BAA number HR001117S0025

Lead Organization Jenshan Lin, University of Florida

Type of organization Other Educational

Proposers internal reference number

Other team members :

Changzhi Li Texas Tech University

YK Yoon University of Florida

Joaquin Casanova University of Florida

Proposal title Biomimetic microfabricated magnetic gradiometer

Administrative PoC :

Technical PoC :

Joaquin Casanova

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352-246-9649, jcasa@ufl.edu

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

AMBIIENT Phase 1 will demonstrate sensor functionality and performance in a laboratory setting meeting the performance metrics as indicated in Table 1.

1.1.1 Modeling and simulation

- The objective in this phase is to simulate the MEMS device, taking into account geometry, material properties, and multiphysics interactions, in order to determine the range of acceptable design options. In addition, scaling laws will be derived, such that a scale model of the sensor could be fabricated from COTS components.
- Our approach here is to initially specify geometry and physical properties by hand calculation, the investigae more deeply in a finite-element multiphysics solver.
- This task will be accomplished at UF by Joaquin Casanova.
- Completion of this task is specified by successful simulation of the MEMS device that meets the physical requirements specified in the BAA.
- Deliverables include successful simulation results and design parameters.
- No government equipment is required.
- To reduce risk of later failure due to non-manufacturability, this task will be accomplished within fabrication constraints specified by the MEMS team at UF. This ensures the design is physically realizable. In parallel, other sensing modalities could be explored in the case that the MEMS cantilever is not practical.

1.1.2 Microfabrication

- The objective in this phase is to develop a microfabrication strategy (materials, deposition, patterning) that can meet the requirements found from simulation.
- Our approach here is to find a range of dimensional constraints and material types that could be physically realizable, and use those options to guide simulation and design of a sensor.
- This task will be accomplished at UF by Dr. YK Yoon.
- Completion of this task is successful specification of a microfabrication plan for the sensor described by the simulation results.

- Deliverables include successful microfabrication plan.
- No government equipment is required.
- To reduce risk of later failure due to non-manufacturability, this task will be accomplished with parallel investigating of alternative MEMS sensing modalities.

1.1.3 Circuit design

- The objective in this phase is to develop a circuit which amplifies and digitizes the the voltage produced by the MEMS elements. Ina ddition to a COTS circuit, we will simultaneously begin investigation of an IC that can be used in later phases.
- Our approach here is to ...
- This task will be accomplished at TTU by Dr. Changzi Li.
- Completion of this task is specified by successful design of a circuit capable of amplifying and digitizing MEMS output voltage with input-referred voltage noise low enough to meet the overall sensitivity requirement.
- Deliverables include successful design and prototype of the circuit, usable with the fabricated MEMS sensor head, using COTS components.
- No government equipment is required.
- To reduce risk of later failure due to excessive noise, this task will investigate only specifically low-noise designs.

1.1.4 Manufacture and testing

- The objective in this phase is to construct the MEMS design using microfabrication processes and design developed in 1.1.1,1.1.2, which includes pads for connection to circuitry.
- Our approach here is to
- This task will be accomplished at UF by Dr. Yoon and Dr. Joaquin Casanova.
- Completion of this task is specified by successful construction and testing of a sensor head, which satisfies Table 1, using the circuitry developed in 1.1.3.
- Deliverables include successful prototype of the sensor and sensor electronics.
- No government equipment is required.
- To reduce risk of failure, fabrication will begin early in Phase 1, enabling us to revise our design to reduce manufacturing defects orenhance sensivity.

1.2 Phase II

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.

IC design? Size?

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

AMBIIENT Phase 3 will demonstrate a fully integrated gradiometer comprising all control electronics, power conditioning, and packaging, meeting all performance metrics of Table 1

ADC? Size?

