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Office of the Undersecretary of Defense, Research and Engineering (OUSD(R&E))
Basic Research Office (BRO)
21.C Small Business Technology Transfer (STTR)
PROPOSAL SUBMISSION INSTRUCTIONS

The Office of the Undersecretary of Defense, Research and Engineering (OUSD(R&E)) Basic Research Office (BRO) STTR Program aims to facilitate the transition of basic research to applied research by collaborations between academic researchers and small businesses, as well as stimulating technological innovation, strengthening the role of small business in meeting DoD research and development needs, fostering and encouraging participation by minority and disadvantaged persons in technological innovation, and increasing the commercial application of DoD-supported research or research and development results. The BRO STTR program focuses on exploiting scientific discoveries from the DoD Basic Research Programs and providing a mechanism to further scientific development, maturation, and commercialization. **High-risk with potential for high-reward approaches are sought in addressing the scientific challenges described in the topics below.** These approaches should be stimulated by early research in academia supported by DoD basic research programs.

Offerors responding to this BAA must follow all general instructions provided in the Department of Defense (DoD) 21.C STTR Program BAA. Specific BRO STTR requirements that add to or deviate from the DoD Program BAA instructions are provided in the instructions below.

Specific questions pertaining to the BRO STTR Program should be submitted to: Dr. Jennifer Becker, Jennifer.j.becker.civ@army.mil

PHASE I PROPOSAL GUIDELINES

Phase I is to determine, to the extent possible, the scientific, technical, and commercial merit and feasibility of ideas submitted under the STTR Program. Proposals should concentrate on research or research and development which will significantly contribute to proving the scientific and technical feasibility, and commercialization potential of the proposed effort, the successful completion of which is a prerequisite for further DoD support in Phase II. **Phase I proposals should clearly articulate the basic research advances that will be exploited. Phase I proposals should also include a tentative plan for Phase II. Evaluation of the Phase I proposal will include an assessment of not only the feasibility studies planned for Phase I but the overall approach and product proposed at the end of Phase II.** The BRO anticipates funding one (1) STTR Phase I contract to small businesses with their research institution partner for each topic. The BRO reserves the right to not fund a topic if the proposals received have insufficient merit.

The Phase I Base amount must not exceed $150,000 over a period of exactly 6 months and the Phase I Option amount must not exceed $100,000, with a period of performance of exactly 6 additional months. Costs for the Base and Option must be separated and clearly identified on the Proposal Cover Sheet (Volume 1) and in the Cost Volume (Volume 3).

Awards will be made on the basis of technical evaluations using the criteria described in the DoD STTR Program BAA and availability of BRO STTR funds.

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PHASE I PROPOSAL SUBMISSION REQUIREMENTS
The following MUST BE MET or the proposal will be deemed noncompliant and may be REJECTED.

- **Proposal Cover Sheet (Volume 1).** As specified in DoD STTR Program BAA.

- **Technical Proposal (Volume 2).** Technical Proposal (Volume 2) must meet the following requirements:

  - Content is responsive to evaluation criteria as specified in DoD STTR Program BAA and below.
  - Not to exceed **15** pages, regardless of page content
  - **In addition to the Phase I proposal content specified in DoD STTR BAA, this program requires a narrative description on how early research in academic labs will be transitioned to the small business via this opportunity. In addition, the Phase I Technical Proposal must also include a preliminary Phase II Plan specifying the overall vision, approach and potential product proposed at the end of Phase II.**
  - Single column format, single-spaced typed lines
  - Standard 8 ½" x 11" paper
  - Page margins one-inch on all sides. A header and footer may be included in the one-inch margin.
  - No font size smaller than 10-point*
  - Include, within the **15-page limit of Volume 2**, an Option that furthers the effort in preparation for Phase II and will bridge the funding gap between the end of Phase I and the start of Phase II. Tasks for both the Phase I Base and the Phase I Option must be clearly identified. Option tasks should be those tasks that would enable rapid transition from the Phase I feasibility effort into the Phase II prototype effort.

    *For headers, footers, listed references, and imbedded tables, figures, images, or graphics that include text, a font size smaller than 10-point is allowable; however, proposers are cautioned that the text may be unreadable by evaluators.

- **Cost Volume (Volume 3).** The Phase I Base amount must not exceed $150,000 and the Phase I Option amount must not exceed $100,000. Costs for the Base and Option must be separated and clearly identified on the Proposal Cover Sheet (Volume 1) and in Volume 3.

- **Period of Performance.** The Phase I Base Period of Performance must be exactly six (6) months and the Phase I Option Period of Performance must be exactly six (6) months.

- **Company Commercialization Report (Volume 4)**. As specified in DoD STTR Program BAA. Information contained in the CCR will not be considered during proposal evaluations.

- **Supporting Documents (Volume 5).** BRO will only accept Supporting Documents required by the DoD STTR Program BAA:
  1. Contractor Certification Regarding Provision of Prohibited Video Surveillance and Telecommunications Services and Equipment (REQUIRED)
  2. Foreign Ownership or Control Disclosure (BAA Attachment 2) (Proposers must review Attachment 2: Foreign Ownership or Control Disclosure to determine applicability)

- **Fraud, Waste and Abuse Training (Volume 6).** Please refer to instructions provided in the DoD STTR Program BAA.

