Disruption Opportunity
DARPA-PA-24-04-03
NIMBle Ultrafast microSystems (NIMBUS)
Amendment 2

I. Opportunity Description

The Defense Advanced Research Projects Agency (DARPA) Defense Sciences Office (DSO) is issuing a Disruption Opportunity (DO), inviting submissions of innovative applied research concepts in the technical domain of novel micro-mechanical oscillators for applications towards precision positioning and navigation systems. This DO is issued under the Program Announcement for Disruptioneering, DARPA-PA-24-04. All awards will be made in the form of an Other Transaction (OT) for Prototype project. The total award value for the combined Phase 1 base (Feasibility Study) and Phase 2 option (Proof of Concept) is limited to $2,000,000. This total award value includes Government funding and performer cost share if required or proposed.

To view the original DARPA Program Announcement (PA) for Disruptioneering, visit SAM.gov under solicitation number DARPA-PA-24-04: https://sam.gov/opp/cb7a935d59bb4ceeb62b9515f7d9f9b0/view.

A. Introduction

The last two decades have seen technological innovation, development, and maturity of micro-electromechanical systems (MEMS) for positioning and navigation applications. Despite these rapid advances in the maturity of MEMS-based inertial sensors for commercial applications, in the defense realm the core technology has not achieved an important goal – to provide navigation for a warfighter in a GPS-denied environment with a hand-held platform. One reason for not achieving this goal is the scale factor of the MEMS sensor. The scale-factor is the relationship between the phenomena of interest to a measurable sensor signal. A large scale-factor in sensing inertial signals is desirable for rapid dead-reckoning and abrupt course correction for applications such as unmanned air, land, and water vehicles. MEMS sensor scale-factors have plateaued because of traditional approaches to operating sensors in linear vibration regimes.

Linear operation is deeply rooted in the conservative nature of the MEMS inertial sensors manufacturing industry, whose primary and dominant customer base is automotive transportation manufacturers. Although there are now at least two examples of MEMS products that operate at or just above the linearity limit, further progress is stymied by the need for rapid productization and by a disinclination to spending time understanding, characterizing, and refining the models of sensor operation in the non-linear range. Progress in readout circuit capabilities such as dynamic range, bandwidth, power consumption, and noise has improved significantly due to continued transistor scaling and can be leveraged if the MEMS sensor scale-factor can be pushed past linear operation.

NIMBUS aims to increase sensor scale-factor by exploring operating dynamics of the sensing mass beyond the linear regime and to model, control, and demonstrate tethered MEMS whose velocities reach the fracture limit of the material constituting the sensor's technology platform.

B. Objective/Technical Scope

Warfighters in the field must make rapid course corrections, requiring positioning or dead reckoning with accuracy and speed. In such cases, sensor resolution at small timescales is

important. To achieve high accuracy in such scenarios, it is critical to enhance the sensors' scale-factor.

NIMBUS aims to demonstrate tethered resonant systems that operate just below the mechanical fracture velocity of the MEMS technology platform. For inertial sensors such as gyroscopes or resonant accelerometers, the scale-factor is directly proportional to proof-mass velocity. Today's MEMS oscillators are limited to a maximum velocity of 5 m/s because of fabrication, anchor design, transducer defects, and chaotic motion caused by non-linear mechanical springs. These limitations thwart MEMS engineers from reaching the fundamental fracture velocity limit of micro-mechanical materials. NIMBUS performers will co-design the fabrication process and anchor, transducer integration, and adaptive control algorithms, research their interplay, and perform iterations to reach the material fracture velocity limit. With better understanding into the origins of failure and new insights into overcoming them, select performers will improve upon their approaches to achieve velocity >200m/s. The velocity goal is for single-crystal silicon, and performers should state the calculated material limit of their chosen MEMS technology in the proposal with appropriate citations.

C. Structure

Proposals submitted in response to this DO must be unclassified and must address two sequential project phases: a Phase 1 (base) to achieve velocities up to the fracture velocity limit of poly-silicon and a Phase 2 (option) to achieve velocities exceeding poly-silicon and reach the fundamental velocity limits of single-crystal materials such as silicon, silicon carbide, or similar materials chosen by the performer. The periods of performance for these phases are 12 months for the Phase 1 base effort and 12 months for the Phase 2 option effort. Combined Phase 1 base and Phase 2 option efforts for this DO should not exceed 24 months. The Phase 1 (base) award value is limited to $1,000,000. The Phase 2 (option) award value is limited to $1,000,000. Both Phase 1 and Phase 2 award value limits include performer cost share, if required or if proposed. The total award value for the combined Phase 1 and Phase 2 is limited to $2,000,000. This total award value includes Government funding and performer cost share, if required or if proposed.

