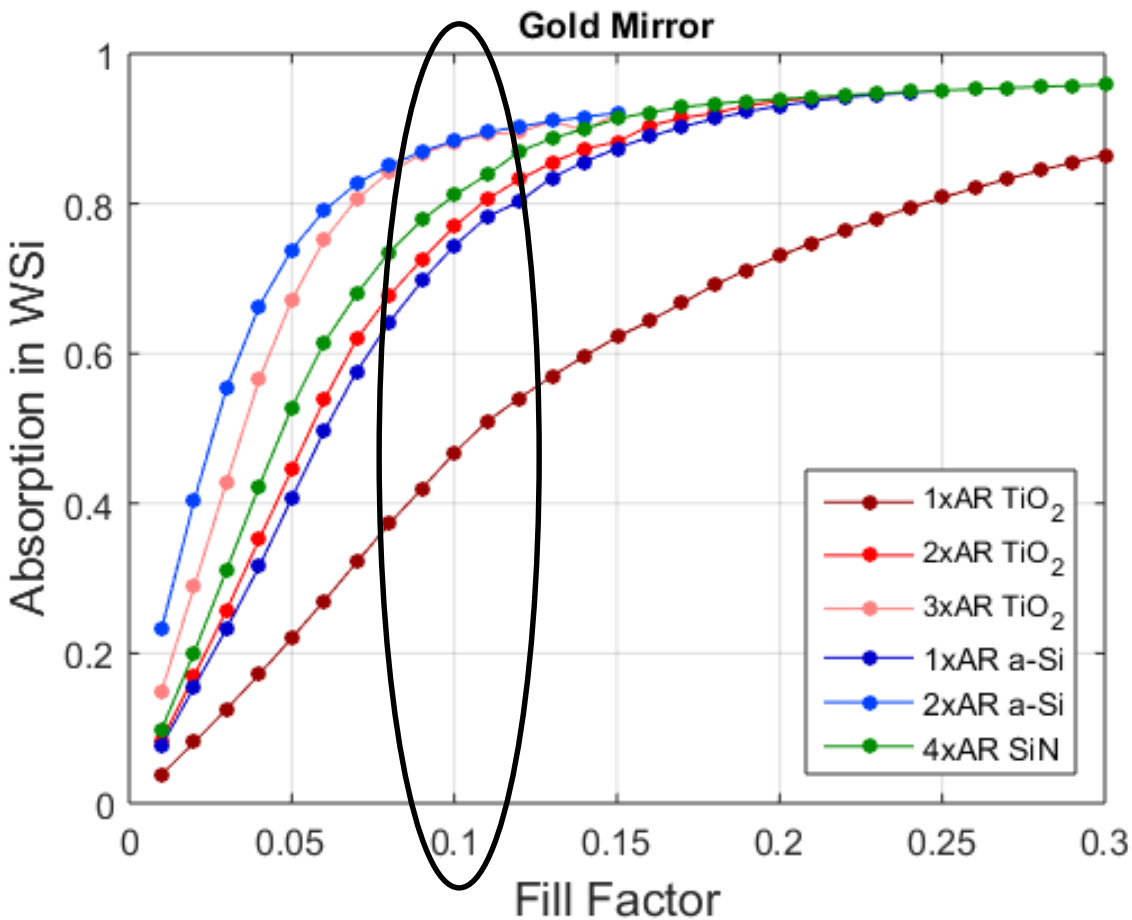


Optical Design



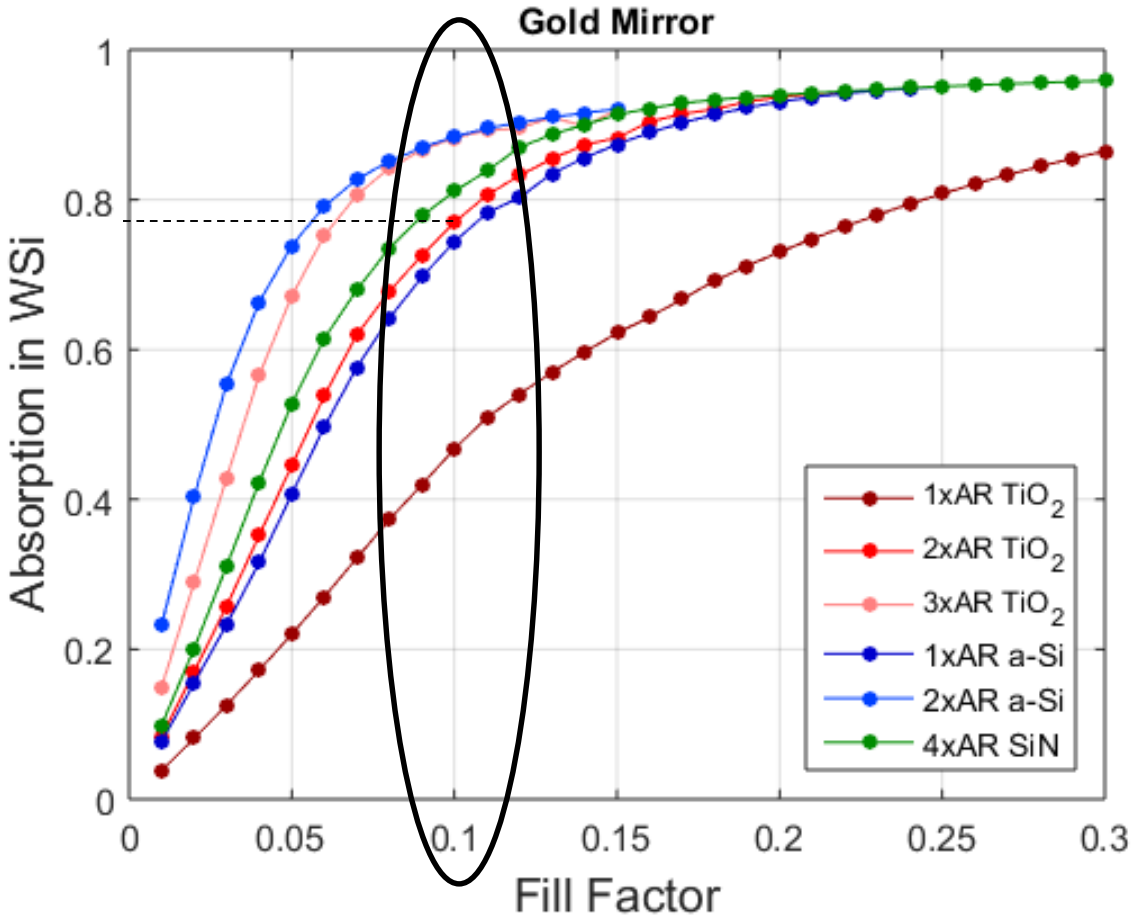
- Simulated optimized optical stacks using RCWA software

Optical Design



- Simulated optimized optical stacks using RCWA software
- Thermal crosstalk nonexistent at 10% fill factor