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The BRO has established a **15-page limitation** for Technical Volumes submitted in response to its topics. This does not include the Proposal Cover Sheet, the Cost Volume, or the CCR. The Technical Volume includes, but is not limited to: table of contents, pages left blank, references and letters of support, appendices, key personnel biographical information, and all attachments. The BRO requires that small businesses complete the Cost Volume form on the DoD Submission site versus submitting it within the body of the uploaded Technical Volume. It is the responsibility of submitters to ensure that the Technical Volume portion of the proposal does not exceed the 15-page limit. Do not include blank pages, duplicate the electronically generated cover pages or put information normally associated with the Technical Volume such as descriptions of capability or intent in other sections of the proposal as these will count toward the 15-page limit. **BRO STTR Phase I proposals submitted containing a Technical Volume over 15 pages will be deemed NON-COMPLIANT and will not be evaluated. It is the responsibility of the Small Business to ensure that once the proposal is submitted and uploaded into the system that the technical volume .pdf document complies with the 15 page limit.** If you experience problems uploading a proposal, email the DoD SBIR/STTR Help Desk at DoDSBIRSupport@reisystems.com. Questions will be addressed in the order received, during normal operating hours (Monday through Friday, 9:00 a.m. to 5:00 p.m. ET).

Proposals not conforming to the terms of the DoD Program BAA and these supplemental instructions will not be considered.

EVALUATION AND SELECTION

The BRO will evaluate and select Phase I and Phase II proposals using the evaluation criteria in the DoD STTR Program BAA. The criteria will be in descending order of importance with technical merit, soundness, and innovation of the proposed approach being the most important, followed by qualifications of key personnel, and followed by the commercialization potential. Due to limited funding, the BRO reserves the right to limit awards under any topic.

Approximately one week after the Phase I BAA closing, e-mail notifications that proposals have been received and processed for evaluation will be sent to the point-of-contact listed as the Corporate Official on the proposal Cover Sheet. Consequently, the e-mail address on the proposal Cover Sheet must be correct.

Only Government personnel will evaluate proposals with the exception of technical personnel from Strategic Analysis, Inc who will provide Advisory and Assistance Services and technical analysis for all topics and Allegient Defense, Inc., who will provide Advisory and Assistance Services and technical analysis in the evaluation of proposals submitted against OSD BRO topic number OSD21C-003.

Requests for a debrief must be made within 15 calendar days of select/non-select notification via email as specified in the select/non-select notification. Please note debriefs are typically provided in writing via email to the Corporate Official identified in the firm proposal within 60 days of receipt of the request. Requests for oral debriefs may not be accommodated. If contact information for the Corporate Official has changed since proposal submission, a notice of the change on company letterhead signed by the Corporate Official must accompany the debrief request.

Companies should plan carefully for research involving animal or human subjects, biological agents, etc. (reference details provided in the DoD STTR Program BAA). The short duration of a Phase I effort may preclude plans including these elements unless coordinated before a contract is awarded.

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If the offeror proposes to employ a foreign national, refer to the DoD STTR Program BAA for definitions and reporting requirements. Please ensure no Privacy Act information is included in this submittal.

If a small business concern is selected for an STTR award, they must negotiate a written agreement between the small business and their selected research institution that allocates intellectual property rights and rights to carry out follow-on research, development, or commercialization (see Model Agreement for the Allocation of Rights).

PHASE II PROPOSAL GUIDELINES
All Phase I awardees are eligible to submit a Phase II proposal. Please note that Phase II selections are based, in large part, on the success of the Phase I effort, so it is vital for SBCs to discuss the Phase I project results with their BRO Technical Point of Contact (TPOC). The 30-day window to submit a Phase II proposal will commence at the end of the Phase I Base Period. The details on the due date, content, and submission requirements of the Phase II proposal will be provided to Phase I awardees by the BRO STTR PMO via subsequent notification. This will be the only opportunity to submit a Phase II proposal for the BRO topics. The BRO STTR Program *cannot* accept proposals outside the Phase II submission dates established. Proposals received by the DoD at any time other than the submission period will not be evaluated.

Phase II proposals expected to be structured as follows: a 10-12 month base period not to exceed $850,000; a 10-12 month option period not to exceed $850,000. The entire Phase II effort should not exceed $1,700,000.

DISCRETIONARY TECHNICAL AND BUSINESS ASSISTANCE (TABA)
Technical and Business Assistance is not offered for the BRO topics.

NOTIFICATION SCHEDULE OF PROPOSAL STATUS AND DEBRIEFS
Once the selection process is complete, the BRO STTR Program Manager will send an email to the "Corporate Official" listed on the Proposal Coversheet with an attached notification letter indicating selection or non-selection. Small Businesses will receive a notification letter for each proposal they submitted. The notification letter will provide instructions for requesting a proposal debriefing. The BRO STTR Program Manager will provide ***written*** debriefings upon request to offerors in accordance with Federal Acquisition Regulation (FAR) Subpart 15.5.

PROTEST PROCEDURES –
Protests to this BAA and proposal submission must be directed to the DoD SBIR/STTR BAA Contracting Officer, or filed with the GAO. Contact information for the DoD SBIR/STTR BAA Contracting Officer can be found in the DoD STTR Program BAA.
As further prescribed in FAR 33.106(b), FAR 52.233-3, Protests after Award should be submitted to: usarmy.rtp.aro.mail.sttr-pmo@mail.mil

BRO PROPOSAL CHECKLIST
Please review the checklist below to ensure that your proposal meets the BRO STTR requirements. You must also meet the general DoD requirements specified in the STTR Program BAA. **Failure to meet all the requirements may result in your proposal not being evaluated or considered for award**. Do not include this checklist with your proposal.
1. The proposal addresses a Phase I effort (up to **$150,000** for a six-month duration base and $100K for a six-month duration option).
2. The proposal is addressing only **ONE** BRO STTR topic.

