National Aeronautics and Space Administration

Waveguide coupled high speed quantum well detectors for astronomy applications

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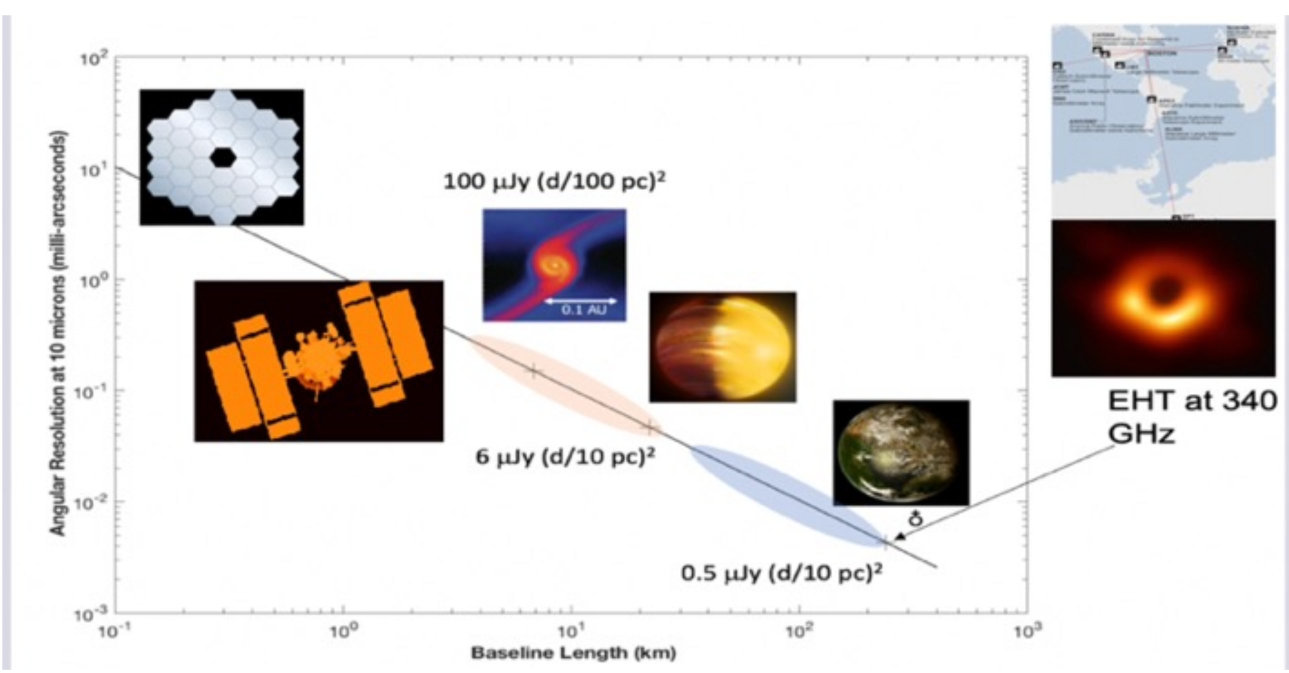
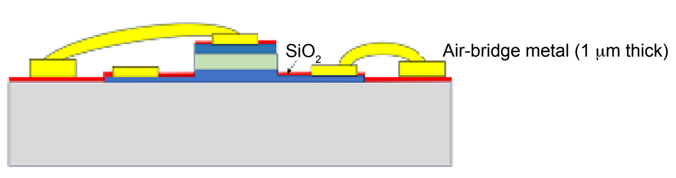
Program: FY24R&TD Topics
Strategic Focus Area: Nano- and Micro- Devices/Systems

