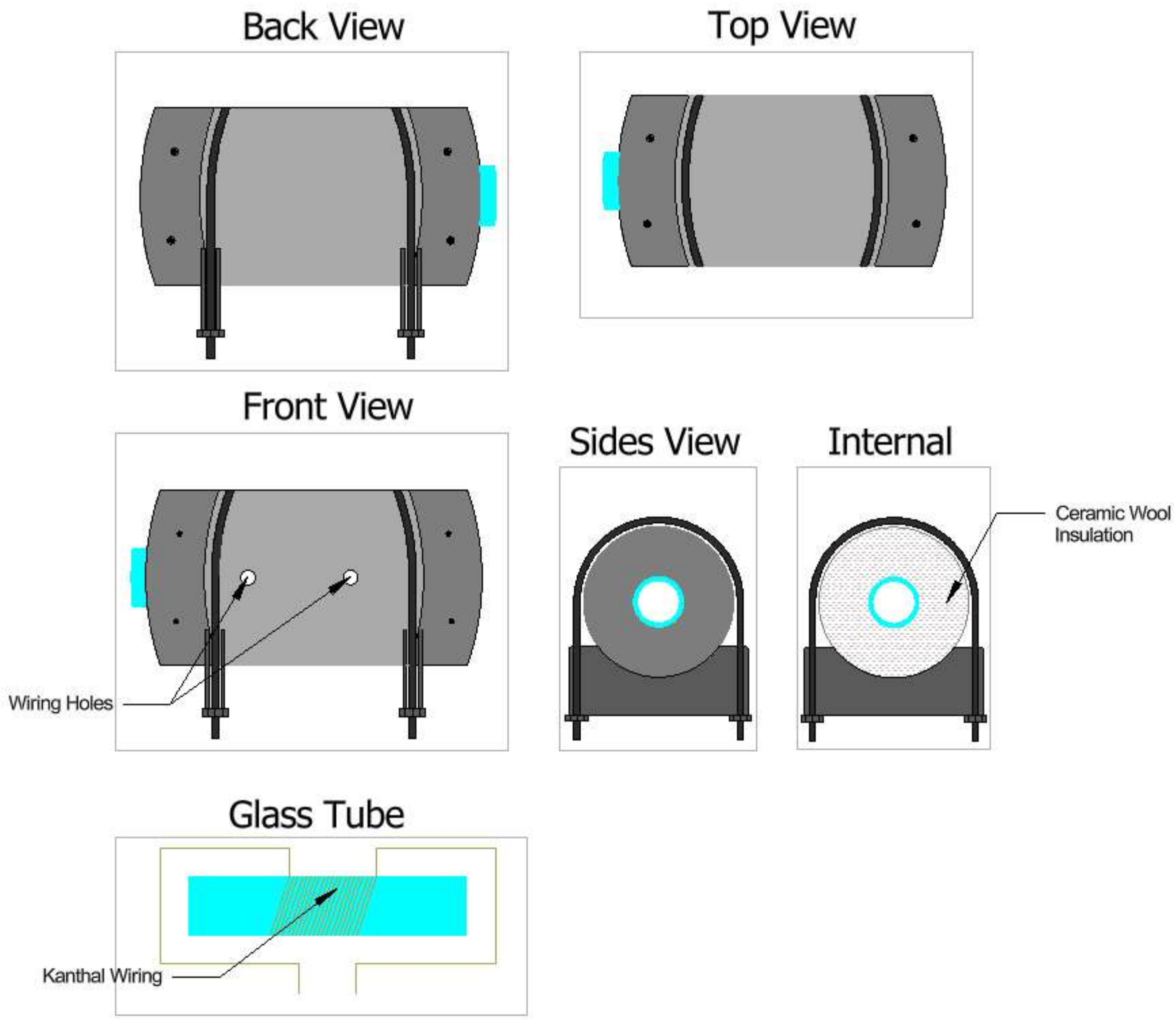
Tube Furnace

All articles in this section are written by Nathaniel Jordan

Tube furnaces are often used in the heat processing steps of refining silicon for use in microchips and transistors due to their ability to safely reach temperatures of over 1000 oC using less power than that of typical ovens. The tube shape of the furnace allows for the introduction of steam and other diffusing substances using the process of heating, allowing for rapid oxidation or diffusion of dopants onto polished silicon. However, efficient tube furnaces often come with four figure plus price tags attached, and are often lab grade machines to withstand the repeated subjection to high temperatures. Despite this, tube furnaces are not particularly complex in construction, if the user's goal is simply to use the machine to safely achieve the high temperatures needed to create semiconductors. Although a homemade furnace would likely not be up to standard with an industrial tube furnace, the absence of luxuries such as ease of diffusion, control system regulation of temperature, and minimizing external factors means that, in an educational environment, forging semiconductors can be simplified to a high school level of understanding. Additionally, there is more freedom in the process as a result, allowing for instructors to slow down or explain certain processes to a greater degree, and for hobbyists to have more control over certain aspects in the process.

Tube Furnace 6: Silver



1. Goals and operating parameters

The ideal goal for the Silver furnace would be to reach 1000 degrees C with around 500 Watts of power, and be able to maintain this temperature for long periods of time without failure. Additionally, this tube furnace should be able to utilize the PID controller successfully to maintain this temperature.

