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

Provide evidence that your project is of sufficient technical complexity. Use the following metric or argue for one of your own. Justify your statements (e.g., list the components/subsystems and describe the applicable scientific, mathematical, or engineering principles)

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 are all reliant 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 utilize 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, this makes tracking data 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

What modern engineering tools were used for this design? Their roles.

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

Describe the broader context in which your design problem is situated. What communities are you designing for? What communities are affected by your design? What societal needs does your project address?

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. Currently, 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 to design a computer that can function with the properties of our Qubit. We are attempting to address a problem in a field that as a whole 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 really predict.

List relevant considerations related to your project in each of the following areas:

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., 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 limited to specific communities, nations, professions, workplaces, and ethnic cultures.	The problem we are working to solve is a widely accepted issue in the quantum computing community, as current systems are impractical for 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 practices related to materials manufacture or procurement.	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 temoperatures 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 down due to the nature of the materials we are using. This is due to the fact that the materials we are researching are already suited to integration with iother systems and are less likely to need complex interpreter systems to make them useful in practical applications.

4.5 Prior Work/Solutions

Include relevant background/literature review for the project

– If similar products exist in the market, describe what has already been done

– If you are following previous work, cite that and discuss the **advantages/shortcomings**

– Note that while you are not expected to "compete" with other existing products / research groups, you should be able to differentiate your project from what is available. Thus, provide a list of pros and cons of your target solution compared to all other related products/systems.

Detail any similar products or research done on this topic previously. Please cite your sources and include them in your references. All figures must be captioned and referenced in your text.

There are several methods that have been attempted to create Qubits, but our method is essentially a new method. There are other groups working on the same thing, such as the University of Chicago, but it is still a work in progress. This means that there isn't really 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.

4.6 Design Decisions

List key design decisions (at least three) that you have made or will need to make in relation to your proposed solution. These can include, but are not limited to, materials, subsystems, physical components, sensors/chips/devices, physical layout, features, etc.

1. Design a host material given our chosen dopant (Erbium) in order 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 consider to include in our simulator.

4.7 Proposed Design

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

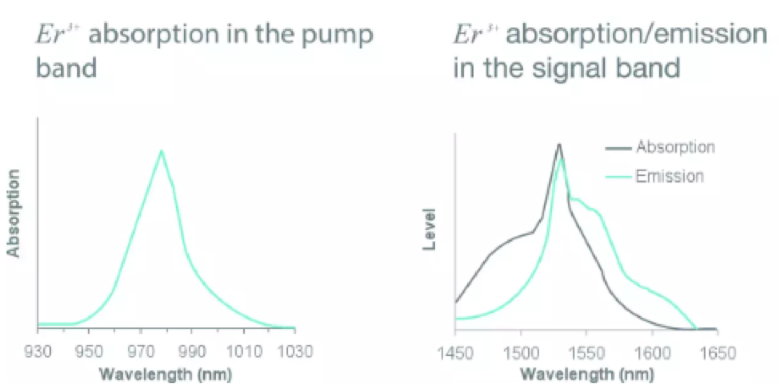
4.7.1 Design 0 (Initial Design)

Design Visual and Description

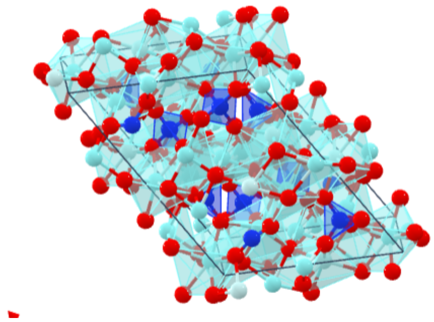
Include a visual depiction of your current design. Different visual types may be relevant to different types of projects. You may include: a block diagram of individual components or subsystems and their interconnections, a circuit diagram, a sketch of physical components and their operation, etc.

Describe your current design, referencing the visual. This design description should be in sufficient detail that another team of engineers can look through it and implement it.

