ISS NATIONAL LABORATORY PROJECT CONCEPT SUMMARY

Technology Advancement and Applied Research Leveraging the ISS National Lab

ISS National Lab Research Announcement 2023-8

(Do not exceed 3 pages when complete)

Proposed project name: Experiments with Silicon Quantum Dots and Silicon Quantum Dots spin qubits in the Microgravity Environment	
Principal investigator (PI): Ilakkuvaselvi Manoharan	**Project type:** ☒ Flight ☐ Ground ☐ Other
Email address: ilakk2023@gmail.com	**Space experience:** ☐ High ☐ Low ☐ None
PI citizenship status: ☐ U.S. citizen ✔ Permanent resident ☐ Non-U.S. Person	**PI country of citizenship (if non-U.S.):** India
Organization legal name: Bubbles & Cafe	
Organization status: ✔ U.S. Entity ☐ Non-U.S. Entity	**Organization address:**
Organization type: ✔ Commercial ☐ Academic ☐ Government ☐ Nonprofit	
Organization Unique Entity ID: / **Organization CAGE code:**	
Is this research or technology subject to U.S. export laws and regulations? ✔ No ☐ Yes, explain below	
How did you hear about this research announcement? ✔ ISS National Lab website ☐ Email ☐ News article ☐ Advertisement ☐ NASA ☐ NSF ☐ ISS Research and Development Conference ☐ Other conference ☐ Other (please describe):	

Objectives:

Project Vision and Rationale: The project "Experiments with Silicon Quantum Dots and Silicon Quantum Dots Spin Qubits in the Microgravity Environment" aims to investigate the behavior and properties of silicon quantum dots and their potential as stable spin qubits in the unique microgravity environment of the International Space Station (ISS) National Laboratory. Quantum dots are nanoscale semiconductor structures that can trap and manipulate individual electrons, exhibiting quantum properties that make them promising candidates for qubits in quantum computing and communication systems. However, their behavior and performance in a microgravity environment are not well-understood.

The rationale for conducting this experiment on the ISS is multi-fold. Firstly, the microgravity conditions in space provide an ideal setting for studying quantum dots and their interactions with electrons without the interference of gravity-related effects. This allows researchers to explore the fundamental quantum phenomena associated with these systems more accurately.

Secondly, by investigating the behavior of silicon quantum dots in a microgravity environment, the project aims to gain insights into their potential for long-term stability and coherence, which are crucial factors for the successful implementation of quantum technologies. The absence of environmental disturbances on the ISS, such as magnetic fluctuations and vibrations, enhances the precision and control of the experiments, leading to more reliable data.

Effective Use of the ISS National Laboratory: The ISS National Laboratory serves as a unique research platform that enables experiments in a microgravity environment, offering opportunities for cutting-edge scientific investigations that cannot be replicated on Earth. In this project, the ISS National Laboratory is utilized effectively as a controlled and stable environment, free from Earth's interference, to perform intricate quantum experiments with silicon quantum dots and spin qubits.

Goals:

1. Characterize the behavior and properties of silicon quantum dots in a microgravity environment.
2. Investigate the coherence and stability of silicon quantum dots as spin qubits in microgravity.
3. Explore potential applications of silicon quantum dot spin qubits for quantum computing and communication in space.

Deliverables:

1. Detailed analysis of the quantum dot behavior in microgravity, including measurements of their physical characteristics and interactions with electrons.
2. Assessment of the coherence times and entanglement capabilities of silicon quantum dot spin qubits in the microgravity environment.
3. Insights into the suitability and challenges of utilizing silicon quantum dot spin qubits for quantum information processing and communication tasks in space.

By accomplishing these goals and deliverables, the project aims to advance the understanding of quantum dots and their potential as stable spin qubits, especially in space-based applications. The findings from this research can contribute to the development of more robust and reliable quantum technologies, both in space and on Earth. Furthermore, the project demonstrates the effective use of the ISS National Laboratory for cutting-edge quantum experiments, showcasing the invaluable role of the ISS in advancing scientific knowledge and technology.

- State the test objective and the starting and ending technology readiness level (TRL).

Test Objective: The "Experiments with Silicon Quantum Dots and Spin Qubits in Microgravity" project aims to investigate the behavior and properties of silicon quantum dots as stable spin qubits in the microgravity environment of the International Space Station (ISS) National Laboratory. The goal is to gain insights into their coherence, stability, and potential applications for quantum computing and communication in space.

