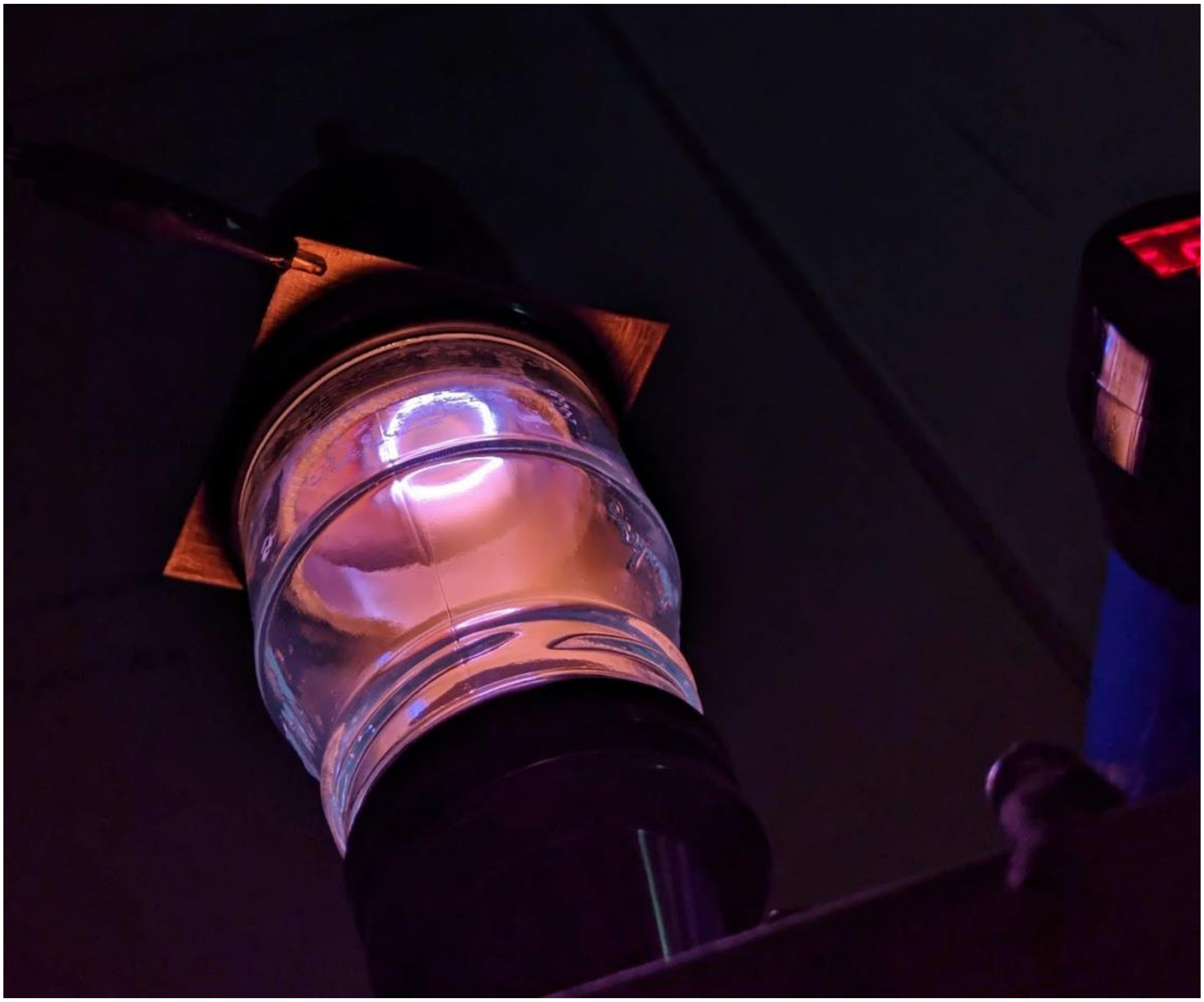
The LINDSEYLab Magnetron Sputterer

A Guide to Patience, Perseverance, and Plasma



Compiled and Composed by Peter Jacobson
Berry College 2020 Revised 2021

To all the Lab Champions

Table of Contents

“Holy crap. That looks like death. Y’all be careful”

