SBIR/STTR
Small Business Innovation Research / Small Business Technology Transfer

NASA SBIR 2021 Phase I Solicitation

S1.04 Sensor and Detector Technologies for Visible, Infrared (IR), Far-IR, and Submillimeter

Lead Center: JPL

Participating Center(s): ARC, GSFC, LaRC

Scope Title:

Sensor and Detector Technologies for Visible, Infrared (IR), Far-IR, and Submillimeter

Scope Description:

NASA is seeking new technologies or improvements to existing technologies to meet the detector needs of future missions, as described in the most recent decadal surveys:

- Earth Science and Applications from Space: http://www.nap.edu/catalog/11820.html(link is external)
- New Frontiers in the Solar System: http://www.nap.edu/catalog/10432.html(link is external)
- Astronomy and Astrophysics in the New Millennium: http://www.nap.edu/books/0309070317/html/(link is external)

Please note:

1. Technologies for visible detectors are ***not*** *being solicited this year*.

2. *Proposers should direct proposals to S1.01 for technologies that don't address fundamental photodetection process improvements, (i.e., improvement in detection efficiency, excess noise, dark count rate, gain characteristics, afterpulsing, etc.), but instead focus on lidar-only solutions for detection and readout technologies not widely applicable to other fields. Please see the S1.01 scope for further clarification on what is being solicited.*

LOW-POWER AND LOW-COST READOUT INTEGRATED ELECTRONICS

- Photodiode Arrays: In-pixel Digital Readout Integrated Circuit (DROIC) for high-dynamic-range IR imaging and spectral imaging (10 to 60 Hz operation) focal plane arrays to circumvent the limitations in charge well capacity, by using in-pixel digital counters that can provide orders-of-magnitude larger effective well depth, thereby affording longer integration times.
- Microwave Kinetic Inductance Detector/Transition-Edge Sensor (MKID/TES) Detectors: A radiation-tolerant, digital readout system is needed for the readout of low-temperature detectors such as MKIDs or other detector types that use microwave-frequency-domain multiplexing techniques. Each readout channel of the system should be capable of generating a set of at least 1,500 carrier tones in a bandwidth of at least 1 GHz with 14-bit precision and 1-kHz frequency placement resolution. The returning-frequency multiplexed

signals from the detector array will be digitized with at least 12-bit resolution. A channelizer will then perform a down-conversion at each carrier frequency with a configurable decimation factor and maximum individual subchannel bandwidth of at least 50 Hz. The power consumption of a system consisting of multiple readout channels should be at most 20 mW per subchannel or 30 W per 1-GHz readout channel. That requirement would most likely indicate the use of a radio-frequency (RF) system on a chip (SoC) or application-specific integrated circuit (ASIC) with combined digitizer and channelizer functionality.

- Bolometric Arrays: Low-power, low-noise, cryogenic multiplexed readout for large format two-dimensional (2D) bolometer arrays with 1,000 or more pixels, operating at 65 to 350 mK. We require a superconducting readout capable of reading two TESs per pixel within a 1 mm^2 spacing. The wafer-scale readout of interest will be capable of being indium-bump bonded directly to 2D arrays of membrane bolometers. We require row and column readout with very low crosstalk, low read noise \, and low detector noise-equivalent power degradation.
- Thermopile Detector Arrays: Mars Climate Sounder (MCS), the Diviner Lunar Radiometer Experiment (DLRE), and the Polar Radiant Energy in the Far Infrared Experiment (PREFIRE) are NASA space-borne radiometers that utilize custom thermopile detector arrays. Next-generation radiometers will use larger format thermopile detector arrays, indium bump bonding to hybridize the detector arrays to the Readout Integrated Circuits (ROICs), low input-referred noise, and low power consumption. ROICs compatible with 128×64 element Bi-Sb-Te thermopile arrays with low 1/f noise, an operating temperature between 200 and 300 K, radiation hardness to 300 krad, and on-ROIC analog-to-digital converter (ADC) will be desirable.