Starting Technology Readiness Level (TRL): The project begins at TRL 3 or 4, with basic research and experimentation on silicon quantum dots as spin qubits in laboratory settings, establishing a scientific foundation for potential applications.

Ending Technology Readiness Level (TRL): The project is expected to reach TRL 5 or 6. It demonstrates the feasibility of using silicon quantum dots as stable spin qubits in microgravity, advancing understanding of their behavior and potential for space-based quantum technologies. While validated in relevant environments, further development and refinement may be required for practical deployment in commercial applications.

- Describe how the project utilizes the conditions of a space-based laboratory or environment (e.g., extended access to microgravity, extreme environmental conditions).

This proposed project leverages the unique conditions of the International Space Station (ISS) to advance research on quantum dots and spin qubits. Key benefits include:

1. Extended Microgravity Access: The ISS provides an extended period of microgravity, allowing for in-depth, long-duration experiments compared to terrestrial laboratories with limited microgravity exposure.
2. Reduced Environmental Disturbances: Space microgravity minimizes disturbances that could interfere with quantum systems, creating a cleaner and controlled environment for precise quantum measurements.
3. Isolation from Gravity-Related Effects: Studying quantum dots and spin qubits in space isolates gravity's impact, offering insights into their intrinsic properties and behavior without gravitational interference.
4. Space-based Quantum Applications: The project explores the potential of silicon quantum dots as spin qubits for space-based quantum computing, communication, and navigation systems.

Overall, this research opens avenues for advancements in quantum technologies, benefiting both space-based applications and terrestrial quantum systems.

- Describe how the project's outcome will further technology development that will ultimately lead to a commercial product or solutions offering.

This proposed project has significant potential to advance quantum technology and its commercialization. Here's how the project's outcomes can contribute to commercialization:

Improved Quantum Dot Behavior: Studying silicon quantum dots as spin qubits in the ISS microgravity environment will provide valuable data on their behavior. This understanding will help design quantum dots with better control, stability, and coherence, crucial for developing reliable commercial products based on this technology.

Enhanced Coherence and Stability: The microgravity experiments will identify factors contributing to better coherence and stability of spin qubits. Optimizing the coherence time of silicon quantum dots will make them more suitable for practical quantum computing applications.

Validation for Space Applications: Experiments on the ISS validate the behavior of silicon quantum dots in space, essential for space-based quantum applications. Successful validation opens opportunities for using this technology in future space missions, communication, and navigation systems.

Space-Based Quantum Applications: Findings will highlight potential space-based quantum computing and communication applications. This can drive the development of commercial solutions for space exploration and secure communication.

Industry Collaboration and Investment: Success in demonstrating stable spin qubits in microgravity will attract industry interest and investment. Collaboration with companies and space agencies can accelerate research translation into commercial products.

Overall, the project's outcomes will be pivotal in advancing technology development, leading to commercial products or solutions utilizing silicon quantum dots as spin qubits for quantum computing and communication applications, both on Earth and in space.

Concept of Operations:

- Provide a basic description of the project's in-orbit requirements and experimental setup.

  Specific details are given in the implementation partner document. Here is the basic overview:

This proposed project requires specific in-orbit requirements and an experimental setup on the International Space Station (ISS) for effective quantum experiments. Here's a concise description:

In-Orbit Requirements:

Extended Microgravity: Access to an extended period of microgravity on the ISS is crucial for studying the behavior, coherence, and stability of silicon quantum dots and spin qubits without interference from Earth's gravity.

Controlled Environment: The ISS provides a controlled environment, shielding quantum systems from external factors like magnetic fluctuations and vibrations that could affect precision.

Safety Protocols: Strict safety protocols are followed to ensure the well-being of astronauts and the integrity of the space station during quantum experiments.

Payload Transportation: The experimental payload is transported to the ISS using cargo resupply missions or commercial launch services.

Launch Integration: The payload must comply with launch vehicle requirements and be integrated into the cargo spacecraft safely.

Experimental Setup:

Quantum Dot Growth System: A specialized system for growing silicon quantum dots is set up to study microgravity's impact on growth, crystalline structure, and size distribution.

Sample Containment: Containers and growth chambers securely contain quantum dot materials in the microgravity environment.

Environmental Control: Systems maintain stable temperature, pressure, and other conditions for consistent growth.

