Macro and Microscopic Ion Trap Junction Design for Quantum Computing

Design Document

sdmay24-38
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Revised: December 3rd, 2023

Executive Summary

Preface

Qubits are a necessary component of almost all quantum technologies. Despite great efforts, not all the properties and behaviors of the presently known qubits are understood. Furthermore, various quantum technologies require novel solutions; thus, new qubit designs should be explored. These issues call for developing ab initio methods that accurately yield the key parameters of qubits and vastly accelerate the identification of novel ones for a target quantum technology application. We aim to create a microscopic design that could be used as a quantum junction using Rare Earth Elements and then to create a scaled-up macroscopic version as a proof of concept.

Note: Please be aware that there have been significant changes from the initial direction of the project. Our initial direction was to simulate solid-state qubits, but when presented with an opportunity to pivot, we chose to do so. The fundamental research still applies, as there is minimal difference. Please refer to the 4.7.1 for our previous design.

Development Standards & Practices Used

Circuit and Hardware Practices:

- Quantum Hardware
- Measurement Equipment
- Electrical Circuit Analysis
- High-Precision Positioning Systems

Software Practices:

- Quantum Simulation Software
- Numerical Simulation Tools
- Data Analysis Tools
- Documentation
- High-Performance Computing

Engineering Standards:

- ISO 9001
- IEEE Standards
- Safety Standards
- Environmental Standards

- Data Security Standards
- Laboratory Standards
- Ethical Standards
- Reporting and Publication Standards

Summary of Requirements

- Investigate solid-state defects for use as single photon sources and qubits in quantum technologies
- Understand the properties and behaviors of known solid-state defect qubits
- Explore new solid-state defect qubits for various quantum technology applications
- Calculate excited states of defects using quantum mechanical forces
- Design effective mass-like excited states of deep defects
- Understand microscopic effects in the spin of relaxation of rare Earth dopants in wide bandgap oxide hosts

Applicable Courses from Iowa State University Curriculum

- Semiconductor Materials and Devices (EE 332)
- Digital Logic (CPRE 281)
- Electromagnetics (EE 311)
- Signals and Systems (EE 224/324)
- Semiconductor Fabrication Techniques (EE 432)
- Differential Equations (MATH 267)
- Electronic Circuits and Systems (EE 230)
- Communication Systems (EE 321/422)

New Skills/Knowledge acquired that was not taught in courses

- Quantum Computing
- Materials Science
- Quantum Simulation Software
- Project Management
- Intellectual Property and Patents

Table of Contents

Chapter 1: Team

1.1: Team Members:

1. Ezra Manus
2. Andrew Wilken
3. Calvin Mitchell

4. Robert Laskey

1.2: Required Skill Sets for Project

- Quantum Mechanics and Quantum Computing
- Computational Methods
- Quantum Simulation Software
- Laboratory Techniques
- Data Analysis
- Programming and Software Development
- Team Collaboration and Communication
- Project Management
- Research Ethics and Safety
- Materials Science

1.3: Skill Sets Covered by Team

- Semiconductor physics
- Communication systems
- Circuit analysis and design
- Systems analysis and design
- Embedded Software
- MATLAB
- VHDL
- Discrete component design and characterization
- Device failure analysis

1.4: Project Management Style Adopted by Team

To foster a collaborative, accessible, and inclusive environment; our project management of the completion and success of this project will be heavily team focused, meaning everyone will equally contribute to the collaboration and research required. We plan on using a shared Google Drive folder to pool our information on articles related to the project, along with documentation of the progression of this project. We will use a Discord channel to effectively communicate with each other, along with email to contact our advisor. We plan on meeting with our group once a week (in person) and once a week with our advisor (in person).

1.5: Initial Project Management Roles

- Ezra Manus: Research Lead

- Calvin Mitchell: Structural Engineer
- Andrew Wilken: Code Monkey
- Robert Laskey: Client interaction, literature review/concepts for component design

Chapter 2: Team

2.1: Problem Statement

Problem: Qubits (quantum representations of classical bits) are necessary for Quantum computing, Quantum Networks, and more, and improvements to efficiency and performance are necessary to develop better systems. Current systems require extremely low temperatures (T<1°K) to operate, and the coherence time (the amount of time a qubit state can exist before degrading) is very low for classic materials. Improvements in operating temperature and coherence times are necessary for the future of quantum systems.

Proposed solution: Research existing and emerging materials to create simulations of qubits created by rare-earth doped crystals. Rare earth materials have much longer coherence times (~1-4ms) and can exist at higher temperatures (1<T°K<3) than existing qubit structures, and have intrinsic "shielding" effects that prevent external stimuli from disrupting the qubit. Due to other material properties, they are also much more scalable for larger and more powerful systems.

2.2: Requirements & Constraints

Our component must be an accurate representation of Qubit. This means it is capable of representing values from 0 to 1. The electron spin of the Rare earth metals in our compound will represent this.

The method necessitates using Rare Earth metals, this being Lanthanides, Yttrium, and Scandium. These elements have properties that are necessary for the performance of our project.

Because of resource limitations, we can only test compounds in simulation. The timeframe required to create these compounds is simply too long for this course to encompass.