-Dr. Zachary Lindsey

August 6, 2020

Introduction

A magnetron sputterer is a device used to coat targets in a thin layer of metal. It works by creating a vacuum, introducing argon, applying a voltage to spark a plasma, and knocking loose atoms from a sputtering target. These atoms are guided by a magnetic field to thinly coat a desired substrate. This is a deceptively simple function, but achieving the desired results is more complex.

That’s as much theoretical explanation as I’ll do for this manual. Far smarter and more educated people than me have explained magnetron sputtering, your time is better spent looking for their words rather than hearing them poorly repeated by me.

This manual is a guidebook for making a magnetron sputterer and using it. The design used here is mostly of LINDSEYLab’s own creation, though it is loosely based on a model constructed in part by Dr. Lindsey in his grad school days at UAB.

Making a magnetron sputterer and getting it to work is not easy. The “final” model we have is the result of much frustration and troubleshooting, and this sputterer is still undergoing revision.

There is a literal light at the end of the tunnel. When it’s all said and done, you can sputter, but more importantly, you get a front row seat to your very own aurora borealis.

Keep the fight, and happy sputtering!

Section I: How to Sputter

This is not intended as a build guide; all that information is in Section III. This chapter is intended as a manual, explaining the function and use of each segment of the system. The end of the section provides a walkthrough of every step of a deposition.

Segmented Breakdown

The following sections detail the use and details of each portion of the system. These portions should be used as a reference when more information is needed than the straight-forward directions in the deposition walkthrough.

Power Supply

The power supply of the system is undeniably the jankiest and most dangerous element. Because of that, it's important to understand how it works.

The first checkpoint between the wall and the power supply is a variable transformer. A switch allows power to be cut off completely from the power supply, and the top knob also is adjustable to output between 0 and 140 volts. For reference, 120 V is wall power; we typically get a spark of plasma between 40 and 60 volts and run the depositions at 70 volts.
We replaced our 10-amp fuse with a 20-amp fuse. Let the fact that we were blowing 10 amp fuses serve as a warning to handle things carefully.

The final stop before the contained power supply is the "operator presence control," typically called a dead man's switch by less formal crowds. The button must actively be held down for power to be transmitted. The hope is that if something goes wrong, the button will get released, cutting the power to the system.

The metal box holds all the high-power parts of the power supply. See figure 1 below for a circuit diagram.