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, magne-

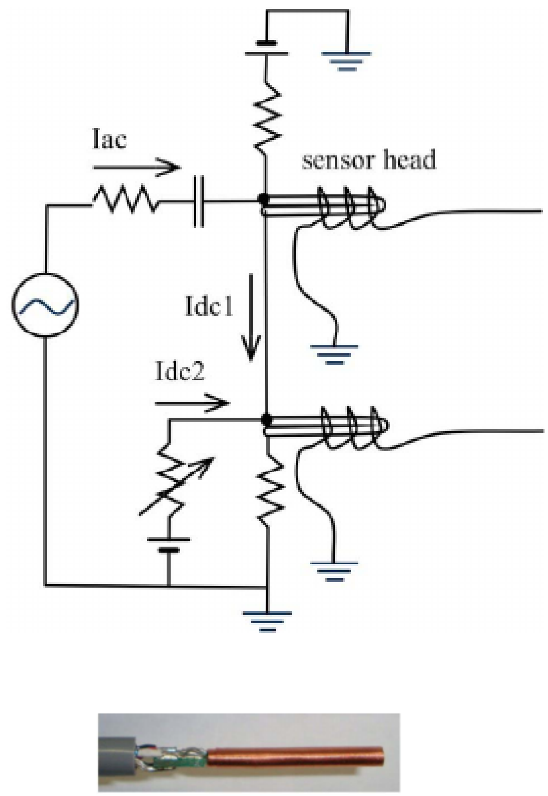

Figure 1: Fundamental-mode orthogonal fluxgate gradiometer [16].

tometers 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 [12]. 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 [17]. Fluxgates (Figure 1) have achieved pT level resolution at small size, but this is insufficient for biomagnetic field measurement [15,16,22]

Lorenz-type magnetometers (which translate magnetic fields into mechanical actuation of a magnet or current carrying wire) have been built in MEMS substrates (Figure 2), but are as yet insufficiently sensitive and require shielding [10, 11, 19, 21]

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 (Figure 3) [5, 8, 9]. Measurements of these magnetosomes show a magnetic dipole moment of up to 100fA/m^2 [6, 7].

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 a permanent magnetic layer on top of piezoelectric

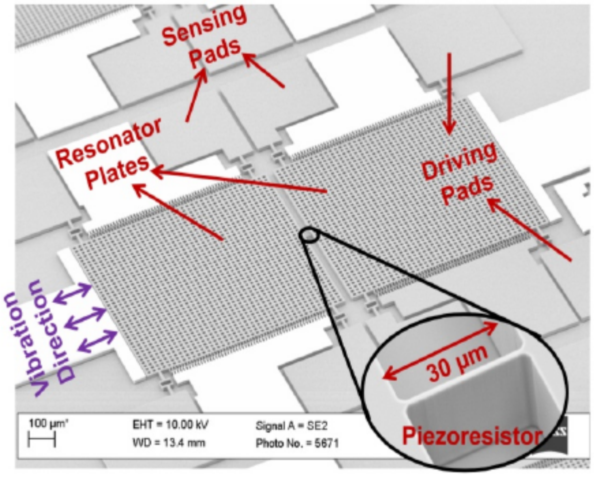

Figure 2: Lorenz-type magnetometer [10].

cantilevers. The moment M induced on the magnetic layer with moment $\vec{\mu}$ and field $\vec{B}$ is:

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

Interpreted as a point load (M/L) at the cantilever tip, this moment causes a stress distribution on a cantilever of length L, thickness t, second moment I, piezoelectric constant g_{31}, and modulus E, at point x, of

$$\sigma = \frac{Mt(L-x)}{2LI}$$

and n in series generates a voltage

$$V = \int_0^L \frac{Mt(L-x)}{2LI} g_{31} n dx$$

Two features are possible from the cantilever design: frequency selection and gradiometery. As in [18], a cantilever has a resonant frequency, which can be modified through geometrical parameters. Peak response will be achieved at this frequency. By selecting 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 (Figure 5).

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, 4] we can have much higher magnetic dipole moment, and thus higher moment. Second, by careful selection of geometery, we can employ parametric resonance [23]. Finally, using two banks of cantilevers in series in anti-series, we both boost the voltage and create a high resolution gradiometer.

