

Microsystems Exploration Topic (μ E)
Solicitation No. DARPA-PA-19-04-04
Gain Enhancement by Novel Impact Ionization (GENII)

I. Topic Description

The Defense Advanced Research Projects Agency (DARPA) is issuing a Microsystems Exploration topic (μ E) inviting submissions of innovative basic or applied research concepts in the technical domain of design, modeling, and device demonstration of high gain, low noise avalanche photodiodes (APD) operating at $\geq 240\text{K}$ with cutoff wavelength $\geq 2\text{ }\mu\text{m}$. This μ E is issued under the Program Announcement for Microsystems Exploration, DARPA-PA-19-04 (through Amendment No. 6, dated 5 February 2020). All proposals in response to the technical area(s) described herein will be submitted to DARPA-PA-19-04 and if selected, will result in an award of an Other Transaction (OT) for prototype project not to exceed \$1,000,000.

A. Introduction

Avalanche photodiodes are a prevalent device structure for a number of applications, such as laser rangefinders, optical communications, and three dimensional imaging laser radar (LADAR) due to their internal photo-electronic signal gain. Current state-of-the-art APDs rely upon intrinsic material characteristics to produce impact ionization and resulting gain. However, this gain is usually accompanied by “excess noise” as both electrons and holes can initiate multiplication. APDs can operate in *linear mode*, in which the photocurrent is proportional to the signal received and is below the breakdown voltage of the APD, or in *Geiger mode*, in which the photocurrent saturates at any level of optical signal received and operates above the breakdown voltage of the APD. Although Geiger mode APDs (GmAPDs) are much more sensitive, they are prone to upset and long dead times. Conversely, linear mode APDs (LmAPDs) can resolve signal amplitude, be thresholded, and would be preferred over GmAPDs if their sensitivity can be increased without generating excess noise.

B. Objective/Scope

The objective of the GENII μ E is to identify, develop, and demonstrate new approaches to achieve low excess noise, high gain infrared LmAPD structures with cutoff wavelength $\geq 2.0\text{ }\mu\text{m}$, operating at $\geq 240\text{K}$, with low dark current. Modern bandgap engineering techniques have been developed to bring about new optoelectronic device structures that feature high sensitivity, low noise, high temperature operation, or a combination thereof. Such techniques can be applied to novel APD structures in order to maintain exquisite performance at higher operating temperatures and longer cutoff wavelengths. GENII seeks to explore and expand such bandgap engineering strategies as applied to LmAPDs to determine the trade space for future full scale DARPA Microsystems Technology Office (MTO) solutions. GENII will be a two-phase program, with Phase I focused on an iterative device design, modeling, and materials exploration and characterization to optimize performance, and Phase II focused on optimizing pixel pitch to minimize crosstalk and enable small pixel pitch. The final product of Phase I should be a model showing the ability to meet performance expectations with device measurements consistent with the model. The final product of Phase II should be an analysis of appropriate pixel pitch to

mitigate crosstalk effects down to 1% with device measurements that are consistent with that measurement. GENII's overall performance goals are detailed in Table 1 below. Proposers should strive to meet all the metrics simultaneously; however, in the event the proposed structure is not able to meet all metrics simultaneously, the proposal must clearly detail overall performance trades as it relates to these metrics.

Table 1. GENII Performance Goals

Metric	Performance Goal
Cutoff wavelength (μm)	≥ 2
Operating Temperature (K)	≥ 240
Gain (M)	1000
Excess noise factor (F)	1.1
Dark Current ($\mu\text{A}/\text{cm}^2$)	10

GENII places strong emphasis on demonstrating LmAPDs with exquisite performance at high operating temperature with cutoffs $\geq 2.0 \mu\text{m}$ that are capable of transitioning into commercially viable manufacturing environments. Accordingly, proposals must describe the LmAPD deposition technique(s), including processing methods, range of dopant levels, film thicknesses, and corresponding modeling, prediction, and measurement of material and APD properties. Phase II devices should prove the feasibility of small pitch devices for use in infrared imagers.