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3. The technical content of the proposal includes all proposal volumes identified in these instructions and the DoD STTR Program BAA.
5. The Cost Volume has been completed and submitted for Phase I effort. The **total cost should match** the amount on the Proposal Cover Sheet.
6. Requirement for Army Accounting for Contract Services, otherwise known as CMRA reporting is included in the Cost Volume (offerors are instructed to include an estimate for the cost of complying with CMRA – see website at https://www.ecmra.mil/.)
7. If applicable, the Bio Hazard Material level has been identified in the Technical Volume.
8. If applicable, include a plan for research involving animal or human subjects, or requiring access to government resources of any kind.
9. The Phase I Proposal describes the "vision" or "end-state" of the research and the most likely strategy or path for achieving that end-state.
10. If applicable, Foreign Nationals are identified in the proposal. Include country of origin, type of visa/work permit under which they are performing, and anticipated level of involvement in the project.

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BRO STTR 21.C Topic Index

OSD21C-001	Solid State Non-Reciprocal Microwave Devices
OSD21C-002	Magnetic-free non-reciprocal and topological integrated microwave components
OSD21C-003	Modular Energetic Materials Synthesis Platform
OSD21C-004	Epsilon-near-zero tunneling diodes for room-temperature infrared detectors and light sources
OSD21C-005	Ultra-Sensitive Microwave, THz, and IR Sensors Based on Tunable Josephson Junctions, Realized in Graphene Moiré Superconductors
OSD21C-006	Public Observatory for Integrated Population Migration Data and Modeling
OSD21C-007	Biologically-informed Unmanned Underwater Vehicles (BIUUVs)

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OSD21C-001 TITLE: Solid State Non-Reciprocal Microwave Devices

OUSD (R&E) MODERNIZATION PRIORITY: Quantum Sciences; Microelectronics; Control and Communications; General Warfighting Requirements (GWR)

TECHNOLOGY AREA(S): Materials; Information Systems; Human Systems; Air Platform; Battlespace

The technology within this topic is restricted under the International Traffic in Arms Regulation (ITAR), 22 CFR Parts 120-130, which controls the export and import of defense-related material and services, including export of sensitive technical data, or the Export Administration Regulation (EAR), 15 CFR Parts 730-774, which controls dual use items. Offerors must disclose any proposed use of foreign nationals (FNs), their country(ies) of origin, the type of visa or work permit possessed, and the statement of work (SOW) tasks intended for accomplishment by the FN(s) in accordance with section 3.5 of the Announcement. Offerors are advised foreign nationals proposed to perform on this topic may be restricted due to the technical data under US Export Control Laws.

OBJECTIVE: Design, build and test non-reciprocal microwave devices fabricated from novel materials predicted from theory and validated at frequency regime exceeding 10 THz (preferably reaching as high as 100 THz) with insertion losses less than 3dB, and isolation losses less than 20dB. Microwave devices include but are not limited to gyrators, isolators and circulators fabricated from novel materials.

DESCRIPTION: Current microwave devices based on ferrites are the mainstay of telecommunications. They have increasingly high insertion losses at high frequencies, limiting their useful frequency range typically below 100 GHz. The same functionality can be designed in semiconductor-based integrated circuits but operation at a few THz is the extreme limit of those devices. Non-reciprocal microwave devices, namely gyrators, isolators and circulators fabricated from novel materials are expected to have the potential to operate at high-THz frequencies, as the electron scattering is theoretically the limiting factor for the maximum operating frequency [1, 2]. Novel materials pertinent for high frequency applications include but are not limited to some non-magnetic metals [3], degenerately doped semiconductors [4], and goniopolar materials in which the dominant charge carrier exhibits n-type conduction in one direction and p-type conduction in another [5-7]. The material's resistivity induced insertion losses need to be taken into account in the device design and performance as well.

PHASE I: Formulate complete designs for a series of high frequency devices (gyrator, or isolator, or circulator) that optimize contact technology and can have frequency response characteristics exceeding 10THz at room temperature. The choice of material, operating characteristics and design should be justified on rigorous scientific principles, using experimental results to-date and theoretical models.

PHASE II: Construct and optimize device geometry with respect to S-parameters. Demonstrate optimization based on measured trans-conductance matrix and insertion losses for a series of

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devices showing room temperature frequency response exceeding 10 THz (preferably up to 100 THz) and high temperature capability up to 10 GHz at temperatures up to 1000 C.

PHASE III DUAL USE APPLICATIONS: Commercialize electronics switching platform. Expand the capability to meet requirements for other Air Force test facilities and mature the technology for commercialization to all DoD facilities and the private sector.

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KEYWORDS: Microwave; insertion loss; n-type conduction; gyrator; isolator; circulator; S-parameters

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OSD21C-002 TITLE: Magnetic-free non-reciprocal and topological integrated microwave components

OUSD (R&E) MODERNIZATION PRIORITY: Microelectronics

TECHNOLOGY AREA(S): Electronics

OBJECTIVE: Design, fabricate, and demonstrate a new category of subwavelength non-reciprocal circulators, including arrays of them to form photonic topological insulators, operating at microwave frequencies without the need of magnetic materials and/or magnetic bias, which are compatible with integrated circuits technology. In contrast to conventional magnetic-based non-reciprocal components, the proposed components will be based on suitably tailored time-varying networks, they shall be fully integrable within the same substrate of common microwave integrated components, such as filters, mixers, oscillators, etc…, they should be deeply subwavelength in size, and at the same time they should achieve an isolation of at least 20 dB, an insertion loss lower than 1 dB and ensure broadband operation, spanning an octave or more. Arrays of these elements to realize topological insulators should guarantee reconfigurability and inherent robustness to disorder and imperfections, ideally suited for advanced 5G and 6G wireless systems.