The noise floor of magnetic materials is governed by Barkhausen noise - the random flipping of magnetic domains [3]; this noise is characterized as a flux noise level. The flux noise can be converted into a magnetic moment noise, and thus moment noise. Piezo noise floor is largely

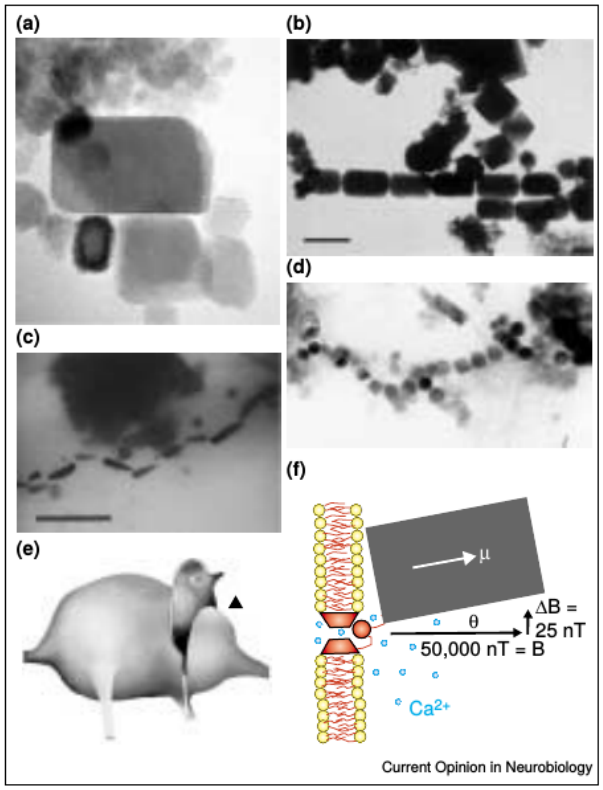

Figure 3: Magnetosomal mechanism [9].

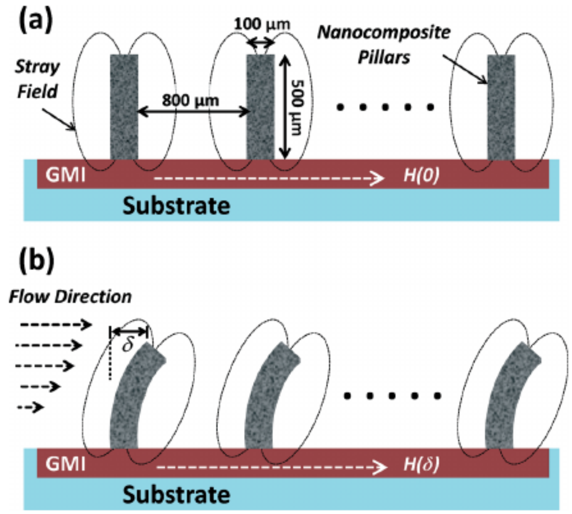

Figure 4: Magnetic cilia flow sensor [1].

a function of piezo losses [13]. Additionally, there is the input-referred noise of any amplifier. With conservative estimates for all of these, and two anti-series banks of 30 cantilevers each with dimensions 400x40x3 μm, the sensitivity level is less than 10 fT/cm/$\sqrt{Hz}$.

MEMS fabrication processes are capable of constructing the above-described sensor. This consists of two main fabrication tasks: piezo cantilever construction, and magnetic material integration. The process described in [18] can be used for our task, with an additional step to apply the magnetic layer. PZT has a high voltage coefficient and is highly suitable for the piezo elements [20] and can be deposited with pulsed laser deposition or solution-based deposition and patterned with chemical etching or ion etching. Rare-earth magnetic materials, such as alloys of Sm-Co, offer high magnetic energy product at room temperature and can be integrated into MEMS using sputtering or pulsed laser deposition [2]. However, patterning of these materials is slow, using wet etching or ion-beam milling. A likely strategy will be to use a sacrificial polymer pattern, depositing electrodes, piezo, then magnet layers, and then etching the sacrificial layers.

