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Outgassing Test Stand for Quantum Computing Components

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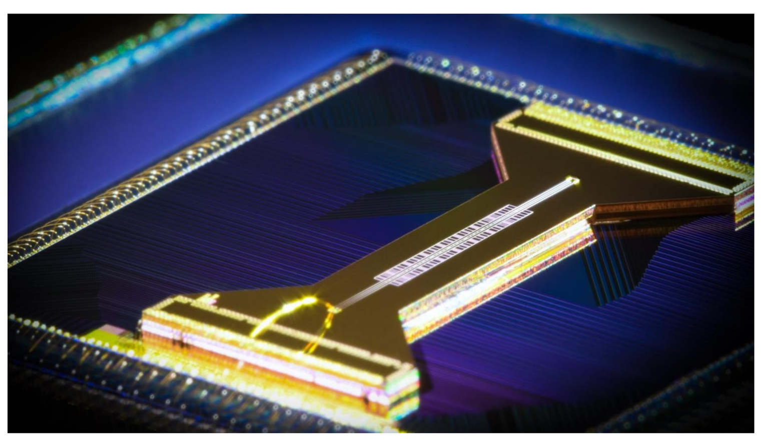
Objective: Re-envision Quantinuum's outgassing test stand for materials characterization

Key deliverables:

1. Chamber can fit a 5" x 5" x 12" sample.
2. System can reach 10^{-9} Pa
3. Chamber must be heated to 150C steadily over time.
4. System footprint must be minimized.
5. **Minimize time required for testing.**

Trapped Ion Quantum Computing:

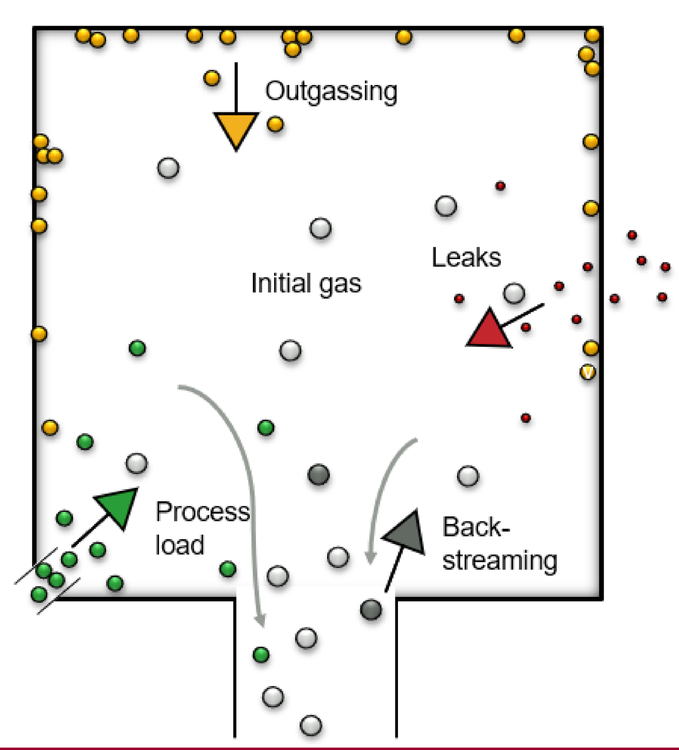
Involves the manipulation of individual ions trapped in electromagnetic fields to perform logic operations.



Quantinuum's Ion Trap

Ion trapping is done under Ultra-High Vacuum (UHV: 10^{-7} to 10^{-10} Pa) to prevent collisions with ions.

Outgassing: Materials can release lightweight molecules that would contaminate the environment. Reducing gas loads within Quantinuum's vacuum systems is critical.



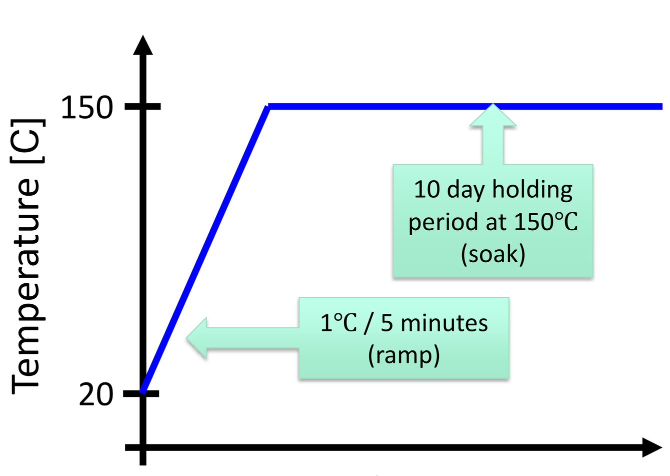
Automated Heating System:

Outgassing characteristics are heavily dependent on temperature, and can be greatly reduced by heating up, or "baking" the material.