DESCRIPTION: Non-reciprocal microwave components are the basis of many sensing, defense and communication systems. Their functionality is almost exclusively achieved through magnetic materials, which are incompatible with integrated technology [1]. Recent work has shown that biasing with EM vectors (other than the magnetic field) which are odd under time reversal, such as the electric current [2] or the linear momentum [3], can also produce a non-reciprocal effect, relaxing the requirements on magnetic materials. These alternatives, however, are currently limited by typically weak effects, requiring large volumes of operation, and in some instances large power consumption and/or narrow bandwidths. Recent efforts have shown that temporal variations synthesizing angular momentum bias can actually overcome these problems [4-5], and realize broadband, ultracompact nonreciprocal devices. The ultimate goal of this project is to fabricate and demonstrate microwave devices exhibiting strong non-reciprocal responses in a deeply subwavelength scale, without the need of magnetic materials and with adequate bandwidth for the majority of practical applications. The fabrication methods must allow realization at low cost with conventional integrated technology. We envision arrays of these elements to implement true-time-delay (TTD) beamforming networks in which reconfigurable signal routing and wideband nanosecond-scale delays enable TTD-based beam forming of ultra-wideband signals spanning DC to GHz frequencies. We also envision arrays of integrated nonreciprocal elements to realize full-duplex phased-arrays in which programmable delays within each element enable independent phased-array beam forming in transmit- and receive-modes, and whose isolation features enable full-duplex simultaneous transmission and reception of broadband radio-wave signals. These devices will enable highly reconfigurable antenna systems for e.g. radar and communication systems, enhancing the spectrum efficiency, and drastically reducing weight, cost and avoiding the need of scarce magneto-optical materials.

PHASE I: In the Phase I effort, a complete design of the proposed non-reciprocal components will be formulated and fabrication procedures will be developed. The proposed designs should

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include realistic layouts of the proposed integrated circuitry. Full-wave / circuit simulations should be based on accepted analytical methods or rigorous numerical models. Phase I efforts should also include designs of arrays of these elements to realize topological insulators with robust and reconfigurable nonreciprocal signal transport.

PHASE II: In the Phase II effort, the design and fabrication process identified in Phase I will be evolved towards the integration of the proposed non-reciprocal components in realistic circuits, and evaluation of their performance. The robust response of the circulators and topological insulators under harsh environmental conditions and their integration in electronic circuits should also be verified.

PHASE III DUAL USE APPLICATIONS: The Phase III work will demonstrate the repeatability of the fabrication process and the system integrability in true-time delay and advanced wireless antenna systems. Besides the applications across all branches of the armed forces, civilian applications of this technology will be explored, including communication systems, high-fidelity circuitry, etc.

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KEYWORDS: Magnetic-free, Non-reciprocal, Topological integrated microwave components

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OSD21C-003 TITLE: Modular Energetic Materials Synthesis Platform

OUSD (R&E) MODERNIZATION PRIORITY: Hypersonics, General Warfighting Requirements (GWR)

TECHNOLOGY AREA(S): Weapons

The technology within this topic is restricted under the International Traffic in Arms Regulation (ITAR), 22 CFR Parts 120-130, which controls the export and import of defense-related material and services, including export of sensitive technical data, or the Export Administration Regulation (EAR), 15 CFR Parts 730-774, which controls dual use items. Offerors must disclose any proposed use of foreign nationals (FNs), their country(ies) of origin, the type of visa or work permit possessed, and the statement of work (SOW) tasks intended for accomplishment by the FN(s) in accordance with section 3.5 of the Announcement. Offerors are advised foreign nationals proposed to perform on this topic may be restricted due to the technical data under US Export Control Laws.

OBJECTIVE: To create a scalable, highly-modular, platform that can accommodate a wide variety of synthesis strategies to produce a large number of fine/specialty chemicals relevant to the energetics community, economically and on-demand. This platform needs to be nimble enough to take advantage of new and old synthetic routes to manufacture traditional energetic materials to maximize cost and efficiency as well as put new compounds into production.

DESCRIPTION: Ingredients used in explosive, propellant, and pyrotechnic formulations comprise a wide array of chemistries, including organic (C, H, N, O based) and inorganic explosives and oxidizers, polymeric and oligomeric binders, metal fuel particles, plasticizers, catalysts, burn rate modifiers and a variety of other additives. For common formulation ingredients that are used in large volume such as high explosives, bulk-production generally occurs at large-scale specialty manufacturing plants. In contrast, boutique ingredients that are used either in smaller fractional amounts in energetic formulations or are only needed for periodic production runs are increasingly difficult to procure.

Often the only available sources for these critical ingredients and precursors are now OCONUS, if available at all. This dearth of US sources and market drivers strong enough to produce in-service ingredients makes it difficult to rapidly prototype new, higher performing energetic formulations. Causes of this divestiture are multifaceted and include: being unfamiliar with unique synthetic processes such as nitration and reactions on highly strained systems, a lack experience with qualification specification requirements, and a lack of flexibility when it comes to handling sporadic and highly-variable (in terms of quantity) production runs.

Coupled with the necessity for scalable synthesis platforms to produce critical, already-fielded ingredients; there is a similar need for small-scale, agile production to support synthesis of new and emerging energetic ingredients for rapid formulations development leading to higher performing propellants and explosives. The time between energetic molecule discovery to scaled-up batch synthesis in sufficient quantity for formulation and safety testing can often take many years. This lack of high-throughput synthetic strategies and tools at developmental

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quantities severely hinders the ability to rapidly prototype, test, and transition new energetic formulations.

Considering recent progress in theoretical/predictive chemical synthesis [1] [2], scalable flow chemistry methods [3] [4] [5] and microfluidics [6], in-situ diagnostics to inform synthetic strategies, feedback control [7], modular chemical processes [8] [9] [10] [11] [12], and related advances pushed by pharmaceuticals [13] [14] [15] [16] [17] [18] and other chemical industries [19] [20] [21] [22] [23], it is anticipated that safe [24], cost-effective [25], switchable, and modular chemical synthesis platforms with a small and portable footprint can now be developed to change the paradigm of “less-than-bulk” production for critical/fielded and emerging energetic ingredients and precursors.