Justify each component in the design with respect to requirements.



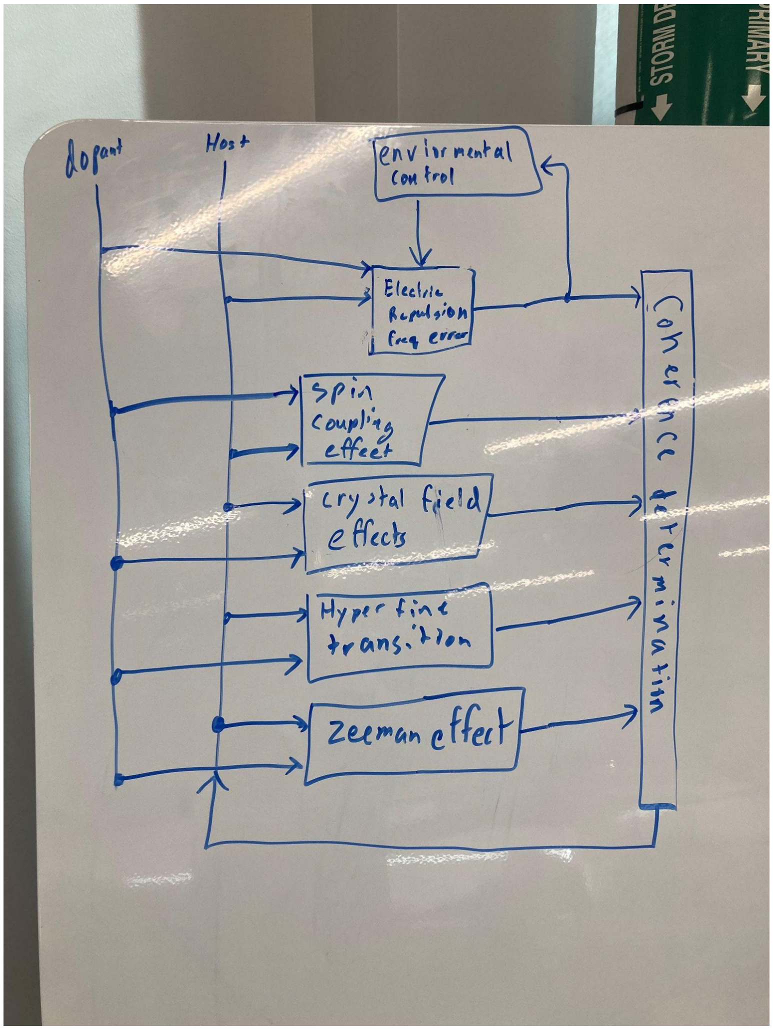
The design of our Host dopant system is currently as follows: Yttrium Silicide as our Host, and Erbium as our dopant. Above you can see the absorption spectrum of Erbium. The Bandgap of Yttrium Silicide is 4.77eV. You can see the Crystal structure of the host below. The Large bandgap of our host and 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

Describe how your design is intended to operate in its user and/or real-world context. This description can be supplemented by a visual, such as a timeline, storyboard, or sketch.

How well does the current design satisfy functional and non-functional requirements?

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)

Include another most matured design iteration details. Describe what led to this iteration and what are the major changes that were needed in Design 0.

Design Visual and Description

Include a visual depiction of this design as well highlighting changes from Design 0. Describe these changes in detail. Justify them with respect to requirements.

NOTE: The following sections will be included in your final design document but do not need to be completed for the current assignment. They are included for your reference. If you have ideas for these sections, they can also be discussed with your TA and/or faculty adviser.

4.8 Technology Considerations

Highlight the strengths, weaknesses, and trade-offs made in technology available.

strengths -

weaknesses -

trade-offs -

Discuss possible solutions and design alternatives

(?) Simulation and modeling over synthesization

4.9 Design Analysis

- Did your proposed design from 4.7 work? Why or why not?
- What are your observations, thoughts, and ideas to modify or iterate further over the design?