2. Major components

The tube of the furnace is a 2″ diameter quartz class tube with 5mm thickness, wrapped in about 3 layers of ceramic wool and held together with metal zip ties. Wrapped around the glass tube is 24g double twisted kanthal wiring, held in place with refractory cement. Surrounding this is a tube of sheet metal held by sheet metal screws and two metal end caps with holes cut through to allow access to the tube and for the wiring to stick out. A stand and handle made out of sewer pipe brackets is included in the design, and attached to the stand is a bracket with a plastic wiring box to act as a space to attach the PID controller, PID relay, and fuse reset. The kanthal wiring that extends beyond the tube is folded in half lengthwise (thickness of 4 24g kanthal wires) and covered in a ceramic weave tube for insulation. The wiring used for the PID and associated devices are recycled wires from an old chandelier, coated in a rubber insulation. Heat resistant tape is used to protect the wires in places where needed. A thermocouple is attached to the PID controller and inserted in the furnace. The furnace is wired to an extension cord and plugged into a programmable circuit breaker to protect the main power grid.

3. Materials

Sheet metal, kanthal wire, refractory cement, ceramic wool, quartz glass tube, nuts and bolts, sewer pipe brackets, ceramic weave wire insulation, motor control, thermocouple, heat resistant tape, voltmeter, programmable circuit breaker, handle, PID controller, PID relay, plastic circuit box, metal bracket, rivets, metal zip ties, fuse reset, metal end caps

Item	Specifications
Quartz Glass Tube	9.5″ long, 2″ diameter, 5 mm thickness
Sheet Metal	Folded into a tube of 8.5″ length and 5″ diameter
Kanthal Wire	24g, 20′+, wrapped into 20 loops around glass tube
Ceramic Wool	1″ thick, cut to wrap 3x around the glass tube
Thermocouple	6″ long, mount has less than 2″ diameter
Metal End Caps	5″ diameter to fit around sheet metal tube, with a 2″ circle cut in center to allow for access to glass tube
Sewer Pipe Brackets	Circle diameter of around 5″, adjusted using bolts to fit the furnace snugly

4. Construction

1. Coat mid section of glass tube in refractory cement, score lines to allow for shrinkage during curing, let cure for several hours

2. Measure kanthal wire using the desired number of loops around the tube, with some extra length, then double the total length. Fold in half and twist the entire wire tightly using a power drill and tension. Carefully wrap wire around the cemented area of the tube, holding firmly. Hold with rubber bands and cement on top, let cure.

3. Wrap tube with wire in 3 layers of ceramic wool. Bend the twisted kanthal wiring in half to increase resistance and extend to fit where the hole sites in the casing would be. Use ceramic weave insulation and heat resistance tape. to prevent contact between wiring and the casing.

4. Bend sheet metal into a tube and secure together with screws or rivets. Drill holes to allow for wiring to come through the casing. Drill 2″ holes through the end caps and secure to the tube furnace with sheet metal screws.

5. Screw on stand, add bracket with holes to the stand and screw the plastic circuit box to the bracket. Pull insulated kanthal wires into the box and wire PID controller, relay, fuse reset, and thermocouple.


SKUTT
FireBox


Programmable circuit breaker to protect the power grid and voltmeter for thermocouple readings