2.3: Engineering Standards

IEEE P2995: Trial-Use Standard for Quantum Algorithm Design and Development:

- This trial-use standard defines a standardized method for the design of quantum algorithms. The defined methods apply to any type of algorithm that can be assimilated into quantum primitives and/or quantum applications. The design of the algorithms is done preceding quantum programming.

IEEE P7130 Standard for Quantum Technologies Definitions:

- This standard addresses quantum technologies-specific terminology and establishes definitions necessary to facilitate clarity of understanding to enable compatibility and interoperability.

Due to Quantum computing being a relatively new field with few industry applications at this time, the active standards related to this field are not fully developed and are more or less proposed by researchers studying the topic.

2.4: Intended Users and Uses

The main group of people who will benefit from the results of this project include workers studying in the field of quantum computing and quantum technologies, such as:

- Researchers and Scientists
- Hardware/Software Developers
- Government and Defense Agencies.

The qubits are useful for their ability to do parallel computation and their theoretical properties for communication systems.

3 Project Plan

3.1: Task Decomposition

Required tasks needed to be completed in order for the successful completion of the project:

1. Research vast amounts of information related to quantum computing, quantum mechanics, and qubit design.
    a. There are several terms we need to fully understand in order to move forward onto the next step such as:
        i. Coherence time, entanglement, Rabi frequency and it's relationship with wavelength, quantum transconduction, quantum memory, quantu sensing

   b. We also need a solid amount of knowledge acquired relating to rare earth's (RE)
      i. For this project, we will be using a RE dopant with a suitable host (most likely also RE) to design a qubit with a coherence time of ~1 second.
2. After the research stage, we need to begin and develop our simulator to test for coherence time. This will be done in Python, and in order for it to work we need to really understand how the math works and relates to what we are trying to accomplish.
3. Once we build the simulator, we need to test different RE's based on its atomic properties and likelihood of being able to manipulate electrons.
4. Depending on how far we can get, our client wants us to write some sort of paper detailing our findings/discoveries.

3.2: Project Management/Tracking Procedures

Our project management style most aligns with the "waterfall" methodology. This is because our project has very distinct goals:

1. Research and gather information regarding quantum mechanics, quantum computing, design of a qubit, and knowledge on rare earth dopants.
2. Develop a simulation that can test the coherence time of our proposed qubit design.
3. Test different compounds to see which dopant and host yield a coherence time of ~ 1 second.

For the meantime, we have been importing our research into a Google Drive folder, along with all of our assignments/presentations. We have also been using Discord to communicate and share helpful links.

Our project's proposed milestones and evaluation criteria are going to differ slightly from some of the other product-focused projects that other groups are working on.

The majority of the first semester is going to consist of mainly researching the quantum field and learning everything we can to develop a fundamental understanding of the physics and chemistry behind the quantum systems and materials we are working with

our mission statement, or purpose is to Design a qubit with a coherence time of 1 second using a RE dopant and suitable host, which is the very definition of "easier said than done"

Our first task is to perform ongoing literature reviews to gather insight about the physics and chemistry of the materials we are working with and the equations that define their performance and material characteristics.

There are numerous factors we need to consider to develop a host-dopant system that yields the result we are pursuing.

Once a fundamental understanding is reached, we can then begin to develop Python code that, when given the characteristics of a material, will be able to produce an estimated coherence time; the preface to this is that we work to ensure that the system will even work in the first place at a chemical and physics level.

the actual sequence of events we are utilizing is similar to a sprint-based approach, where we will research and develop a theory on what system will work, manipulate eth Python code to simulate that system and produce some characteristics, and then analyze those results to determine if we need to repeat the process or not

The ultimate goal of this semester is to obtain a fundamental understanding of how these quantum systems work and develop some amount of ideas of what to simulate. In addition to this, we hope to have at least some shell code that outlines how the simulation is going to operate. It is likely that we will be able to produce a document containing a compilation of everything we have learned, and a clear direction of how to move forward.

3.3: Project Proposed Milestones, Metrics, and Evaluation Criteria

Our project is quite different from most of the senior design projects this semester. Most of this semester will be dedicated to learning/researching the quantum field and gaining a strong grasp of how the physics/math/chemistry work.

The mission statement for our project is simply put: Design a qubit with a coherence time of 1 second using a RE dopant and a suitable host.

However, that is not as easy as it sounds, since we haven't had a lot of exposure to quantum mechanics/computing outside of EE332 (semiconductor physics). And even from that course, we are learning that relating semiconductor physics to quantum computing is not as easy as we'd hope, forcing us to dive deep into reading material.

Building our simulator is also something we need to be extremely knowledgable about how the math relates to coherence time along with our chosen dopant and host. Before we are fully aware of this, it is hard to predict how our simulator will work and what important aspects need to be incorporated into it. There are several quantum terms that will need to be inputted such as: Rabi frequency, T1 and T2 times, quantum memory, quantum transconductance, etc.

