**Bio-Inspired Platform for Enhanced Quantum Coherence**

By: Rowan Brad Quni; Bradley Gudzinas

**BACKGROUND**

**1. Field of the Invention**

The present invention relates to the field of quantum computing, and more specifically, to a bio-inspired quantum computing device that mimics aspects of neuronal microtubules in its structure and utilizes specific materials to enhance qubit coherence and improve the performance of quantum computations. The invention also relates to methods for fabricating and operating such a device. The technical fields implicated by the invention include those of Computer Devices, Computer Processes, Electrical Systems, Methods/Processes, and Systems generally.

**2. Background**

Quantum computing holds the potential to revolutionize computation by leveraging the principles of quantum mechanics to solve problems currently intractable for even the most powerful classical supercomputers. However, realizing the full potential of quantum computing has been hindered by significant technological hurdles. Existing quantum computing platforms, primarily based on superconducting circuits or trapped ions, face challenges in achieving scalability, maintaining qubit coherence, achieving fault tolerance, and operating at practical temperatures, all while remaining cost-effective. These challenges present a critical bottleneck to the widespread adoption and commercialization of quantum computing.

Qubits, the fundamental units of quantum information, are highly susceptible to environmental noise, leading to rapid decoherence and errors in computation. Most current platforms require extremely low temperatures (millikelvin range) to minimize thermal noise, necessitating complex and expensive cryogenic cooling systems. Scalability is also a major hurdle, with many architectures facing challenges in controlling and minimizing cross-talk between increasing numbers of qubits.

Currently, there are a number of solutions for achieving practical quantum computation. Some of these solutions attempt to utilize superconducting qubits in planar architectures, but these solutions fail to meet the needs of the industry because they suffer from short coherence times due to their sensitivity to environmental noise, require extremely low operating temperatures (millikelvin range) which necessitates complex and expensive dilution refrigerators, and face significant challenges in scaling up to a large number of qubits due to complex wiring and cross-talk issues. Other solutions attempt to leverage trapped-ion technology, but these solutions are similarly unable to meet the needs of the industry because they face challenges in scalability due to the complexity of trapping and manipulating individual ions, and they typically exhibit slower gate speeds compared to superconducting qubits. Still, other solutions seek to exploit quantum annealing for specific optimization problems, but these solutions also fail to meet industry needs because they are not capable of universal quantum computation and are limited in their applicability to a narrow range of problems, also they still operate at millikelvin temperatures.

**SUMMARY OF THE INVENTION**

This invention introduces a novel quantum computing platform inspired by biological structures, and in particular the structure and function of neuronal microtubules. The platform is designed to enhance qubit coherence, potentially enable operation across a wider range of temperatures compared to conventional superconducting qubit platforms, and offer a path towards improved scalability. The invention addresses the limitations of existing quantum computing approaches by leveraging principles of biomimicry to create a more favorable environment for quantum computation.

It would be desirable to have a device that performs quantum computations which exhibits significantly enhanced qubit coherence times compared to existing technologies. Furthermore, it would also be desirable to have a device that is capable of operating across a wider range of temperatures compared to current superconducting quantum computers, reducing the complexity and cost of cryogenic cooling. Still, further, it would be desirable to have a device that is scalable to a large number of qubits using existing CMOS fabrication infrastructure. Therefore, there currently exists a need in the industry for a device that enables more robust, scalable, and cost-effective quantum computation by leveraging a novel bio-inspired design. Similarly, it would be desirable to have an associated method that utilizes a bio-inspired lattice structure and a specialized dielectric material to create a tailored electromagnetic environment for the qubits. Therefore, there currently exists a need in the industry for a process that significantly reduces qubit decoherence, allows for operation across a wider range of temperatures, and facilitates the development of scalable and fault-tolerant quantum computing systems.