PID and Relay setup

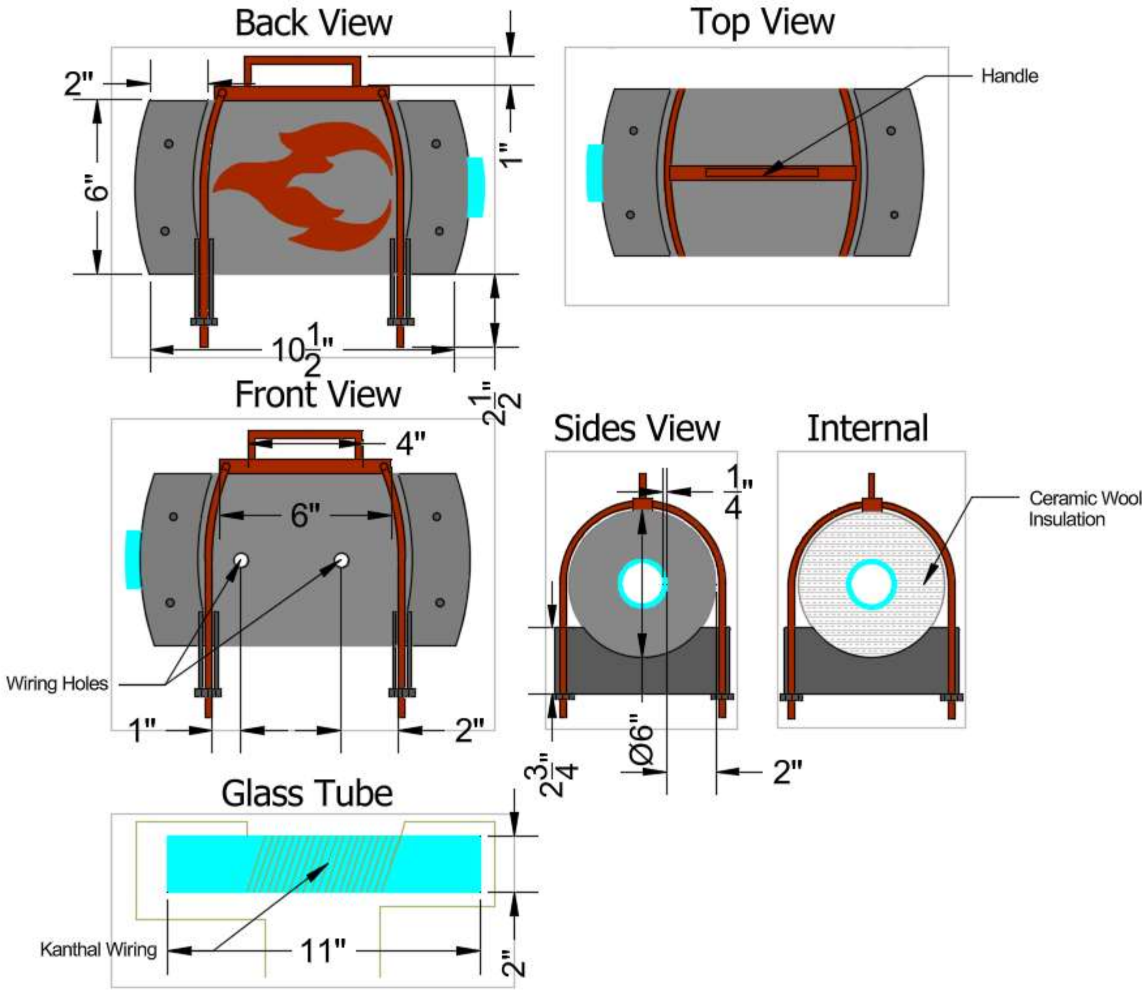
5. Testing and performance

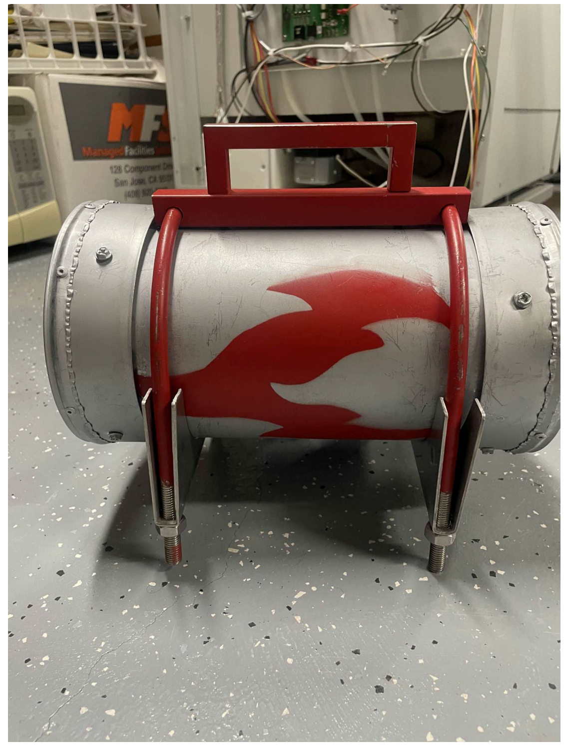
- Hit the energy and temperature requirements
- Still functional after may test runs
- Failings with the PID controller, requires the use of the motor control to control the current and prevent the furnace wires from overheating, additionally requires the use of a lightbulb to kickstart the motor control into drawing power and heating using the PID is inconsistent due to the jumps in current.
- Despite this, when the current is controlled with the motor control, the PID controller works effectively in maintaining a specific heat in the furnace

6. Things to improve on

- Need to figure out circuit configuration to power furnace without use of light bulb
- Need to figure out how to control current without motor control (for simplicity)
- Need to figure out insulation problem for wires to prevent them from becoming too hot

Tube Furnace 5: Flame





Programmable circuit breaker to protect the power grid and voltmeter for thermocouple readings

PID and Relay setup

1. Goals and operating parameters

The ideal goal for the Flame furnace would be to reach 1000 degrees C with around 500 Watts of power. Maintaining this temperature for long periods without oxidation of wiring is also important. Furthermore, this design needs to be durable and operational for multiple trials. An additional goal is to set this furnace up with a PID (Proportional Integral Derivative) controller to control the maximum heat of the furnace.

2. Major components

The tube of the furnace is a 2″ diameter quartz class tube with 5mm thickness, wrapped in about 3 layers of ceramic wool and held together with metal zip ties. Wrapped around the glass tube is 24g double twisted kanthal wiring, held in place with refractory cement. Surrounding this is a tube of sheet metal held by sheet metal screws and two metal end caps with holes cut through to allow access to the tube and for the wiring to stick out. A stand and handle made out of sewer pipe brackets is included in the design, and attached to the stand is a bracket with a plastic wiring box to act as a space to attach the PID controller, PID relay, and fuse reset. The kanthal wiring that extends beyond the tube is folded in half lengthwise (thickness of 4 24g kanthal wires) and covered in a ceramic weave tube for insulation. The wiring used for the PID and associated devices are recycled wires from an old chandelier, coated in a rubber insulation. Heat resistant tape is used to protect the wires in places where needed. A thermocouple is attached to the PID controller and inserted in the furnace. The furnace is wired to an extension cord and plugged into a programmable circuit breaker to protect the main power grid.