In our system, we designed an automated heating system that facilitates the desired temperature profile for optimized sample testing.

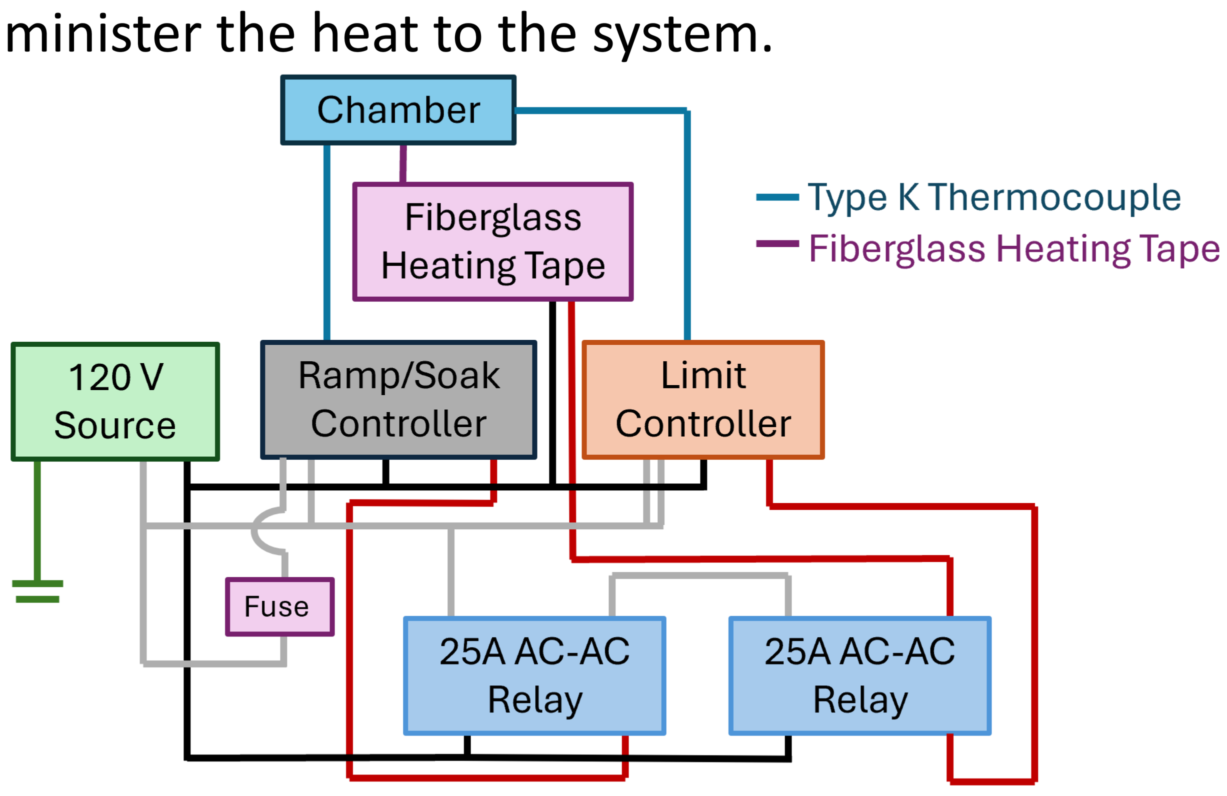
Temperature Profile:

The required temperature profile was provided by our client and was achieved by using a ramp/soak controller.



Heating System Schematic:

The heating system we designed includes a Ramp/Soak Controller, a limit controller, and uses fiberglass heating tape to administer the heat to the system.



Designing for Ultra-High Vacuum: *Maximizing Vacuum Conductance*

To decrease sample test time, we designed a system to decrease the time it takes to pump down the sample chamber.