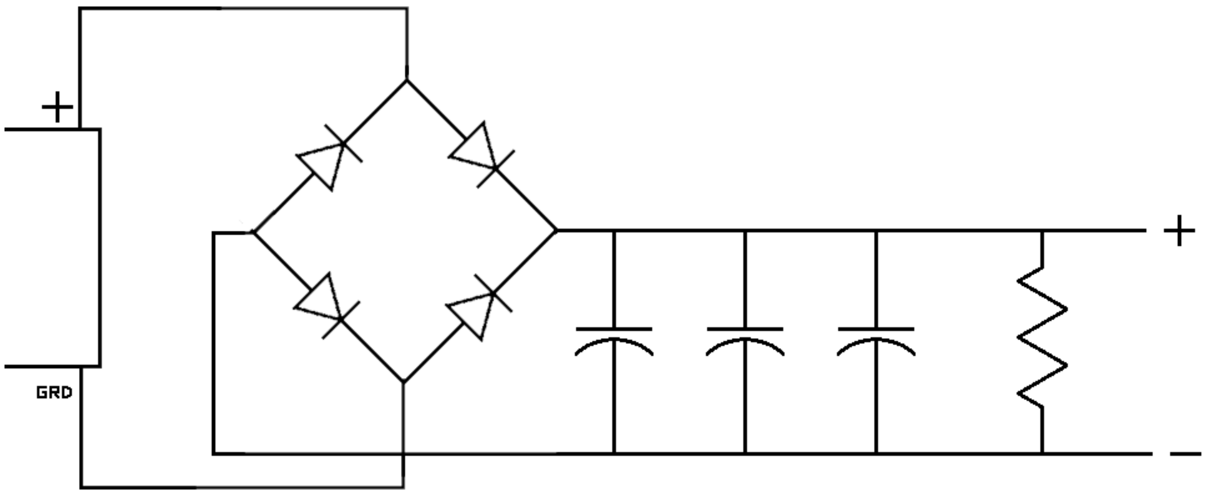


Figure 1: Circuit diagram for the full bridge rectifier. + is clipped to the flange while - is clipped to whatever is being sputtered.

Power enters the transformer, and the high voltage electricity is run through a full-bridge rectifier to convert our AC power to DC. The capacitors help achieve a smoother DC power transmission by flattening down the bumps, and the resistor is there to calm the circuit down some.

Two cables with alligator clips output from the box. The red is negative[1] and should be clipped onto the sputtering target, a copper or nickel plate in our case. The black clip is positive and should be clipped onto the flange.
It sounds silly, but make sure the clips are attached before applying power. Not doing so could burnout diodes at best and cause serious harm at worse.

After a deposition is run, discharge all capacitors. The ones in the power supply should be bridged with a pair of needle-nose pliers.
The power resistor will be extremely hot, so much so that you'll probably feel the heat radiating off from a foot away. Don't touch it until it's cooled.

[1] This is the opposite of convention. I misremembered while constructing the power supply.

Argon to the Chamber

There is a total of four knobs between the argon and the chamber. For all of them, counter-clockwise turns allow more gas through.

Knob number one is on top of the actual argon tank. This one opens very far I assume, but I've never turned it more than about ¼ turn and you shouldn't either. The sputterer needs such low amounts of argon to run that the minimum opening should more than suffice.
Important Note: make sure to close this after you're done. It isn't horribly expensive to get more argon, but you'll feel stupid.

Knob number two is on the regulator and one of the two main knobs you'll be working with. I start with this knob fully open and the argon tank closed to pump the whole system down to vacuum. Once that's done, I keep it barely cracked.

Knob number three is just after the regulator and before the hose. This stage was created in case we need even higher precision, but to be honest it's rarely used. We usually end up leaving this know fully open and forgetting it exists. You could skip this knob if you're constructing from scratch.

Knob number four is on the flowmeter; you and this knob will become the best of friends. As with number two, I start with this all the way open to pump everything down to vacuum, but once that's done this becomes the adjustment knob. With argon flow turned on, this is the knob to be turned to reach the desired pressure.

The system we used isn't the most precise, but it should be good enough to easily get within 5 mtorr of the desired pressure.
Do bear in mind that the pressure is unlikely to hold steady forever. Even once a pressure is "set" it will slowly drop as the pump keeps running and equilibrium is established.

After the deposition, <u>close the argon</u>. This is my second time mentioning this, but you will feel very silly if you lose the argon. Ask me how I know.

The Vacuum Chamber

There isn't anything that needs to be changed/maintained during a deposition related to the aluminum and stainless steel central sputtering area. This section is on the glass vacuum chamber and its surrounding parts.

The reducer on the top of the central area immediately terminates in a stub with two O-rings around it. The glass only forms a seal with the outer ring, but the inner ring is necessary to keep that outer ring in place. The glass should be able to sit on top and form a seal with no real issues.
We've also found that the glass can also sit on the O-ring connecting the reducer to the stub, eliminating the need for the stub.

Inside the glass is the table and its setup. These parts are detailed in section III; what matters here is the seating a glass slide and leveling the surface.
If a Dremel was used to carve a slot for a glass slide or otherwise, it should be simple to sit a slide into the lowered square and prevent it from sliding off. If no carving was done, center the slide and try to ensure that there are wide areas of contact between the glass and the epoxy. This will provide friction which should hopefully keep the slide in place.
The High-voltage feedthrough at the bottom is not wholly rigid, it can be bent slightly to get a more level top surface.