3. Materials

Sheet metal, kanthal wire, refractory cement, ceramic wool, quartz glass tube, nuts and bolts, sewer pipe brackets, ceramic weave wire insulation, motor control, thermocouple, heat resistant tape, voltmeter, programmable circuit breaker, handle, PID controller, PID relay, plastic circuit box, metal bracket, rivets, metal zip ties, fuse reset, metal end caps

Item	Specifications
Quartz Glass Tube	11.5″ long, 2″ diameter, 5 mm thickness
Sheet Metal	Folded into a tube of 10.5″ length and 6″ diameter
Kanthal Wire	24g, 20′+, wrapped into 20 loops around glass tube
Ceramic Wool	1″ thick, cut to wrap 3x around the glass tube
Thermocouple	6″ long, mount has less than 2″ diameter
Metal End Caps	6″ diameter to fit around sheet metal tube, with a 2″ circle cut in center to allow for access to glass tube
Sewer Pipe Brackets	Circle diameter of around 6″, adjusted using bolts to fit the furnace snugly

4. Construction

1. Coat mid section of glass tube in refractory cement, score lines to allow for shrinkage during curing, let cure for several hours

2. Measure kanthal wire using the desired number of loops around the tube, with some extra length, then double the total length. Fold in half and twist the entire wire tightly using a power drill and tension. Carefully wrap wire around the cemented area of the tube, holding firmly. Hold with rubber bands and cement on top, let cure.

3. Wrap tube with wire in 3 layers of ceramic wool. Bend the twisted kanthal wiring in half to increase resistance and extend to fit where the hole sites in the casing would be. Use ceramic weave insulation and heat resistance tape. to prevent contact between wiring and the casing.

4. Bend sheet metal into a tube and secure together with screws or rivets. Drill holes to allow for wiring to come through the casing. Drill 2″ holes through the end caps and secure to the tube furnace with sheet metal screws.

5. Screw on stand, add bracket with holes to the stand and screw the plastic circuit box to the bracket. Pull insulated kanthal wires into the box and wire PID controller, relay, fuse reset, and thermocouple.