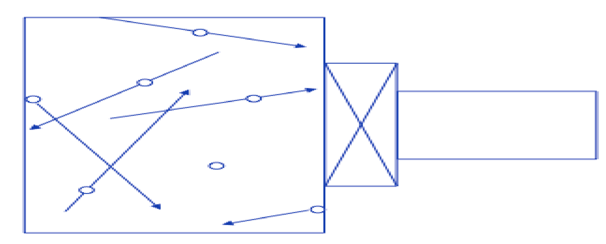
Total System Conductance:

$$\frac{1}{C_{tot}} = \sum_{i=1}^{n} \frac{1}{C_n}$$

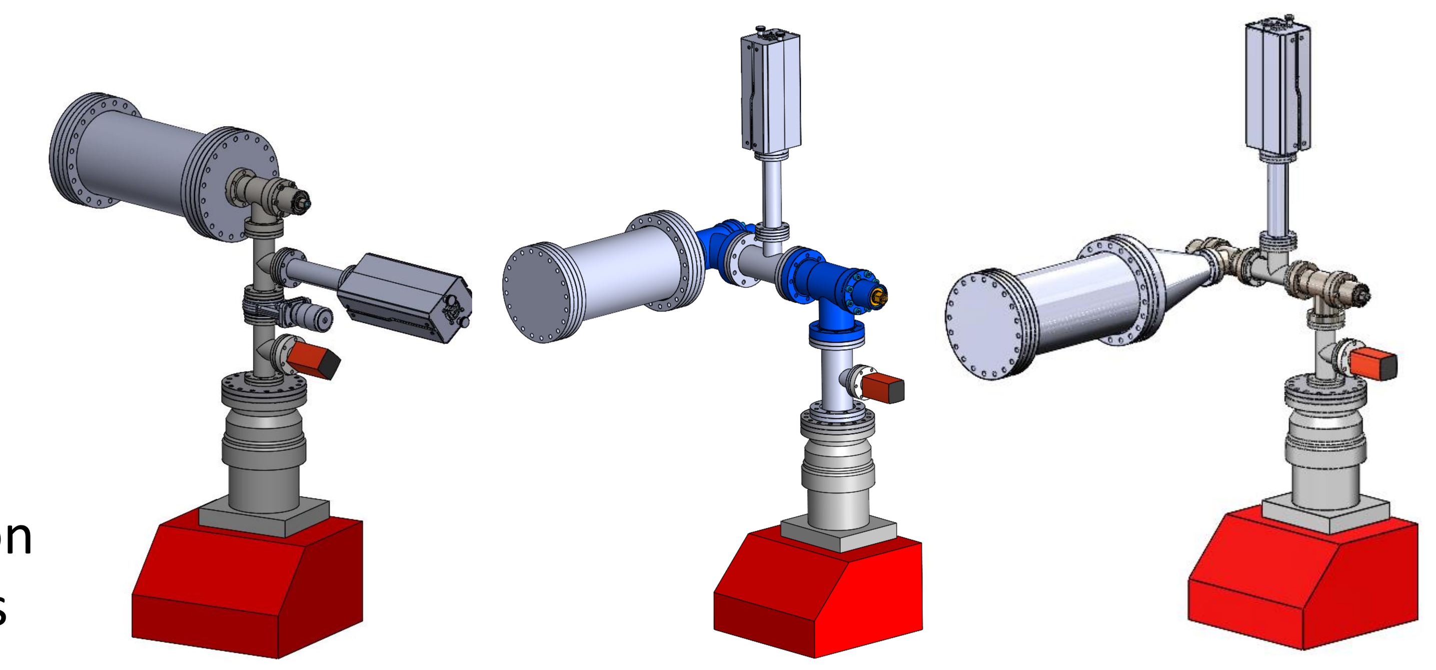
Effective Pumping Speed:

$$\frac{1}{S_{effective}} = \frac{1}{S_{max}} + \frac{1}{C_{tot}}$$

Vacuum Conductance:



A measure of how easily particles can flow through a system. At UHV this depends on system geometry. Our theories on how to maximize vacuum conductance are characterized by our three design options:



1. Minimize bends in piping geometry. *2. Increase diameter of piping.* *3. Minimize abrupt reductions in piping diameter.*

Design Determination: *Simulation*

Using a vacuum simulation software called *VacTran*, we simulated the pump-down times and conductances of each of our proposed systems. This required modeling the gas load of our system using experimental data for our materials:

