BAA number HR001117S0025

Lead Organization University of Florida

Type of organization Other Educational

Proposers internal reference number

Other team members :

Changzhi Li Texas Tech University

David Arnold? University of Florida

Proposal title Biomimetic microfabricated magnetic gradiometer

APoC :

TPoC :

Casanova, Joaquin

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Total funds requested

Submitted XX/YY/2017

Official transmittal letter

The transmittal letter should identify the BAA number, the proposal by name, and the organizations proposal reference number (if any), and should be signed by an individual who is authorized to submit proposals to the Government.

1 Statement of Work (SOW)

The project's aim is to develop a minaturized high-sensitivity, low-noise magnetic gradiometer. Our approach is to mimic the mechanism found in magnetosomes, the specialized cells four from bacteria to higher vertebrates such as fish and birds (see 2). This is comprised of four main tasks: modeling and simulation, microfabrication process design, circuit design, and device manufacture and testing. Each Phase (I,II,III) will include these four tasks.

1.1 Phase I

1.1.1 Modeling and simulation

- A general description of the objective (for each defined task/activity)
- A detailed description of the approach to be taken to accomplish each defined task/activity
- Identification of the primary organization responsible for task execution (prime, sub, team member, by name, etc.)
- The completion criteria for each task/activity - a product, event or milestone that defines its completion
- Define all deliverables (reporting, data, reports, software, etc.) to be provided to the Government in support of the proposed research tasks/activities
- Identify whether government-furnished equipment is requested and, if so, the required quantity and delivery schedule
- Clearly identify any Risk Reduction tasks AND
- Clearly identify any tasks/subtasks (prime or subcontracted) that will be accomplished on-campus at a university. Note: Each program phase must be separately defined in the SOW. Include a SOW for each subcontractor and/or consultant in the Cost Proposal Volume. Do not include any proprietary information in the SOW(s).

1.1.2 Microfabrication

1.1.3 Circuit design

1.1.4 Manufacture and testing

1.2 Phase II

1.2.1 Modeling and simulation

1.2.2 Microfabrication

1.2.3 Circuit design

1.2.4 Manufacture and testing

1.3 Phase III

1.3.1 Modeling and simulation

1.3.2 Microfabrication

1.3.3 Circuit design

1.3.4 Manufacture and testing

2 Innovative Claims

Our approach is to design a sensor based on a magnetoreceptive mechanism used in nature - magnetite crystals torqued by external magnetic fields open ion channels in the cell wall. To mimic this, we propose a microfabricated MEMS sensor, with a layer of magnetic material on top of piezo electric cantilevers. When forced with an exernal field, torque induced on the magnet create stress in the piezo, and thus a voltage is produced. There are three advantages to this approach. First, microfabrication allows for a small size. Second, by orienting individual sensing elements in anti-series order, the output is natively a gradiometer. Third, by selecting the resonant frequency of the cantilever carefully, we can create a gradiometer which outputs a spectrogram directly. Though fluxgates can be microfabricated and function as gradiometers, they suffer a size/sensitivity tradeoff. Microfabricated atmonic magnetometers are sensitive but don't function natively as gradiometers. Other micro-scale magnetometers, namely Lorentz-type, which operate on a similar mechanism, are not yet sensitive enough and haven't been used as frequency-domain gradiometers, as in the proposed design.

3 Detailed Technical Approach

Magnetometers serve an important role in investigating biologically generated electromagnetic fields, such as those created by neuronal currents, or geological magnetic fields. Typically, magnetometers are unable to achieve high sensitivity in an ambient, unshielded environment - getting to femtotesla level sensitivity requires magnetic shield and cryogenic sensors, such as SQUID [11]. The novel spin relaxation free magnetometer has been minaturized and achieves less than 10 fT/$\sqrt{Hz}$, but still requires shielding and lacks directional sensitivity [15]. Fluxgates have achieved pT level resolution at small size, but this is insufficient for biomagnetic field measurement [13, 14, 19]

