National Aeronautics and Space Administration

Waveguide coupled high speed quantum well detectors for astronomy applications

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Program: FY22 R&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 mm 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.

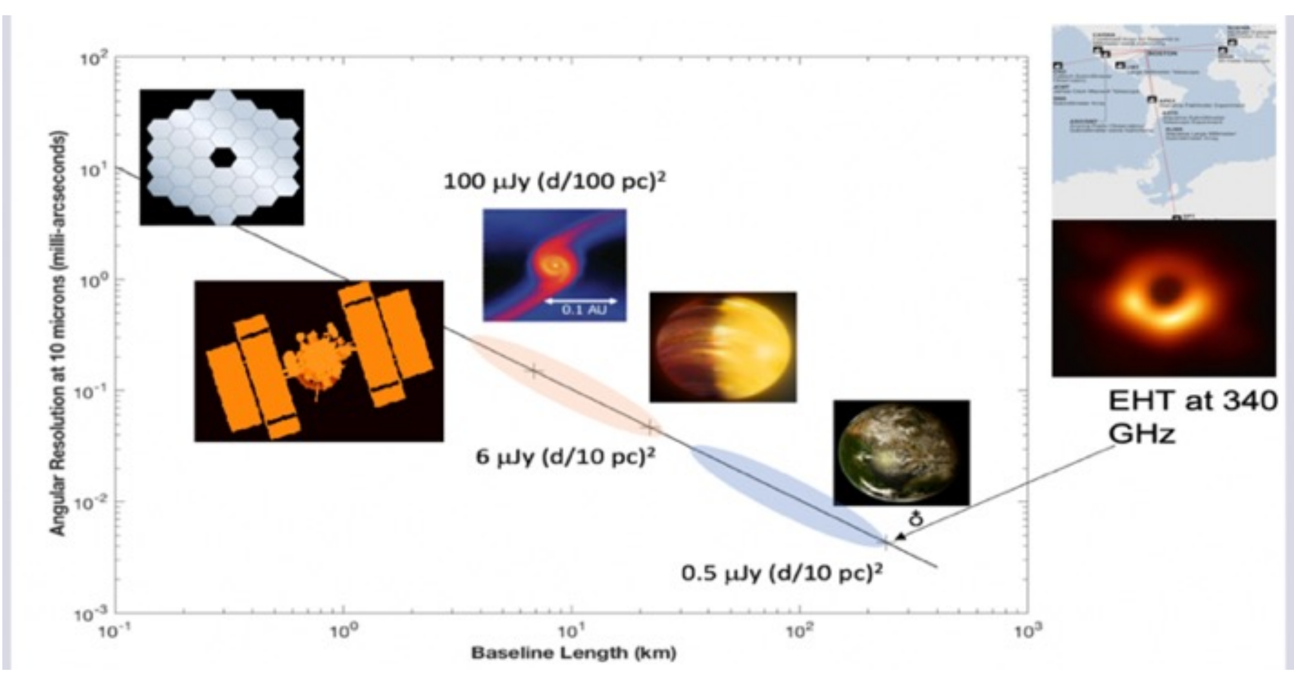

Figure 1-1: Interferometric baseline vs. imaging angular resolution of interest to NASA and DoD. GEOSATs are bright in the mid IR, and imaging them at small spatial scales requires baselines up to 1-2 km. In astrophysics, nearby giant (exo) planets and terrestrial planets can be resolved with longer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

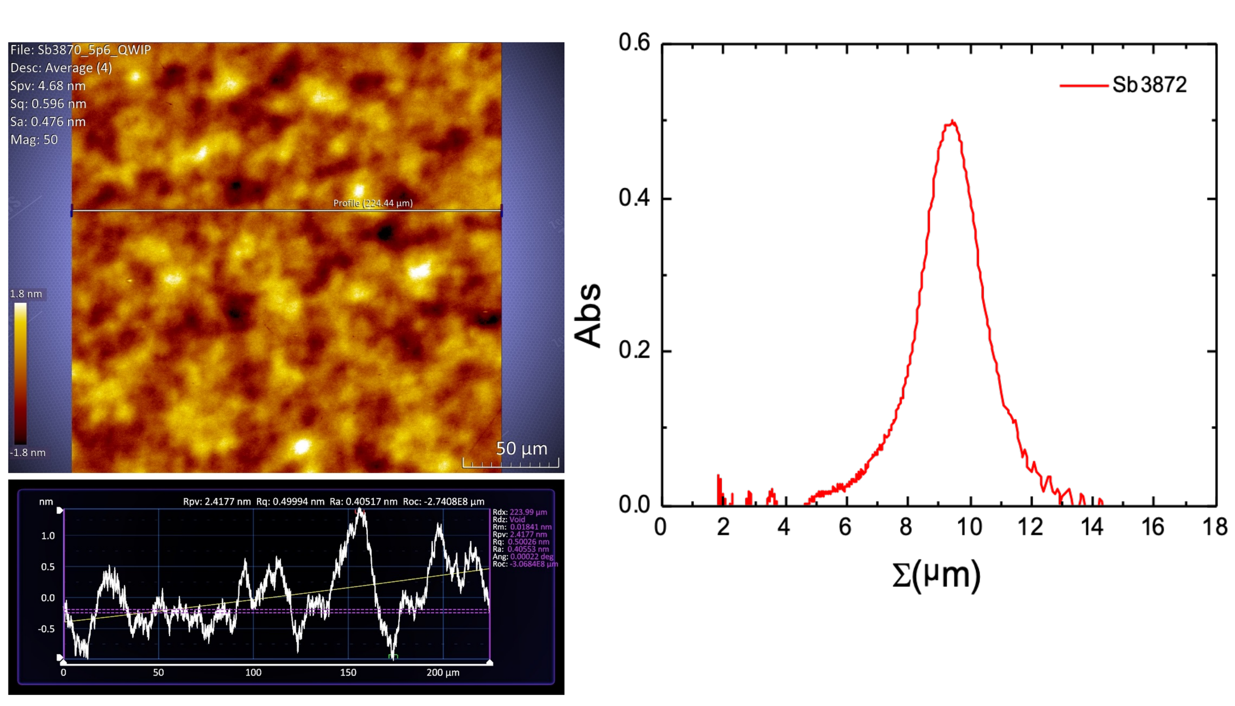

Figure 1-2 Material characterization: The figure on the left shows very smooth and defect free, high quality QWIP detector growth. The figure on the right shows absorption peak at 9 μm from the grown detector.