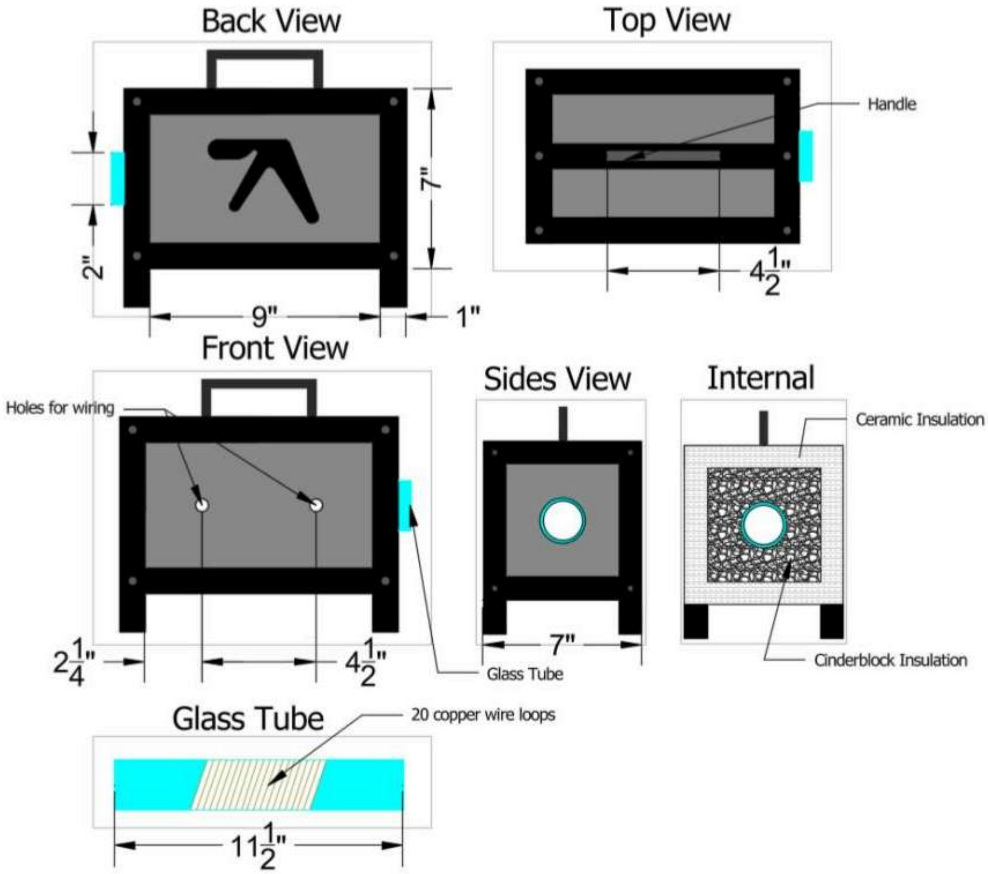
5. Testing and performance

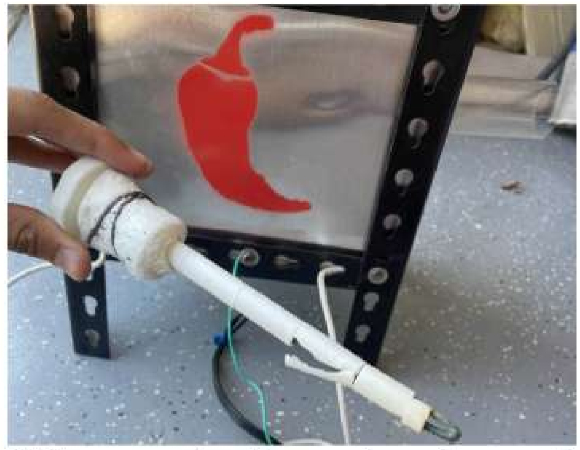
- Hit the energy and temperature requirements
- Still functional after may test runs
- Failings with the PID controller, requires the use of the motor control to control the current and prevent the furnace wires from overheating, additionally requires the use of a lightbulb to kickstart the motor control into drawing power and heating using the PID is inconsistent due to the jumps in current.

6. Things to improve on

- Need to figure out circuit configuration to power furnace without use of light bulb
- Need to figure out how to control current without motor control (for simplicity)
- Design can always be more energy efficient

Tube Furnace 4: Aphex





8” Thermocouple, with ceramic wool wrapped with copper wiring to hold firmly into tube

 Programmable circuit breaker to protect the power grid and voltmeter for thermocouple readings	 Motor controller for adjusting current

1. Goals and operating parameters

The minimum goal of the Tabasco iteration of the tube furnace was to reach 1000 degrees C with no more than 1000 Watts of power. The ideal goal for Aphex would be to reach this temperature with around 500 Watts of power. Maintaining this temperature for long periods of oxidation is also important.

2. Major components

The tube of the furnace is a 2 inch diameter quartz glass tube, with a center covered in refractory cement, and approximately 20 loops of double twisted 24g kanthal wire wrapped over the cement portion. This is wrapped in several layers of ceramic wool insulation, and then covered with sheet metal. The sheet metal is held together with shelf brackets and a handle. On the back of the tube is an attached thermocouple for temperature measurement. Other parts of the setup include a programmable circuit breaker to protect the local circuit from overloading, a motor control to control the voltage/current flowing into the furnace, and a voltmeter attached to the thermocouple for temperature readings.

3. Materials

Shelf brackets, sheet metal, kanthal wire, refractory cement, ceramic wool, quartz glass tube, nuts and bolts, refractory bricks, ceramic weave insulated copper wiring, motor control, thermocouple, ceramic beads, voltmeter, controlled power box, handle

Item	Specifications
Quartz Glass Tube	11.5″ long, 2″ diameter, 5 mm thickness
Sheet Metal	Folded into a 7″ x 7″ x 9″ box
Kanthal Wire	24g, 20′+, wrapped into 20 loops around glass tube
Ceramic Wool	1″ thick, cut to wrap once around the tube and to wrap around refractory bricks 5″ x 5″ x 1″ refractory bricks
Thermocouple	8″ long, mount has less than 2″ diameter
Refractory Bricks	5″ x 5″ x 1″ each, 2″ hole cut through middle for glass tube, approximately 8 used and held together by refractory cement
Cut Brackets	Approximately 5′8″ of bracketing used, each bracket side is 1″ wide with about 4 mm thickness, additional half bracket bar was cut to hold the handle going across

4. Construction

1. Coat mid section of glass tube in refractory cement, score lines to allow for shrinkage during curing, let cure for several hours

2. Measure kanthal wire using the desired number of loops around the tube, with some extra length, then double the total length. Fold in half and twist the entire wire tightly using a power drill and tension. Carefully wrap wire around the cemented area of the tube, holding firmly. Hold with rubber bands and cement on top, let cure.

3. Wrap tube with wire in ceramic wool. Extend kanthal wiring to fit where the hole sites in the casing would be. Use ceramic beads to prevent contact between wiring and the casing. Connect ceramic wiring to the extra kanthal wiring.

4. Bend sheet metal into a box, drill hole to fit tube through as it sticks through insulation. Place the tube through sheet metal box. Drill holes for wires, add more ceramic beads to prevent contact if necessary. Pull the wires through the holes and fit the tube with insulation through the case.