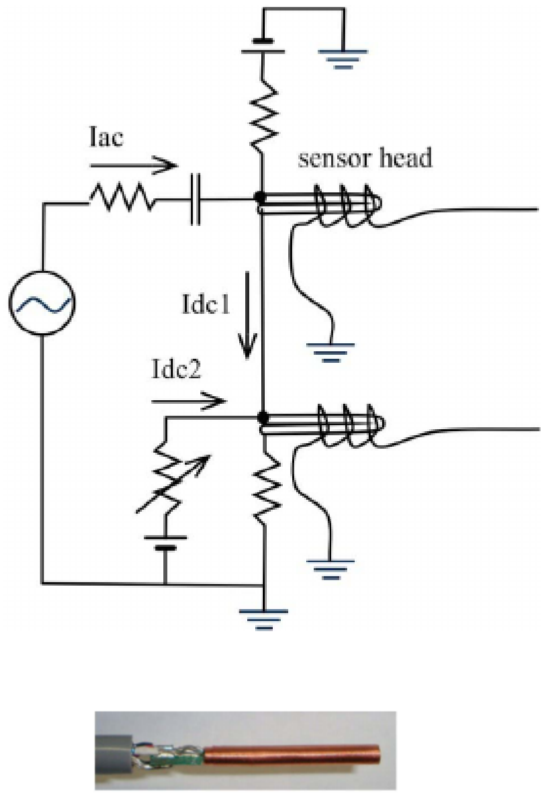

Figure 1: Fundamental-mode orthogonal fluxgate gradiometer [14].

Lorenz-type magnetometers (which translate magnetic fields into mechanical actuation of a magnet or current carrying wire) have been built in MEMS substrates, but are as yet insufficiently sensitive and require shielding [9, 10, 17, 18]

In nature, many organisms have a sense of magnetoreception used for navigation, from magnetotactic bacteria to birds. Two mechanisms have been proposed: a spin-selective (and thus field-sensitive) chemical reaction rate, or magnetite crystals which are actuated by external fields and activate ion channels in the cell membrane [4, 7, 8]. Mesurements of these magnetosomes show a magnetic dipole moment of up to 100fA/m^2 [5, 6].

Our approach is to mimic the approach found in magnetosomes, with some key modifications so that is frequency-selective and functions inherently as a gradiometer and thus does not require shielding. The closest biomimetic sensor is a flow sensor which uses ferromagnetic cilia to detect microfluidic flow rates [1].

To acomplish this, we propose layering single-domain magnetic crystals on top of piezoelectric cantilevers. The moment induced on the magnetic layer is:

$$M = \vec{\mu} \times \vec{B} \tag{1}$$

which induces stress in the cantilever, and the piezoelectric effect generates a voltage. Two

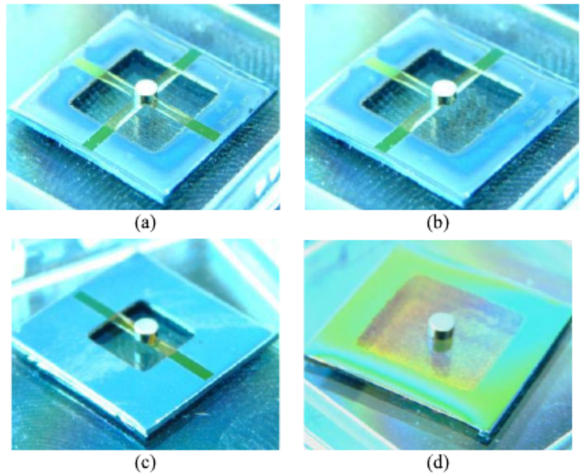

Figure 2: Lorenz-type magnetometer [17].

features are possible from the cantilever design: frequency selection and grdiometery. As in [16], a cantilever has a resonant frequency, which can be modifying through geometrical parameters. Peak response will be achieved at this frequency. By selection many cantilevers of different dimensions, each corresponding to a separate output, the magnetometer output is a spectrometer. Many cantilevers at the same resonance in series generate a largeer voltage; in anti-series, the difference is taken, thus functioning as a gradiometer with very high spatial resolution.

Even though biological magnetoreception is limited to nT sensitivity, our design will allow us to surpass this. First, by careful selection of materials (such as Co-Pt or rare-earth magnets) [2,3] we can have much higher magnetic dipole moment, and thus higher moment. Second, by careful selection of geometery, we can employ parametric resonance [20]. Finally, using two banks of cantilevers in series in anti-series, we both boost the voltage and create a high resolution gradiometer.