3.4: Project Timeline/Schedule

Month	Task
Month 1	Research: Learning from our client, diving deep into research articles related to designing a qubit, and trying to understand complex quantum terms and definitions.
Month 2	Research: Learning from our client, diving deep into research articles related to designing a qubit, and trying to understand complex quantum terms and definitions.
Month 3	The beginning of the third month will still most likely be dedicated towards continuing research. About halfway through this month

	(maybe more near the end) we hope to begin building our simulator in Python.
Month 4	This month will be dedicated to finalizing our simulator and making sure all constraints and features required to know the coherence time of our qubit are correctly implemented.
Month 5	Test different RE dopants and hosts in the hopes we can find a successful pair that gives us a coherence time of 1 second. If this happens sooner than later, we will begin writing our paper (but that is unlikely to happen this semester due to the complexity of this project.)

3.5: Risks And Risk Management/Mitigation

(Task 1) Research: There is zero to no risk in this stage of the project. The main outcome is to just put in a lot of time reading information related to our project. The hardest part of this section is purely just understanding the material. Our client has told us on many instances that it's highly unlikely that we are going to understand this material right away, and it is important to just keep re-reading until something starts to click.

(Task 2) Building simulator: This part of the project will most likely have the highest risk of success. For it to work, we need to have a strong understanding of what mathematical modeling is most important in determining our coherence time, along with the simulator being able to take information about our dopant and host material to formulate a coherence time. Since we are still in the research phase, we will have to add more to this section on the risk, which will be hard to truly know until we begin developing it.

(Task 3) Testing different RE dopants and host materials: This section also has a decent amount of risk that goes into it. For the simulator to work, it will need to know a lot of the chemical and physical properties to determine how it would react on the atomic level. We can definitely have a better idea of a dopant success from reading articles related to qubit design, but it will still take lots of trial and error until we hopefully find a suitable candidate.

3.6 Personnel Effort Requirements

This project's largest task by some margin is found in the research, both for creating our simulator and for identifying promising compounds to simulate. We estimate that during the research period, we will be spending roughly 150 hours this semester, including the time already spent this semester.

Creating a simulator should take about 15 hours, once all the information required has been required.

This semester no simulations will take place, although actual simulation time once the simulator has been completed should be approximately 8 man hours.

Meetings are expected to take another 30 hours total this semester, although some less formal meetings may be classified in research.

3.7: Other Resource Requirements

We will need a high-voltage transformer, such as those found in neon signs. We will also need electrodes and likely safety equipment, which the TLA has on stock.

4 Design

4.1 Design Content

Briefly describe what is the design content in your project.

At its most fundamental, our project has two outputs, both requiring design input. First, our primary goal is to design a Erbium doped Qubit. In order to confirm that this element has been designed successfully, we also need to design a simulator capable of evaluating the performance of our Qubit.

4.2 Design Complexity

1. The design consists of multiple components/subsystems that each utilize distinct scientific, mathematical, or engineering principles.

The design of the Host and dopant system contains several components that rely on engineering principles. First, the dopant's own interactions in its atomic structure must be capable of reaching multiple levels of excitation with good separation, which is a principle of communication theory, as if they aren't the signal would be unintelligible. Furthermore, the interactions of the Host and the dopant must be considered. The Absorption spectra of the Dopant and the Bandgap of the Host must match.

The Simulator we create will have all the above levels of complexity, as it must be capable of evaluating all the interactions listed above and be capable of predicting the actual outputs. There are several effects that the two can have on each other. There are 5 levels of interaction in the system we will be focusing on: Electronic Repulsion, Spin-orbit coupling, Crystal Field interactions, Hyperfine Transitions, and the Zeeman Effect. Each of these interactions utilizes Quantum mechanics.

2. The problem scope contains multiple challenging requirements that match or exceed current solutions or industry standards.

Since this project is in the field of quantum computing, our design challenge is something that easily matches, and perhaps exceeds current solutions. Since the field is still in development stage, the industry standards for what we are trying to achieve are not really developed at all. Our biggest challenge is finding a host material with our chosen dopant material, which encompasses knowledge learned from semiconductor physics, but is a little different since we're not using only silicon as our host. There are parallels we can take away from semiconductor fabrication, but since this is a totally new technology, there are a lot of differences when it comes down to the properties we want to utilize.

For the simulator, the biggest challenge comes with trying to find the necessary mathematical equations that will help determine coherence time. Because quantum computing is probabilistic and not deterministic, tracking data is far more complex and will make us have to perform a hefty amount of trial and error in our pursuit of producing a coherence time of 1 second. Aside from the mathematical equations, there are several other environmental constraints we have to take into consideration such as temperature, magnetic and electric field, rabi frequency, and even theoretical models for how electrons and other subatomic particles move from a quantum lens.

4.3 Modern Engineering Tools

The modern engineering tools used currently are Python and the Atom Spectra Database, but our output is not a physical product.

4.4 Design Context

The fundamental application of our project would be that these Qubits we're designing could be used in quantum computers. Quantum computers have a variety of possible applications, from improving processing speed to incredible communication speed. We are designing specifically for Quantum researchers, who will be able to use our product to its full potential. Our goal is to improve upon available options, which limits the scope considerably. The largest affected community would again be quantum designers, who would be given a goal of designing a computer that can function with the properties of our Qubit. We are attempting to address a problem in a field that is trying to address the need for faster communication and increased processing power. Economically, a change in communication to this degree would cause changes that are difficult to predict.