Characterization Instruments: Instruments such as spectroscopy, SEM, and XRD characterize the properties of grown quantum dots.

Samples from Earth: Nanoscale semiconductor structures are fabricated on Earth in specialized cleanrooms to ensure uniformity.

Transport to ISS: Fabricated quantum dots are transported to the ISS in specialized containers to maintain stability.

Laboratory Space: A designated laboratory space within the ISS provides a controlled setting for quantum measurements.

Quantum Experiment Setup: Specialized equipment, including lasers and magnetic field generators, manipulates and probes the quantum dots as spin qubits.

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Complexity: R C A S
IP Portal Needed: Y N

Operations Lead: ____________________
Science Lead: ____________________

Data Acquisition: Advanced systems record and transmit experimental data back to Earth for analysis.

Overall, the project requires microgravity access and a well-equipped experimental setup on the ISS to advance our understanding of silicon quantum dots and spin qubits.

- **Describe any specific hardware or in-orbit facilities necessary to support this project, if known.**

  Specific details are given in the implementation partner document. Here is the basic overview:

1. Specialized Quantum Dot Growth System: The experimental setup requires a system capable of growing silicon quantum dots in a controlled manner. Techniques like chemical vapor deposition (CVD) or other suitable methods will be utilized to produce nanoscale materials.
2. Sample Containment: To prevent particles from escaping in the microgravity environment, the setup must securely contain the materials used for growing the silicon quantum dots. Specialized containers and growth chambers are employed to maintain samples in a controlled environment.
3. Environmental Control Systems: The experimental setup should have systems to control temperature, pressure, and other environmental conditions. This ensures the growth process remains stable and unaffected by fluctuations in the space environment.
4. Characterization Instruments: Instruments like spectroscopy, scanning electron microscope (SEM), and X-ray diffraction (XRD) are included in the payload to analyze and characterize the properties of the grown silicon quantum dots.
5. Laboratory Space on ISS: The ISS National Laboratory provides a designated space for conducting quantum experiments. The experimental setup is installed within the laboratory module, ensuring a stable and controlled environment for quantum measurements.
6. Quantum Experiment Setup: Specialized equipment, such as lasers, magnetic field generators, microwave sources, and quantum sensors, is necessary for the manipulation and probing of the silicon quantum dots as spin qubits. Researchers perform measurements and manipulations to study their coherence, stability, and interactions with electrons.
7. Thermal Control Systems: Temperature stability is crucial for precise control and measurement of quantum systems. Sensitive equipment like silicon quantum dot qubits requires proper thermal management to avoid fluctuations that could affect experimental results.
8. Data Acquisition Systems: Advanced data acquisition systems are utilized to record and transmit vast amounts of experimental data back to Earth for analysis and interpretation.
9. Transportation to ISS: Fabricated quantum dots are transported to the ISS using resupply missions or designated cargo vessels. They are typically carried in specialized containers to maintain stability and protect them during transit.

Overall, the project requires specialized hardware and access to the controlled microgravity environment of the ISS to conduct experiments on silicon quantum dots and spin qubits effectively.

- **Define the logistical support and payload return requirements.**

  To conduct experiments with Silicon Quantum Dots and Silicon Quantum Dots spin qubits in microgravity, successful mission logistics and payload return are crucial. Key aspects include:
  Logistical Support:

1. Mission Planning and Management: Thorough planning, defining objectives, hardware specs, and safety protocols with collaboration among stakeholders.
2. Spacecraft or Satellite Selection: Choosing a suitable spacecraft with stable microgravity, power supply, and communication capabilities.
3. Integration and Testing: Rigorous integration and testing of experimental hardware and instruments.
4. Launch Services: Securing a fitting launch vehicle for safe transport to the designated orbit.
5. Ground Control Center: Establishing a control center for real-time monitoring and communication.
6. Communication Network: Setting up a reliable network for continuous contact with the spacecraft.
7. Mission Operations: A dedicated team overseeing the experiment and spacecraft health.
8. Scientific Team: Expert researchers specializing in quantum physics and silicon quantum dots.

Payload Return Requirements:

1. Re-entry and Recovery System: Including a system for the safe return of hardware after the experiment.
2. Sample Containment: Ensuring containment systems for handling materials during return.
3. Recovery Operations: Preparedness for payload recovery, data retrieval, and post-experiment procedures.
4. Data Analysis and Dissemination: Analyzing data and disseminating findings through research and conferences.
5. Hardware Maintenance and Disposal: Proper disposal of non-reusable components to minimize environmental impact.