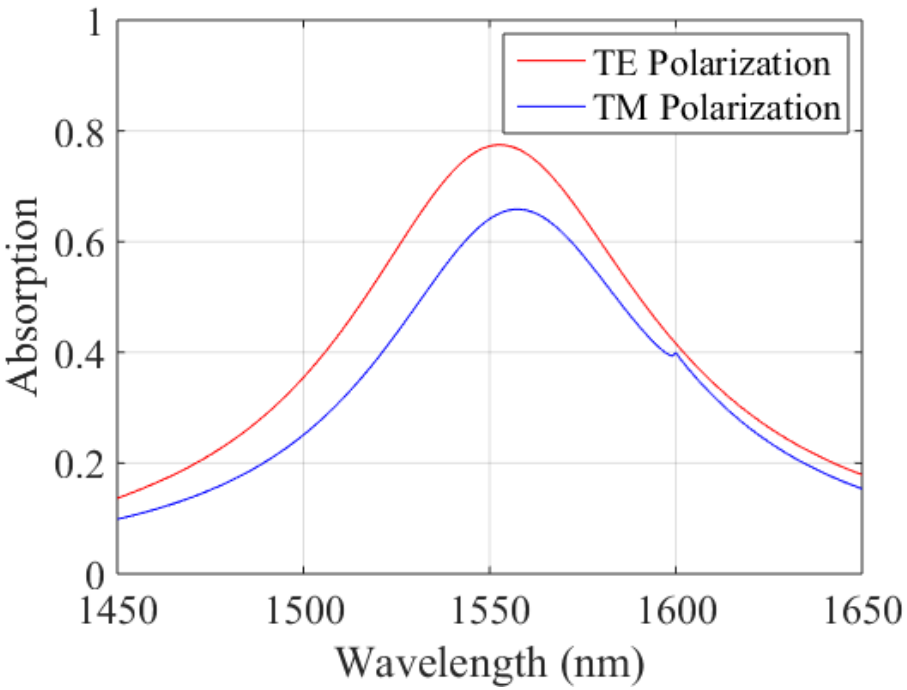
Optical Design



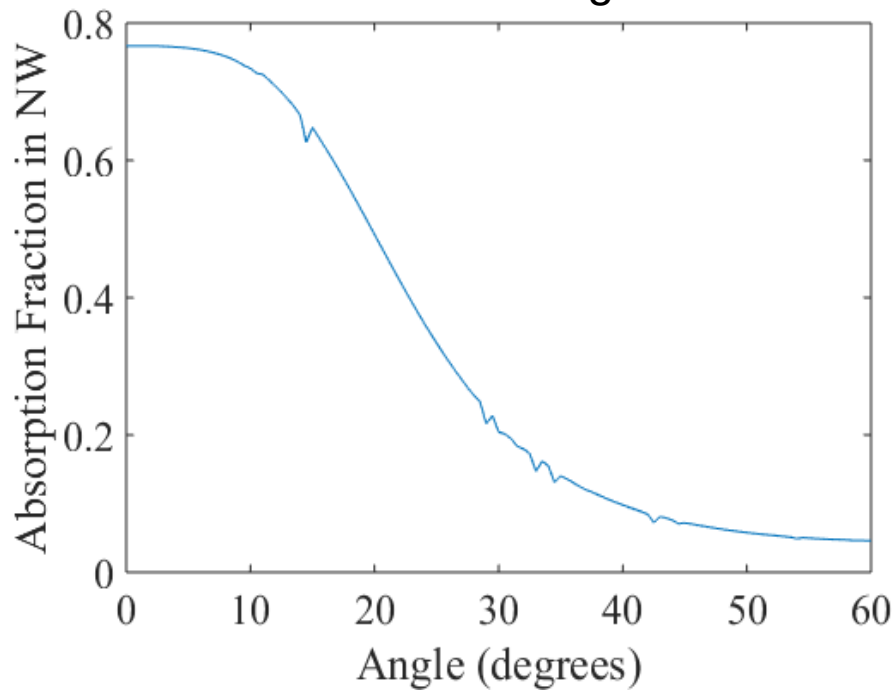
- Simulated optimized optical stacks using RCWA software
- Thermal crosstalk nonexistent at 10% fill factor
- 2x AR of TiO_2 and SiO_2 provides a balance of performance and fabrication simplicity