There are two possible circuit approaches we can consider for this cantilever approach. On one hand, very many small cantilevers, arranged in series in groups; or multiple, larger cantilevers. In the former case, we would individually address the sensor banks, effectively fitting multiple sensors on the same substrate, allowing differential or common-mode measurements. Many, smaller cantilevers would require a voltage amplifier; additionally, smaller cantilevers have higher resonant frequency, so in order to operate near resonance for maximum sensitivity they would need to be externally driven near resonance, and the signal would be demodulated to get measurements of the baseband signals. In the second approach, a few, larger cantilevers would have lower resonant frequencies and could directly sense at baseband. Their larger area produces a larger charge, so a charge amplifier would be more suitable. Ultimately, the number and size of cantilevers, and the circuit approach, is a tradeoff between the complexity of the interconnects, resonance of the structures, and the number of cantilevers which fit in the target volume.

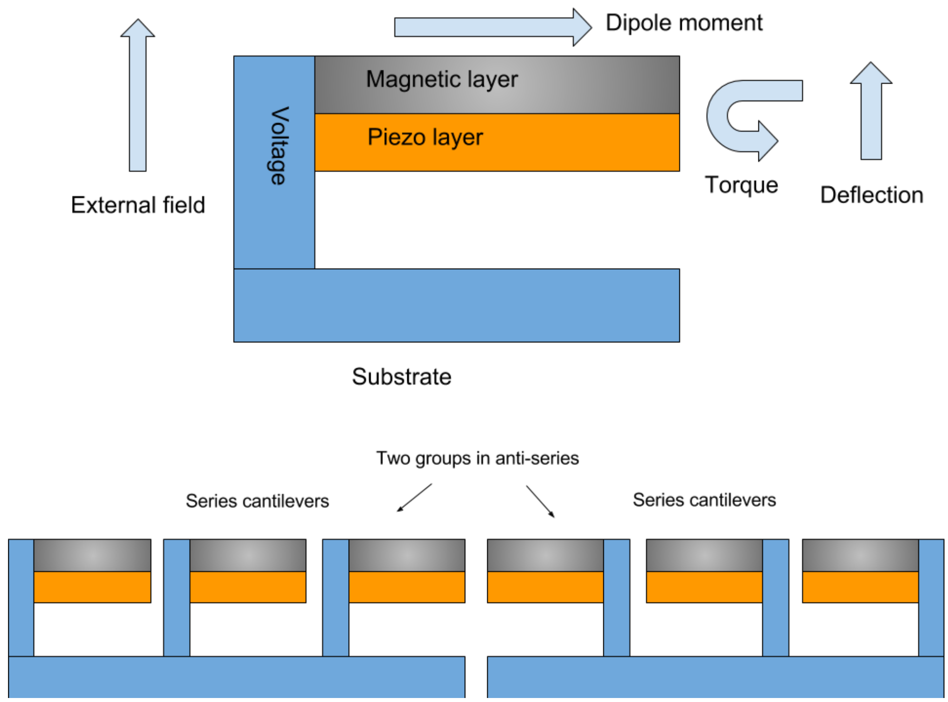

Figure 5: Diagram of proposed design.