Complex space missions with quantum systems require extensive collaboration among research institutions, space agencies, and commercial partners. Meticulous coordination is essential from planning to payload return to achieve successful scientific outcomes.

- **Identify any preliminary discussions the offeror has had with an Implementation Partner, including evidence that the Implementation Partner can meet the proposed technical and schedule requirements. Please see the implementation partner document for the details.**
- **If known, provide an in-orbit operations timeframe (i.e., desired launch date and flight duration).**
- **Offerors anticipating the requirement for iterative microgravity studies are encouraged to generally describe those successive experiments, noting whether they could be completed within one flight or whether they would require multiple flights. (Note: Only one flight project at a time will be funded.)**

Experiments with silicon quantum dots:

- First Iteration (Flight 1):
  - Objective: The initial experiment's objective could be to establish a baseline for silicon quantum dot growth in the microgravity environment. Researchers may focus on the effects of microgravity on size, shape, and basic properties of the quantum dots.
  - Feasibility: The first iteration is typically designed to be completed within one flight, allowing researchers to understand the fundamental behavior of silicon quantum dots in microgravity and identify any initial challenges or adjustments required.

1. Second Iteration (Flight 2):

  - Objective: Building upon the knowledge gained from the first flight, the second experiment's objective may involve optimizing the growth process to achieve more uniform and controllable quantum dots.
  - Feasibility: Depending on the complexity and the availability of follow-up flight opportunities, the second iteration may be completed within one additional flight.

1. Third Iteration (Flight 3 or Multiple Flights):
   - Objective: The third iteration might involve further refinement and investigation of specific properties, such as optical or electronic behaviors, as well as testing different growth parameters.
   - Feasibility: Depending on the duration of the experiments and the availability of flight opportunities, the third iteration may require multiple flights.

1. Additional Iterations (Flight 4+):
   - Objective: Subsequent iterations can explore advanced applications or investigate how other factors, such as varying environmental conditions, impact silicon quantum dot behavior in microgravity.
   - Feasibility: As the complexity and objectives increase, it is more likely that additional iterations will require multiple flights to conduct comprehensive studies.

   Experiments with silicon quantum dots spin qubits:

Experiment 1: Characterization of Spin Qubits in Microgravity

- Objective: The first experiment focuses on characterizing the behavior and properties of spin qubits in a microgravity environment.
- Experimental Setup: The initial experiment involves deploying a spin qubit platform in a microgravity environment, such as on the International Space Station (ISS) or a dedicated satellite. The setup includes sensors, control systems, and measurement devices to assess coherence time, stability, and quantum properties of spin qubits.
- Data Analysis: The experimental data collected from Experiment 1 is analyzed to gain insights into the impact of microgravity on spin qubits. This analysis helps identify any observed differences compared to ground-based experiments and establishes a baseline understanding of spin qubits in microgravity.

Experiment 2: Coherence Time Enhancement Strategies

- Objective: Building upon the findings from Experiment 1, the second experiment focuses on exploring strategies to enhance the coherence time of spin qubits in a microgravity environment.
- Experimental Setup: The setup for Experiment 2 incorporates modifications to the spin qubit platform or introduces new techniques to mitigate decoherence effects. This can involve implementing improved shielding techniques, exploring new materials, or refining quantum control protocols.
- Data Analysis: The coherence time of spin qubits is measured and compared with the results from Experiment 1. The data analysis helps assess the effectiveness of the coherence time enhancement strategies and provides insights into the feasibility of extending spin qubit coherence in microgravity.

Experiment 3: Quantum Error Correction and Fault-Tolerance

- Objective: The third experiment focuses on exploring quantum error correction and fault-tolerance techniques in a microgravity environment.

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Complexity: R C A S
IP Portal Needed: Y N

Operations Lead: ____________________
Science Lead: ____________________

- Experimental Setup: The setup incorporates additional hardware and software components to implement quantum error correction codes and fault-tolerant operations. This enables the identification and mitigation of errors introduced during the operation of spin qubits in microgravity.
- Data Analysis: The experimental data is analyzed to assess the effectiveness of the error correction techniques and fault-tolerant operations. The analysis aims to understand the performance limits, error rates, and thresholds for achieving reliable quantum information processing with spin qubits in microgravity.