PHASE I: Design on paper a modular and scalable synthetic platform that is configurable to produce representatives of four or more classes of energetic material ingredients and/or precursors with minimal configurational changes. The platform can integrate any synthetic process (continuous flow, microfluidics, batch, etc.) that is amendable to the modular and switchable platform goals. Other emerging advances in synthesis S&T should be exploited, examples including theoretical synthesis planning strategies [1], electro- and photo-catalysis [8], etc. Selected reactions should be justified by the ability to showcase platform chemical variability. The design should outline configuration changes (time, effort, cleanup, etc.) necessary to accommodate switching between the selected ingredients/precursors and cost analysis should be prepared comparing to current production cost as appropriate. Issues of scalability should be addressed; i.e., if scaling to progressively larger quantities is accomplished by larger volume or more rapid reagent throughput, parallel modules to multiply output, or some other means. Emphasis should be placed on creating the on-demand ability to switch between target material syntheses through system modularity, accounting for material handling safety concerns. Remote operation for safety considerations should be integrated into overall design.

Phase I should present two or more “modules” that perform particular chemical synthesis and/or diagnostic functions. Elements within the modules can include regulated solid and or liquid reagent addition/dispensing, mixing protocols, exquisite control of temperature, chemical separation/purification steps. Control hardware and software must be included in the overall description of each module. In situ chemical diagnostics may be an integral part of the platform modules, but at least one should be dedicated to evaluate the synthetic strategy (FTIR, HPLC, GCMS, etc.) and should back-feed into any theoretical predictive strategies. The process modules can be COTS or custom built, but should be rationally chosen to facilitate multiple kinds of reaction environments with relevance to energetic materials chemistry.

Details to integrate each of the modules is not required in phase I; however, plans to integrate into the complete synthetic platform should be outlined in the overall platform paper design. Emphasis is to be placed on any modules/operations that are special to new/emerging energetic materials synthesis strategies, but are not confined to particular end products. For example, nitration reaction strategies, cage formations, feedback to theoretical synthesis tools, etc.

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PHASE II: Prototype the switchable, modular on-demand synthesis capability to produce representatives of four or more classes of energetic material ingredients and/or precursors based on the Phase I design. Selected ingredients should be justified by critical need and (lack of) availability, DoD importance, and ability to showcase platform chemical variability. All appropriate synthesis process modules should be physically integrated into the overall platform with appropriate in situ diagnostic modules to inform/streamline synthetic strategies. Necessary process control hardware and software should be complete and running the modules. Capability to switch between and produce the example ingredients/precursors to completion (readiness to be formulated) should be confirmed. Ingredients produced using the new synthesis platform should be characterized and compared to ingredient/precursor specifications and requirements (MIL-SPEC, MIL-STD, ASTM, etc.) where possible. Platform scalability (grams to kilograms) should be demonstrated for at least one of the example ingredients.

Pursue efforts to partner with appropriate DoD or other DoD contractor points of contact (POCs) for transition of manufacturing capabilities.

PHASE III DUAL USE APPLICATIONS: Work with DoD or DoD contractor energetic material production community to duplicate and integrate new modular synthetic platform(s) to best fill critical EM material needs. Efforts will be guided by Navy TPOC and other SMEs, including the Critical Energetic Materials Working Group (CEMWG), Energetic Materials ManTech, and other stakeholders.

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KEYWORDS: Energetic Materials; Energetic Ingredients; Critical Chemicals; Chemical Synthesis; Explosives; Oxidizers; Propellants; Pyrotechnics

VERSION 2

OSD21C-004 TITLE: Epsilon-near-zero tunneling diodes for room-temperature infrared detectors and light sources

OUSD (R&E) MODERNIZATION PRIORITY: Microelectronics; General Warfighting Requirements (GWR)

TECHNOLOGY AREA(S): Sensors; Materials

OBJECTIVE: Develop, optimize, and demonstrate electrical tunneling-based nanophotonic devices that can sense and emit frequency-tunable infrared light at room temperature through the epsilon-near-zero phenomenon.

DESCRIPTION: The Department of Defense (DoD) has an enduring need for imaging systems that operate across infrared (IR) frequencies with low size, weight, power, and cost (SWAP-C). A critical SWAP-C requirement for future systems is the ability to operate at ambient temperature. Recent work shows that tunnel diodes based on metal-insulator-metal (MIM) rectenna structures can convert infrared light into an electrical signal, but efforts have focused on broadband light harvesting, rather than spectrally resolved IR imaging. [1 – 3] Compound semiconductors, such as cadmium oxide, exhibit low losses at IR frequencies and support zero-index phenomena like epsilon near-zero (ENZ) polaritonic modes. [4 – 6] Salient features of ENZ modes—coherent perfect absorption and extreme field enhancement [6]—are ideal characteristics for an absorber layer in a MIM rectenna. Through choice of material and doping, ENZ modes are tunable across the IR, from 1 – 30 microns [4], narrow-band [5], amenable to charge and energy transfer at ultra-fast time scales [7], and support strong non-linear optical behaviors [8]. MIM diodes run in reverse bias emit light through inelastic electron tunneling, [9 – 11] so ENZ-based tunnel diodes could also serve as new, tunable IR light sources.

PHASE I: Develop concepts supported with feasibility modeling for ENZ-based MIM IR (1) imaging and (2) emitting devices measuring 10x10 pixels, with each pixel separately able to detect or emit four different wavelengths between 2 – 14 microns, each with a maximum bandwidth of 100 meV. Design for an operating temperature range of -20 – 50˚C. The applied voltage needed to detect IR light should be less than 1V (ideally 0V). Outline the techniques and procedures to fabricate and characterize these devices. Describe a control scheme with which to achieve solid-state beam steering (e.g., phased array) for the emitter device.