D. Detailed Technical Description

Five factors have played a prominent role preventing high velocities on tethered chip-scale microsystems: inefficient transducers, weak anchors, microcracks and their propagation, nonlinear chaotic behavior of the oscillating proof-mass, and material fatigue. NIMBUS program goals can only be achieved by addressing all of these challenges together with innovation and design space exploration.

Program metrics are detailed in Table 1 below. In Phase 1 of the program, performers will demonstrate tethered microsystems with velocity >65m/s (the fracture velocity of poly-silicon, the most commonly used material in MEMS sensors for positioning and navigation), show wafer-scale yield of >50%, and provide samples for Independent Verification &Validation (IV&V) testing at Polytec and/or NIST. With better understanding into failure modes and with insight and innovation into overcoming them, in Phase 2 performers will improve upon their approaches to achieve a velocity >200 m/s with a wafer-scale yield of >70%. To avoid the "hero device" mentality, the NIMBUS program incorporates demonstrating small-scale wafer-yield and seeks long-term accelerated testing with overdrive to study fatigue and fracture.

Table 1: Program Metrics Summary:

	Metric	Phase 1 (12 months)	Phase 2 (12 months)
Tethered Microsystem	Velocity	>65 m/s	>200 m/s
	Stress Limit	Up to the stress limit of polysilicon	Reach the stress limit of MEMS material
	Wafer-scale Yield	>50% on 3 wafers	>70% on 10 wafers

Improving sensor velocity and momentum by 40X will directly result in superior sensor performance. As an example, if a commercial off-the-shelf gyroscope today can resolve the rotation rate of the Earth in 10 minutes, a NIMBUS-enhanced gyroscope would be able to achieve the same resolution in <1 minute. While NIMBUS focuses on achieving proof-mass "tip" velocity, the goal is to define the foundational underpinnings of small-scale navigation sensors. Therefore, programmatic decisions regarding performers will be based upon the scalability and wafer-scale fabrication yield of the design toward achieving maximum momentum and kinetic energy per oscillation.

This DO does not provide size, weight and power (SWaP) metrics for the NIMBUS system. However, proposals should calculate and share the SWaP for their architecture and discuss potential scaling pathways toward an autonomous system. Selected performers will be expected not only to report on the maximum velocity achieved, but also to perform a complete exploration of the design space by hand calculation and finite element analysis and provide estimates on accuracy of the simulation space and confidence level in the simulations.

E. Schedule/Milestones

Proposers must address the following fixed payable milestones in their proposals. Proposers must complete the "Schedule of Milestones and Payments" Excel Attachment provided with this DO to submit a complete proposal and fulfill the requirements under Volume 2, Price Volume. If selected for award negotiation, the fixed payable milestones provided will be directly incorporated into Attachment 3 of the OT agreement ("Schedule of Milestones and Payments"). Proposers must use the Task Description Document template provided with the Program Announcement DARPA-PA-24-04, which will be Attachment 1 of the OT agreement.

Phase 1 fixed milestones for this program must include, at a minimum, the following:

- Month 1:
  - Phase 1 kickoff meeting presentation, including preliminary description of proposed NIMBUS microsystem platform with suitable justification in modeling, simulation, and prior theoretical or experimental results
  - All supporting positions identified in the proposal are assigned to personnel, and names are provided to the Government
- Month 4:
  - Theoretical analysis and computational/FEA simulations to engineer NIMBUS high-velocity oscillator with potential system scalability to large momentum and kinetic energy
  - Estimates of SWaP will be reported
  - All proposed personnel must be working on the effort at the planned level of effort

- Month 10:
    - Demonstrate NIMBUS system at performer and IV&V evaluator designed to overcome linear travel range and achieve program metrics
- Month 12:
    - Assess micro-resonator velocity achieving >65 m/s and lab demonstration of microsystem
    - Provide comprehensive final report describing NIMBUS
    - Report must contain SWaP, comprehensive design space exploration, and estimation of accuracy of simulation and confidence in it