C. Structure

Proposals submitted to DARPA-PA-19-04 in response to this μE topic must be UNCLASSIFIED and must address two independent and sequential project phases: Phase I Growth Iterations (base) and Phase II Crosstalk Measurements (option). The periods of performance for these phases are 12 months for the Phase I base effort and 6 months for the Phase II option effort. Combined Phase 1 base and Phase 2 option efforts for this μE topic should not exceed 18 months. The Phase I (base) award value should not exceed \$725K. The Phase II (option) award value should not exceed \$275K. The total award value for the combined Phase I and Phase II is limited to \$1,000,000. Anticipated program funding will be 6.2. Therefore, research conducted by universities (prime or subcontractor) would be fundamental research and research conducted by all other organizations (prime or subcontractor) would be restricted research.

Proposals should clearly detail:

- The proposed approach and any initial experimental or modeling results for demonstration of low excess noise, high gain infrared LmAPDs with cutoffs $\geq 2.0 \mu\text{m}$ at higher operating temperatures;
- The theoretical basis for pursuing the approach, with best-case projections for gain, excess noise factor, dark current, pixel pitch, and cutoff wavelength;
- The expected performance as a function of operating temperature;
- The expected crosstalk at small pixel pitches in the proposed device structure;
- The proposed characterization plan, including breakdown, gain, excess noise factor, ionization ratio, dark current, leakage current, spectral noise, noise equivalent power, signal to noise, and crosstalk;
- Comparison to current state of the art APDs; and

- Potential militarily-relevant transitions and any initial discussions with both internal and external transition partners.

D. Schedule/Milestones

Proposers must address the following research project objectives, metrics, milestones, and deliverables in their proposals. The task structure must be consistent across the proposed schedule, Task Description Document (TDD), and the Vol. 2 - Price Volume. If selected for award negotiation, the fixed payable milestones will be directly incorporated into Attachment 2 of the OT agreement (“Schedule of Milestones and Payments”). Please see the sample OT for Prototype provided as an attachment to DARPA-PA-19-04.

For planning and budgetary purposes, proposers should assume a program start date that is 90 days from μ E topic announcement on beta.sam.gov. Schedules will be synchronized across performers, as required, and monitored/revised as necessary throughout the program.

Phase I:

- LmAPD Design: Use modeling tools to design the LmAPD device structure(s). Test chips should include variable area diodes with device size down to 10 μm . Test chips must be in a form which allows them to be inserted into cold dewars for probe and test.
- Device Growth Iterations: Utilizing at least three iterative design-then-grow cycles, develop fabrication processes to show device level performance of low excess noise, low dark current, high gain infrared LmAPDs with cutoffs $\geq 2.0 \mu\text{m}$.

The outcome of Phase I efforts will result in a refined design of a LmAPD structure based on at least 3 iterations, as well as the delivery of the detector level performance data of the tested LmAPD devices.

Phase I Milestones:

- Milestone 1 (Month 1): Provide a comprehensive description of the proposed LmAPD structure, the fabrication process, simulated performance (QE, cutoff, band diagrams, dark current, temperature dependent properties, etc.), and initial experimental data, if available. Specify what further experimentation/analysis will be performed by Milestone 2 to establish material level performance of critical LmAPD regions with performance estimations.
- Milestone 2 (Month 3): Provide an interim report describing test chip design and the material-level characterization of critical LmAPD regions (e.g. absorber, multiplication, etc.). Specify what further experimentation/analysis will be performed by Milestone 3 to develop an Iteration 1 LmAPD device design with performance estimations.
- Milestone 3 (Month 6): Provide an interim report describing the Iteration 1 device fabrication, measured performance of Iteration 1 devices, and refined performance models based on initial data. Specify what further experimentation/analysis will be performed by Milestone 4 to develop an Iteration 2 LmAPD device design with performance estimations.

