National Aeronautics and Space Administration

FY23 Strategic Initiatives Research and Technology Development (SRTD)

Superconducting Detector Arrays for Imaging and Spectroscopy at Mid-Infrared Wavelengths

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Strategic Focus Area: Long-Wavelength Detectors | **Strategic Initiative Leader:** Charles Lawrence

Objectives:
- Optically demonstrate closely-packed, micro-lens coupled Kinetic Inductance Detector (KID) arrays at 25-microns wavelength
- Target NEP, loading and pitch requirements for PRIMA
- Factor of ~10 shorter wavelength than previous FIR KID implementations.

Background:
- The Astro 2020 Decadal Survey strongly endorsed a line of Astrophysics Probe missions.
- JPL is developing a proposal for a mission called PRIMA
- Proposing mid- and far-infrared kinetic inductance detectors (KIDs), a superconducting detector technology originally developed at JPL [1].

Approach and Results:
- *Detector array implementation*:
  - Similar design to KID used in the MAKO instrument [2]
  - But departs significantly in the resonator design and material used (aluminum instead of TiN).
- *Resonant absorbers:*
  - How do we absorb 25-micron wavelength light in a relatively reflective aluminum film?
  - We developed a resonant absorber concept (fig. 1) that allows for the extension of the frequency range of aluminum KID arrays down to as short as 10 micros.
  - Pattern the aluminum absorbing element of the KID into a frequency selective surface with resonant characteristics that effectively impedance matches to free space
  - The absorption characteristics of the resonant absorber were tested with an FTS (fig. 1).
- *Parallel-plate Capacitors (PPC):*
  - Innovative use of multilayer structures with amorphous silicon dielectric in the KID design. 97% yield for a kpixel array (fig. 4)
  - PPCs with loss tangent $\delta = 10^{-5}$ (Q = 100,000), easily large enough for the KID resonator.
  - Very good dielectric fluctuation noise, particularly at low frequency (fig. 3).

Significance/Benefits to JPL and NASA:
- Beyond PRIMA, the Origins flagship mission concept calls for 5×10^4 detectors spanning wavelengths continuously from 10 to 400 microns, with noise equivalent powers (NEPs) of 4×10^{-20} W $Hz^{-1/2}$