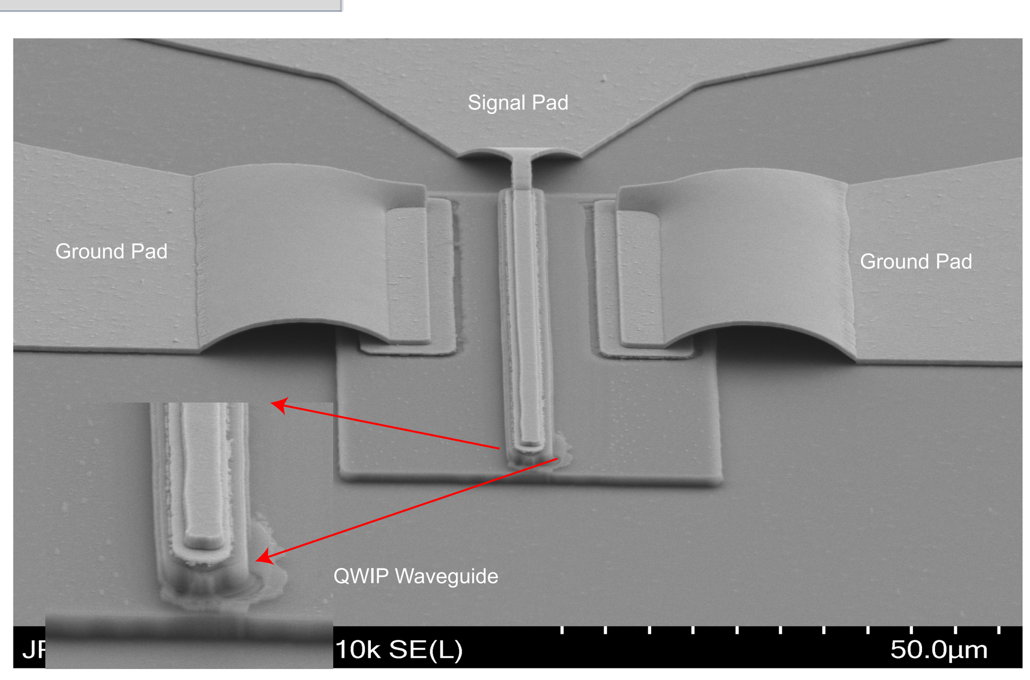
Project Objective:

The objective was to develop fast heterodyne mixers based on Quantum-Well Infrared Photodetectors (QWIPs). The development allows for detection of long-wavelength light around 9 µm with close to unity quantum efficiencies and quantum limited noise at unprecedented electrical bandwidths exceeding 30 GHz. Such detectors will be a game changing technology enabling long baseline heterodyne imaging of astrophysical targets.

