Parallel Plate Capacitor Aluminum KIDs for Future Far-Infrared Space-Based Observatories

NASA Postdoctoral Program

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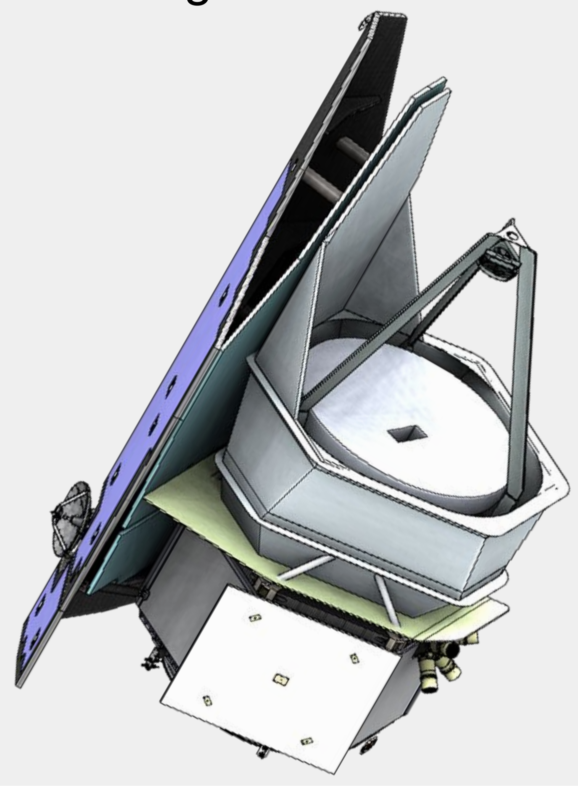
NASA

The PRobe far-Infrared Mission for Astrophysics

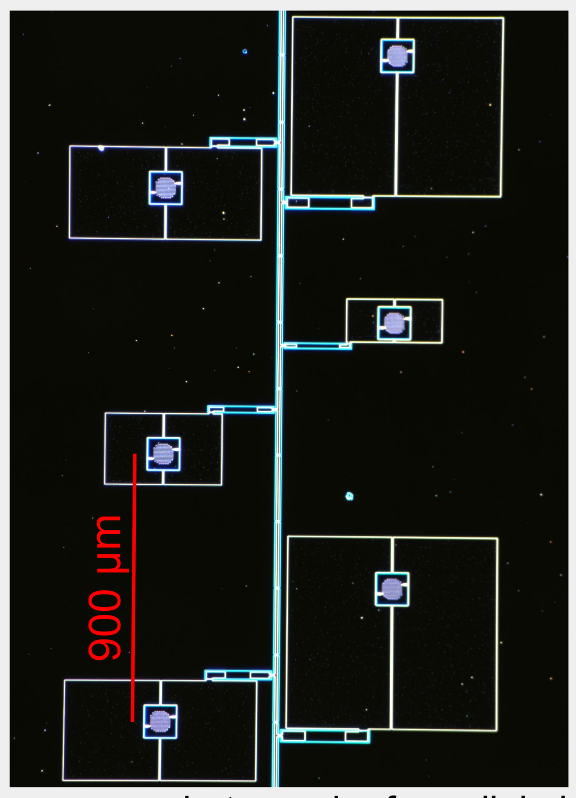
- The PRobe far-Infrared Mission for Astrophysics (PRIMA)
  - Bridging wavelength gap between ALMA and JWST
  - Observations of AGN feedback, interstellar medium physics in galaxies
  - Growth over cosmic time of stars, black holes, heavy elements, dust
- Telescope and observing bands
  - 2 meter, 4.5 Kelvin primary mirror
  - Spectrometer and imager modules
  - Short (24 – 75 µm) and long (75 – 235 µm) wavelength bands
- Short wavelength band spectrometer detectors
  - Kinetic Inductance Detectors (KIDs) [1,2,3]
  - Low-volume aluminum resonant absorber
  - Many kilopixel KID arrays