At the top of the glass is the trickiest seal to get: the glass to the flange. There are a few tricks which tend to help out:

- Remove the O-ring and ensure both it and the flange are dry. A wet ring has a greater chance of slipping down and breaking the seal.
- Use one hand to apply even pressure around the O-ring when the pump is turned on. This helps prevent one side from being sucked down.

It may take a few tries, but it gets easier once you get the hang of it.

The top flange is also tricky due to the thinness of the edge to be alligator clipped. When you clip the positive alligator clip onto the flange, give it some test pokes to make sure it's really on there. The last thing you want is a few hundred volts flailing around.

The O-ring between the sputtering target and flange should be a non-issue as it's two flat pieces being sealed. Make sure the ring is roughly centered, but it shouldn't require any more attention.

The magnets can be unceremoniously plopped on top of the sputtering target. I usually wait until the vacuum is formed to do this as the extra weight can make it trickier to align things to seal. Once seated, the central bar of the magnets can be adjusted to point it more centrally.

With our setup, the system sometimes wants to lean forwards or backwards. This can be fixed by placing a popsicle stick or some thin foam between the junctions and the struts of the stand.

The vacuum gauge should be plugged in before pumping. If it's reading roughly 760 torr at room pressure, you're fine. If it isn't, see the troubleshooting section.

After the deposition, there are some safety procedures. The gap between the flange and sputtering target should be bridged with a screwdriver to discharge any capacitance that may have been built up. Be careful with the sputtering target, it will get hot over the course of the deposition. I recommend grabbing it with pliers once vacuum is broken and letting it cool. It's also generally a good idea to set the glass chamber on a more sturdy, stable surface afterwards to prevent it from falling and breaking.

The Vacuum Pump

The vacuum pump is simple as far as operation is concerned. Before pumping down to vacuum, run the pump with the water ballast open (see Figure 3 for guidance) and disconnected from everything for 30 minutes or until the sides of the pump are warm. This allows the pump to get warmed up with light work instead of attempting to pump to vacuum from a cold start. Afterwards, turn the pump off and connect the bellows to complete the chamber.

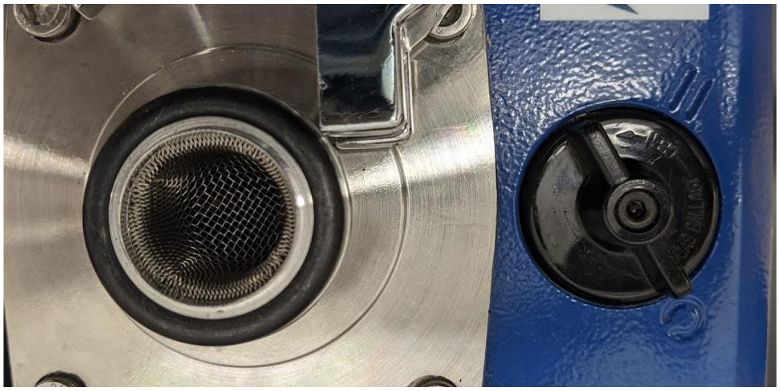


Figure 2: The knob on the right side is the "Water Ballast" control. The C symbol is the closed position and the || symbol is the open position. There is a stop between those two, I don't know what it does.

When the whole system is ready to be pumped down (see preparation of the chamber in the previous section), turn the pump on. When the pressure drops below 37.5 torr, close the water ballast. (This will happen almost immediately if you've got a good seal).
If a pressure isn't dropping and a seal isn't forming, turn off the pump, readjust the O-rings, and try it again.

Once the deposition is done, turn off the pump. The system is still at vacuum and will be at vacuum for quite some time. To speed up this process, disconnect the hose at the pump inlet. It shouldn't be too difficult to pry the bellows off at the pump inlet and restore the system to atmosphere.
Note: Keep an eye on the chamber when you return to atmosphere. I recommend removing the magnets beforehand as the high center of mass can cause tipping.