Phase 2 fixed milestones for this program must include, at a minimum, the following:

- Month 14:
    - Revised design, simulation and fabrication of microsystem to achieve fundamental limit of selected single crystal structural material based on measured experimental parameters in Phase 1
    - Outline strategy to reach > 200 m/s
    - All proposed personnel must be working on the effort at the planned level of effort
- Month 16:
    - Report on NIMBUS material, transducers, fabrication, and control system improvements to achieve maximum velocity
- Month 22:
    - Demonstrate NIMBUS system at performer and IV&V evaluator with small-sized wafer lots to demonstrate yield and reproducibility of NIMBUS technology
- Month 24:
    - Final demonstration report providing specific, detailed NIMBUS designs with a performance summary, comparison of performance to existing SoA, and discussion of scalability of platform for 3D confinement
    - Report must contain SWaP, design space exploration and simulation accuracy, and confidence estimates

The milestones should focus on the work required to meet the program metrics. Completion of a milestone is not dependent on demonstrated performance, but on a technical analysis of the performance results and approach. Proposers should note that meeting the Phase 1 metric does not guarantee a Phase 2 award. Likewise, if a performer fails to meet the Phase 1 metrics but has a highly innovative, and potentially disruptive approach, DARPA may decide to continue those efforts into Phase 2, subject to the availability of funds.

For planning and budgetary purposes, proposers should assume a program start date of February 17, 2025. Schedules will be synchronized across performers, as required, and monitored/revised as necessary throughout the program's period of performance.

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 virtual Principal Investigator (PI) meeting will be held approximately every six months.
- Regular quarterly teleconference meetings will be scheduled with the Government team for progress reporting, video demonstrations of experimental progress, and risk

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 toward agreed-upon milestones.

Proposals should not include conference travel or publications costs.

F. Deliverables

Performers will be expected to provide, at a minimum, the following deliverables that meet the program metrics summarized in the table below:

- Negotiated deliverables specific to the objectives of the individual efforts. These may include registered reports, experimental protocols, publications, intermediate and final versions of documentation and user manuals, and/or a comprehensive assemblage of design documents, models, modeling data and results, and model validation data.
- Provide packaged microsystem for testing at IV&V partner at the end of Month 10 of Phase 1 and Month 22 of Phase 2.

II. Award Information

Selected proposals that are successfully negotiated will result in the award of an OT for Prototype project. See Section 4 of DARPA-PA-24-04 for information on awards that may result from proposals submitted in response to this announcement.

Proposers must review the model OT for Prototype agreement provided as an attachment to DARPA-PA-24-04 prior to submitting a proposal. DARPA has provided the model OT to expedite the negotiation and award process and ensure DARPA achieves the goal of Disruptioneering, which is to enable DARPA to initiate a new investment in less than 120 calendar days from idea inception. The model OT is representative of the terms and conditions that DARPA intends to include in all DO 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.

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. DARPA may not accept suggested edits. The Government reserves the right to remove a proposal from award consideration should the parties fail to reach an agreement on OT award terms and conditions. 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 model OT agreement provided as an attachment, indicating agreement (in principle) with the listed terms and conditions applicable to the specific award instrument.

To ensure that DARPA achieves the goal of an award within 118 calendar days from the posting date (October 23, 2024) of this announcement, DARPA reserves the right to cease negotiations when an award is not executed by both parties (DARPA and the selected organization) on or before February 17, 2025.

III. Eligibility

See Section 7 of DARPA-PA-24-04 for information on who may be eligible to respond to this announcement.

IV. Disruption Opportunity Responses

A. Proposal Content and Format

All proposals submitted in response to this announcement must comply with the content and format instructions in Section 5 of DARPA-PA-24-04. All proposals must use the templates provided as Attachments to DARPA-PA-24-04 and the "Schedule of Milestones and Payments" Excel Attachment provided with this DO and follow the instructions therein.

Information not explicitly requested in DARPA-PA-24-04, its Attachments, or this announcement may not be evaluated.

B. Proposal Submission Instructions

Responses to DARPA-PA-24-04-03 shall be submitted electronically to DARPA's Broad Agency Announcement (BAA) Portal (https://baa.darpa.mil).