Area	Description	Answers
Public health, safety, and welfare.	How does your project affect the general well-being of various stakeholder groups? These groups may be direct users or may be indirectly affected (e.g., the solution is implemented in their communities)	More efficient qubits mean more efficient and widely-applicable quantum computing systems, which can be applied to research and educational institutions to massively increase productivity when it comes to computational needs
Global, cultural, and social	How well does your project reflect the values, practices, and aims of the cultural groups it affects? Groups may include but are not	The problem we are working to solve is a widely accepted issue in the quantum computing community, as current systems are impractical for

	limited to specific communities, nations, professions, workplaces, and ethnic cultures.	large-scale use and integration. Any progress made can massively benefit other groups working to develop quantum systems.
Environmental	What environmental impact might your project have? This can include indirect effects, such as deforestation or unsustainable materials manufacture or procurement practices.	Running quantum systems currently takes roughly 26kW to run, just under 25kW of which is just the refrigeration systems to keep the system cooled to 15 millikelvin (Source link) Designing qubits that can operate at higher temperatures will significantly reduce the overall power consumption of these systems.
Economic	What economic impact might your project have? This can include the financial viability of your product within your team or company, cost to consumers, or broader economic effects on communities, markets, nations, and other groups.	The cost for designing and building quantum systems is already massive; using certain rare-earth materials could drop the overall cost of integration due to the nature of the materials we are using. This is because the materials we are researching are already suited to integration with other systems and are less likely to need complex interpreter systems to make them useful in practical applications.

4.5 Prior Work/Solutions

There are several methods that have been attempted to create Qubits, but our method is essentially a new method. Other groups are working on the same thing, such as the University of Chicago, but it is still a work in progress. This means that there aren't any comparisons with other groups to be made. As for background literature, we have read about 30 papers, although the most important reading is "Rare Earth-Doped Crystals for Quantum Information Processing," which is something our client recommended we read.

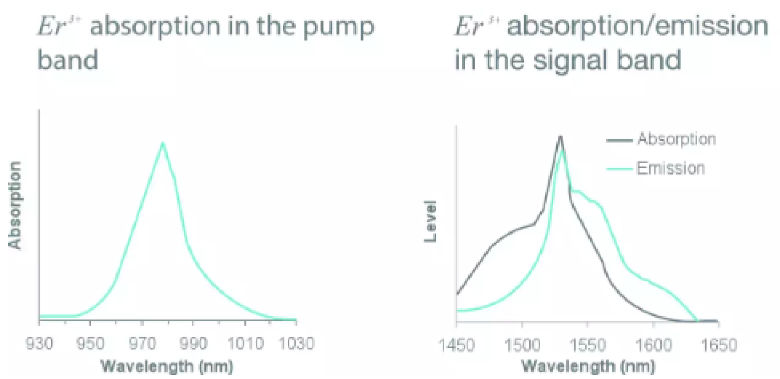
4.6Design Decisions

1. Design a host material given our chosen dopant (Erbium) to produce a coherence time for our qubit of 1 second.
2. Determine necessary information from our host and dopant to input into our simulator to test for coherence time.
3. Include any other factors/limitations needed to be considered in our simulator.

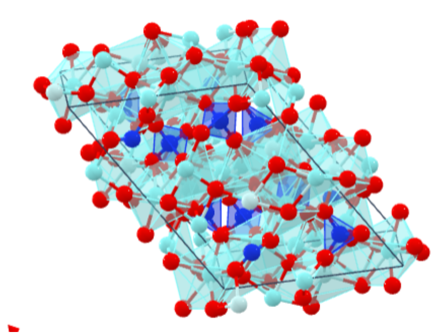
4.7 Proposed Design

Discuss what you have done so far – what have you tried/implemented/tested?