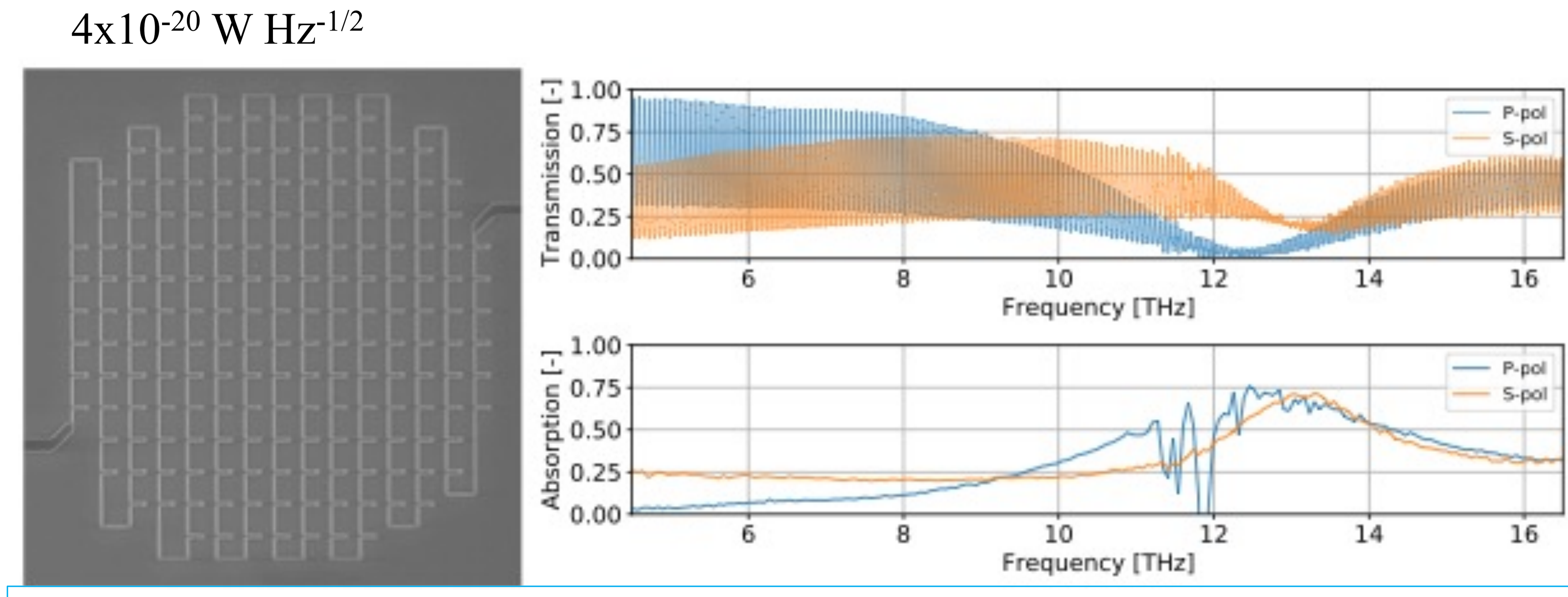

fig. 1 Left: A scanning electron microscope image of a 70 µm diameter aluminum resonant absorber. The periodic "hairpin" structure results in resonant absorption for both polarizations. Top Right: Polarized Fourier transform spectrometer (FTS) data of a silicon sample covered with the absorber structure, cooled to 5 K. Bottom Right: Absorption spectra extracted from the FTS transmission measurements.

References: [1] P. K. Day et al, Nature, 425, 6960, (2003). doi:10.1038/nature02037. [2] Swenson, Loren J., et al. "MAKO: a pathfinder instrument for on-sky demonstration of low-cost 350-micron imaging arrays." (2012).

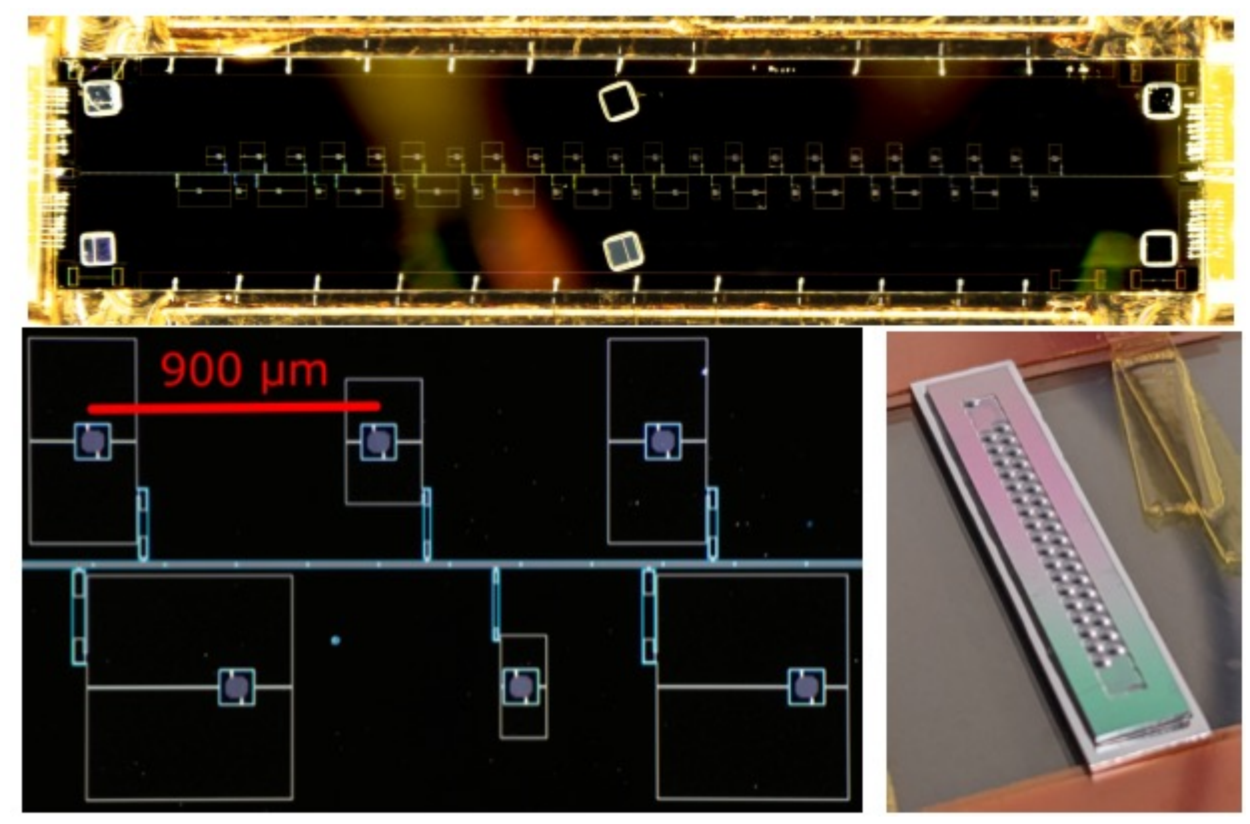

fig. 2 Top : A 44-pixel array of PPC Al KIDs. Bottom Left : A microscope image showing the pixel layout. The 70 µm diameter resonant aluminum absorbers are surrounded by a pair of PPCs. Bottom Right : A prototype 44-pixel silicon microlens array