Metric	Phase 1	Phase 2	Phase 3
Power consumption	150 mW	50 mW	100 mW
Sensor Volume	3x3x10 cm	1x1x7 cm	1x1x7 cm
Control Electronics Volume	N/A	N/A	¡ 20cm^2
Ambient Magnetic Field	$\pm$ 100 μT	$\pm$ 100 μT	$\pm$ 100 μT
Ambient Operating Temperature	N/A	0° C to 50° C	0° C to 50° C
Gradient Full-scale Range	1 nT/cm	1 nT/cm	1 nT/cm
Gradient Sensitivity	10 fT/cm/$\sqrt{Hz}$	3 fT/cm/$\sqrt{Hz}$	1 fT/cm/$\sqrt{Hz}$
Gradient Accuracy	100 fT/cm	30 fT/cm	10 fT/cm
Total Field Range	100 μT	100 μT	100 μT
Total Field Sensitivity	100 pT/$\sqrt{Hz}$	30 pT/$\sqrt{Hz}$	10 pT/$\sqrt{Hz}$
Total Field Accuracy	1 nT	500 pT	100 pT
Data Rate	100/s	200/s	500/s
3 dB Bandwidth	200 Hz	400 Hz	1000 Hz

Table 1: Design objectives, by phase.

4 Risk Analysis and Mitigation Plan

There are several risks and challenges associated with this design. Most can be addressed simply by doing careful analysis of the problem within the range of constraints on materials and processes. Others (the density of interconnects, or resonant frequency, is too high) can be address by reducing

Phase	Milestone	Date
1	Cantilever simulation and design	
1	Fabrication plan	
1	Circuit design	
1	Scale model design and testing	
2	Cantilever simulation and design	
2	Fabrication plan	
2	Circuit design	
2	MEMS fabrication and testing	
3	Cantilever simulation and design	
3	Fabrication plan	
3	Circuit design	
3	MEMS fabrication and testing	

Table 2: Milestones schedule

Risk	Probability	Impact	Plan
Insufficient sensitivity in simulation	3	10	Optimize design architecture.
Best available MEMS processes infeasible	4	10	Begin design process within constraints of available processes.
Interconnects infeasible	3	5	Operate fewer, larger cantilevers
Viscous damping hurts sensitivity	3	5	Operate in vacuum packaging
Resonance frequency infeasibly high	3	5	Operate fewer, larger cantilevers
Fabrication unreliable/mismatch	3	5	Begin fabrication early, so process can be adjusted; dynamic element matching.
Fabrication time/window exceeds deadlines	3	5	Fabricate COTS scale model instead.
Circuit/sensor sensitive to mechanical vibration	5	8	Use additional sensors without magnetic layer to independently measure mechanical vibrations.
Circuit/sensor fails final tests	3	9	Identify points of failure for next design.

Table 3: Risk matrix

the number of elements and increasing their size. Damping do to the viscosity of air could hurt sensitivity could be addressed by vacuum packaging the sensor head. Manufacturing mismatch of the sensing elements can be effectively removed by dynamic element matching, where the transducers are switched electronically to average out fabrication differences.

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 and removal of redundant tasks.

6 Test Plan

To test, in Phase 1, the sensor will first be connected to the circuitry and powered to established basic functionality. Prior to testing, noise from the Helmholtz coils, power supplies, and any other necessary signal generation sources will be characterized. Further, the sensor will be placed in a pair of Helmholtz coils driven with precision current sources, inside magnetic shield, so we can gauge accuracy and sensitivity in a controlled environment. Field gradient, intensity, and frequency will be swept over the range specified in 1. Finally, the same test will be repeated in an unshielded environment. In each case, we will monitor power consumption, signal output, and mesure sensor and sensor control electronics volume. Subsequent phases will follow a similar testing protocol, except using specifications for those phases. Additionally, in Phases 2 and 3, where an IC will be developed and integrated with the sensor head, the IC will be tested independently to verify basic input/output functionality before slicing and bonding to the MEMS substrate.

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

Presently, Drs. Lin, Li, and Casanova are presently involved (until 6/2017) in a DARPA project for detection and inversion of MEG/EEG signals. They have worked on all phases, from sensor design to circuit design to inversion algorithm. Additionally, Drs. Lin and Li have worked exensively on vital signs radar, and Dr. Casanova has worked on electromagnetic sensors for agriculture and analytical chemistry. Dr. Yoon has conducted research in MEMS systems of all types, including piezoelectronics and magnetics. Presently his work ...