Optical Design

Simulated Absorption vs Wavelength



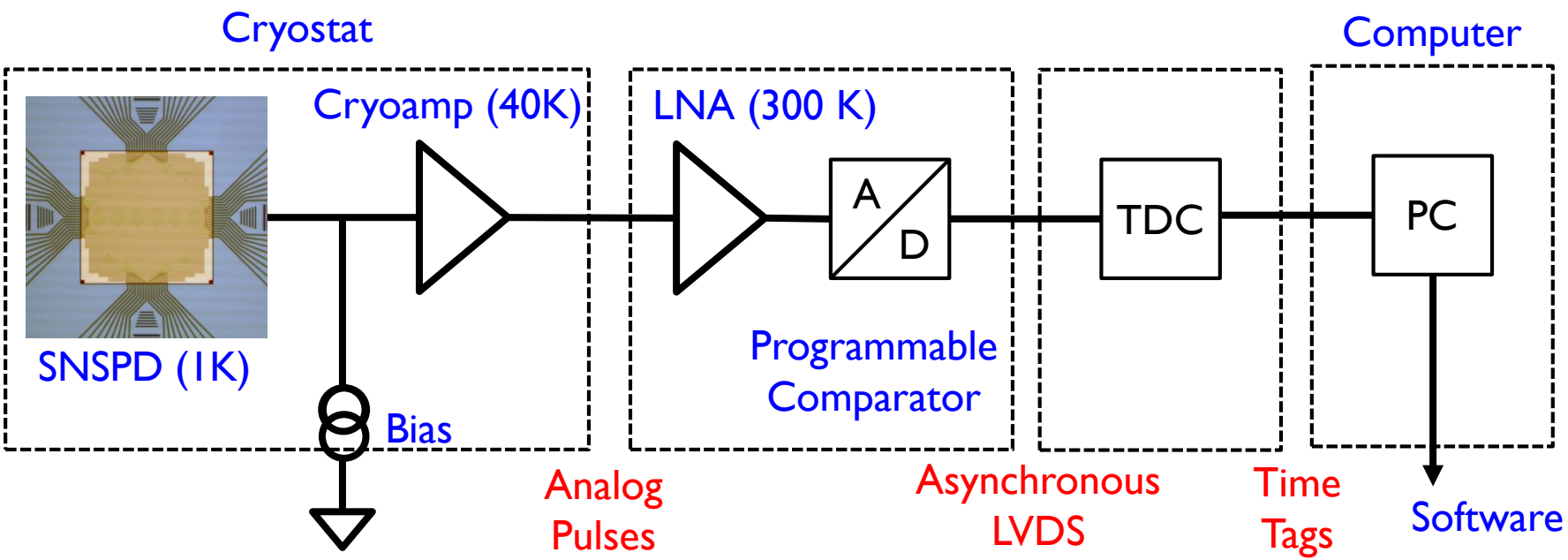
Simulated Absorption vs Incident Angle



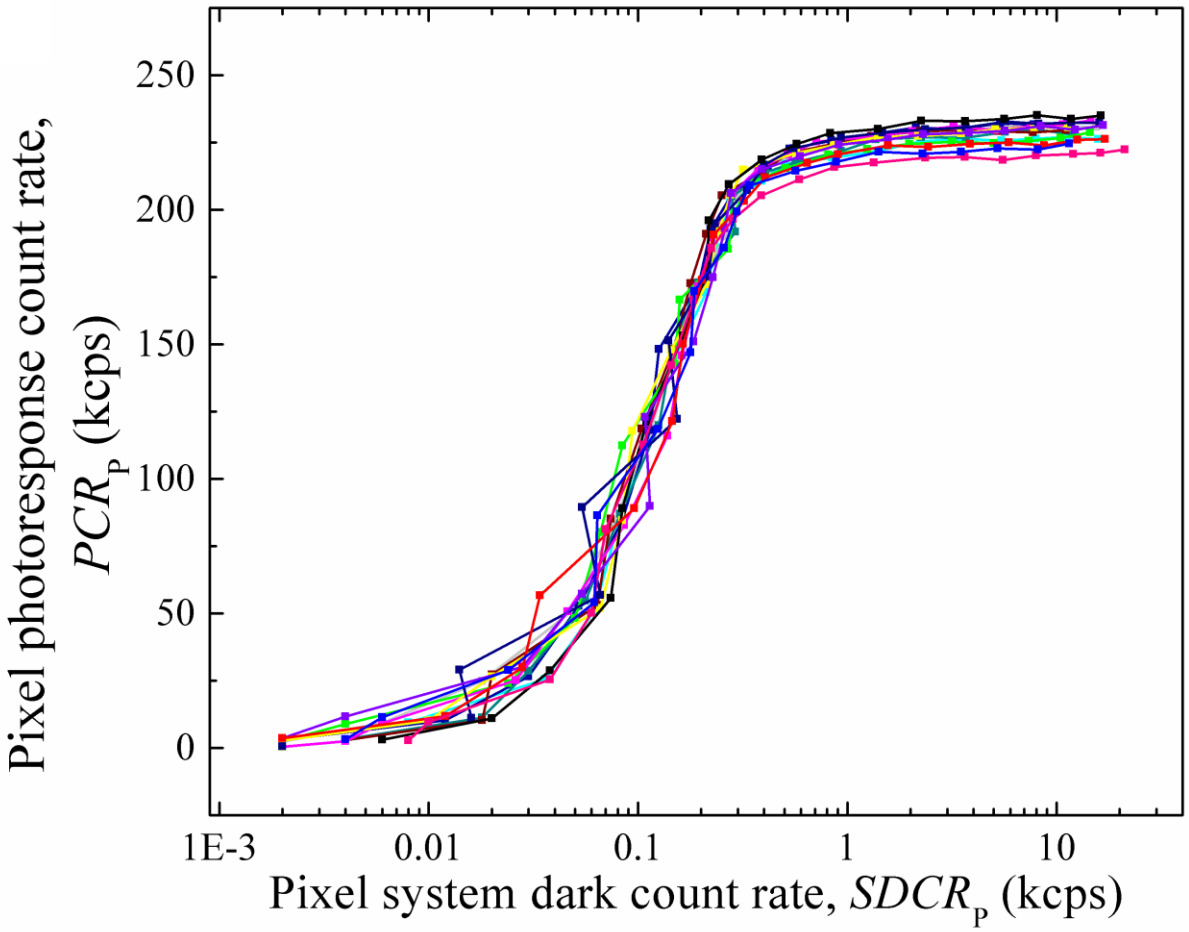
- Simulated optical performance for 2x AR of TiO_2 and SiO_2 optical cavity suggests 78% efficiency at normal incidence at 1550 nm

SNSPD Readout Concept

- Reading out a 64-pixel SNSPD array is a nontrivial engineering challenge
- To maintain high time resolution and maximum count rate, each pixel requires its own readout channel with ~2 GHz bandwidth