[12] Fundamental noise limit of piezoelectric accelerometer

Fabrication methods? Scaling COTS

Phase	Milestone	Date

Table 1: Milestones schedule

Phase 1: Base Period (18 months) AMBIIENT Phase 1 will demonstrate sensor functionality and performance in a laboratory setting meeting the performance metrics as indicated in Table 1. The sensor volume requirements are relaxed in Phase 1 to allow independent development of components and/or use of COTS components for initial proof of concept. The power metric reflects the total consumption of all sensor components (P=Vi*Ii), including all vacuum and photonic com-

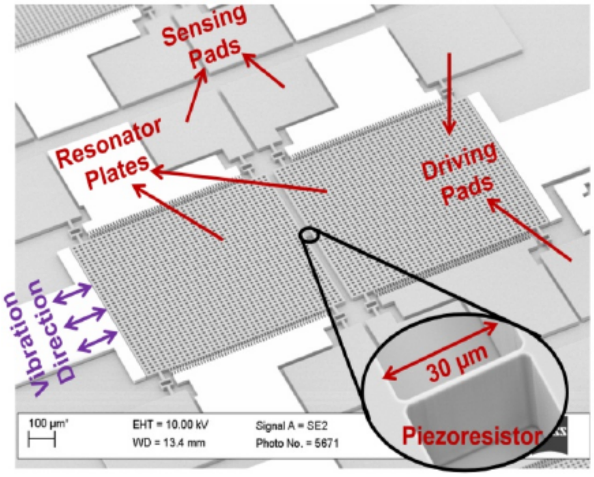

Figure 3: Lorenz-type magnetometer [9].

ponents, as well as any necessary thermal control. Power conditioning and controlling electronics are not included in the power consumption metric of this phase. Phase 2: Option 1 (12 months) AMBIIENT Phase 2 will develop and demonstrate an integrated sensor head meeting the performance and SWaP metrics of Table 1, and including all vacuum, photonic, and thermal control components. The sensor volume assumes a rectangular parallelepiped or cylindrical geometry. The sensor will be sufficiently rugged and compact to allow for temperature testing as indicated in Table 1. The performer will support transportation to and test of one sensor, along with suitably portable control electronics, at a government testing facility as directed by DARPA, two months prior to the conclusion of Phase 2. Phase 3: Option 2 (12 months) AMBIIENT Phase 3 will demonstrate a fully integrated gradiometer comprising all control electronics, power conditioning, and packaging, meeting all performance metrics of Table 1. Phase 3 prototype gradiometers should require only a single external power source and will provide digital output of total field and gradient at data rates as indicated in Table 1. Power consumption will be determined by P = V * I of the power input and volume will be separately computed for the sensor and control modules. Five complete prototype gradiometers will be delivered to a government testing facility, as directed by DARPA, at the conclusion of Phase 3.

This is the centerpiece of the proposal and should provide a detailed description of the proposed technology, including analysis and modeling where available, to substantiate the innovative claims of Section II.B.

This section must include a proposed milestone table and performance objectives, by phase, similar to Table 1 of this BAA. Proposals should clearly explain the technical approach that will be employed to meet or exceed each program metric and provide ample justification as to why the approach is feasible. Where applicable, analysis should include concise performance budget tables, e.g. for contributory error or power budget elements.