LIDAR DETECTORS

- Enhanced photon detection efficiency (PDE), low excess noise, low dark noise, radiation-tolerant detectors for space-based 1.064-µm cloud profiling lidar applications. Detector should operate at a noncryogenic temperature. Solutions could include patterned/black silicon and III-V materials, but should optimize for signal-to-noise ratio in the ~3.7 fW to 190 nW optical power range ($\sim 2\times10^4$ to 1×10^{12} photons/sec) at 1.064 µm. Architectures might include massively parallel, fast-photon counting arrays of diodes operated in Geiger mode, or avalanche photodiodes (APDs) operated in linear mode with higher PDE than existing silicon APDs (PDE > 40%), but with a comparable or lower excess noise factor (ENF < 3). Improved absorption of 1.064 µm than bulk silicon is desired for better radiation tolerance and lower noise. A timing resolution of 67 ns (~10 m) is desired for atmospheric profiling, but resolutions of 1 ns (~15 cm) or better would make this detector more widely applicable to hard target ranging in areas such as planetary surface mapping, and vegetation/canopy lidar. Sensitivity of such a detector to the near-IR from 800 to 950 nm would also enable high-precision atmospheric profiling of key trace gases such as water vapor.

IR & Far-IR/SUBMILLIMETER-WAVE DETECTORS

- Novel Materials and Devices**:** New or improved technologies leading to measurement of trace atmospheric species (e.g., CO, CH_4, N_2O) or broadband energy balance in the IR and far-IR from geostationary and low-Earth orbital platforms. Of particular interest are new direct detector or heterodyne detector technologies made using high-temperature superconducting films (YBCO, MgB_2) or engineered semiconductor materials, especially 2D electron gas (2DEG) and quantum wells (QW).
- Array Receivers**:** Development of a robust wafer-level packaging/integration technology that will allow high-frequency-capable interconnects and allow two dissimilar substrates (i.e., silicon and GaAs) to be aligned and mechanically 'welded' together. Specially develop ball grid and/or through-silicon via (TSV) technology that can support submillimeter-wave (frequency above 300 GHz) arrays. Compact and efficient systems for array receiver calibration and control are also needed.
- Receiver Components**:** Local oscillators capable of spectral coverage 2 to 5 THz; Output power up to >2 mW; frequency agility with >1 GHz near chosen THz frequency; Continuous phase-locking ability over the terahertz-tunable range with <100-kHz line width. Both solid-state (low-parasitic Schottky diodes) as well as quantum cascade lasers (for f > 2 THz) will be needed. Components and devices such as mixers, isolators, and orthomode transducers, working in the terahertz range, that enable future heterodyne array receivers are also desired. GaN-based power amplifiers at frequencies above 100 GHz and with power-added efficiency (PAE) > 25% are also needed. ASIC-based SoC solutions are needed for heterodyne receiver backends. ASICs capable of binning >6 GHz intermediate frequency bandwidth into 0.1- to 0.5-MHz channels with low power dissipation <0.5 W would be needed for array receivers.

Expected TRL or TRL Range at completion of the Project: 2 to 4
Primary Technology Taxonomy:
Level 1: TX 08 Sensors and Instruments
Level 2: TX 08.1 Remote Sensing Instruments/Sensors
Desired Deliverables of Phase I and Phase II:

- Analysis
- Prototype

Desired Deliverables Description:

For Phase I activities the deliverables are nominally feasibility studies, detailed design, or determination of the trade space and detailed optimization of the design, as described in a final report. In some circumstances simple prototype models for the hardware can be demonstrated and tested.

For Phase II studies a working prototype that can be tested at one of the NASA centers is highly desirable.

State of the Art and Critical Gaps:

Efficient multipixel readout electronics are needed both for room-temperature operation as well as cryogenic temperatures. We can produce millions-of-pixel detector arrays at IR wavelengths up to about 14 µm, only because there are ROICs available on the market. Without these, high-density, large-format IR arrays such as quantum well infrared photodetectors, HgCdTe, and strained-layer superlattice would not exist. The Moore's Law corollary for pixel count describes the number of pixels for the digital camera industry as growing in an exponential manner over the past several decades, and the trend is continuing. The future of long-wave detectors is moving toward tens of thousands of pixels and beyond. Readout circuits capable of addressing their needs do not exist, and without them the astronomical community will not be able to keep up with the needs of the future. These technology needs must be addressed now, or we are at risk of being unable to meet the science requirements of the future.