4.7.1 Design 0(Initial Design)
Design Visual and Description



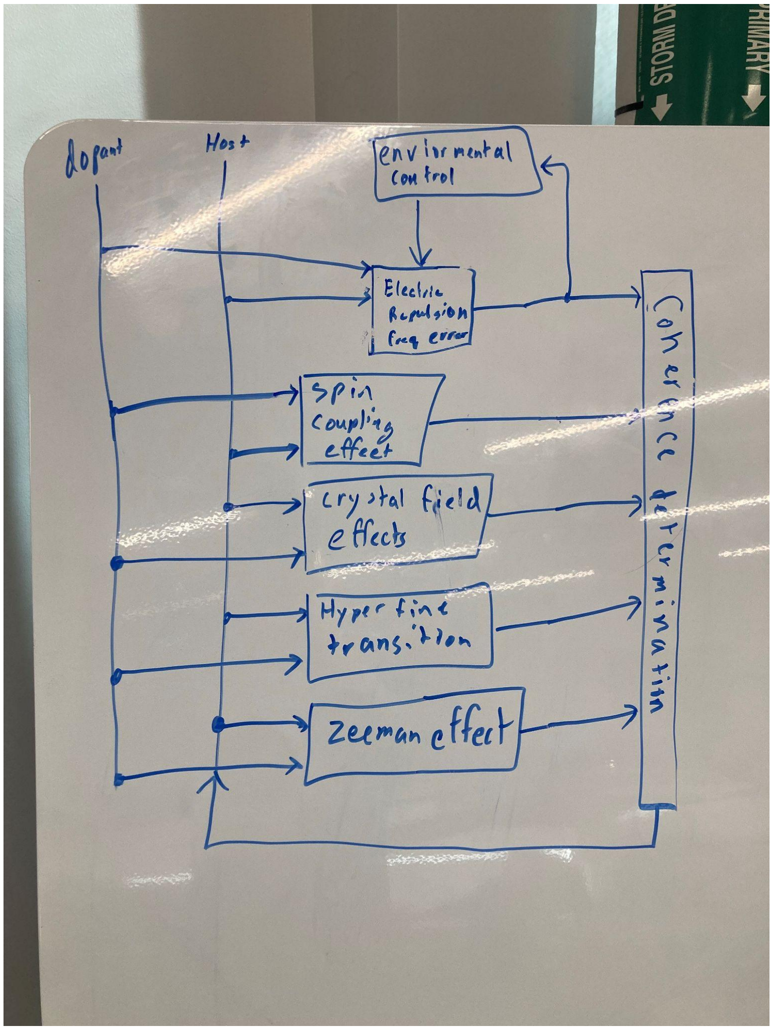
The design of our Host dopant system is currently as follows: Yttrium Silicide as our Host, and Erbium as our dopant. Above you can see the absorption spectrum of Erbium. The Bandgap of Yttrium Silicide is 4.77eV. You can see the Crystal structure of the host below. The Large bandgap of our host and the fact that it's spacing is large enough to support Er doping means that it is an ideal candidate for our Qubit.



Simulator:

Below you can see our block diagram for our simulator. The current design of the simulator is as follows: It takes as an input a Dopant and probable hosts. These two inputs are then put through 5 blocks, which are the major determinants of coherence time. Some, like electronic repulsion error, will be fed back into our environmental control block, which will allow us to change the environment in reasonable ways. After each block influencing Coherence time is run, the outputs are taken into the final computational block, which will calculate the final coherence time, which will be saved, and trigger the next iteration of the host.

Code Block Diagram



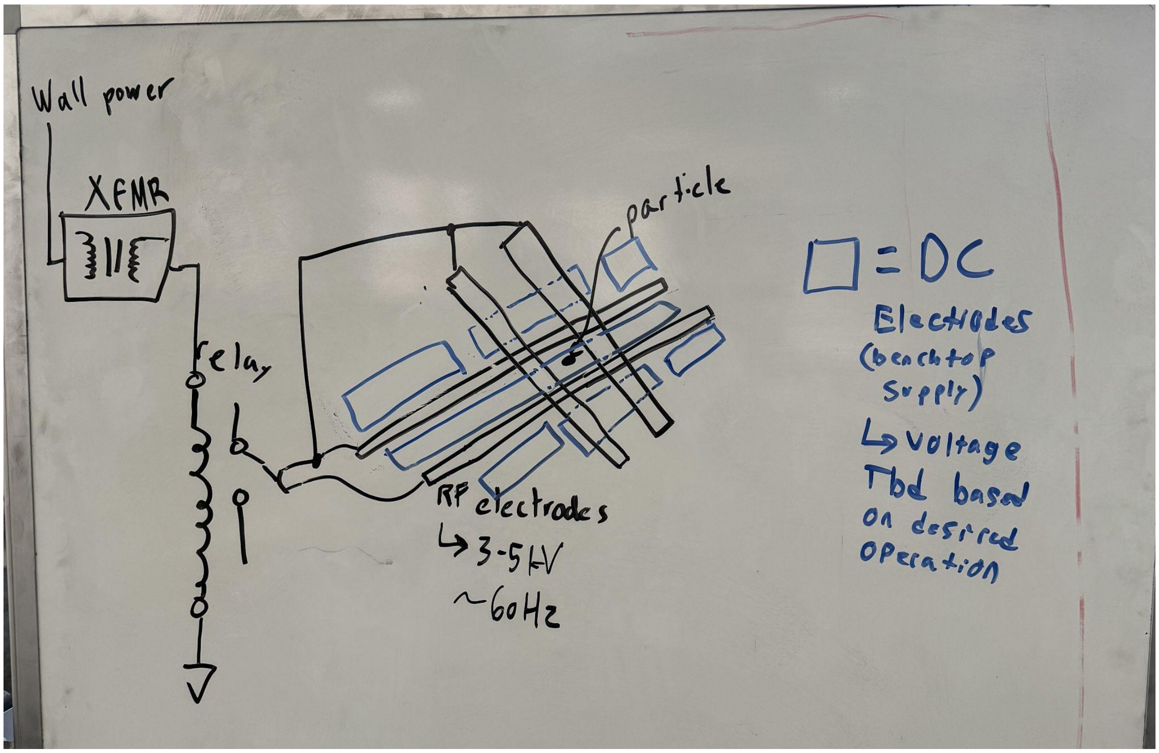
Functionality

Currently, the design of the simulator should be about as good as it gets with our current method. There are other methods of simulation, but they involve massive amounts of processing power that we simply don't have access to.