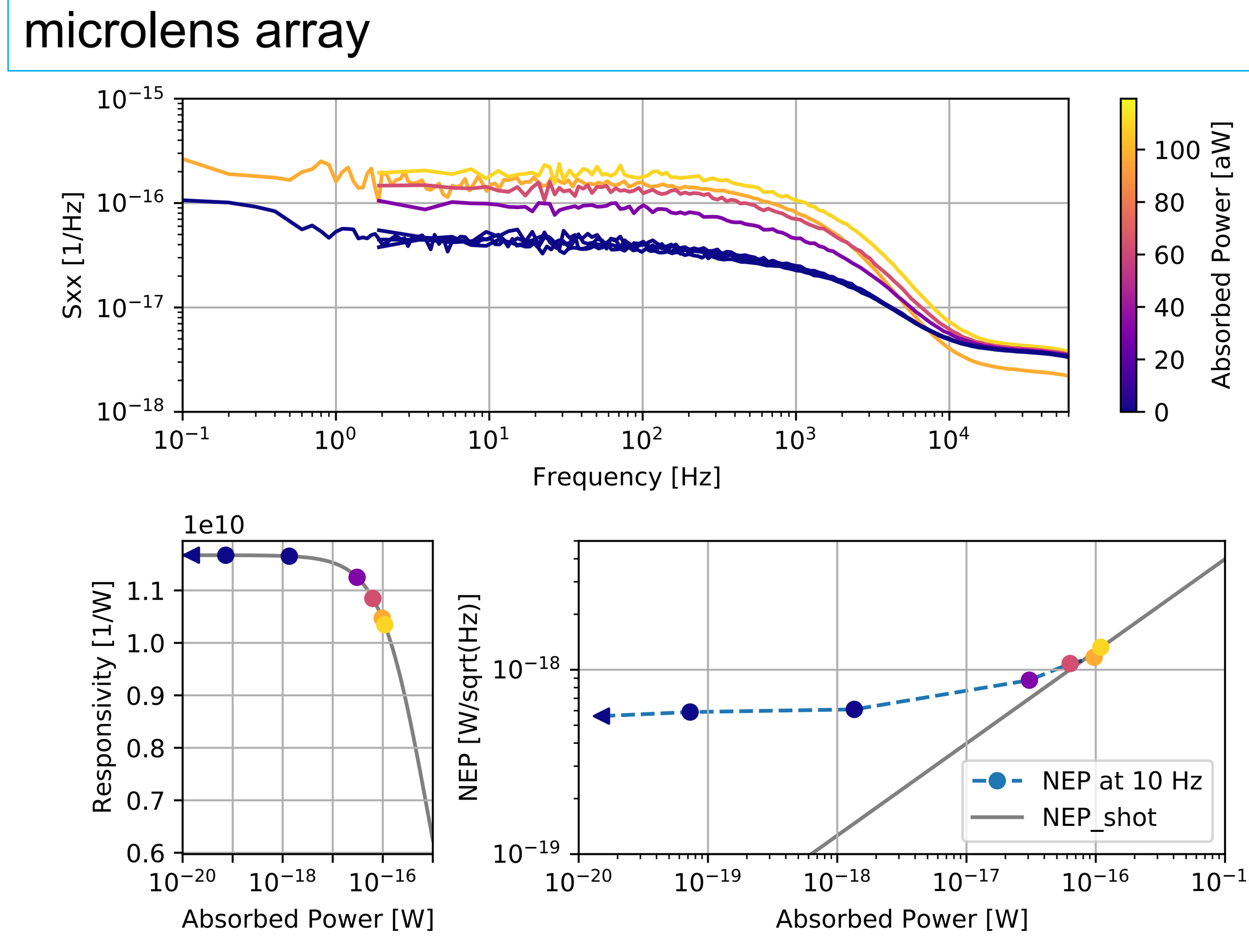

fig 3. Top : Fractional frequency shift noise spectra. Bottom Left : Responsivity vs. power. Bottom Right : Optical NEP result.