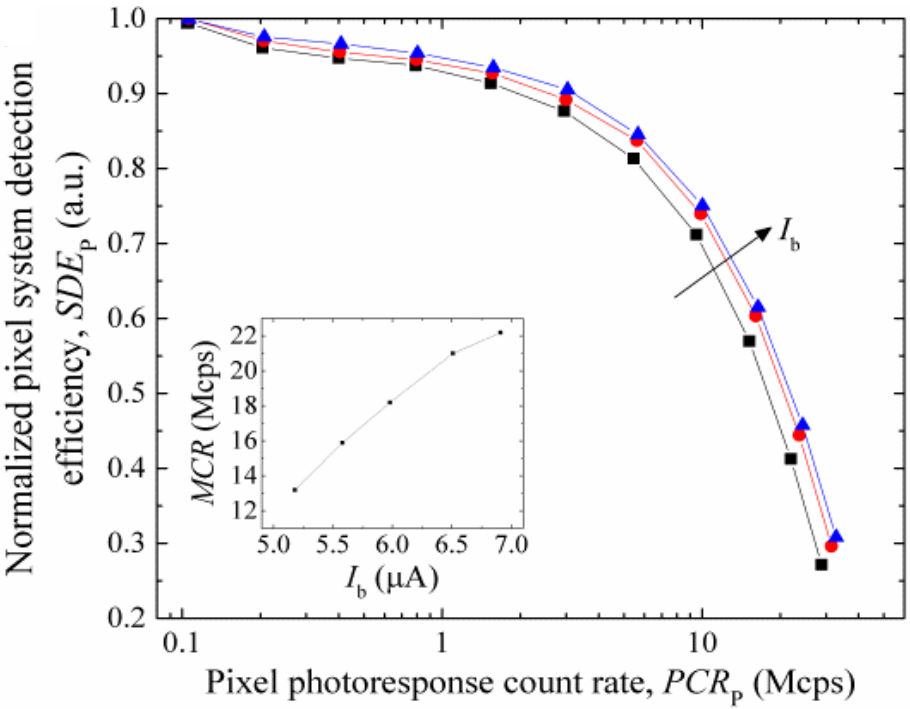


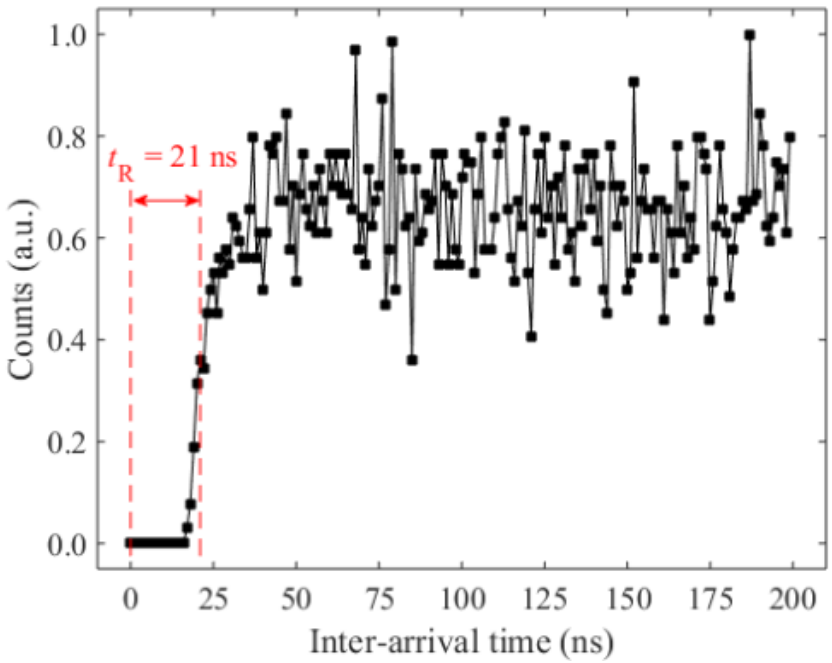
Dark Count Rate



- Dark count rate is limited by background
- Less than 20 kcps per pixel measured at the highest bias levels