4.7.2 Design 1 (Design Iteration)

As mentioned in the preface, this is a fairly substantial change. Our current design on a micro-scale is to create a qubit using Erbium, but instead of a crystal host we will use planar ion traps. Anything said about Erbium as ideal from the previous design will carry over, so please refer to 4.7.1 for reasons why Erbium was chosen. As for the Ion trap, it removes many of the errors caused by crystal field effects, and that is why we have chosen this. Our design in particular uses planar ion traps to suspend the ions and allow for multidimensional movement. We have added a macroscopic element to our design, which will be a proof of concept for our micro-scale design.

Design Visual and Description



4.8 Technology Considerations

Existing quantum computing systems:

strengths -

Solving Complex Problems: Quantum computers have the potential to solve complex problems that classical computers cannot handle in a timely manner.

Quantum Advantage: Quantum computers can potentially provide a competitive advantage in various fields, stimulating investment, promoting healthy competition, and deepening collaboration.

weaknesses -

Technological Challenges: Quantum computing faces significant technological challenges. For instance, when transistors become small enough, electrons have a hard time staying in their intended logic gates.

High Investment: Quantum computing requires substantial investment. It is estimated that an additional $10 billion must still be invested in developing hardware.

trade-offs -

Different Approaches: There are different quantum computing models, each with pros and cons, timetables for realization, and optimal applications2. For example, some systems use quantum gates, a basic quantum circuit that operates on a number of qubits2.

Benchmarking: Performance benchmarking can accelerate progress in quantum computing. However, designing benchmarks that are useful, scalable, and comprehensive is challenging for such a radical and complex technology1.

Existing ion trap systems:

strengths -

High Qubit Quality: Trapped Ion (TI) qubits have fundamental advantages over other technologies, featuring high qubit quality.

Coherence Time: TI qubits have a long coherence time.

Qubit Connectivity: TI qubits have high qubit connectivity.

weaknesses -

Scalability Limitations: Current TI systems are small in size and typically use a single trap architecture, which has fundamental scalability limitations.

Increasing Unreliability: In the single-trap architecture, ion spacing and ion-ion interaction strength reduce as more ions are added to the trap. Hence, with an increasing number of qubits, qubit control and gate implementation become increasingly unreliable and time-consuming.

trade-offs -

Design Possibilities: Building a 50-100 qubit system is challenging because of a wide range of design possibilities for trap sizing, communication topology, and gate implementations1.

Application Resource Requirements: The need to match diverse application resource requirements is a significant challenge.

Solutions:

- The novel trap design we are investigating allows for hundreds of qubits to be used in the same system (Devices made by Sandia labs have produced devices capable of “housing” up to 200 individual qubits
- Creating a larger device allows for more traps and more qubits
-

Discuss possible solutions and design alternatives

(?) Simulation and modeling over synthesization

5 Testing

5.1 Unit Testing

The goal for our project is to be able to simulate a trapped Ion Qubit. The implementation will involve a new layout using 2 peregrine traps, where one will serve as a level plane, while the other will be inverted and rotated above to allow for multidimensional movement of qubits. There is no set name, so for now I will simply call it a novel trap. The peregrine tap itself will be a unit to be tested.

As to how we will be scaling up the design as a proof of concept. To do this we will use pieces of paper as our trapped ion, and high-voltage rails to power our trap. It will be visually apparent if it has been successful, as the paper will float in the air.

We will use a high-voltage generator (5kV) to power conductors in our design. No other tools are planned for use in testing.

5.2 Interface Testing

There are a couple of interfaces in our design. The primary interface will be between the 2 units. 1 will need to be rotated and suspended, so our suspension will need to be able to support the trap without causing electromagnetic interference capable of ruining the trap. The second interface will be on the smaller electrodes that move the trapped ions. Tools for this will be limited to things like probes and, again our high-voltage generator.

5.3 Integration Testing

The most critical integration will be between the 2 units. These must work together to provide multidimensional control over the trapped ions. The integration will be tested identically to the unit testing. The last thing to be integrated will be the control charges used to move the ions

5.4 System Testing

The System testing will involve all components in the novel trap. The above tests, in particular the integration testing, will suffice, as the final integration test will have the entire unit.

5.5 Regression Testing

There are essentially 2 major steps that may break previous steps. The part for concern is when the 2 peregrine traps are combined. These traps must not stop each other from performing. If this breaks, we lose the multidimensionality that the trap has, and will have failed. The other area that is less likely to cause issues but still might would be the charges used to move our simulated trapped ions. It is unlikely, but possible that this could cause a failure in the traps themselves. Luckily, neither steps should be able to cause any actual damage to the unit, meaning if the combination is unsuccessful, they can be taken apart without any harm. This will allow us to change the design without having to go all the way back to stage 0.

5.6 Acceptance Testing

Our client intends to be present for this testing, as they are very involved in the criteria. Our for how we will demonstrate, it should be quite apparent. Our design will be able to cause trapped particles to float and allow us to manipulate them. There are not specific criteria for things like height or movement speed, merely a conceptual proof is desired, so a video will suffice.