5. Bracket the edges of the box, leaving extra bracket to allow the furnace to stand up. Fix in thermocouple.

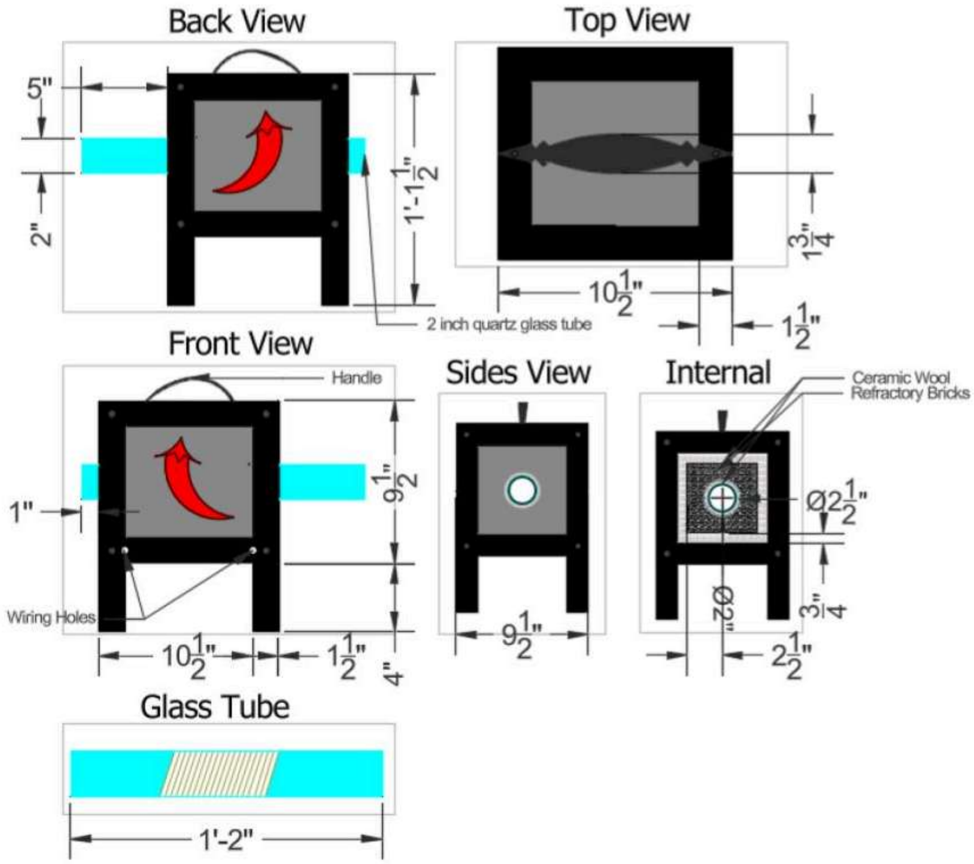
5. Testing and performance

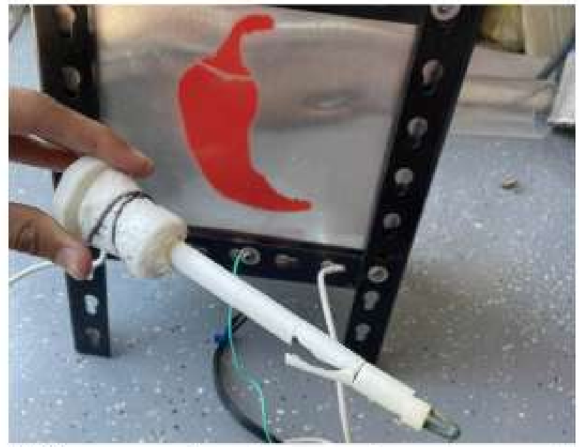
- Failed 2x due to oxidation of ceramic wires while heating, 2nd attempt lasted long enough for several hours of oxidation and 3rd attempt lasted for entire process
- Can maintain heat for long periods
- Despite this, doesn’t hit power goal of 500 W for 1000 degrees C (~ 1000W), although closer than then previous iteration
- Very light design compared to previous model

6. Things to improve on

- Can be more efficient in trapping heat and power usage
- Thermocouple could be mounted better
- Very hard to assemble bracketing
- Wires need to be positioned in such a way to prevent oxidation and loss of contact

Tube Furnace 3: Tabasco



	 8" Thermocouple, with ceramic wool wrapped with copper wiring to hold firmly into tube
	

 Programmable circuit breaker to protect the power grid and voltmeter for thermocouple readings	 Motor controller for adjusting current

1. Goals and operating parameters

The minimum goal to reach with the tabasco iteration of the tube furnace is to reach 1000C with no more than a calculated 1000 Watts of power. The ideal goal would be to reach this temperature with around 500 Watts of power. Maintaining this temperature for long periods of oxidation is also important.

2. Major components

The tube of the furnace is a 2 inch quartz glass tube, with a center covered in refractory cement, and approximately 20 loops of double twisted 24g kanthal wire wrapped over the cement portion. This is wrapped in several layers of ceramic wool insulation, and then covered with sheet metal. The sheet metal is held together with shelf brackets and a handle. On the back of the tube is an attached thermocouple for temperature measurement. Other parts of the setup include a programmable circuit breaker to protect the local circuit from overloading, a motor control to control the voltage/current flowing into the furnace, and a voltmeter attached to the thermocouple for temperature readings.

3. Materials

Shelf brackets, sheet metal, kanthal wire, refractory cement, ceramic wool, quartz glass tube, nuts and bolts, refractory bricks, ceramic weave insulated copper wiring, motor control, thermocouple, ceramic beads, voltmeter, controlled power box, handle

Item	Specifications
Quartz Glass Tube	14″ long, 2″ diameter, 2 mm thickness
Sheet Metal	Folded into a 9.5″ x 9.5″ x 10.5″ box
Kanthal Wire	24g, 20′+, wrapped into 20 loops around glass tube
Ceramic Wool	1″ thick, cut to wrap once around the tube and to wrap around refractory bricks 5″ x 5″ x 1″ refractory bricks
Thermocouple	8″ long, mount has less than 2″ diameter
Refractory Bricks	5″ x 5″ x 1″ each, 2″ hole cut through middle for glass tube, approximately 5 used and held together by refractory cement
Shelf Brackets	Approximately 8′ of bracketing used, each bracket side is 1.5″ wide with about 2 mm thickness

4. Construction

1. Coat outer mid section of glass tube in refractory cement, score lines to allow for shrinkage during curing, let cure for several hours

2. Measure kanthal wire using the desired number of loops around the tube, with some extra length, then double the total length. Fold in half and twist the entire wire tightly using a power drill and tension. Carefully wrap wire around the cemented area of the tube, holding firmly. Hold with rubber bands and cement on top, let cure.