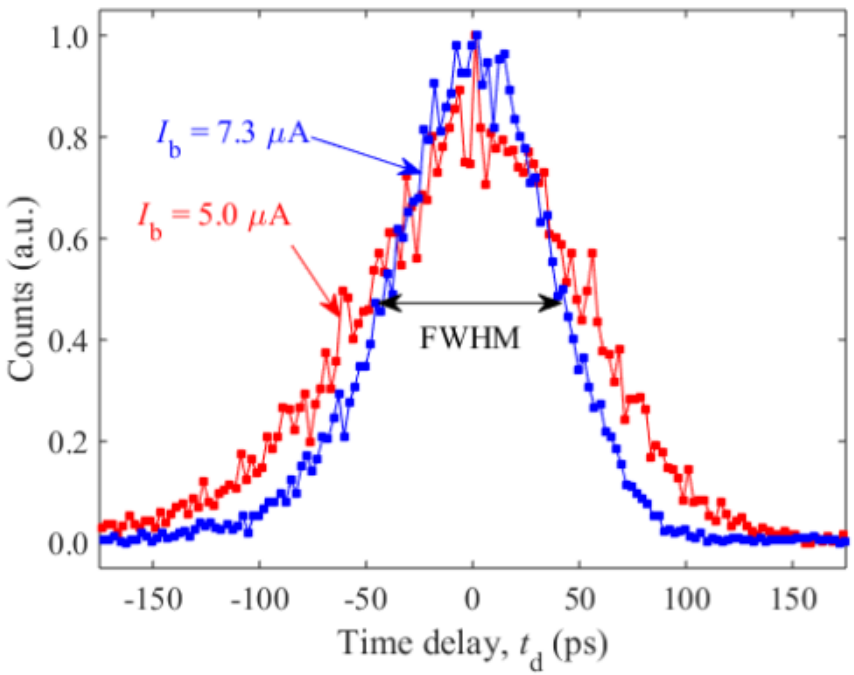
Maximum Count Rate

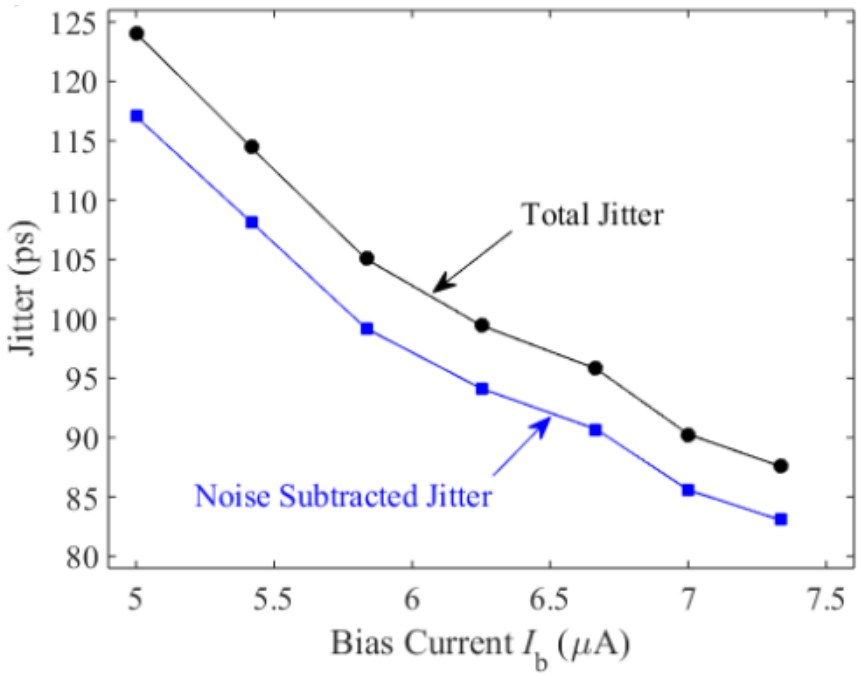




- 3dB MCR of 15 Mcps at the back of the plateau, 22 Mcps at the front
- Data taken through prototype DC coupled cryogenic amplifier chain at 40K
- For 60 working pixels, this gives an array MCR of 900 Mcps at the back, 1.3 Gcps at the front