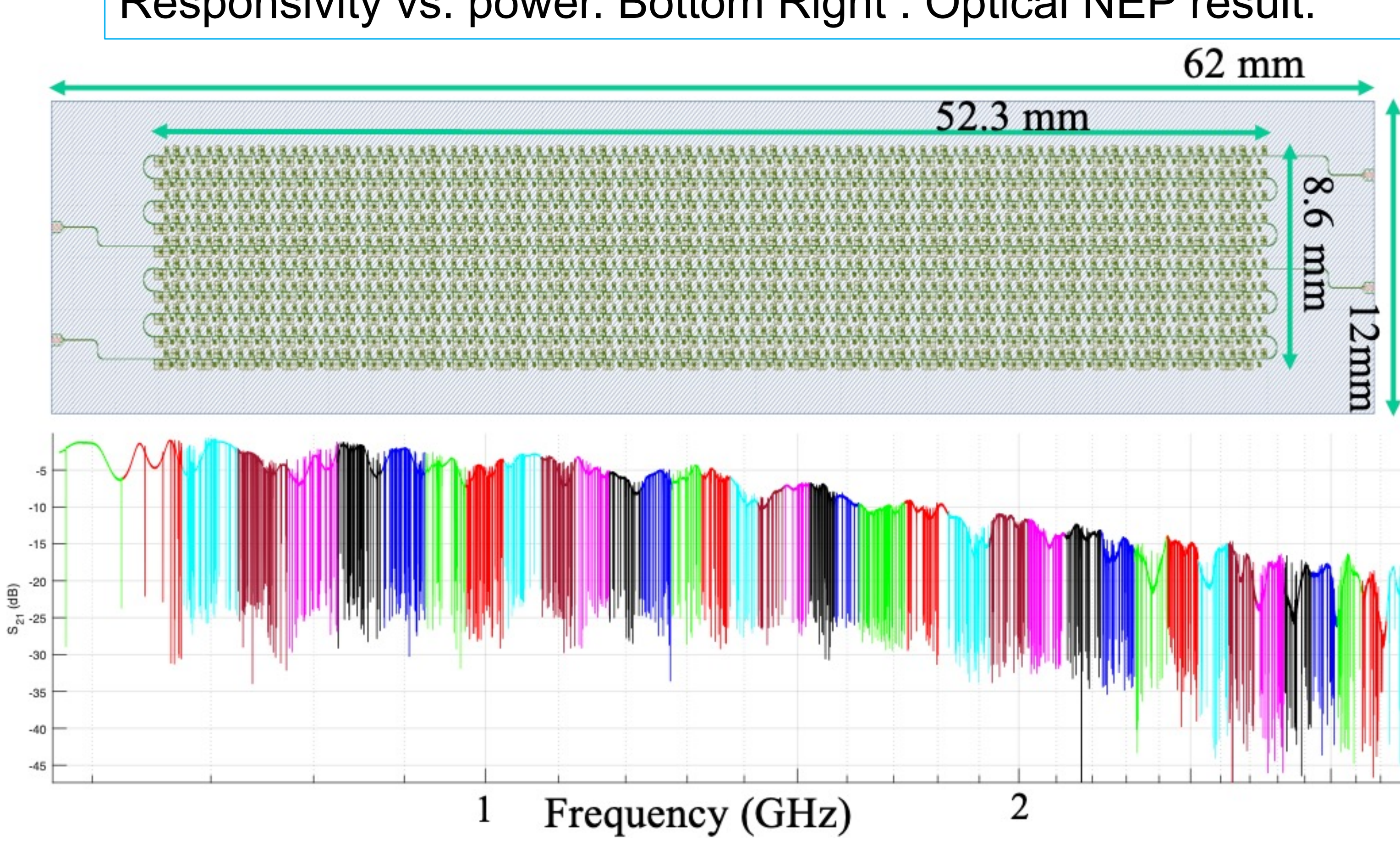

fig 4. (Top) 25-micron wavelength PRIMA 2048-pixel array chip. (Bottom) VNA trace showing microwave transmission. Yield of detected resonances is 97%.

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Publications:

N. F. Cothard, C. Albert, A. Beyer, C. M. Bradford, P. Echternach, B. H. Eom, L. Foote, S. Hailey-Dunsheath, R.M. J. Janssen, E. Kane, R. Leduc, J. Perido, P. K. Day, J. Glenn, "Parallel Plate Capacitor Aluminum KIDs for Future Far-Infrared Space-Based Observatories", Proceedings of the 20th International Conference on LowTemperature Detectors.

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