3. Wrap tube with wire in ceramic wool. Connect ceramic wiring to the extra kanthal wiring.

4. Bend sheet metal into a box, drill hole to fit tube through as it sticks through insulation. Place the tube through sheet metal box. Drill holes for wires, use ceramic beads to prevent contact between wiring and the sheet metal box.

5. Bracket the edges of the box, leaving extra bracket to allow the furnace to stand up. Fix in thermocouple.

5. Testing and performance

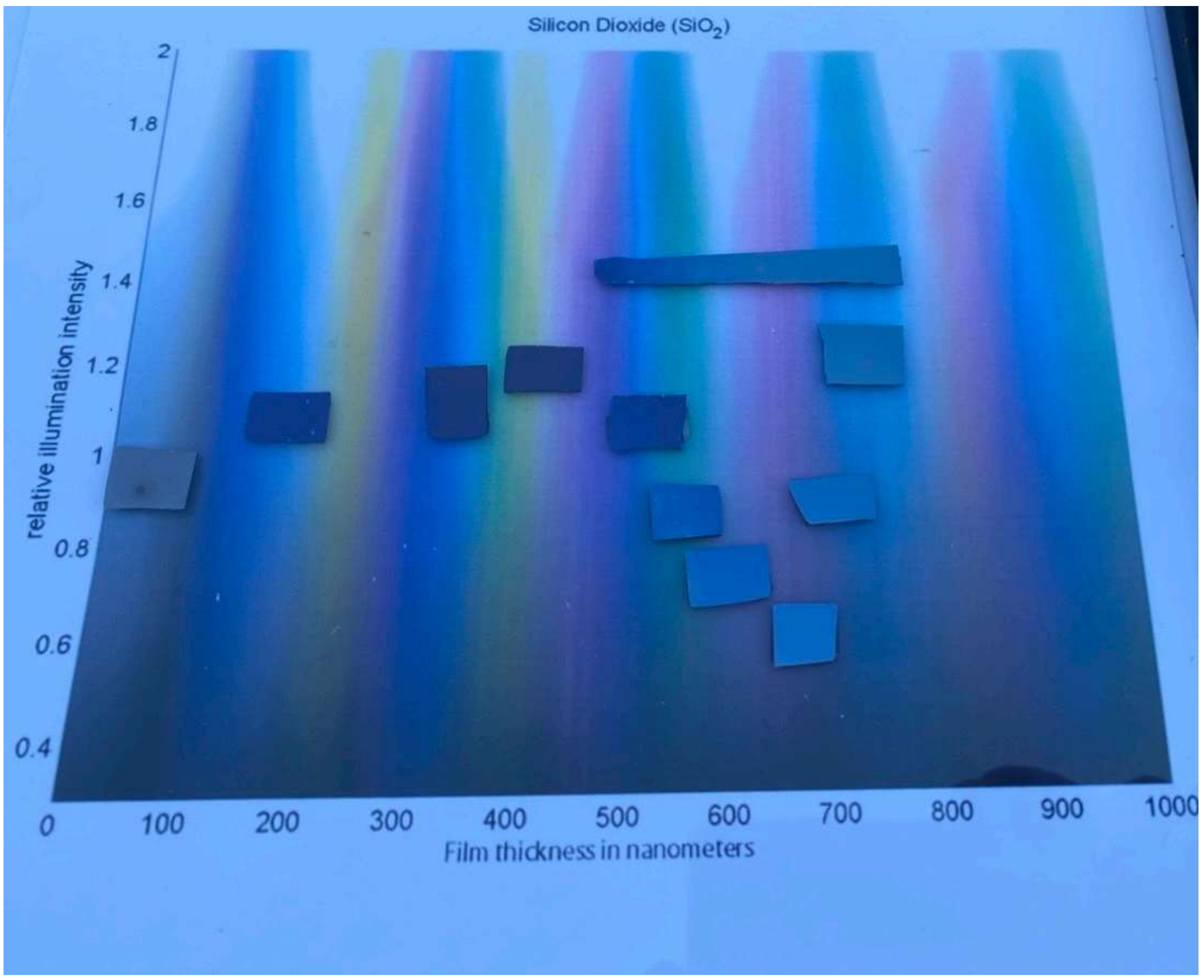
- Successful for oxidation purposes
- Can maintain heat for long periods
- Despite this, doesn't hit power goal of 500 W for 1000oC (~1400w)

6. Things to improve on

- Can be more efficient in trapping heat and power usage
- Heavy and bulky
- Thermocouple could be mounted better
- Glass used was too thin