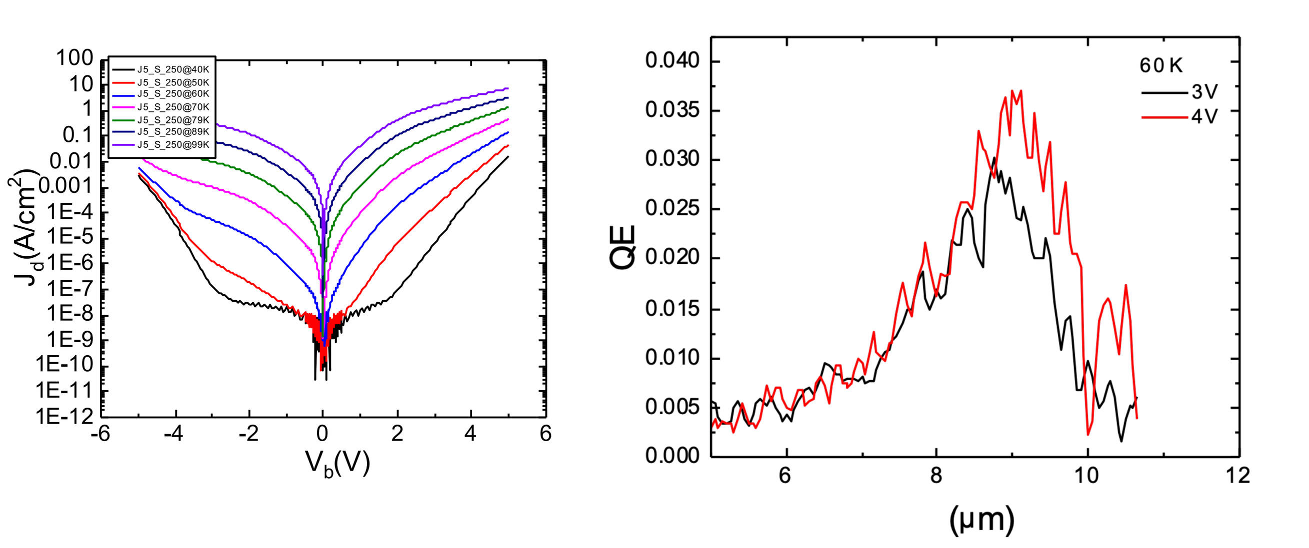

Figure 2 Device characterization: The figure on the left shows dark current density of the processed QWIP detector. The figure on the right shows quantum efficiency spectrum from the grown detector.

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.

FY 22 Approach

Quantum well infrared photodetectors (QWIPs): Liquid-nitrogen cooled QWIPs provide high response and high-speed detection of 9 μm radiation. A highly favorable and little exploited intrinsic property of inter-subband QWIPs based on group III-V semiconductor materials is the very short lifetime of their excited carriers, typically of order a few picoseconds. This has two important consequences: the detector frequency response can reach ~100 GHz [2] and its saturation intensity is very high (1e7 W cm^{-2}) [3]. These properties are ideal for a heterodyne detection scheme in which a laser LO can drive a strong photocurrent that can coherently mix with a signal shifted in frequency with respect to the LO. Notably, very high speeds are difficult to obtain in infrared inter-band detectors based on the state of the art mercury–cadmium–telluride (MCT) alloys currently at about < 5 GHz.

After material growth and material characterization, mesa devices were made using standard GaAs fabrication techniques and will be evaluated for electrical characteristics. The QWIPs were characterized by conventional I-V and spectral responsivity measurements. The initial stand-alone QWIP devices were fabricated with large area mesas (200 μm x 200 μm or larger). The second generation smaller QWIP devices will be designed and fabricated for side illumination (via waveguide) to achieve absorption QE > 50%.
In last year's effort, we focused on scaling single pixel high bandwidth QWIP detectors at 9 μm. The objectives for the first year was to design, grow, single pixel fabrication and characterization of 9 μm QWIPs. The QWIP detectors were designed for 9 μm, fully characterized for material quality. The material characterization showed high crystallin growth for detectors. Detectors have been fabricated and being characterized for noise and signal (see figure 1-2). The detectors were fabricated and IV and QE results are shown in figure 2.

References:

1 Townes and Wishnow, Proc. SPIE, 7013, 70130D (2008)., **2** J. Li et al., Proc. SPIE 2685, Photodetectors: Materials and Devices, (12 April 1996)., **3** Vodopyanov,et al.,. Semicond. Sci. Technol. 12, pp 708–714 (1997).

FY23 Plans

1.Characterization of passive waveguides coupled to QWIPs
2. Design, growth, fabrication and characterization (signal, noise and electrical bandwidth) of 9 μm QWIP linear array with 10 pixels
3.Integration and characterization of linear detector arrays with arrays of optical waveguides.

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