A highly desirable objective is to experimentally demonstrate IR detection and/or emission at a single wavelength between 2 – 14 microns using a single-pixel breadboard MIM device. Demonstrate operational temperature of 0 ˚C or above (25 ˚C desired). Characterize optoelectronic performance characteristics—100 meV maximum bandwidth and minimum 3dB minimum signal-to-noise ratio are desired.

PHASE II: Based on Phase 1 results, fabricate, test, and demonstrate at least one operational ENZ-based MIM IR imaging device prototype, and at least one operational ENZ-based MIM IR emitter device prototype. Imaging and emitter shall operate fully across a temperature range of -20 – 50˚C, with 100 meV maximum bandwidth and 3dB minimum signal-to-noise ratio at each wavelength. Response times shall be on the order of 100 ps or less. Fully characterize the

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optoelectronic performance of the imaging device (e.g., I-V curves, signal-to-noise ratios vs. temperature, efficiency, detectivity or D*, etc.) and of the emitter device (power and spectral output, efficiency, etc.). The emitter shall demonstrate an optical phase array that can achieve beam steering over a 60˚ solid angle. Compare performance against existing commercial IR detectors and emitters that operate at ambient temperatures.

PHASE III DUAL USE APPLICATIONS: Demonstrate ENZ-based IR imaging and emitting devices that will be appropriate for integration with existing and/or future DoD IR imaging and signaling systems. Partner with DoD laboratories and interested industrial parties to further define necessary capabilities and metrics, as well as the research and development necessary for commercialization and adoption. Expand devices to 100-by-100 pixels or more, and 25 frequencies or more. Achieve response times of 6 – 50 femtoseconds for 2 – 14 micron light. Consideration will include SWAP-C in design.

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KEYWORDS: Infrared sensors; nanophotonics; epsilon-near-zero materials; tunneling diodes

VERSION 2

OSD21C-005 TITLE: Ultra-Sensitive Microwave, THz, and IR Sensors Based on Tunable Josephson Junctions, Realized in Graphene Moiré Superconductors

OUSD (R&E) MODERNIZATION PRIORITY: Microelectronics; Quantum Sciences

TECHNOLOGY AREA(S): Electronics

OBJECTIVE: Develop highly sensitive tunable sensors in microwave, THz, and IR regions via Josephson Junctions, based on twisted 2D heterostructures of graphene Moiré superconductors.

DESCRIPTION: In order to address the future demands on sensitivity, robustness and overall multi-functionality, future multi-domain sensing systems in all environments will need highly sensitive sensors with tunable spectral characteristics. A recently emerged novel Moiré quantum matter paradigm using two graphene sheets twisted by an angle close to a theoretically predicted 'magic angle', can result in flat band structure near the Dirac point, giving rise to a strongly-correlated electronic system and enabling quantum phases, such as correlated insulators, Chern insulators, superconductivity, etc. Further advances in modeling, design, fabrication and measurement of twisted 2D heterostructures are needed for better understanding these phenomena in order to be employed for microwave, THz, and far-IR detectors with improved sensitivity by up to three orders of magnitude over current capabilities [a,b].

The goal of this technology development is to design, develop and demonstrate a prototype Moiré based tunable detector with improved sensitivity by at least an order of magnitude. While the overall goal is to address the need for advanced detection systems (e.g., microwave, THz, or IR) by exploring new phenomena in Moiré quantum materials, here the focus is on the approach of tunable Josephson junction based on graphene Moiré superconductors.

PHASE I: Develop necessary computational methods, rigorously model the proposed heterostructure-based sensor system, and formulate and provide a detailed plan for fabricating and demonstrating the twistronics-based sensor system. Summarize the recent scientific and technical progress being relied on, relevant to the measurement, modeling, design, and fabrication of twisted 2D heterostructure-based devices. Detail the designs improving microwave, THz, and far-IR detector technology via the Moiré superconductivity, and develop and present modeling and quantitative arguments to establish feasibility.

PHASE II: Construct and demonstrate prototype devices based on Phase 1 feasibility and design. Apply RF techniques to develop Josephson sensors based on Moiré superconductivity [c]. Exploit and demonstrate the gate-tunable superconductivity in the twisted Moiré system as a unique opportunity to develop a sensitive detector for lower-energy photons, and for broader bandwidth, that makes it feasible for hyperspectral imaging. Employ higher ratios of kinetic inductance (higher than conventional superconductivity) and demonstrate high signal-to-noise ratios. The twisted Moiré system consisting of only two [d] or three [e] active material layers has an extremely small heat capacity, on the order of one Boltzmann constant, which can enable a giant thermal response from even just a single photon. Address practical issues of making consistent twist angles between layers in a reproducible way using a scalable process and

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incorporate into an atomically thin twisted moiré system that has promise of providing the ultimate material platform for microwave and THz sensing.

PHASE III DUAL USE APPLICATIONS: The proposer is required to obtain funding from either the private sector, a non-STTR Government source, or both, to develop the prototype into a viable product or non-R&D service for sale in military or private sector markets. STTR Phase III refers to work that derives from, extends, or completes an effort made under prior STTR funding agreements, but is funded by sources other than the STTR Program. Phase III work is typically oriented towards commercialization of STTR research or technology.

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b. Microwave characterization of Josephson junction arrays: Implementing a low loss superinductance, Masluk, Kamal, Minev, Devoret, Phys. Rev. Lett. 109, 137002 (2012).
c. Magic-angle bilayer graphene nanocalorimeters: toward broadband, energy-resolving single photon detection, Seifert, X. Lu, Stepanov, Durán Retamal, Nano Lett. 20, 3459 (2020).
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KEYWORDS: 2-D heterostructure; Graphene; Moiré quantum matter; Twistronics; single photon detection; Superconductivity

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OSD21C-006 TITLE: Public Observatory for Integrated Population Migration Data and Modeling

OUSD (R&E) MODERNIZATION PRIORITY: Artificial Intelligence/ Machine Learning; General Warfighting Requirements (GWR)

TECHNOLOGY AREA(S): Information Systems; Human Systems

OBJECTIVE: Create a data repository for population migration data and modeling for public use consisting of data that can be integrated from diverse open sources, codebooks, computational models with source code, and a tool suite to enable researchers to develop new analytic models as well as upload new data, codebooks, and computational models to support predictive and causal modeling of global population migration patterns alongside causes and consequences of population migration, as well as mitigating factors that determine those patterns.