Iterative Studies and Refinement:

- The project team continues to design successive experiments, building upon the insights and outcomes of previous experiments. These iterative studies aim to refine the understanding of spin qubits in microgravity, explore new strategies, and further optimize the performance of spin qubits for practical quantum technologies.
- The iterative studies may involve exploring different spin qubit implementations, testing novel materials or fabrication techniques, and refining control and measurement protocols to enhance the stability, coherence time, and overall performance of spin qubits in microgravity.

Benefits/Business Case:

The proposed project, Experiments with Silicon Quantum Dots and Silicon Quantum Dots spin qubits in the Microgravity Environment, is vital for advancing quantum computing. Conducting research in microgravity can lead to a disruptive product: an advanced silicon-based quantum computer. This technology has the potential to revolutionize industries like cryptography, pharmaceuticals, and AI. Large enterprises and governments would be primary users. Revenue generation could be substantial, potentially reaching billions annually within a decade. A consortium of research institutions, high-tech companies, and venture capital firms will commercialize the product. Funding will come from government grants, corporate funding, and venture capital investments. This project holds the key to unlocking the full potential of silicon quantum dots in quantum computing applications.

Budget and Funding Sources:

Budget Narrative:

- **If the project is receiving funds from an external source, identify the organization and funding amount.** **Funding not secured yet.**
- **Does the offeror require support from the ISS National Lab to identify potential investors or to obtain additional funding?** **Yes**
- **Does the offeror or any funding partners have the intent, resources, or experience to develop and/or commercialize project outcomes?** **Yes**

Item	Description	Amount ($K)
1	Project Costs	400K
2	Implementation Partner (Mission Integration & Operations) Costs	400K

3	**Total Project Funding Required (1 + 2)**	800K
FUNDING SOURCES		
4	Funds Provided by PI's Organization	0
5	Funds Requested from CASIS (5a + 5b)	800K
5a	Project Funding Requested from CASIS	400K
5b	Implementation Partner (Mission Integration & Operations) Funding Requested from CASIS	400K
6	Funds Provided by Other Sources	
7	In-Kind Contributions	
8	**Total from All Funding Sources (must equal Item 3)**	800K

Signature: ______________________________

Prepared By: ______________________________

Title: ______________________________

Date: ______________________________

Guidelines and Helpful Links (Do not include this page in the Concept Summary submission)

All offerors must complete and submit for review a Step 1: Concept Summary form. The purpose of Step 1 is to evaluate an offeror's concept for operational feasibility, scientific, technological, and economic/business merit, compliance with the CASIS Cooperative Agreement, and alignment with the scope of the solicitation. Concept summaries must use the template provided in this document, and all sections must be completed. As funding is limited for this research announcement, the level of funding requested will be a factor in concept approval.

Offerors are strongly encouraged to begin now during Step 1: Concept Summary preparation to identify and consult with an Implementation Partner—organizations that work with the ISS National Lab to provide services related to payload development. For more information, see the Instructions to Offerors for this research announcement.

The U.S. General Services Administration (GSA) has officially transitioned the System for Award Management (SAM.gov) to no longer use data universal numbering system (DUNS) numbers from Dun & Bradstreet (D&B) and instead use government-issued Unique Entity IDs. GSA implemented the change effective April 4, 2022. The new ID can be found on the offeror's SAM.gov profile.

It can take several weeks or longer to apply for and receive a Commercial and Government Entity (CAGE) Code. If an offeror is unable to obtain this code in time for submission of the concept summary, indicate the date one was applied for on the concept summary form. To obtain a CAGE code, go to https://cage.dla.mil/request or apply to the System for Award Management Registration at https://sam.gov/content/home. Before one can register with SAM or obtain a CAGE code, he or she will need to first obtain a Unique Entity ID.

Offerors should note that CASIS funding is to be allocated toward Implementation Partner costs only. All other costs will be covered by the principal investigator. Concerning the In-Kind Contribution line item in the budget table, this value should include the estimated value of any facilities, hardware, or support services provided by the offeror's institution to support the project.

Useful Links:

ISS National Lab Project Overviews: www.issnationallab.org/projects

ISS National Lab Implementation Partner Database: www.issnationallab.org/implementation-partners

NASA's Export Control Program: www.nasa.gov/oiir/export-control

NASA Designated Countries: www.nasa.gov/oiir/export-control

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