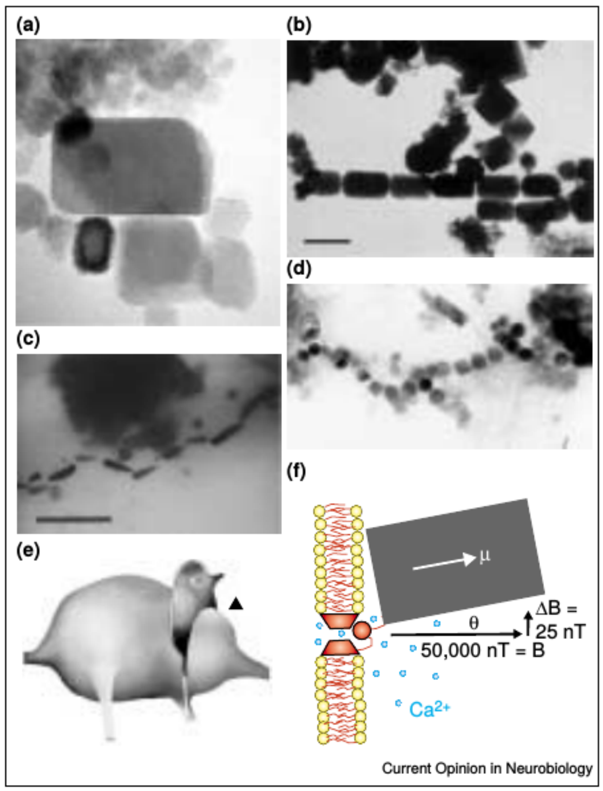

Figure 4: Magnetosomal mechanism [8].

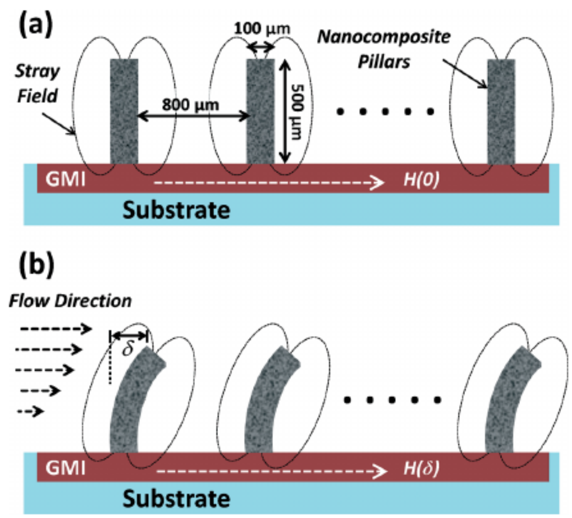

Figure 5: Magnetic cilia flow sensor [1].

Risk	Probability	Impact	Plan

Table 2: Risk matrix

4 Risk Analysis and Mitigation Plan

Identify the major technical and programmatic risks in the program. Include a risk matrix. For each risk, assign a probability of occurrence on a scale of 1-10, where 10 indicates a high likelihood that the risk will impact program success, as well as an assessment of impact, also on a scale of 1-10, where 10 indicates that this risk would maximally limit the program from delivering prototypes on schedule or meeting performance objectives. For each item with total risk (likelihood impact) exceeding 40, include a plan for mitigating the risk and assessing risk reduction. Where necessary, parallel risk reduction tasks may be proposed, e.g. concurrent development of redundant techniques or components. The proposal must differentiate the primary technical path from risk reduction tasks, which should be uniquely identified in the SOW and separately costed as optional tasks in Volume II.

5 Schedule and Milestones

Include a high-level Gantt chart outlining major technical tasks and measureable milestones by phase. At a minimum, the schedule should include each SOW task of Volume 1, Section II.A. Where risk reduction tasks are proposed, the schedule should include a milestone for assessment