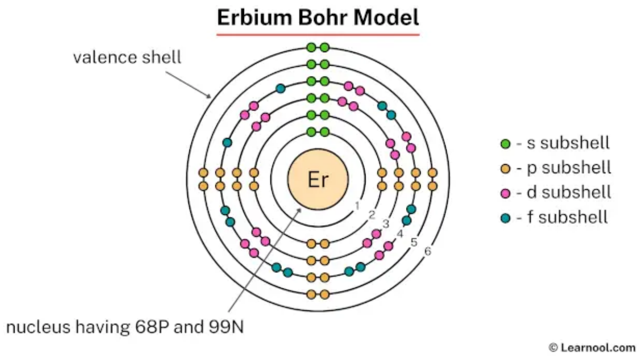
5.7 Results

As stated in 5.6, the result of our testing would be a video proof of successfully trapping particles and moving them around. As these are the requirements, a video will ensure compliance. The use of this product itself will be ___

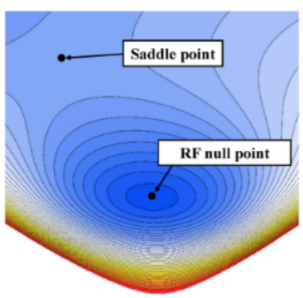
6 Implementation

- Microscopic vs macroscopic representations
    - Microscopic model
        - Real-world implementation would include the use of an Erbium Ion
        - Ability to manipulate the location of the ion without changing the electron configuration of the particle
    - Macroscopic model
        - Utilizes a piece of styrofoam or paper that has been charged by some method (TBD)
        - Step one: Single surface trap
            - RF electrodes: 3kV, 60Hz AC electrodes (in phase)
            - DC electrodes: TBD based on ion representation and outcomes of testing
- Ion design
    - Erbium Ion can be created by adding or removing an electron to charge the particle (unexplored)
    - Natural shielding of the 4f subshell by the 5th valence band, allowing for more precise qubit operations and longer coherence times when using electrons in the 4f

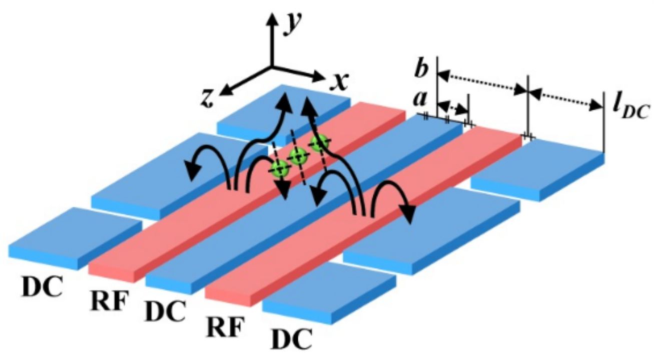
subshell



- Electromagnetic fields
  - RF Electrode voltages will vary in order to create a saddle point in the electric field (time-averaged null space) that will constrain the particle in 3D space (Earnshaw's Theorem, linear Paul trap)
- Single trap design

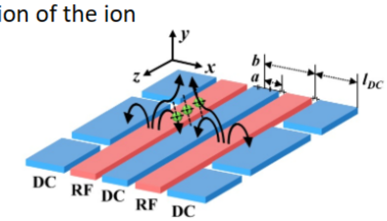


Contour plot of total potential generated by a surface ion trap indicating the RF null point and saddle point



Schematic of a surface ion trap in a symmetric five-rail geometry. The red and blue rectangles indicate the RF and DC electrodes, respectively. The curved arrows denote the direction of the electric field when the RF voltage is positive.

- Hair dryer represents DC electrode, strength of field dictates ion trap height
- Arrows represent time-averaged forces from RF electric field leading to 360° confinement on a horizontal plane
- Due to natural shielding, EM fields used for confinement do not affect the electron configuration of the ion



- Dual-Trap design
    - Grid of traps where ions can exist during measurement or manipulation
    - Green represents RF electrodes, gold represents DC control electrodes
    - RF electrodes are responsible for ion confinement, control electrodes are used for movement

7 Professionalism

7.1 Areas of Responsibility

- Ethical Considerations
- Legal Compliance
- Safety Protocols
- Security Measures
- Environmental Impact
- Professional Development and Training
- Open Communication and Collaboration
- Social Responsibility
- Documentation and Record-Keeping
- Review and Accountability

7.2 Project Specific Professional Responsibility Areas

- Scientific Integrity
- Experimental Design and Reproducibility

- Technology Accessibility
- Collaboration with Client/Advisors
- Intellectual Property Protection
- Long-Term Impact Assessment

7.3 Most Applicable Professional Responsibility Area

- Intellectual Property Protection: Our goal is to build our design in the hopes of a proof of concept. If this device can be successfully built, our advisors from the University are hoping to file a patent for the novel ion trap.

8 Closing Material

8.1 Discussion

This semester has been an intensive amount of exposure to the current quantum computing landscape. We focused on diving deeper into our overall understanding of quantum to gain new insights into how we could design a more efficient qubit than what currently exists in research/industry. Although our initial design was predicated on the use of a rare earth dopant material to optimize coherence time, our shift to trapping ions did change our conceptual design a significant amount, but the research we performed was still highly applicable. Our research on rare earth elements helped us gain new insights into our current design of a novel ion trap. In our hope using Ionized Erbium would yield the desired qubit properties; we believe this design will be a groundbreaking new technology for quantum networks.