- Commercially available ROICs typically have well depths of less than 10 million electrons.
- 6- to 9-bit, ROACH-2 board solutions with 2,000 bands, <10 kHz bandwidth in each are state of the art (SOA).
- IR detector systems are needed for Earth imaging based on the recently released Earth Decadal Survey.
- Direct detectors with D ~ 10^9 cm-rtHz/W achieved in this range. Technologies with new materials that take advantage of cooling to the 30 to 100 K range are capable of D ~ 10^{12} cm-rtHz/W. Broadband (>15%) heterodyne detectors that can provide sensitivities of 5× to 10× the quantum limit in the submillimeter-wave range while operating at 30 to 77 K are an improvement in the state of the art due to higher operating temperature.
- Detector array detection efficiency <20% at 532 nm (including fill factor and probability of detection) for low after pulsing, low dead time designs is SOA.
- Far-IR bolometric heterodyne detectors are limited to 3-dB gain bandwidth of around 3 GHz. Novel superconducting material such a MgB_2 can provide significant enhancement of up to 9 GHz intermediate frequency (IF) bandwidth.
- Cryogenic Low Noise Amplifiers (LNAs) in the 4 to 8 GHz bandwidth with thermal stability are needed for focal plane arrays, Origins Space Telescope (OST) instruments, Origins Survey Spectrometers (OSS), MKIDs, far-IR imager and polarimeters (FIPs), Heterodyne Instrument on OST (HERO), and the Lynx Telescope. DC power dissipation should be only a few milliwatts.
- Another frequency range of interest for LNAs is 0.5 to 8.5 GHz. This is useful for HERO. Other NASA systems in the Space Geodesy Project (SGP) would be interested in bandwidths up to 2 to 14 GHz.
- 15 to 20 dB gain and <5 K noise over the 4 to 8 GHz bandwidth has been demonstrated.
- -Currently, all space-borne heterodyne receivers are single pixel. Novel architectures are needed for ~100 pixel arrays at 1.9 THz
- The current SOA readout circuit is capable of reading one TES per pixel in a 1-mm^2 area. 2D arrays developed by NIST have been a boon for current NASA programs. However, NIST has declined to continue to produce 2D circuits or to develop one capable of two TES-per-pixel readout. This work is extremely important to NASA’s filled, kilopixel bolometer array program.
- 2D cryogenic readout circuits are analogous to semiconductor ROICs operating at much higher

temperatures. We can produce millions-of-pixel detector arrays at IR wavelengths up to about 14 µm, only because there are ROICs available on the market. Without these, high-density, large-format IR arrays such as quantum well infrared photodiode, HgCdTe, and strained-layer superlattice would not exist.
- For lidar detectors, extended-wavelength InGaAs detector/preamplifier packages operating at 2- to 2.1-µm wavelengths with high quantum efficiency (>90%) operating up to about 1 GHz bandwidth are available, as are packages operating up to about 10 GHz with lower quantum efficiency. Detectors that have >90% quantum efficiency over the full bandwidth from near DC to >5 GHz and capable of achieving near-shot-noise limited operation are not currently available.

Relevance / Science Traceability:

- Future short-, mid-, and long-wave IR Earth science and planetary science missions all require detectors that are sensitive and broadband with low power requirements.
- Future astrophysics instruments require cryogenic detectors that are supersensitive and broadband and provide imaging capability (multipixel).
- Aerosol spaceborne lidar as identified by 2017 decadal survey to reduce uncertainty about climate forcing in aerosol-cloud interactions and ocean ecosystem carbon dioxide uptake. Additional applications in planetary surface mapping, vegetation, and trace-gas lidar.
- Earth radiation budget measurement per 2007 decadal survey Clouds and Earth's Radiant Energy System (CERES) Tier-1 designation to maintain the continuous radiation budget measurement for climate modeling and better understand radiative forcings.
- Astrophysical missions such as OST will need IR and far-IR detector and related technologies.
- LANDSAT Thermal InfraRed Sensor (TIRS), Climate Absolute Radiance and Refractivity Observatory (CLARREO), BOReal Ecosystem Atmosphere Study (BOREAS), Methane Trace Gas Sounder, or other IR Earth-observing missions.
- Current science missions utilizing 2D, large-format cryogenic readout circuits:
  (1) HAWC + (High Resolution Airborne Wideband Camera Upgrade) for SOFIA (Stratospheric Observatory for Infrared Astronomy) future missions:
    - PIPER (Primordial Inflation Polarization Experiment), balloon-borne.
    - PICO (Probe of Inflation and Cosmic Origins), a probe-class cosmic microwave background mission concept.
- Lidar detectors are needed for 3D wind measurements from space.

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