The disclosed device is unique when compared with other known devices and solutions because it provides (1) significantly enhanced qubit coherence times through a novel bio-inspired lattice structure and a specialized dielectric environment; (2) operational flexibility across a wider range of temperatures due to its bio-inspired design principles, reducing cryogenic complexity and cost; and (3) a potentially more scalable architecture leveraging CMOS-compatible fabrication and a modular design. Similarly, the associated method is unique in that it: (1) employs a bio-inspired lattice geometry to create a tailored electromagnetic environment that minimizes qubit decoherence; (2) utilizes a room-temperature stable dielectric to further enhance coherence and simplify system design; and (3) is designed to be compatible with existing fabrication techniques. Similarly, the disclosed method is unique when compared with other known processes and solutions in that it: (1) leverages principles of biomimicry and cavity QED to achieve enhanced quantum performance through environmental control; (2) potentially enables a path toward fault-tolerant quantum computation through the incorporation of error correction techniques; and (3) offers a clear path to scalable fabrication using existing semiconductor manufacturing infrastructure, making it potentially more cost-effective and accessible compared to other approaches.

The disclosed device is unique in that it is structurally different from other known devices or solutions. More specifically, the device is unique due to the presence of (1) a bio-inspired lattice structure that provides a tailored electromagnetic environment for qubits, unlike the planar or multi-chip architectures used in other superconducting qubit platforms; (2) a room-temperature stable dielectric that fills the lattice structure, designed to mimic aspects of a biological environment, a feature not found in any other quantum computing device; and (3) integration of materials within the lattice that allow for a wider range of operating temperatures.

Furthermore, the process associated with the aforementioned device is likewise unique. More specifically, the disclosed process owes its uniqueness to the fact that it (1) involves the fabrication of a complex, three-dimensional, bio-inspired lattice structure using CMOS-compatible processes, which is unlike the fabrication methods used for planar superconducting qubit architectures or trapped-ion systems; (2) incorporates a unique step of integrating a specially engineered dielectric material within the lattice structure at room temperature, a process not employed in other quantum computing platforms; and (3) utilizes materials and a specifically designed structure to enable operation at a wider range of temperatures than those used in traditional superconducting quantum computers, simplifying the cryogenic requirements and potentially reducing fabrication complexity.

Core Components:

* *Bio-Inspired Structure*: A structure, inspired by the geometry of biological systems, such as neuronal microtubules, fabricated using CMOS-compatible processes. The structure's geometry is designed to create a tailored electromagnetic environment that enhances qubit coherence.
* *Dielectric Material*: A specially engineered dielectric material that fills the structure. This material is designed to mimic dielectric properties found in biological environments and contributes to the shielding of qubits from environmental noise.
* *Qubits*: Quantum bits (qubits) integrated within the structure. These could be superconducting transmon qubits, or potentially other qubit modalities in the future.

Key Features:

* *Enhanced Qubit Coherence*: The bio-inspired structure and dielectric material work together to create an environment that minimizes decoherence, leading to longer qubit coherence times.
* *Biomimetic Design*: The platform draws inspiration from biological systems, specifically microtubules, to achieve improved quantum performance.
* *Potential for a Wide Range of Operating Temperatures*: The design offers the potential for operation across a wider range of temperatures compared to traditional superconducting qubits, simplifying cooling requirements.
* *Scalability*: The use of CMOS-compatible fabrication techniques allows for leveraging existing semiconductor manufacturing infrastructure, offering a potential path towards scalable production.
* *Modular Design*: The structure is designed to be modular, allowing for the connection of multiple such structures to increase the number of qubits and enhance scalability.

Method of Operation:

The method of operation involves initializing the qubits within the structure, applying control signals (e.g., through photonic interconnects) to perform quantum gate operations, and utilizing the unique properties of the bio-inspired structure and dielectric to maintain qubit coherence throughout the computation.