DESCRIPTION: There are no existing comprehensive tools to predictively model the impact of the increasing incidence of population migration due to environmental change and human-caused crises, which poses challenges for global security. Large-scale environmental changes such as floods, earthquakes, and droughts, can drive population migration; so to can war and regime change. Both types of events can precipitate impacts on health, crime, and sociopolitical instability as humans relocate to access critical resources. Migration impacts both in- and out-migration regions. Receiving regions for migrants experience stresses on social institutions and infrastructure (e.g., economic, healthcare, education, political systems), and can exacerbate already-present sociocultural conflicts as new cultures come into contact with the receiving culture. Out-migration regions suffer from the loss of human and social capital leading to a crippling of their social institutions and infrastructure, which are precursors to a fragile state. The net outcome is a potential for geopolitical and social conflict that poses a risk to global stability. At the same time, there are opportunities to catalyze new markets that can jump-start economic growth, generate increased cooperation across diverse cultural groups, and introduce new forms of human and social capital to a region receiving migrants. If impacts of naturally occurring environmental change and human-caused crises on migration patterns can be predicted, potential out-migration regions can mitigate the likelihood of mass exoduses of their population through proactive planning, and in-migration regions can prepare for the impact of the new migrants on their culture and infrastructure. To address this issue, scientists across academia and the private sector have begun to create new datasets and mine existing open source data to develop models to predict patterns of population migration and the causes and consequences of these patterns. These scientific efforts, however, require intensive searching for and assessment of diverse data (e.g., meterological, event, demographic, ethnographic, geospatial data) from different sources, that are structured in different ways (e.g., qualitative vs. quantitative data). Moreover, modeling the dynamic relationships between natural and human-induced change and population dynamics is challenging due to both temporal and spatial parameters, alongside human and collective decision-making that determine if/how populations will move in the face of crises. What is needed is a tool to house or link to relevant data sets and computational models to capture interdependencies between human social systems and environmental and human-induced events. Such a tool will facilitate development, validation, and replicability of predictive models of population migration under duress and improve the

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capacity of policymakers and decision leaders to identify potential hot-spots in advance, develop strategic plans to mitigate adverse consequences such as stress on the social infrastructure and cross-cultural conflict, and turn the population dynamics into opportunities for economic growth and cultural enrichment. The aim of this topic is to create a public open-source sustainable platform to integrate diverse data sources and predictive models of population migration resulting from crises; encourage a community of scientists, policymakers, and decision leaders to share data and models; and motivate cross-disciplinary collaboration to generate basic and applied advances to better predict, address the adverse impacts of, and optimize opportunities related to crises-induced population migration.

PHASE I: Develop a prototype of a tool to integrate data, models, and analytics depicting patterns of population migration due to human-induced or environmental events, including a data preparation protocol for ingestion of time series environment or climate data and human-caused crises event data, as well as data from at least two other open sources of population, migration, demographic, or ethnographic data for proof of concept (i.e., test data pool), with at least one source of structured data and one source of unstructured data; develop the protocol for importing computational models that can be applied to an integrated subset of the test data as defined by the data preparation protocol. The data and model formats must be compatible with Department of Defense (DoD) standards to ensure interoperability with other DoD datasets. Phase 1 should also include the development of a prototype tool interface that includes computational output of analyses of data sets included in the tool as well as visualization of those analytic results. A usability test of the prototype tool with a sample of researchers should be conducted and a report issued detailing the analysis of the test.

PHASE II: Expand the data pool to include at least a dozen open sources of data (both structured and unstructured) uploaded by researchers outside the performer's team as well as data sources linked to the tool from existing open source data (e.g., census data, general social survey data, human research area files) to demonstrate the versatility of the ingestion protocol and efficiency of the modeling/analytics component of the tool. Refine the user interface to address improvements discovered in the Phase 1 usability test. Test the refined and expanded tool on a large sample of researchers, to include government scientists and analysts, as well academic and private sector researchers. (1) Develop a continuity plan to enable ongoing viability of the tool subsequent to the STTR award; the continuity plan must describe how/where the tool would reside for broad accessibility (i.e., identify a durable plan and host for the tool capable of sustaining it without additional government funding) and how it will be maintained and refreshed beyond the scope of the STTR award; (2) Generate commercialization plan to ensure continued public access to open-source databases within the tool, while providing a for-profit pathway and/or licensing plan to leverage market demand for proprietary elements of the observatory including computational models, visualization and analytic algorithms, and consulting services.

PHASE III DUAL USE APPLICATIONS: Additional data capabilities and models can be added to the tool, including health data, crime/deviance data, event data (e.g., from news reports), climate and disaster data, utility data (e.g., energy use trends, transportation routes, communication networks), epidemiological models, network models, and survival models to enhance the broad applicability of the tool across sectors interested in population dynamics to increase commercialization potential.

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KEYWORDS: environment; analysis; conflict; data archive

VERSION 2

OSD21C-007 TITLE: Biologically-informed Unmanned Underwater Vehicles (BIUUVs)

OUSD (R&E) MODERNIZATION PRIORITY: General Warfighting Requirements (GWR)

TECHNOLOGY AREA(S): Ground and Sea Vehicles

OBJECTIVE: Utilize the fundamental understanding of biological propulsion to develop and demonstrate a highly efficient, quiet underwater vehicle design optimized for range, endurance and speed. The design should be based on rigorous analysis and leverage results from recent computational and experimental fluid dynamics investigations. Since unmanned platforms do not have human habitation requirements, new design spaces are available that might include novel propulsors (e.g. fins, tails or other bio-inspired mechanisms) that utilize unsteady propulsion, body shape and body deformation. This STTR will provide increased capabilities for UUVs based on the technology push from the fundamental understanding we now have of how biological swimmers propel themselves efficiently and quietly.