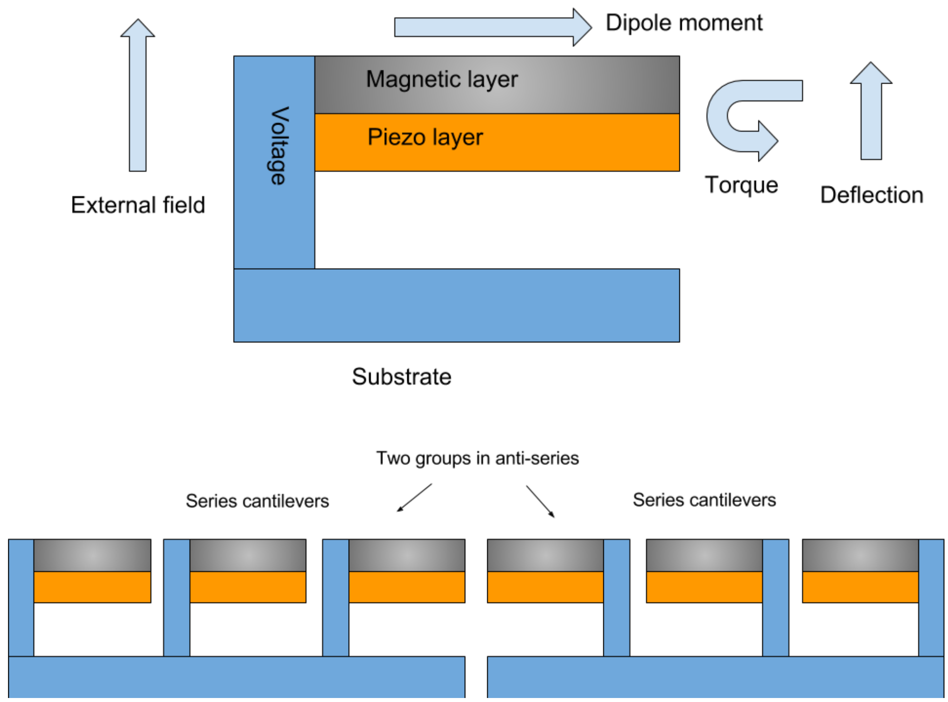

Figure 6: Diagram of proposed design.

and removal of redundant tasks.

6 Test Plan

Describe how compliance with the proposed metrics and milestones will be demonstrated in each phase of the program. The test plan should be structured so that compliant performance can be verified prior to delivery of hardware for government test and evaluation.

6.1 Phase I

6.2 Phase II

6.3 Phase III

7 Results and Technology Transfer

Description of the results, products, transferable technology, and expected technology transfer. This should also address mitigation of life-cycle and sustainment risks associated with transitioning intellectual property for U.S. military applications, if applicable. See also Section IV.B.10, Intellectual Property.

8 Ongoing Research

Comparison with other ongoing research indicating advantages and disadvantages of the proposed effort.

9 Proposer Accomplishments

Discussion of proposers previous accomplishments and work in closely related research areas. In this section, also include any ongoing research projects or pending proposal activity that technically overlaps with the proposed effort, including funding source, administrative point of contact, and the program management plan for combining and de-conflicting the efforts.

10 Facilities

Description of the facilities that will be used for the proposed effort.

11 Teaming

Description of the formal teaming agreements that are required to execute this program. Describe the programmatic relationship between investigators and the rationale for choosing this teaming strategy. Present a coherent organization chart and integrated management strategy for the program team. For each person, indicate: (1) name, (2) affiliation, (3) abbreviated listing of all technical area tasks they will work on with roles, responsibilities, and percent time indicated, (4) discussion of the proposers previous accomplishments, relevant expertise and/or unique capabilities.

References Cited

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[17] Kushagra Sinha and Massood Tabib-Azar. 27 pt silicon nitride mems magnetometer for brain imaging. *IEEE Sensors Journal*, 16(17):6551–6558, 2016.

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Type of organization Other Educational

Proposers internal reference number

Other team members :

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352-246-9649, jcasa@ufl.edu

Total funds requested

Submitted XX/YY/2017

Award instrument requested Cost-Plus-Fixed Fee (CPFF), Cost-contractno fee, cost sharing contractno fee,or other type of procurement contract (specify) or Other Transaction

Place(s) and period(s) of performance

Total proposed cost separated by basic award and option(s), if any, by calendar year and by government fiscal year

Defense Contract Management Agency (DCMA) administration office (if known) Name, address, and telephone number

Defense Contract Audit Agency (DCAA) audit office (if known) Name, address, and telephone number

Date proposal was prepared

DUNS

TIN

CAGE

Subcontractor Information

Proposal validity period (120 days is recommended)

Any Forward Pricing Rate Agreement other such approved rate information, or such documentation that may assist in expediting negotiations (if available). Attachment 1, the Cost Volume Proposer Checklist, must be included with the coversheet of the Cost Proposal.