**DETAILED DESCRIPTION**

Structure:

In its most complete form, the device is made up of the following components:

* *Bio-Inspired Structure*: A structure fabricated on a silicon substrate. The structure is inspired by the geometry and/or function of biological systems, such as neuronal microtubules. Microtubules are cylindrical structures composed of tubulin proteins arranged in a helical pattern, and are found within the cytoskeleton of eukaryotic cells. The structure's geometry is designed to create a specific electromagnetic mode structure that can enhance qubit coherence. The exact geometry can be adapted based on experimental findings and theoretical modeling. Examples include, but are not limited to, substantially cylindrical, hexagonal, cubic, honeycomb, or even irregular or aperiodic structures. The structure may be designed to mimic the dynamic nature of microtubules, potentially incorporating elements that can vibrate or change conformation.
* *High-Temperature Superconducting (HTS) Material*: YBCO (or other suitable HTS material) deposited as a thin film, forming conductive pathways. The use of HTS materials offers the potential for operation at higher temperatures compared to conventional superconductors.
* *Buffer Layer*: A material layer deposited between the silicon substrate and the HTS layer to mitigate lattice mismatch and thermal expansion differences, if necessary.
* *Room-Temperature Stable Dielectric*: A specially engineered dielectric material that fills the interior space of the structure. This material is designed to mimic aspects of the dielectric environment found in biological systems, such as the ordered water surrounding microtubules. The dielectric material is stable at room temperature and is selected for its high dielectric constant and low loss tangent across a wide range of operating temperatures. The dielectric material may also be designed to interact dynamically with the lattice structure, potentially through mechanisms inspired by the interaction of ordered water with microtubules.
* *Transmon Qubits*: Superconducting transmon qubits integrated at specific locations within the structure. These are well-established qubit modalities in the field of quantum computing but other types of qubits may be used, such as but not limited to, flux qubits, phase qubits, and charge qubits.
* *Photonic Interconnects*: Silicon nitride waveguides that could be integrated into the structure for optical control and communication between qubits. These interconnects are designed for low loss at the relevant operating frequencies.
* *Phase-Change Polymer*: A self-healing material that could be incorporated within the structure to repair microfractures and enhance the device's longevity. This is an optional, secondary feature. The phase-change polymer is selected for its ability to melt and flow at a specific temperature above the typical operating range, allowing it to fill microfractures and then solidify to restore structural integrity.
* *CMOS Control Electronics*: (Future integration) Classical control and readout electronics integrated on the same chip or in a multi-chip module.
* *Encapsulation Layer*: A protective layer that encapsulates the entire structure, providing mechanical stability and potentially preventing degradation of the dielectric.

These components are connected and related as follows:

The buffer layer is deposited onto the silicon substrate, followed by the deposition and patterning of the HTS material to form the bio-inspired structure. The dielectric material is then introduced, filling the spaces within the structure. Transmon qubits are fabricated and precisely positioned at designated locations within the structure. Photonic interconnects could be integrated into the structure to enable communication and control of the qubits. The phase-change polymer is incorporated into the structure, and the entire device is sealed with an encapsulation layer.

It should further be noted that:

1. The bio-inspired structure has a specific periodicity and geometry designed to create a tailored electromagnetic mode structure that suppresses decoherence. The dimensions and periodicity of the structure will be determined through theoretical modeling and experimental optimization. The structure may be designed to mimic not only the geometry but also the dynamic nature of biological structures, such as microtubules.
2. The dielectric material has specific properties, including a high dielectric constant and a low loss tangent, across a wide range of operating temperatures. Its composition is carefully controlled to achieve these properties and to mimic aspects of biological environments. The dielectric material may also be designed to interact dynamically with the lattice structure.
3. The HTS material (YBCO) is deposited as a thin film.
4. The buffer layer is a proprietary material and thickness, chosen to minimize stress and chemical interactions between the silicon substrate and the YBCO layer, if necessary.
5. Qubit placement is achieved with high precision using techniques such as pick-and-place robotics or advanced lithographic techniques.
6. The photonic interconnects are fabricated using silicon nitride waveguides, chosen for their low loss at the relevant operating frequencies.
7. The phase-change polymer is selected for its ability to melt and flow at a specific temperature, allowing it to fill microfractures, and then solidify to restore structural integrity. This is an optional, secondary feature.