DESCRIPTION: There is an ongoing desire for greater range, endurance and speed for unmanned underwater vehicles (UUVs). UUV designs that are informed by biology offer the potential for improved performance. Certain aquatic animal species are capable of much higher maximum speeds than man-made UUVs. Furthermore, other species are capable of swimming with a very low cost-of-transport (COT) (energy per mass per distance travelled) compared to man-made UUVs [1], and with much reduced acoustic signatures. The performance of aquatic animals with respect to swimming speed, efficiency and quietness can serve as benchmarks to direct the development of biologically-informed UUVs (BIUUV) with enhanced capabilities. Unlike manned submarines, unmanned underwater vehicles are not constrained in shape by human habitability requirements. Therefore, a significant new design space is accessible for UUVs, for example, in body shape, body deformation and type of propulsor. This new design space may provide advantages in terms of range, stealth, endurance and speed. A great deal of progress has been made in the fundamental understanding of the hydrodynamics of propulsion of aquatic animals, in both experimental and computational investigations [2]:

Flexibility and viscous effects, profile and planform shapes can impact both thrust and efficiency [2], and so do the dynamics: combined heave and pitch motions and phase difference, as well as non-sinusoidal gaits and intermittent actuation. [3]

To explore high-frequency performance space, a platform based on yellowfin tuna (Thunnus albacares) and Atlantic mackerel (Scomber scombrus) was designed and tested [3]. Body kinematics, speed, and power were measured at increasing tail beat frequencies, while experimental analyses of freely swimming tuna and mackerel allowed comparison with the tuna-like robotic system.

Batoid fish such as manta rays (Manta birostris) and cownose rays (Rhinoptera bonasus) being notable for their fast, efficient swimming and high maneuverability, a ray-inspired underwater vehicle – the MantaBot – has been the subject of extensive investigation. [4]

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Scaling laws that elucidate the dominant flow physics for pitching foils have been developed and can provide guidance for the design of bio-inspired propulsive systems. [5]

These findings now enable development of underwater platforms that exploit the fundamental knowledge acquired from such studies above. This Topic will pursue the design and demonstration of innovative, bio-inspired unmanned underwater platforms with capabilities well beyond the state of the art for range, stealth, endurance and speed.

The overall design objective and targeted capabilities apply to an untethered UUV, between 1-5 meters in length, and capable of operating in salt water to depths of 50 ft, to support Phase II and Phase III testing. Conventional designs such as propellers and jets are not in scope for this topic. The design will be evaluated according to measurable performance criteria:
– Speed: minimum of 4 meters/sec, with an objective of 6 meters/sec or higher.
– Cost of Transport (COT): proposed project should optimize the COT and demonstrate clear improvement over the state-of-the-art, for the chosen vehicle length and speed.
– Quietness: underwater acoustic energy generated by the vehicles, should be minimized by design.
– Power: the design shall not rely on energy harvesting from the environment, but can incorporate methods of energy recovery from mechanical motion itself. It shall utilize state of the art energy storage (R&D into energy storage is outside the scope of this topic).
– Power Transmission: the design shall use state of the art means of transferring power to the propulsor. Successful proposals will explain how the proposed means of power transmission will contribute to meeting the performance objectives. The scope of this Topic includes, but is not limited to, R&D into artificial muscles supporting the performance criteria.
– Sensing and control: approaches to sensing and dynamic control that optimize hydrodynamic interactions and flow physics are in-scope for this Topic. A successful proposal will explain how these will contribute to meeting the performance objectives.
– Path Planning: use off-the-shelf components to provide sufficient capability for the BIUUV to perform the demonstrations during Phase II and Phase III, including straight line tracks and simple maneuvers sufficient to demonstrate speed, range, endurance and acoustics. R&D into path planning is outside the scope of this topic.
– Vehicle cost: estimated costs of scaled manufacturing will be a factor in the proposal evaluations, and can be used to guide material and design selection.

PHASE I: The small business shall demonstrate the feasibility of the concept in meeting Navy needs for a BIUUV that is capable of meeting the desired performance objectives, via a variety of possible methods: model-scale experiments, computation, or previous results and data, as well as fabrication of components (if feasible) for any difficult-to manufacture component. This body of evidence shall, as much as possible, support the predicted speed and COT performance and other high risk aspects of the design. The Phase I should convincingly show that the design is sufficiently robust to undergo the testing described in Phase II and Phase III.

PHASE II: The small business shall fabricate a prototype, according to the requirements stated in this Topic, and evaluate the design via in-water tests conducted at a facility arranged by the small business. These tests shall target the listed performance objectives, such as speed, range, endurance, COT and quietness, via untethered operations. At a minimum, the prototype testing shall consist of (1) basic operability testing, (2) speed trials, (3) range/endurance trials, and (4) acoustic testing. The small business may propose other tests as needed to demonstrate the benefits of their design, and perform analyses to establish reliability, identify areas in need of further improvement if necessary, as well as analyze manufacturing scalability in order to transition the design into a useful product for the Navy

PHASE III DUAL USE APPLICATIONS: The small business shall apply the knowledge gained in Phase II to build an advanced prototype BIUUV. The small business shall test the advanced prototype according to the Phase II test goals. The small business shall support Government testing of the advanced prototype BIUUV.

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KEYWORDS: Biological propulsion; unmanned underwater vehicle; biologically-inspired design