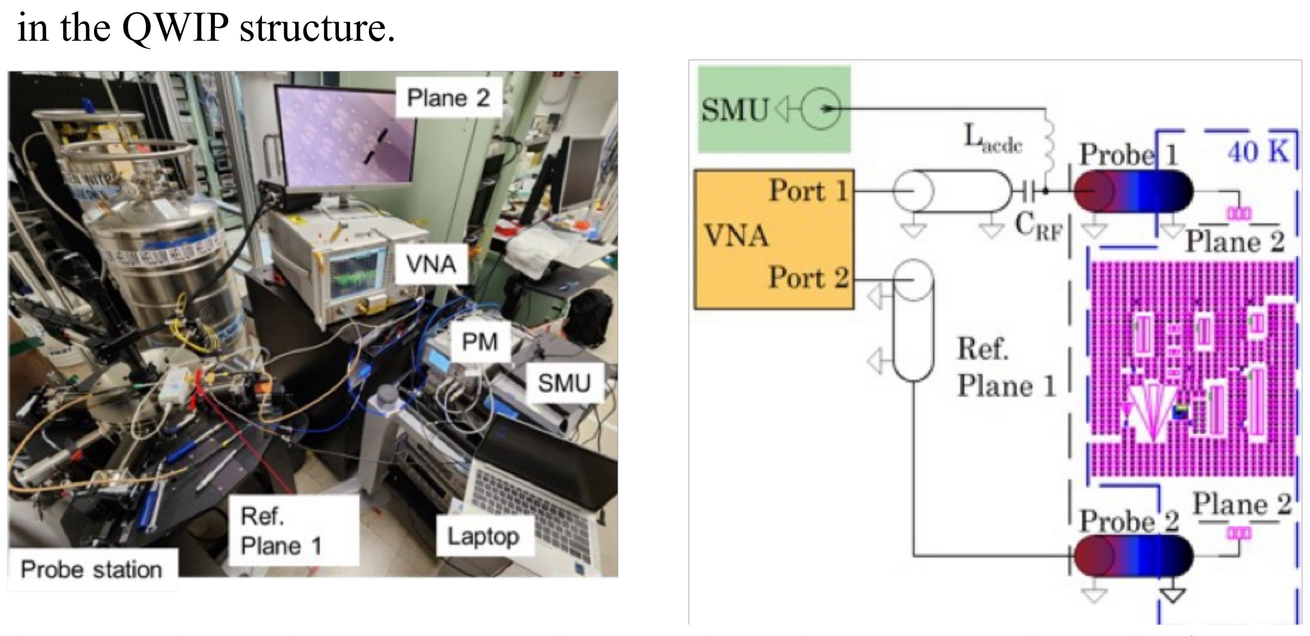


Interferometric baseline vs. imaging angular resolution of interest to NASA and DoD. GEOSATs are bright in the mid IR, and imaging them at small spatial scales requires baselines up to 1-2 km. In astrophysics, nearby giant (exo) planets and terrestrial planets can be resolved with longer 10-200 km. The mid-IR is important for the study of planet formation in view ofbaselines the high dust temperatures in the environments surrounding accreting protoplanets, along with the ~10^3 K temperatures of the young planets themselves.





SEM Image of the fabricated in-plane coupled QWIP waveguides. Light will coupled into the cleaved facet of the QWIP detector and will be detected in the QWIP structure.

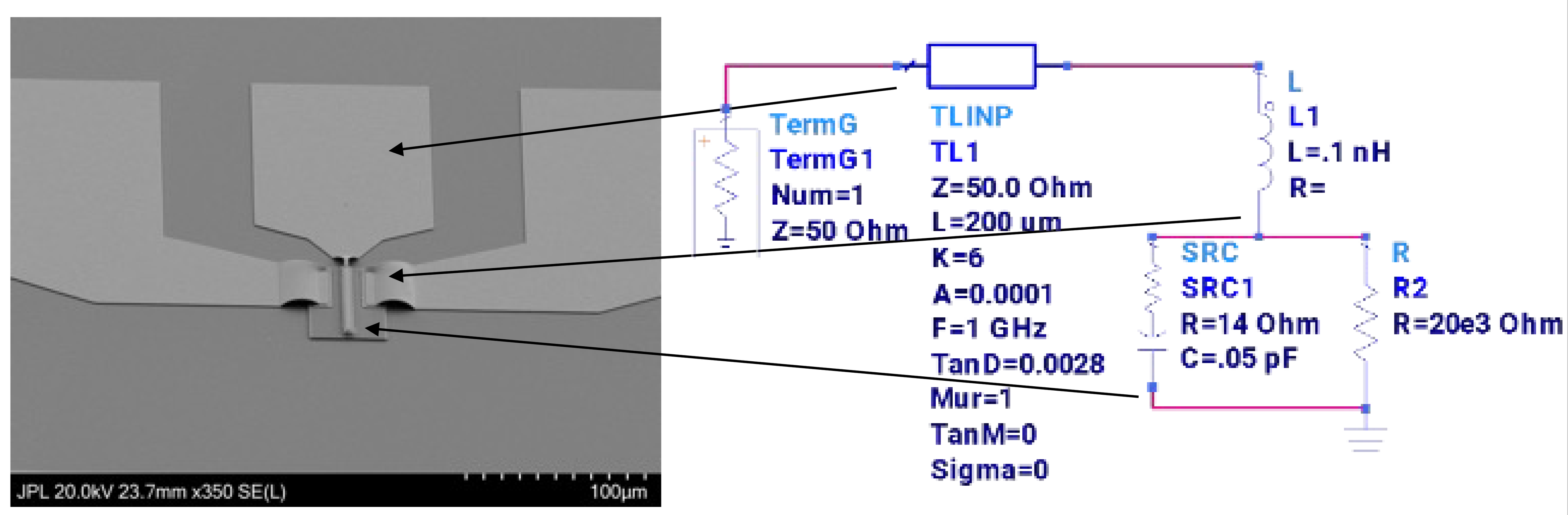


photograph of the test setup (left) and its diagram (right): Probe 1 and Probe 2 are room-temperature-to-cryogenic cabling connecting the RF probes and the chip at 40 K to the outside world.