Operation:

The most complete form of performing the method associated with the disclosed device consists of the following steps:

1. Initializing Qubits: Prepare all qubits in a known initial state (e.g., the ground state).
2. Applying Control Signals: Use photonic interconnects (if implemented) to deliver precisely timed and shaped microwave pulses to individual qubits, performing single-qubit gate operations.
3. Entangling Qubits: Apply control signals to induce interactions between specific pairs of qubits, performing two-qubit gate operations and creating entanglement.
4. Performing Quantum Operations: Execute a sequence of single-qubit and two-qubit gates to perform the desired quantum computation or simulation. This sequence is determined by the specific algorithm being implemented.
5. Error Correction (Future Implementation): Periodically measure ancilla qubits and perform operations to detect and correct errors, as defined by a suitable error correction scheme.
6. Readout: Measure the final state of the qubits using the photonic interconnects or other integrated readout mechanisms.
7. Thermal Cycling (for Self-Healing): If necessary, and if implemented, raise the temperature of the chip to activate the phase-change polymer, allowing it to flow and repair any microfractures that may have occurred during operation.

**CLAIMS**

Device Claims:

1. A quantum computing device, comprising:
   1. a structure inspired by the geometry or function of a biological structure, wherein said structure is designed to enhance qubit coherence; and
   2. a plurality of qubits disposed within said structure.
2. The device of claim 1, further comprising a dielectric material integrated within said structure.
3. The device of claim 2, wherein said dielectric material is formulated to mimic dielectric properties found in biological environments.
4. The device of claim 1, wherein said structure is fabricated using CMOS-compatible processes.
5. The device of claim 1, wherein said structure comprises superconducting materials.
6. The device of claim 1, wherein the operating temperature of said device is determined through the application of biomimetic principles.
7. The device of claim 1, wherein said structure is designed to be modular, allowing for the connection of multiple such structures to increase the number of qubits.
8. The device of claim 1, wherein said structure is designed to dampen vibrations that can cause qubit decoherence.
9. The device of claim 1, further comprising a means for performing quantum error correction.
10. The device of claim 2, wherein the structure and dielectric material provide shielding from at least one of electromagnetic interference, ionizing radiation, or thermal noise.
11. The device of claim 1, wherein the qubits are selected from the group consisting of superconducting qubits, trapped ions, nitrogen-vacancy centers in diamond, and topological qubits.
12. The device of claim 1, wherein the structure is at least partially comprised of high-temperature superconductors.

Method Claims:

1. A method for performing quantum computation, comprising:
   1. providing a plurality of qubits within a bio-inspired structure;
   2. applying control signals to said qubits to perform quantum gate operations; and
   3. maintaining qubit coherence by utilizing a tailored electromagnetic environment created by said structure and an integrated dielectric material.
2. The method of claim 13, wherein the dielectric material is a hydrogel.
3. The method of claim 13, wherein the bio-inspired structure is a lattice structure.
4. The method of claim 13, wherein the bio-inspired structure is configured to mimic at least one of a geometry, a function, or a material property of a neuronal microtubule.
5. The method of claim 13, further comprising selecting the dielectric material based on its ability to mimic dielectric properties found in biological systems.
6. A method for fabricating a quantum computing device, comprising:
   1. forming a structure that mimics at least one of the geometry, function, or material properties of a biological structure; and
   2. integrating a dielectric material within said structure, wherein the dielectric material is selected to have properties that mimic those found in a biological environment.

**CATEGORY OF INVENTION**

Device & Method

**TECHNICAL FIELDS**

* Computer Device
* Computer Process
* Computer Process|Method/Process|Software
* Electrical
* Method/Process
* System

*Different features, variations and multiple different embodiments have been shown and described with various details. What has been described in this application at times in terms of specific embodiments is done for illustrative purposes only and without the intent to limit or suggest that what has been conceived is only one particular embodiment or specific embodiments. It is to be understood that this disclosure is not limited to any single specific embodiments or enumerated variations. Many modifications, variations and other embodiments will come to mind of those skilled in the art, and which are intended to be and are in fact covered by this disclosure. It is indeed intended that the scope of this disclosure should be determined by a proper legal interpretation and construction of the disclosure, including equivalents, as understood by those of skill in the art relying upon the complete disclosure present at the time of filing.*