- Milestone 4 (Month 9): Provide an interim report describing the Iteration 2 device fabrication, measured performance of Iteration 2 devices, and updated performance models based on updated data. Specify what further experimentation/analysis will be performed by Milestone 5 to develop an Iteration 3 LmAPD device design and accompanying performance estimates.
- Milestone 5 (Month 12): Submit Phase I Final Report in preparation for Phase II option. The Phase I final report should describe the Iteration 3 device fabrication, measured performance of Iteration 3 devices, and final performance models based on all Phase I data. The final report should also include a comparison of the three device iterations, a final recommended device design, and summarize the technical approach for Phase II tasks. The report should include a detailed comparison with the established state of the art including quantifiable performance metrics and modeling results that detail the path to the target performance and/or detail the performance trades.

Phase II:

- LmAPD Demonstration: Implement and demonstrate a prototype in a full test bench using the optimum LmAPD structure produced in Phase I. Comprehensive characterization of crosstalk as a function of pixel pitch and temperature must be carried out. The final LmAPD prototype device shall be delivered to DARPA for independent government validation and verification.
- Project Plan: Develop a design and project plan to scale up and implement a future LmAPD-based imager. The project plan should include details on transition partners, manufacturing scale up approach, and associated costs and schedule to execute the plan.

The outcome of Phase II will result in a demonstration of the prototype device to attain the targeted performance goals as well as the future project plan that outlines potential transition and scale up.

Phase II Milestones:

- Milestone 6 (Month 13): Provide a comprehensive description of the test station, detailed test plan, and initial experimental data, if available. Specify what further experimentation/analysis will be performed by Milestone 7 to establish LmAPD performance.
- Milestone 7 (Month 15): Provide an interim report detailing the LmAPD device characterization, including crosstalk and temperature dependent operation. Specify what further testing will be performed by Milestone 8 to demonstrate LmAPD performance.
- Milestone 8 (Month 18): Submit Phase II Final Report to document the LmAPD structure, test details, and device performance for the prototype detector. Document the demonstrated performance metrics with initial simulation. Provide the detailed project plan describing the future scale up and implementation of an LmAPD-based imager, with details on transition partner(s), preliminary cost model, manufacturing scale up approach, as well as associated costs and schedule required to execute the plan.

All proposals must include the following meetings and travel in the proposed schedule and costs:

- To foster collaboration between teams and disseminate program developments, a two-day Principal Investigator (PI) meeting will be held approximately every six months, with locations split between the East and West Coasts of the United States. For budgeting purposes, plan for three two-day meetings over the course of 18 months: two meetings in the Washington, D.C. area and one meeting in the San Francisco, CA area.
- Regular teleconference meetings will be scheduled with the Government team for progress reporting as well as problem identification and mitigation. Proposers should also anticipate at least one site visit per phase by the DARPA Program Manager during which they will have the opportunity to demonstrate progress towards agreed-upon milestones.

E. Deliverables

Performers will be expected to provide at a minimum the following deliverables:

- Deliverables specific to the objectives of the individual efforts. These may include registered reports, experimental protocols, publications, intermediate and final versions of software libraries, code, and APIs, including documentation and user manuals, and/or a comprehensive assemblage of design documents, models, modeling data and results, and model validation data.
- Modeling results/design showing path to performance goals
- The highest performing LmAPD iteration from Phase 1 shall be delivered to DARPA for government performance validation and verification.

II. Award Information

Selected proposals that are successfully negotiated will result in award of an OT for prototype project. See Section 3 of DARPA-PA-19-04 for information on awards that may result from proposals submitted in response to this notice.

Proposers must review the model OT for Prototype agreement provided as an attachment to DARPA-PA-19-04 prior to submitting a proposal. DARPA has provided the model OT in order to expedite the negotiation and award process and ensure DARPA achieves the goal of Microsystems Exploration, which is to enable DARPA to initiate a new investment in less than 90 days from each μ E topic announcement. The model OT is representative of the terms and conditions that DARPA intends to award for all Microsystems Exploration Awards. The task description document, schedule of milestones and payments, and data rights assertions requested under Volumes 1, 2, and 3 will be included as attachments to the OT agreement upon negotiation and award.