Detailed Cost Information (Prime and Subcontractors)

The proposers (to include FFRDCs and Government Labs) cost volume shall provide cost and pricing information, or other than cost or pricing information if the total price is under the referenced threshold (See Note 1), in sufficient detail to substantiate the program price proposed (e.g., realism and reasonableness). In doing so, the proposer shall provide, for both the prime and each subcontractor, a Summary Cost Breakdown by phase and performer fiscal year, and a Detailed Cost Breakdown by phase, technical task/sub-task, and month. The breakdown/s shall include, at a minimum, the following major cost item along with associated backup documentation: Total program cost broken down by major cost items:

12 Direct Labor

A breakout clearly identifying the individual labor categories with associated labor hours and direct labor rates, as well as a detailed Basis-of-Estimate (BOE) narrative description of the methods used to estimate labor costs

13 Indirect Costs

Including Fringe Benefits, Overhead, General and Administrative Expense, Cost of Money, Fee, etc. (must show base amount and rate)

14 Travel

Provide the purpose of the trip, number of trips, number of days per trip, departure and arrival destinations, number of people, etc. See Section IV.B.13 for travel funding restrictions

15 Other Direct Costs

Itemized with costs; back-up documentation is to be submitted to support proposed costs

16 Material/Equipment

(i) For IT and equipment purchases, include a letter stating why the proposer cannot provide the requested resources from its own funding. (ii) A priced Bill of Material (BOM) clearly identifying, for each item proposed, the quantity, unit price, the source of the unit price (i.e., vendor quote, engineering estimate, etc.), the type of property (i.e., material, equipment, special test equipment, information technology, etc.), and a cross-reference to the Statement of Work (SOW) task/s that require the item/s. At time of proposal submission, any item with a unit price that exceeds $1,000 must be supported with basis-of-estimate (BOE) documentation such as a copy of catalog price lists, vendor quotes or a detailed written engineering estimate (additional documentation may be required during negotiations, if selected). (iii) If seeking a procurement contract and items of Contractor Acquired Property are proposed, exclusive of material, the proposer shall clearly demonstrate that the inclusion of such items as Government Property is in keeping with the requirements of FAR Part

45.102. In accordance with FAR 35.014, Government property and title, it is the Governments intent that title to all equipment purchased with funds available for research under any resulting contract will vest in the acquiring nonprofit institution (e.g., Nonprofit Institutions of Higher Education and Nonprofit Organizations whose primary purpose is the conduct of scientific research) upon acquisition without further obligation to the Government. Any such equipment shall be used for the conduct of basic and applied scientific research. The above transfer of title to all equipment purchased with funds available for research under any resulting contract is not allowable when the acquiring entity is a for-profit organization; however, such organizations can, in accordance with FAR 52.245-1(j), be given priority to acquire such property at its full acquisition cost.

17 Consultants

If consultants are to be used, proposer must provide a copy of the consultants proposed SOW as well as a signed consultant agreement or other document which verifies the proposed loaded daily / hourly rate and any other proposed consultant costs (e.g. travel);

18 Subcontracts

Itemization of all subcontracts. Additionally, the prime contractor is responsible for compiling and providing, as part of its proposal submission to the Government, subcontractor proposals prepared at the same level of detail as that required by the prime. Subcontractor proposals include Interdivisional Work Transfer Agreements (ITWA) or similar arrangements. If seeking a procurement contract, the prime contractor shall provide a cost reasonableness analysis of all proposed subcontractor costs/prices. Such analysis shall indicate the extent to which the prime contractor has negotiated subcontract costs/prices and whether any such subcontracts are to be placed on a sole-source basis. All proprietary subcontractor proposal documentation (fully disclosed subcontract proposal), prepared at the same level of detail as that required of the prime, which cannot be uploaded to the DARPA BAA website (https://baa.darpa.mil, BAAT) as part of the proposers submission, shall be made immediately available to the Government, upon request, under separate cover (i.e., mail, electronic/email, etc.), either by the proposer or by the subcontractor organization. This does not relieve the proposer from the requirement to include, as part of their submission (via BAAT), subcontract proposals that do not include proprietary pricing information (rates, factors, etc.). A Rough Order of Magnitude (ROM), or similar budgetary estimate, is not considered a fully qualified subcontract cost proposal submission. Inclusion of a ROM, or similar budgetary estimate, may result in the full proposal being deemed non-compliant or evaluation ratings may be lowered;

19 Cost-Sharing

The amount of any industry cost-sharing (the source and nature of any proposed cost-sharing should be discussed in the narrative portion of the cost volume); AND

20 Fundamental Research

Written justification required per Section II.B, Fundamental Research, pertaining to prime and/or subcontracted effort being considered Contracted Fundamental Research.