PRIMA

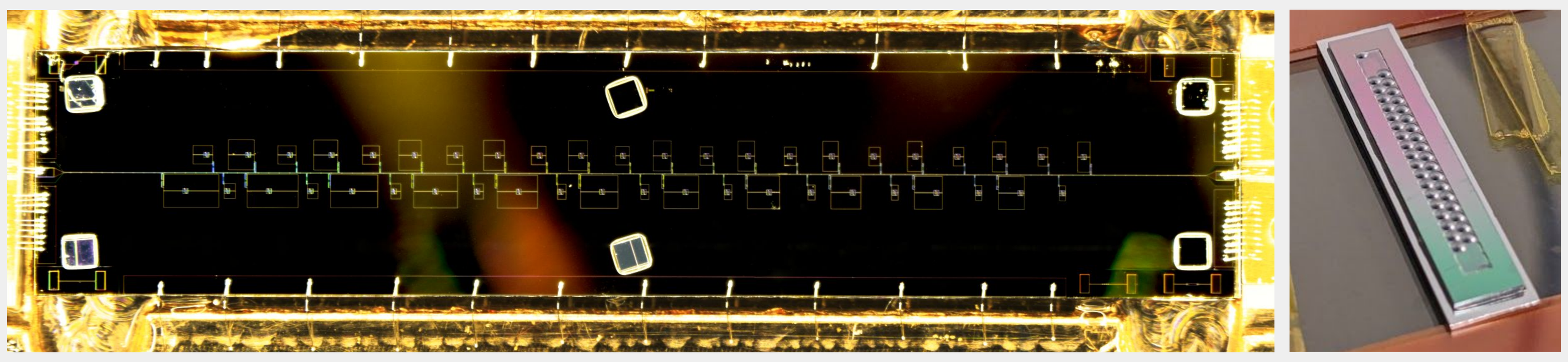


Aluminum Parallel Plate Capacitor Kinetic Inductance Detectors

- Short wavelength band spectrometer KIDs
- Parallel plate capacitors
  - a-Si:H dielectric, Al and Nb electrodes
  - Small footprint, reduces EM crosstalk
- Aluminum absorber
  - Resonant absorption efficiency
  - Niobium quasiparticle plugs
- Prototype kilopixel arrays with high yield
- Monolithic silicon microlens arrays [4]
  - Antireflection coated
  - Efficient optical coupling



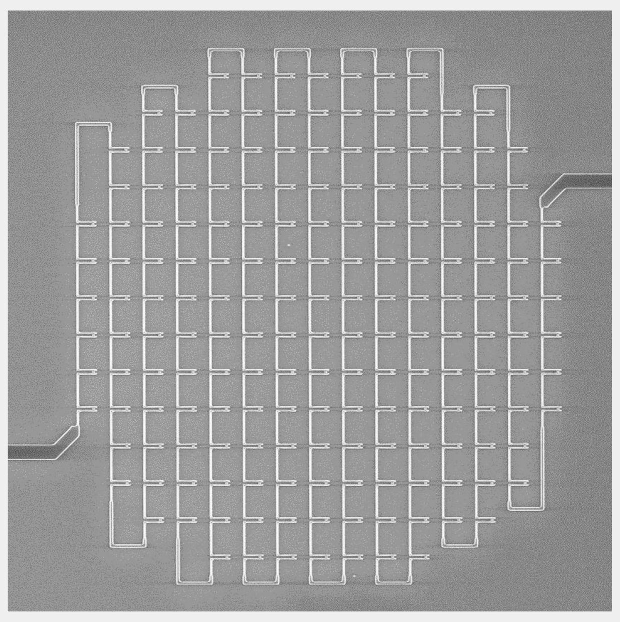
Microscope photograph of parallel plate capacitors with resonant absorbers