Oxidation Chart & Results

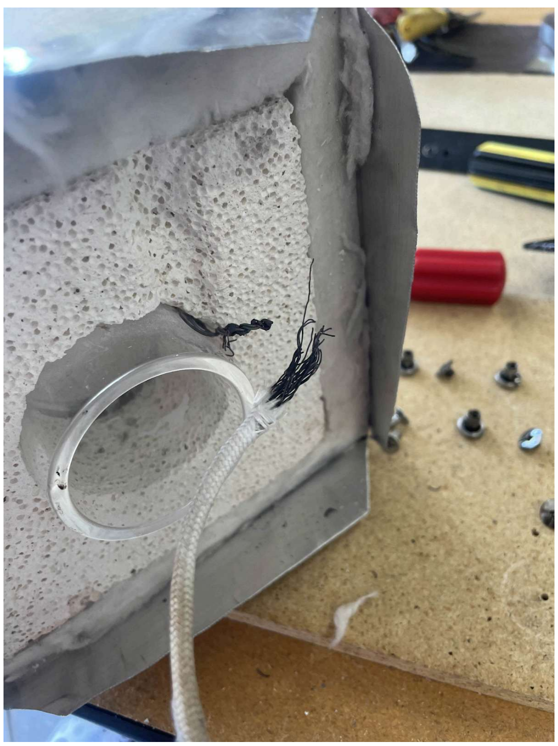
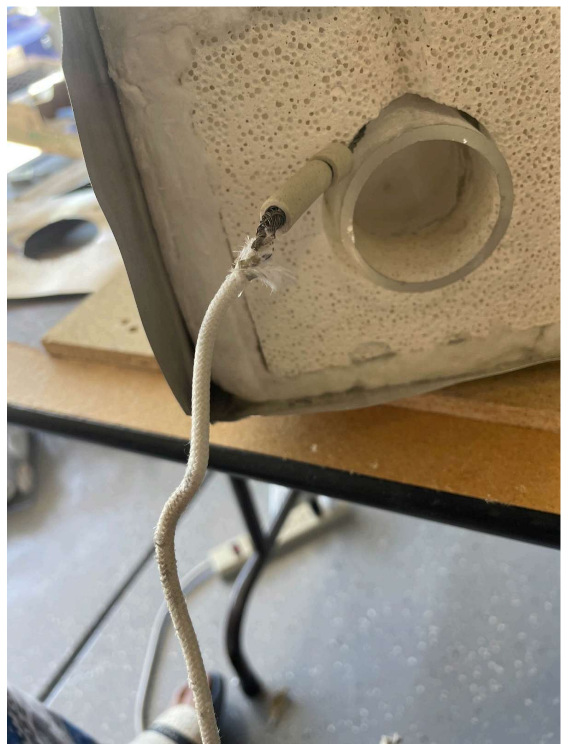
When introduced to steam inside the tube furnace, blank piece of silicon can be oxidized. The color of the oxidation varies on the time, heat, and amount of steam introduced, but the color tends to oscillate based on the thickness of oxidation. Below is a chart of samples comparing the thickness of oxidation to the wavelength of light the sample is observed under. The thickness increases with more time spent in the furnace. Samples were collected in one test run for consistency sake.



Malfunction Log

7/3 - Furnace 5 kanthal wire double twisted fried, had to reattached ceramic wire

7/14 - Furnace 5 ceramic wires fried, first attempt after previous repair, was running for 3+ hours

Thermocouple side	Entry Side
	

Furnace 6 ceramic wires fried, first attempt, ran for 20+ minutes

Thermocouple side	Entry Side
	

Ceramic coating on both furnaces was disintegrating where wires had contact

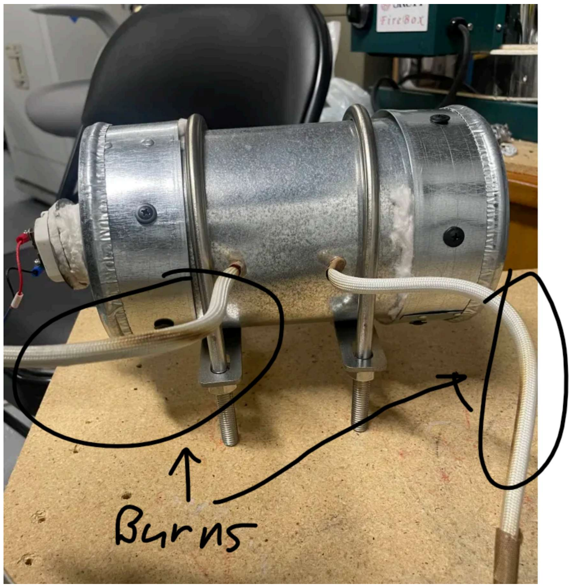
Ceramic beads seem a little burnt but otherwise intact, Furnace 5 and 6 each had one ceramic wire still in contact with kanthal, being held together with bead despite being fried → possible only the thermocouple wire side was completely fried through, however it's clear that both wires are under severe heat stress during operation

7/15 - Discovered kanthal wire coil on furnace 6 had been burned and rusted through

To combat this, next tube was made with as few kinks in wiring as possible, and the kanthal wire is used as the connector to the motor control as opposed to ceramic coated copper

8/25 - Since switching wiring to full kanthal and using one solid piece of wire, shorts have been discovered in the machines after repeated use. Found out the cause was due to the weave casing of wiring was being shredded through

9/8 - Incorporating the PID controller with a lack of motor control results in too much current being drawn and the kanthal wires becoming so hot they burn through the insulation weave



9/9 - Incorporated motor control into PID wiring to control current, but creates a problem where current is not being drawn unless an additional element, such as a lightbulb, is incorporated to trick the system into powering on