9 Facilities

Facilities at UF for sensor development and testing include magnetic shielding, circuit testing instrumentation (power supplies, oscillopes, function generators, VNA). For fabrication, the Nanoscale

Research Facility at UF includes equipment for a variety of processes: plasma, vapor, and sputtering deposition, annealing, wafer bonding, wire bonding, UV and e-beam lithography, reverse ion etching, and wet etching.

TTU?

10 Teaming/Proposer Accomplishments

UF The UF team incluldes the following personnel:

Jenshan Lin will be project lead, and supervise work on the AMBIIENT project. His time commitment is 0%. He received the B.S. degree in Electrophysics from National Chiao Tung University (NCTU), Hsinchu, Taiwan, R.O.C., in 1987, and the M.S. and Ph.D. degrees in Electrical Engineering from the University of California at Los Angeles (UCLA), in 1991 and 1994, respectively. His current research interests include sensors and biomedical applications of microwave and millimeter-wave technologies, wireless energy transfer and conversion, RF system-on-chip integration, and integrated antennas. Dr. Lin has authored or co-authored over 250 technical publications in refereed journals and conference proceedings. He holds 15 patents and has several other patent applications. Since joining University of Florida, he has graduated 22 PhD students.

Joaquin Casanova will conduct electromagnetic simulation and design of the MEMS sensor, and work with Dr. Yoon on process/material selection, and Dr. Li on requirements for the interface and control circuits. His commitment is 50%. He received a B.S. and M.E. in Agricultural and Biological engineering in 2006 and 2007 from UF, and PhD in Electrical Engineering in 2010 from UF. His work has primarily focused on sensors and electromagnetic design, including wireless power, microwave remote sensing, agricultural sensors, analytical chemistry equipment design, and low-field magnetic sensing. He is currently a Research Assistant Professor in UF's Department of Electrical and Computer Engineering.

YK Yoon will guide selection of a microfabrication process and fabrication of the sensor. His commitment is 10%. He received his BS and MS degrees in electrical engineering from Seoul National University in Korea. He also earned an MSEE degree from the New Jersey Institute of Technology, Newark, NJ in 1999 and the Ph.D. degree in electrical and computer engineering from the Georgia Institute of Technology, Atlanta, GA in 2004. He is currently an Associate Professor in the Department of Electrical and Computer Engineering at the University of Florida, Gainesville, FL. His current research interests include three dimensional (3-D) micromachining and nano fabrication; design and implementation of metamaterial for radio frequency (RF) and microwave applications; micromachined millimeter wave and terahertz antennas and waveguides; bio/microfluidic systems for the lab-on-a-chip applications; wireless telemetry systems for biomedical applications; and ferroelectric material development for high density memory devices and/or tunable RF devices.

TTU The TTU team includes:

Changzhi Li will design the electronics for amplifying and digitizing the signals from the sensor head, working with Dr. Casanova to determine ciruit requirements. His time commitment is 10%. He received the B.S. degree in electrical engineering from Zhejiang University, China, in 2004 and the Ph.D. degree in electrical engineering from the University of Florida, Gainesville, FL, in 2009.In the summers of 2007 and 2008, he worked at Alereon Inc., Austin, TX, on ultrawideband (UWB) transceiver. In the summer of 2009, he worked at Coherent Logix Inc., Austin, TX, on software-defined radio. His research interests include analog circuits, microwave circuits, and biomedical applications of microwave/RF.

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BAA number HR001117S0025

Lead Organization Jenshan Lin, University of Florida

Type of organization Other Educational

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Other team members :

Changzhi Li Texas Tech University

YK Yoon University of Florida

Joaquin Casanova University of Florida

Proposal title Biomimetic microfabricated magnetic gradiometer

Administrative PoC :

Technical PoC :

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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:

11 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

12 Indirect Costs

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

13 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

14 Other Direct Costs

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

15 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.

16 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);

17 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;

18 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

19 Fundamental Research

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