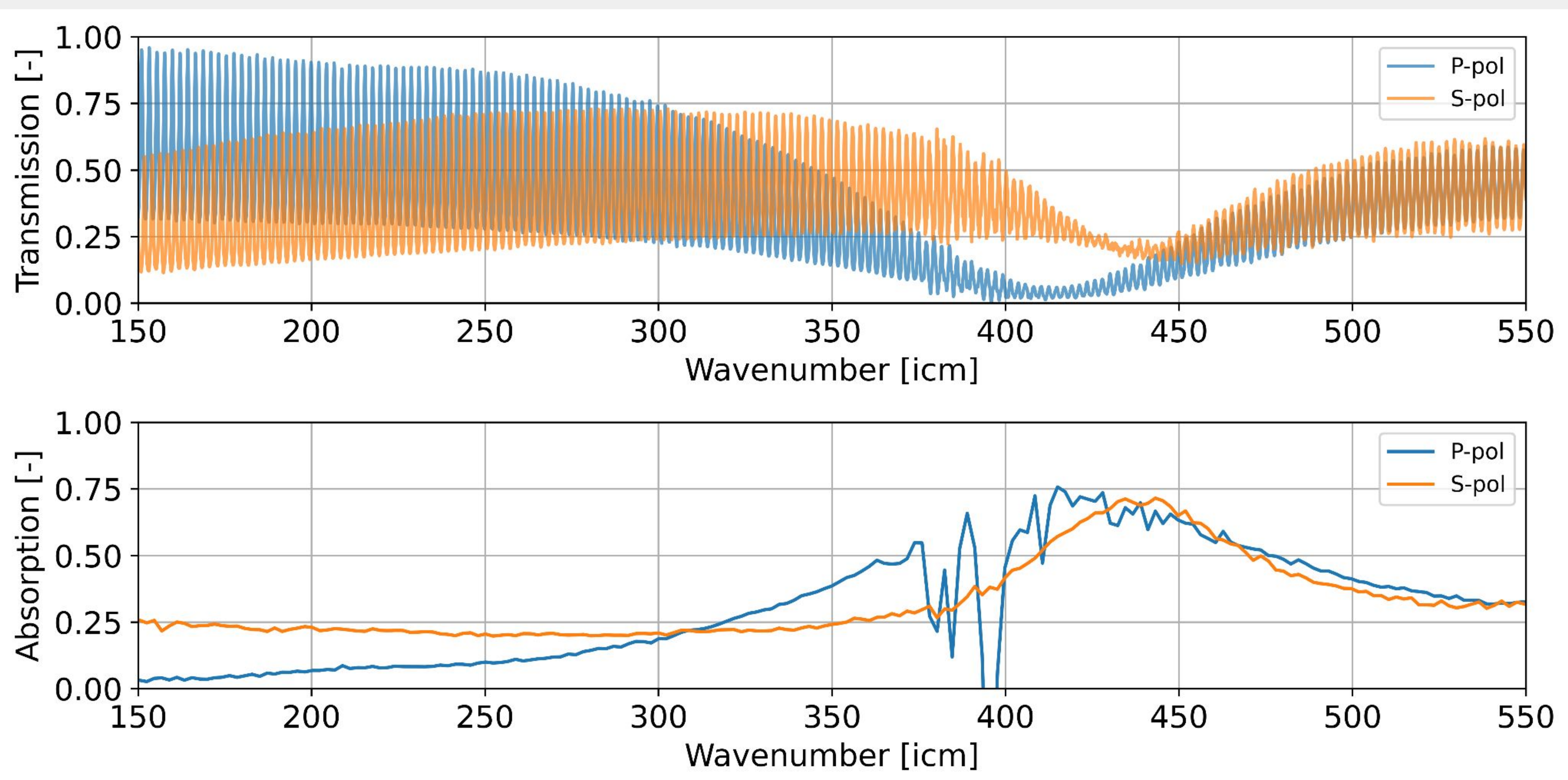
Left: microscope photograph of 44-pixel 900 µm pitch prototype 25 µm wavelength array.
Right: 44-pixel 900 µm pitch microlens-detector hybridized array

Resonant Absorber Coupled Detectors for λ ~ 25 µm

- Dual polarization resonant absorber structure
  - Hairpin-style meandered path
  - 70 µm absorber diameter
  - Increase in-band absorption
  - Simulate geometry in HFSS
- First iteration absorption measurement
  - Pattern design across wafer
  - Fourier Transform Spectroscopy (FTS)
  - Absorption extracted from fringe pattern
  - Found absorption peak near design
- Currently optimizing absorber geometry
  - Shift peak to desired center wavelength
- Comparisons to shot noise indicate expected optical efficiency