8.2 Conclusion

Up to this point, we have all been involved in extensive amounts of research. For the next semester however, we have planned on us doing the following roles:

- Calvin: Structural Lead Designer
- Andrew: Verification Engineer
- Michael: Fabrication Engineer
- Ezra: Research Lead

We are currently working on acquiring components and our plans for next semester mostly include building and testing our proposed design at the Microelectronics Research Center (MRC).

8.3 References

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8.4 Team Contract

Team Name Q-Bit

Team Members:
1) Ezra Manus
2) Andrew Wilken
3) Calvin Mitchell
4) Robert Laskey

Team Procedures

1. Day, time, and location (face-to-face or virtual) for regular team meetings:
   Tuesday's 3:30 PM in Coover (Face-to-face)
2. Preferred method of communication updates, reminders, issues, and scheduling (e.g., e-mail, phone, app, face-to-face):
   e-mail and discord
3. Decision-making policy (e.g., consensus, majority vote):
   Time pressing: Majority vote
   Non-time pressing: Consensus
4. Procedures for record keeping (i.e., who will keep meeting minutes, how will minutes be shared/archived):
   Meeting minutes: Ezra
   Minutes will be archived in Google Drive Folder

Participation Expectations

1. Expected individual attendance, punctuality, and participation at all team meetings:
   Required, if necessary, we can do remote.
2. Expected level of responsibility for fulfilling team assignments, timelines, and deadlines:
   Everyone should have their assignments on time. If unable to complete it on time, ensure the rest of the group is aware and work is delegated so it can still be completed by a set deadline.
3. Expected level of communication with other team members:
   Everyone should communicate their work well enough that other group members know what they are doing. If there are difficulties with performing team duties, they must also communicate this. Individual progress should be shared whenever something is completed/delayed and/or during meetings so that timelines can be updated.
4. Expected level of commitment to team decisions and tasks:
   Unless specified as individual work, everyone should be aware of team decisions that will be voted on by everyone in the group.

Leadership

1. Leadership roles for each team member (e.g., team organization, client interaction, individual component design, testing, etc.):
   a. **Ezra: Team organization**
   b. **Calvin: Sr. Testing Manager**
   c. **Andrew: Code monkey**

   d. **Robert: Client interaction, literature reviews/concepts for component design**

2. Strategies for supporting and guiding the work of all team members:
   Constant communication between team members and advisors, both in-person and virtual. Regular meetings. Constant checklist of required tasks that must be completed.

3. Strategies for recognizing the contributions of all team members:
   Verbal praise and a free meal for the person we think did best

Collaboration and Inclusion

1. Describe the skills, expertise, and unique perspectives each team member brings to the team.
   a. **Ezra: Systems analysis and communication systems**
   b. **Calvin: Circuit analysis, Matlab, communications systems**
   c. **Andrew: Embedded Software, VHDL**
   d. **Robert: Circuit analysis and design, semiconductor physics, discrete component design and characterization, device failure analysis**
2. Strategies for encouraging and support contributions and ideas from all team members:
   Asking for others thoughts, and brainstorming sessions. Frequent team meetings will help with this. Individual contributions can be accounted for when finding the best compromise for a given problem. Decision making policies will be used here when there are too many conflicting ideas
3. Procedures for identifying and resolving collaboration or inclusion issues (e.g., how will a team member inform the team that the team environment is obstructing their opportunity or ability to contribute?)
   This will be a judge-free, open environment where anyone has the right to speak up about issues they are having. If a problem gets out of hand, a group member will contact the advisor for their opinions and suggestions.

Goal-Setting, Planning, and Execution

1. Team goals for this semester:
   A better understanding of how quantum mechanics works, a literature review, and a plan to develop solutions for quantum computing to be used in the future.
2. Strategies for planning and assigning individual and team work:
   The first route would be if anyone on the team would like to volunteer for that assignment. If no one wants to volunteer, we will either have a vote or decide whose skillset most aligns with the given task.
3. Strategies for keeping on task:
   Having regular meetings to go over current targets, and assess progress on deliverables. Meetings with Ta's, Advisors, or Clients will also ensure that progress is made in the correct direction.

Consequences for Not Adhering to Team Contract

1. How will you handle infractions of any of the obligations of this team contract?
   First Step would be a simple verbal warning, followed by additional monitoring such as frequent messages to check progress of tasks. If

obligations cannot be met, some sort of compensation (redelegation of tasks, additional worktime outside of agreed on meeting times, donuts, etc) will be used

2. What will your team do if the infractions continue?

Further infractions will result in mentor/advisor involvement and could result in being removed from the group.

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a) *I participated in formulating the standards, roles, and procedures as stated in this contract.*
b) *I understand that I am obligated to abide by these terms and conditions.*
c) *I understand that if I do not abide by these terms and conditions, I will suffer the consequences as stated in this contract.*

1) Calvin Mitchell DATE 9/5/2023
2) Ezra Manus DATE 9/5/2023
3) Andrew Wilken DATE 9/5/2023
4) Robert Laskey DATE 9/5/2023