DARPA will acknowledge receipt of complete submissions via email and assign identifying numbers that should be used in all further correspondence regarding those submissions. If no confirmation is received within two (2) business days, please contact NIMBUS@darpa.mil to verify receipt.

When planning a response to this DO, proposers should consider the submission time zone and that some parts of the submission process may take from one (1) business day to one month to complete (e.g., registering for a SAM Unique Entity ID (UEI) number or Tax Identification Number (TIN)).

Electronic Upload

First-time users of the DARPA BAA Portal must complete a two-step account creation process. The first step consists of registering for an extranet account by going to the URL above and selecting the "Account Request" link. Upon completion of the online form, proposers will receive two separate emails; one will contain a username, and the second will provide a temporary password. Once both emails have been received, the second step requires proposers to go back to the submission website and log in using that username and password. After accessing the extranet, proposers may then create a user account for the DARPA Submission website by selecting the "Register your Organization" link at the top of the page. Once the user account is created, proposers will be able to see a list of solicitations open for submissions, view submission instructions, and upload/finalize their proposal.

Proposers who already have an account on the DARPA BAA Portal may log in at https://baa.darpa.mil, select this solicitation from the list of open DARPA solicitations and proceed with their proposal submission. Note: proposers who have created a DARPA Submission website account to submit to another DARPA Technical Office's solicitations do not need to create a new account to submit to this solicitation.

All full proposals submitted electronically through the DARPA Submission website must meet the following requirements: (1) uploaded as a zip file (.zip or .zipx extension); (2) only contain the document(s) requested herein; (3) only contain unclassified information; and (4) must not exceed 100 MB in size. Only one zip file will be accepted per full proposal. The DARPA Submission website will reject full proposals not uploaded as zip files. Technical support for the DARPA Submission website is available during regular business hours, Monday – Friday, 9:00 a.m. – 5:00 p.m. Requests for technical support must be emailed to BAAT_Support@darpa.mil with a copy to NIMBUS@darpa.mil. Questions regarding submission contents, format, deadlines, etc., should be emailed to NIMBUS@darpa.mil. Questions/requests for support sent to

any other email address may result in delayed/no response.

Since proposers may encounter heavy traffic on the web server, DARPA discourages waiting until the day proposals are due to request an account and/or upload the submission. Note: Proposers submitting a proposal via the DARPA Submission site MUST (1) click the "Finalize" button for the submission to upload AND (2) do so with sufficient time for the upload to complete prior to the deadline. Failure to do so will result in a late submission.

C. Proposal Due Date and Time

Proposals in response to this announcement are due no later than 4:00 p.m. on December 20, 2024. As described in Section 5 of DARPA-PA-24-04, full proposal packages must be submitted per the instructions outlined in this DO *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. When planning a response to this announcement, proposers should consider that some parts of the submission process may take from one (1) business day to one (1) month to complete.

V. Proposal Evaluation and Selection

Proposals will be evaluated and selected in accordance with Section 6 of DARPA-PA-24-04. Proposers will be notified of the results of this process as described in Section 8.1 of DARPA-PA-24-04.

VI. Administrative and National Policy Requirements

Section 8.2 of DARPA-PA-24-04 provides information on Administrative and National Policy Requirements that may be applicable for proposal submission and performance under an award.

VII. Point of Contact Information

Sunil Bhave, Program Manager, DARPA/DSO, NIMBUS@darpa.mil

VIII. Frequently Asked Questions (FAQs)

All technical, contractual, and administrative questions regarding this announcement must be emailed to NIMBUS@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 the name, email address, and telephone number of a point of contact. DARPA will attempt to answer questions publicly in a timely manner; however, questions submitted within seven (7) calendar days of the proposal due date listed herein may not be answered.

DARPA will post an FAQ list under the DO on the DARPA/DSO Opportunities page at (http://www.darpa.mil/work-with-us/opportunities). The list will be updated on an ongoing basis until one (1) week before the proposal due date.

For those new to DARPA or national security, DARPA makes available a free, comprehensive resource via DARPAConnect on how to do business with the agency. In addition to DARPA 101 materials, relevant preparatory modules include "Understanding DARPA Broad Agency Announcements." Registration and access are free at www.darpaconnect.us.