Gas Load of the System: *Outgassing Flow Rate*

$$\dot{Q}(t) = \frac{q_n A}{t^{\alpha_n}}$$

Where:
q is the instantaneous outgas rate
α is the decay constant of the material
A is the surface area

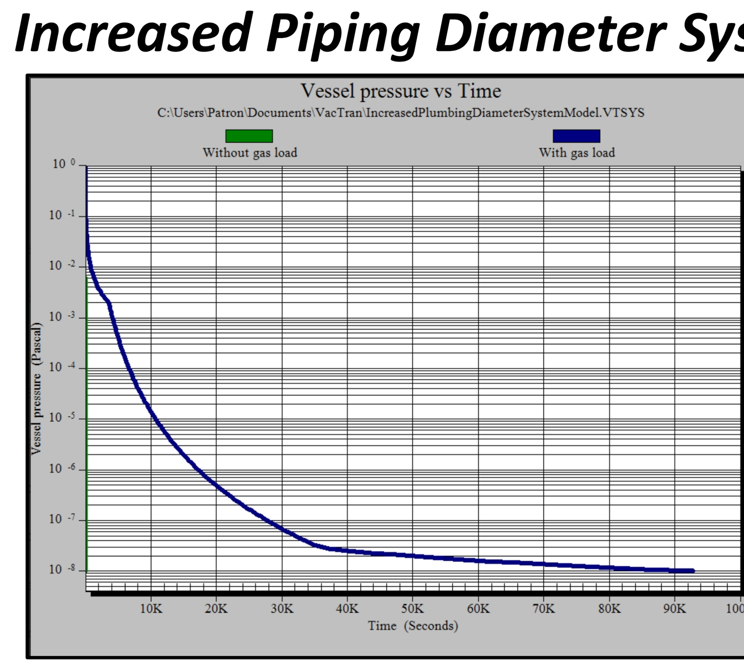
Experimental Values for 304L SS:

q_1 = 1.9E-5 Pa-L/s-cm² (unbaked 304L SS)	**q_2 = 2.7E-10 Pa-L/s-cm²** (304L SS baked 30 hours at 150°C)
α_1 = 1.1	**α_2 = 1.1**

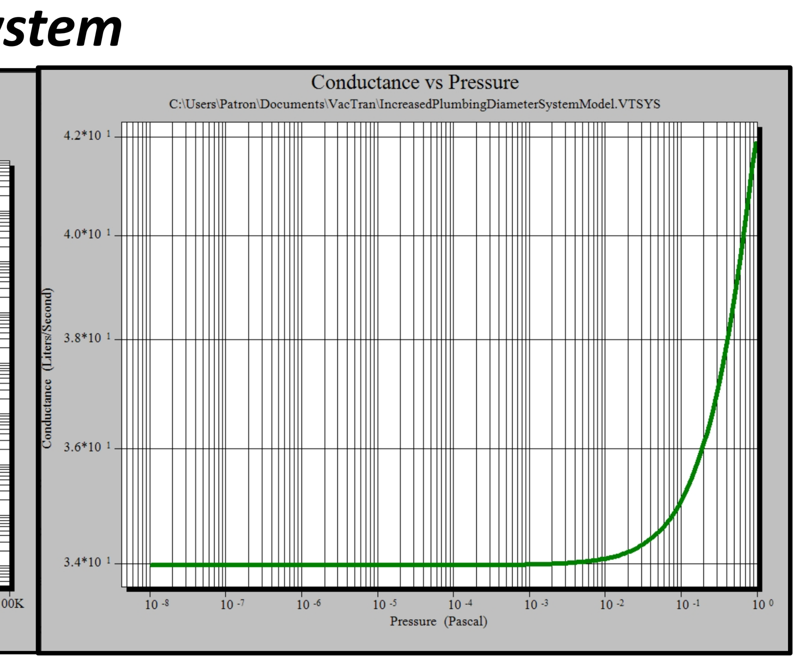
Summarized Numerical Simulation Results:

System Name	Conductance [L/s]	Pump Down Time [hr/in^3]
Current	9.99	0.163
Single Bend	11.58	0.114
Straight	12.90	0.120
Conical Reducer	9.54	0.138
Increased Diameter	33.97	0.0731