As discussed in DARPA-PA-19-04, Section 5, “Application and Submission Information,” proposers may suggest edits to the model OT for consideration by DARPA and provide a copy of the model OT with track changes as part of their proposal package. It is strongly encouraged that proposers include comments providing rationale for any suggested edits of a non-administrative nature. Suggested edits may be rejected at DARPA’s discretion. In order to ensure that DARPA achieves the Microsystems Exploration goal of award within 90 days from the posting date of the μ E topic announcement, DARPA reserves the right to cease negotiations if the parties fail to reach agreement on OT award terms and conditions within this time period. If edits to the model OT are not provided as part of the proposal package, DARPA assumes that the proposer has

reviewed and accepted the award terms and conditions to which they may have to adhere and the sample OT agreement provided as an attachment, indicating agreement with the listed terms and conditions applicable to the specific award instrument.

III. Eligibility

See Section 4 of DARPA-PA-19-04 for information on who may be eligible to respond to this notice.

IV. μ E Topic Responses

Responses to this μ E topic must be submitted as full proposals to DARPA-PA-19-04 as described therein. All proposals must be unclassified.

A. Proposal Content and Format

All proposals submitted in response to this notice must comply with the content and format instructions in Section 5 of DARPA-PA-19-04. There shall be no changes to the research project objectives, metrics, milestones, or deliverables, described therein. All proposals must use the templates provided as Attachments to the PA and follow the instructions therein. Information not explicitly requested in DARPA-PA-19-04, its Attachments, or this notice may not be evaluated.

B. Proposal Submission Instructions

See Section 5 of DARPA-PA-19-04 for proposal submission instructions.

C. Proposal Due Date and Time

Proposals in response to this notice are due no later than 4:00 PM on 20 March 2020. Full proposal packages as described in Section 5 of DARPA-PA-19-04 must be submitted per the instructions outlined therein *and received by DARPA* no later than the above time and date. Proposals received after this time and date may not be reviewed. Proposers are warned that the proposal deadline outlined herein is in Eastern Time and will be strictly enforced.

V. Proposal Evaluation and Selection

Proposals will be evaluated and selected in accordance with Section 6 of DARPA-PA-19-04. Proposers will be notified of the results of this process as described in Section 7.1 of DARPA-PA-19-04.

VI. Administrative and National Policy Requirements

See Section 7.2 of DARPA-PA-19-04.

VII. Point of Contact Information

Whitney Mason, Program Manager, DARPA/MTO, GENII@darpa.mil

VIII. Frequently Asked Questions (FAQs)

All technical, contractual, and administrative questions regarding this notice must be emailed to GENII@darpa.mil. Emails sent directly to the Program Manager or any other address may result in delayed or no response.

All questions must be in English and must include name, email address, and the telephone number of a point of contact. DARPA will attempt to answer questions publically in a timely manner; however, questions submitted within 7 days of the proposal due date listed herein may not be answered.

DARPA will post an FAQ list under the μ E topic on the DARPA/MTO Opportunities page at (<http://www.darpa.mil/work-with-us/opportunities>) The list will be updated on an ongoing basis until one week prior to the proposal due date. In addition to the FAQ specific to this notice, proposers should also review the Program Announcement for Microsystems Exploration General FAQ list on the DARPA/MTO Opportunities page under the Program Announcement (DARPA-PA-19-04).

To aid in the proposal preparation process, a Proposal Preparation Checklist and Tips document has been provided with the μ E topic announcement on beta.sam.gov. This document can also be found along with the FAQ posted on the DARPA/MTO Opportunities page at (<http://www.darpa.mil/work-with-us/opportunities>).