Program Title: "NFAD Arrays for Single Photon Optical Communications at 1.5 µm"
Contract No.: NNX11CB10C
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Identification and Significance of Innovation: Free space optical communication over interplanetary distances epitomizes photon-starved applications, and viable spacecraft receiver technologies should provide high-performance single photon detection while having minimal size, weight, and power requirements. To provide pointing and tracking as well as communication signal detection, arrayed detectors are highly advantageous, as anticipated in the terminal designs for the Deep Space Optical Terminal currently under consideration at NASA/JPL. This SBIR program was used to lay substantial groundwork towards the full-scale development of a lasercom receiver based on an InGaAsP single-photon avalanche diode (SPAD) focal plane array (FPA) for an anticipated Mars mission to demonstrate deep space lasercom in the next decade.

Technical Objectives and Work Plan: The high-level goal of this program was to demonstrate large pixel-count single photon counting detector array technology suitable for deployment in spacecraft terminal receivers supporting long-range laser communication systems. To investigate the viability of large-format negative feedback avalanche diode (NFAD) arrays, we leveraged initial work from Phase I for monolithically integrating negative feedback elements with state-of-the-art discrete SPADs. Through close collaboration with our NASA sponsor, we determined that modification of the program objectives to target a single photon avalanche diode (SPAD) design, instead of NFAD-based arrays, provided a much higher confidence strategy for delivering FPAs for meeting NASA mission requirements. We executed three full iterations of device design, fabrication, and characterization. Additional evolution of technical objectives included the following: (i) a 32 x 32 FPA format was determined to provide adequate performance and substantially lower risk than larger formats; (ii) an uplink wavelength of 1.06 µm was determined to be preferable to 1.55 µm; and (iii) higher confidence risk retirement related to radiation effects instigated additional program tasks to demonstrate substantial improvement in radiation tolerance using improved SPAD designs.

Technical Accomplishments: The cumulative results of our work on this program and other concurrent related efforts to date establish high confidence in the feasibility of SPAD arrays with reduced active volumes to meet NASA mission targets for a deep space laser communication demonstration. Our program deliverables included 32 x 32 SPAD-based arrays suitable for hybridization with our existing ROICs and integration into our existing module platforms for focal plane arrays and cameras based on these detectors. Our program results indicate the ability to meet the following performance attributes with 100 µm pitch 32 x 32 arrays: (i) > 30% photon detection efficiency with < 1 kHz dark count rate at 223 K operation achieved with thermoelectric coolers; (ii) estimated cumulative crosstalk of < 0.5% per detection event; (iii) tolerance to ~8 krad radiation with acceptable DCR elevation (e.g., ~10X); and (iv) modest array-level performance variation with 50 mV bias shift of ~3.5% in PDE and ~6% in DCR.

NASA Applications: Our SPAD technology has potential benefits for many NASA programs since NASA missions are often accompanied by classic examples of photon-starved applications. There are at least three general areas where the potential benefits of this technology are very significant: (i) Free-space optical communications, including deep space laser communication links; (ii) 3-D LIDAR imaging for autonomous navigation and space-craft operations such as rendezvous and docking; and (iii) active remote sensing optical instruments based on LIDAR techniques.

Non-NASA Commercial Applications: In commercial markets, there are applications for SPAD arrays that parallel the uses identified for NASA missions (e.g., free space communications, 3-D imaging, and remote sensing), particularly in defense applications. 3-D LIDAR systems based on SPAD arrays have already been shown to provide the highest performance wide-area, high-resolution imaging and mapping technology available today for generating accurate and precise 3-D data products. There are commercial applications for improved photon counting APDs in various types of lidar systems for measuring atmospheric properties such as wind and weather patterns, air pollution, and general trace gas analysis. Finally, photon counting capability in the near-infrared is highly desirable for the detection of low-light output in fluorescence, photoluminescence, and photoemission processes.