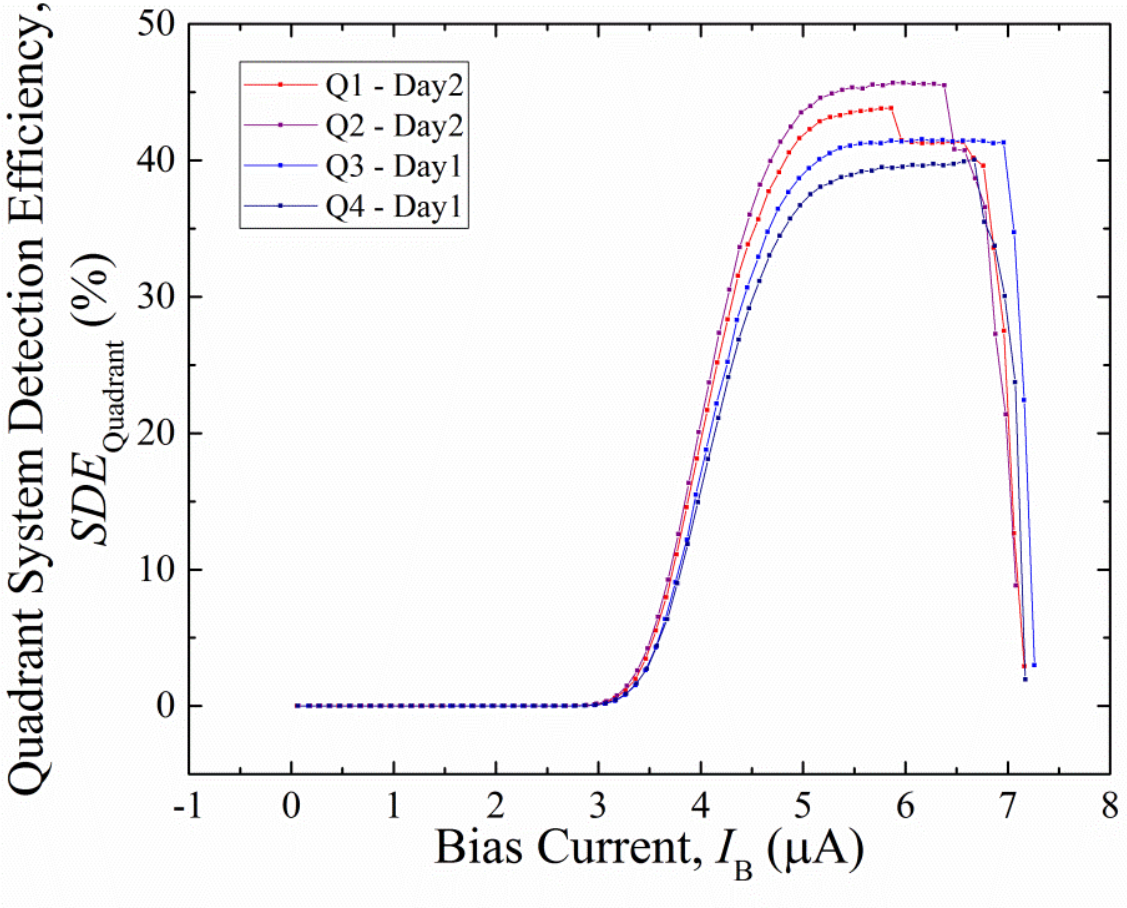
Timing Jitter through Cryoamps





- Timing jitter 125 – 90 ps FWHM across the plateau, or 53 – 38 ps 1-sigma
- Easily meets DSOC requirement of 150 ps 1-sigma
- Jitter is nearly Gaussian at high bias

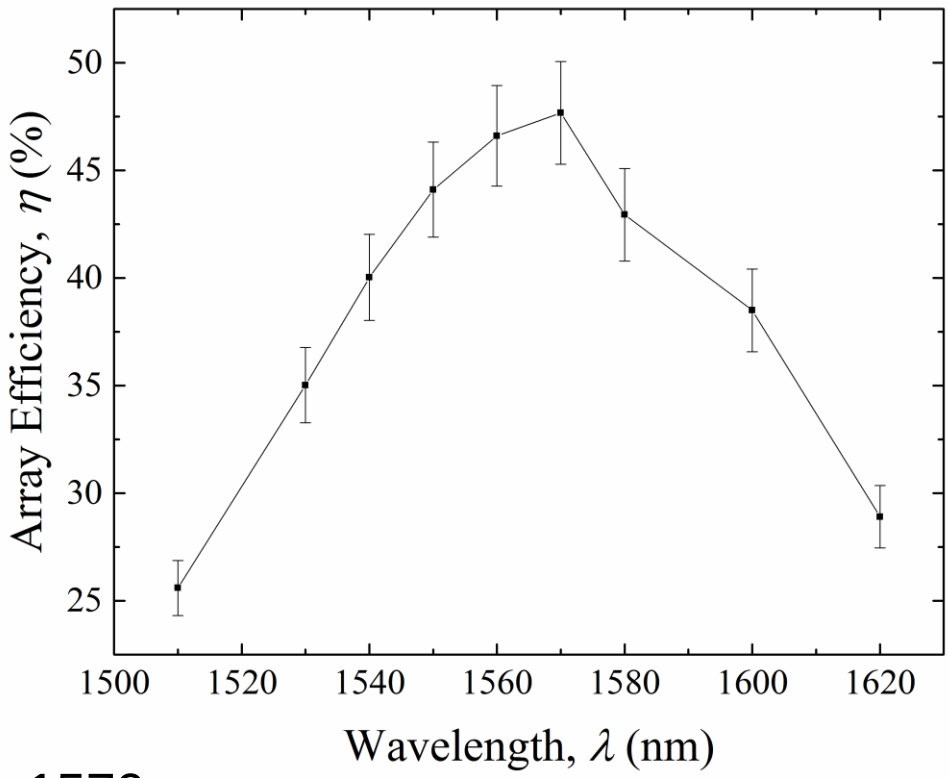
Efficiency



- 43% Efficiency (~ 10% uncertainty)
- Measurements taken over 2 cooldowns due to limited readout lines available
- 63/64 pixels measured saturated internal efficiency