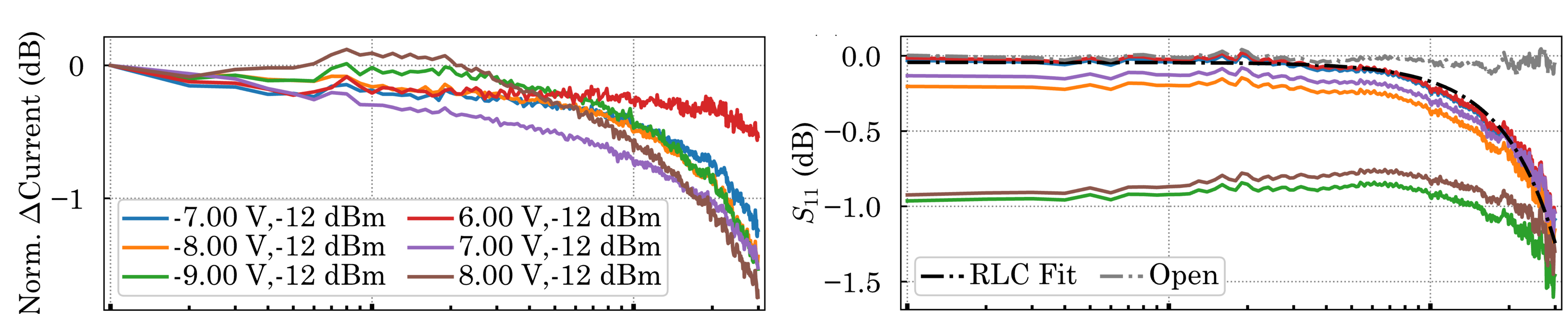
Background and Significance of results to JPL/NASA

Infrared ultralong-baseline heterodyne interferometers with resolving powers on < 100 microarcsecond (µas) angular scales can allow a performance leap in astrophysical imaging, in particular, in exoplanet imaging. With baselines > 100 km and > 10^3 m^2 total collecting area, IR interferometers can reach few µas resolution (similar to that of the mm-wave Event Horizon Telescope) and resolve the planetary disks of the nearest Earth analogs. Resolving exoplanetary surfaces will be the core of NASA science in the so-called visionary era (post LUVOIR or HabEx). In the infrared and optical, direct detection interferometry has thus far ruled the roost. However, direct detection has severe limitations in achievable long baselines, and in optimally combining signals from multiple telescopes. Conversely, heterodyne detection has poor quantum-limited sensitivity at wavelengths shorter than ~9 µm, has had faced severe limitations in achievable signal bandwidth. The Infrared Spatial Interferometer (ISI) [1] on Mount Wilson was limited by the electrical bandwidth of a single HgCdTe photodiode / CO2 laser local oscillator (LO) combination to a relatively low ~ 3 GHz, which is a tiny fractional optical bandwidth (($\delta\nu/\nu$ ~10^{-4}). However, the rapid development of mid IR frequency combs allows us to envision highly broadband heterodyne receivers.

Results and Discussions



SEM image of the the QWIP and the corresponding electrical circuit model that matches the calibrated amplitude and phase measurements



Measured current deviation from the quiescent bias through the detector plotted versus CW frequency at the nominal power level of -10 dBm at the detector input; the numbers in the legend correspond to different detector biasing points (Left) and calibrated curves with corresponding RLC fit model indicating frequency response in excess of 30 GH.

We have successfully developed high-speed quantum well infrared photodetectors (QWIPs) capable of operating at frequencies up to 30 GHz within the 10 µm wavelength range. These advanced detectors leverage the unique properties of quantum wells to achieve exceptional sensitivity and speed, making them ideal for applications such as infrared imaging, spectroscopy, and long base-line interferometry systems.

Publications:

A. A. Babenko et. al, "Microwave Design and Characterization of Cryogenic Quantum-Well Infrared Photodetectors," *to be submitted 2025 IEEE/MTT-S International Microwave Symposium – IMS 2025.*

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