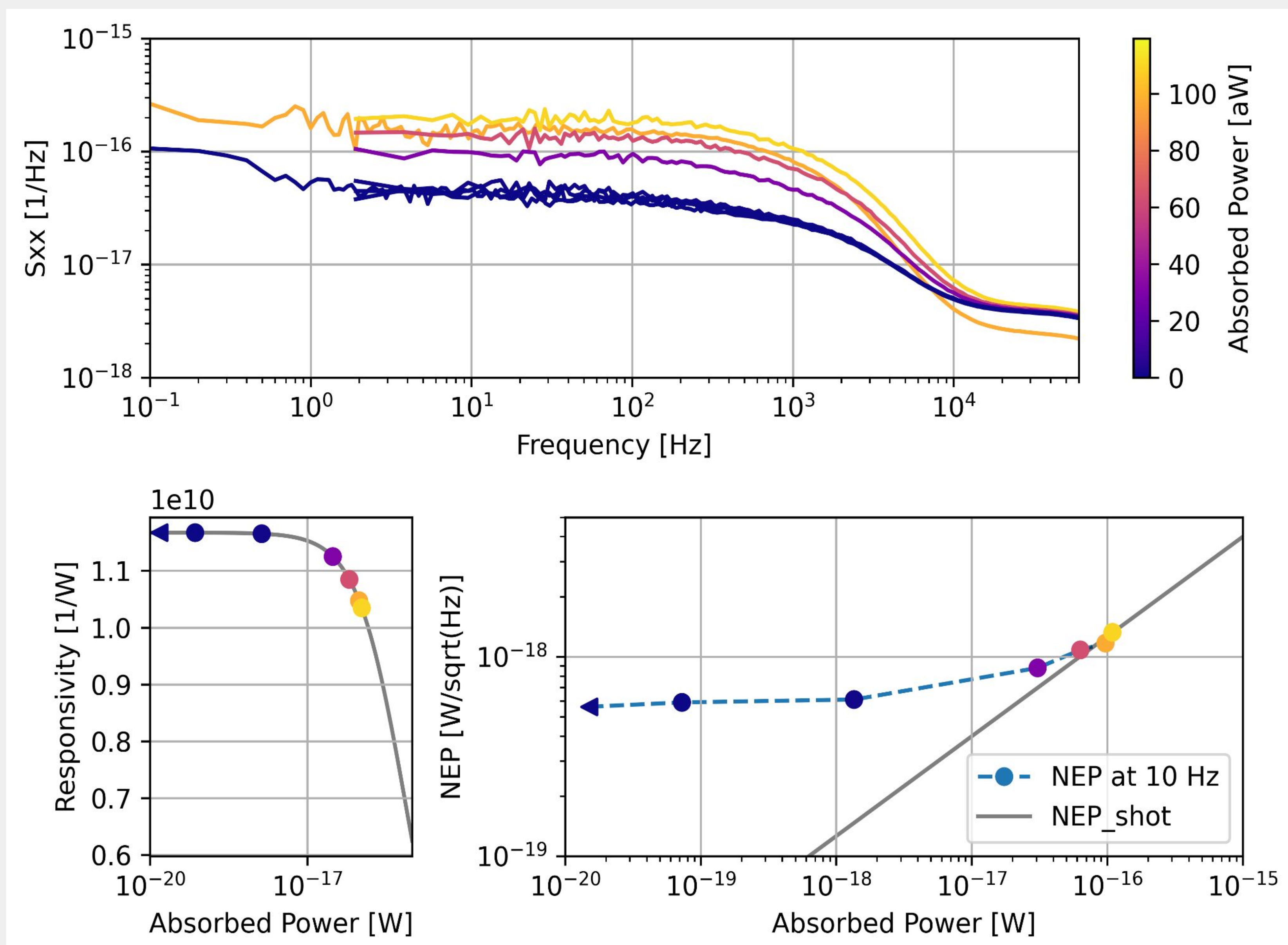
Scanning electron microscope image of aluminum hair-pin style resonant absorber



Upper plot: Cryogenic FTS measurement of sample coated with absorber-structure showing substrate fringe structure and polarization dependent transmission.
Lower plot: Extracted absorption spectra showing peak shifted slightly from design wavelength of 25 µm (400 icm).

Responsivity and NEP Measurements

- 44-pixel short wavelength spectrometer band prototype array
  - Very high yield (43/44) with typical frequencies 250 – 1400 MHz
  - See Logan Foote's poster (TP-029) for TLS details [5]
  - See Elijah Kain's poster (TP-033) for time constants [6]
    - Measured responsivity agrees with measured lifetimes and volume
  - Optical measurements show efficiency working as expected
    - NEP ~ 5.5 x 10^{-19} W/rt(Hz)
  - Lower NEP expected:
    - With upcoming devices with longer recombination times
    - After cryostat stray light improvements



Upper plot: Fractional frequency shift noise spectra of one detector as a function of absorbed power.
Lower left: Responsivity measurements and fit. Lower right: Optical NEP measurement at 10 Hz.

Conclusions and Next Steps

- Demonstrated PRIMA short wavelength band spectrometer KIDs
  - Successful parallel plate capacitor geometry
  - Successful resonant absorber design
  - Successful high-yield kilopixel prototype arrays
  - Successful microlens optical coupling of small-format arrays
  - NEPs near PRIMA target
- Next steps:
  - Improve NEP via absorber design iteration and cryostat improvement
  - Characterize crosstalk for parallel plate capacitor KIDs
  - Demonstrate kilo-pixel array performance

Acknowledgements

This work was supported by internal research and development awards at JPL and NASA GSFC. NFC was supported by an NASA Postdoctoral Program Fellowship at NASA GSFC, administered by ORAU. JP was supported by a NASA Future Investigators in NASA Earth and Space Science and Technology Graduate Fellowship.

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