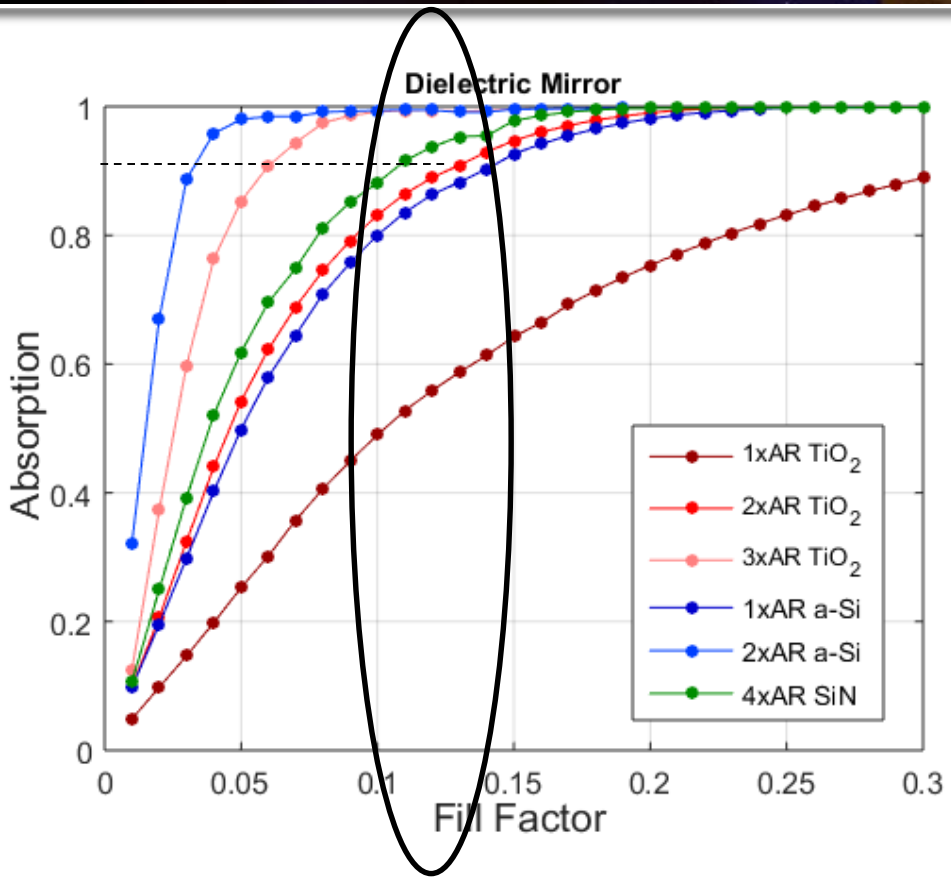
Reasons for Low Efficiency

Efficiency vs Wavelength



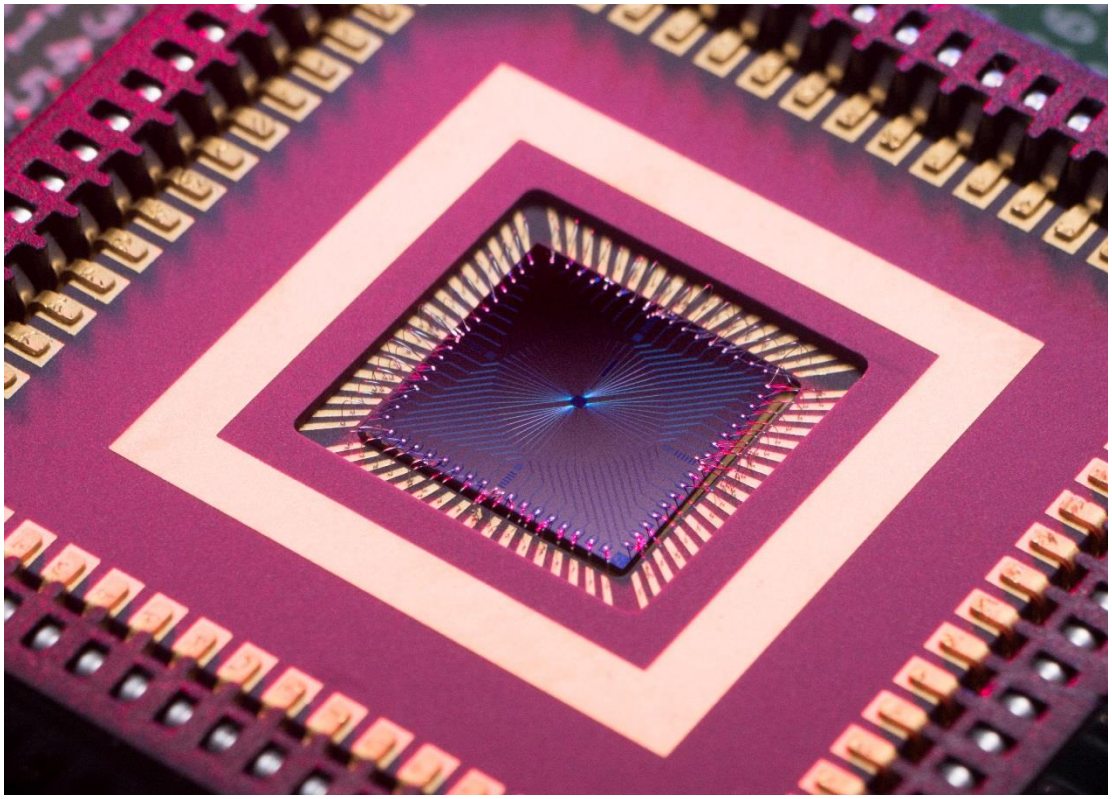
- Cavity tuned to 1570 nm
- 2.5 nm Ti adhesion layer results in additional mirror absorption
- Reflectometry through windows suggests additional losses

Future Design Prospects



- Dielectric mirror for optimal efficiency
- No crosstalk observed at 13.3% fill factor

Conclusion



- Proof of concept SNSPD array suitable for DSOC is good enough for end-to-end testing
- Changes to the optical design should provide improved efficiency
- Much work remains to be done to design, build, and field a ground detector instrument