Program Title: **"NFAD Arrays for Single Photon Optical Communications at 1.5 µm"**

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Final Report: Project Summary

For this Phase 1 SBIR program, we have carried out design work and device characterization to lay the foundation for the development of large pixel-count single photon counting detector arrays suitable for deployment in spacecraft terminal receivers supporting long-range laser communication systems at 1.5 µm. To surmount the present obstacles to higher photon counting rate—as well as the complexity of back-end circuitry required—in using conventional single photon avalanche diodes (SPADs), we have leveraged initial success in monolithically integrating "negative feedback" elements with state-of-the-art SPADs to beneficially modify the device avalanche dynamics. This approach can achieve extremely consistent low-parasitic passive quenching, and appropriate implementations lead to beneficially small avalanches (e.g., ~10^5 carriers) for which reduced carrier trapping provides lower afterpulsing. When correctly implemented, this "negative feedback" avalanche diode (NFAD) design is also extremely simple to operate: with just a fixed dc bias voltage, the NFAD will autonomously execute the entire arm, avalanche, quench, and re-arm cycle required for photon-counting Geiger-mode operation and generate an output pulse every time an avalanche event is induced. During our Phase 1 effort, we carried out comprehensive characterization on five different discrete NFAD designs to identify specific pixel-level design opportunities for reducing afterpulsing and timing jitter. In particular, we have identified a range of design parameters that exhibit afterpulsing levels that may be acceptable for lasercom applications (e.g., ~50%) at photon detection efficiencies approaching 10%. We have carried out modeling for the timing jitter behavior in the NFADs that indicates that a reduction in multiplication layer width can lead to jitter reduction of more than 35%. Measured RMS jitter levels of approximately 200 – 250 ps contain significant measurement system-level jitter contributations; if these can be discounted in future characterization, then a 35% reduction in the intrinsic device jitter—to be achieved by implementing the modeling results—could provide jitter performance of 100 ps or less, consistent with lasercom application requirements. We also fabricated and characterized wafer-level feedback resistance test structures that show excellent yield and uniformity sufficient for large-format NFAD arrays. By evaluating feedback uniformity over the equivalent area of 128 x 128 x 100 µm pitch arrays, we have found the standard deviation of the feedback resistance to be in the range of 4% – 8% of the mean value. This level of consistency will provide sufficiently uniform pixel performance across an NFAD array of these dimensions. These proofs-of-feasibility based on device characterization and test structure fabrication from our Phase 1 work position us well to demonstrate large-format 128 x 128 NFAD arrays during a Phase 2 effort.