Sample Simulation Plot Results: ***Increased Piping Diameter System***



Vessel Pressure vs. Time

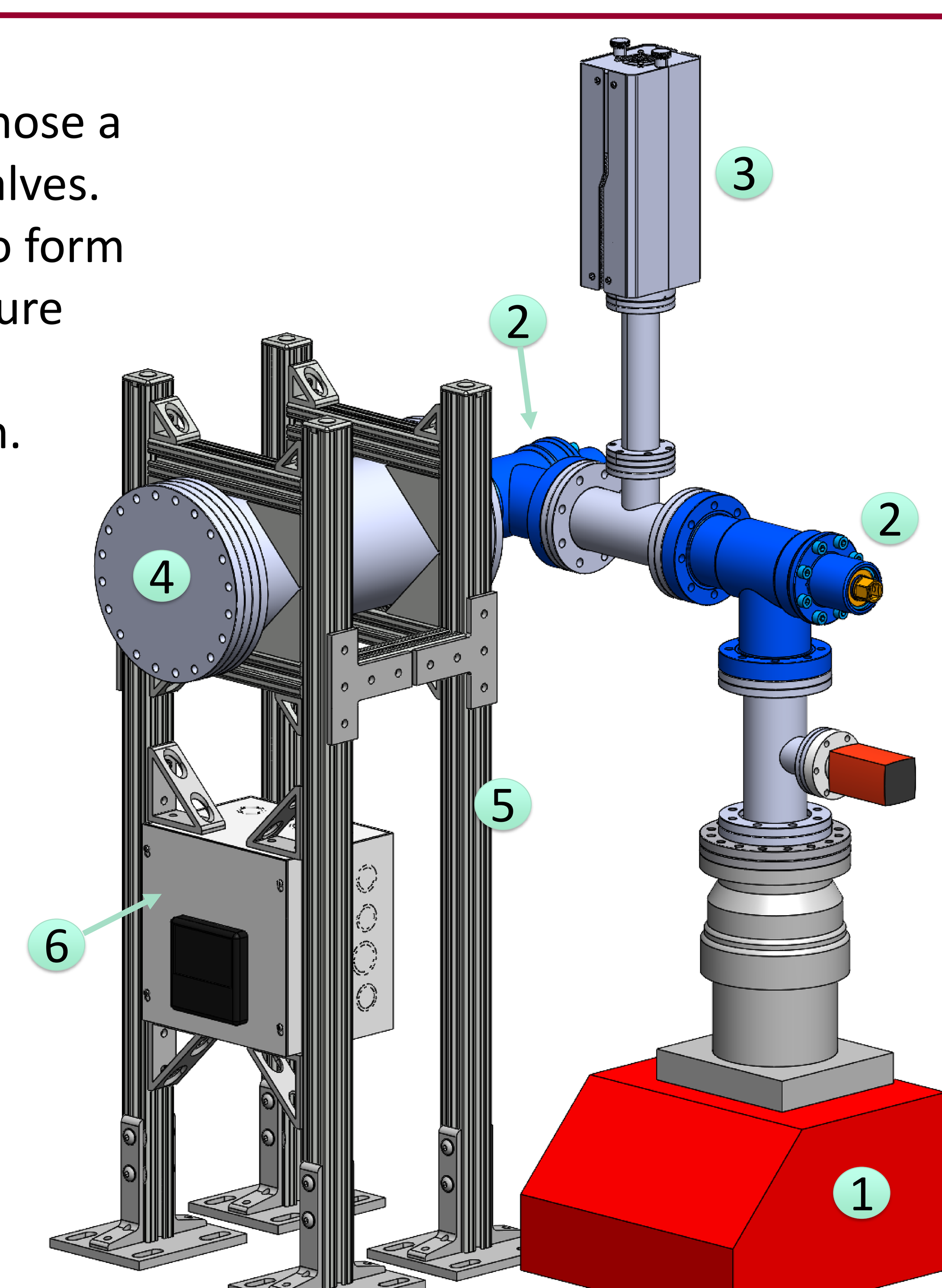


System Conductance vs. Pressure

Final Design:

Based on the results of our simulations, we chose a system of 4.5" CF piping, with 2 right-angle valves. Each flange connection has a copper gasket to form a seal. We designed a rigorous support structure for our cantilevered chamber with a nested controller box that houses our heating system.

1. *Pfieffer Hi Cube Eco 300* Vacuum Pump
2. *VAT* UHV/XHV All-Metal Angle Valve
3. Residual Gas Analyzer (On physical system replaced by a pressure gauge)
4. Sample Chamber
5. Support Structure
6. Control Panel/Housing for Heating System Components



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