After you're done with every deposition for the day, put one of the included blank flanges over the inlet of the pump and run it with the water ballast open for 30 minutes to clear the pump of any debris and condensation.

Cleaning

Anything that is inside the chamber will be sputtered once the plasma and voltage hit. Because of this, it's important to have a clean chamber.

Recommended cleaning supplies are a brush or sponge, gloves, sandpaper, acetone, and some 10% nitric acid.

The glass jar can be cleaned easily with some nitric acid. Put some drops in the inside of the glass and use a gloved finger to wipe the interior of the glass. Do not sand the glass if it can be avoided, sanding will make it nearly impossible to see inside and possibly slice your hands up.

The O-ring between the flange and target can be cleaned like the glass, though it's trickier because the ring is a thinner target. It may also take more persuasive rubbing since the fluorocarbon has high adhesion to the materials.

The steel flange can be cleaned similarly to the glass, but the sputtered materials have more adhesion to the steel. Because of this, it may take more dutiful scrubbing and more drops of nitric acid.
You can sand the steel if you'd like, but I've never found a need to.

The O-ring around the steel flange can be cleaned, but it doesn't need to be an every-deposition sort of affair. Clean the same way as the larger O-ring.

The epoxy table is the lowest element that needs to be cleaned. Typically, a few drops of nitric acid and some rubbing with a gloved finger can get the material off. Sanding can be done if necessary, but epoxy is gummy when sanded and wearing it down chips away at the effectiveness of your slide holding.

The sputtering target is where the sandpaper really comes into play. To clean it, spray some acetone onto the deposition side and sand it down. The acetone aids in removing the sputtering stains while also helping get a nice, shiny surface to be sputtered next time.
If it's the final deposition of the day, I recommend holding off on cleaning the sputtering target until the day of the next deposition. Some materials, especially copper, will oxidize when left to themselves and require you to resand.

Deposition Walkthrough

This section will give some general guidelines as well as walk through an example deposition.

General Guidelines

The variable transformer will usually spark a plasma between 40 and 60 V, and 70 V is a good general value to sputter at. Going beyond that may yield better plumes, but also stress the limits of the electronics, particularly the diodes and 20-amp fuses.

Typically, the chamber should get down to between 10 and 20 mtorr before flowing in argon. Argon pressure can be played with to suit your needs, anywhere between 60 and 120 mtorr has garnered good results in our tests.

Time is the tricky variable because longer times correspond to more sputtering. The difficulty is that the system cannot withstand the heat of deposition for long. Things get dangerously hot (melting silicon and rubber) after about 2 minutes. We've found 1 minute is a good amount of time. If more is needed, it's recommended to do it in 1-minute blocks with allowance for the components to cool down.

Match your colors: Argon plasma is purple, nickel plasma is blue, and copper plasma is green.

If you decide to hook up and ammeter to read the current, you'll likely be within the 250-350 mA range.

Step-by-step Deposition Walkthrough

First, turn on the pump and open the water ballast. Let it run for 30 minutes or until the sides are warm.

While that's happening, plug in the vacuum gauge and see if it's reading roughly 760 torr. If it is, that's awesome. If it's not, see the troubleshooting section.
Also, look over the power supply to double-check everything is connected and nothing seems out of place.

Once the pump is warmed up, turn it off. Go ahead and clamp on the bellows, but don't start the pump just yet.
Slot the epoxy table into place and set your glass slide or whatever is being sputtered onto it. Place the glass jar over that, making sure the rim sits on the outer O-ring around the stub. Set the flange inside the upper opening of the jar and try to center it. Next, set the larger O-ring on top of the flange, and place your sputtering target down on top it. You should now have a sealed chamber.

Place your palm on top of the sputtering target and apply even downwards pressure to try to encourage a seal. While doing this, turn on the vacuum pump. Hopefully, a seal forms and the pressure begins dropping. If it doesn't, turn the pump off and try again. You may need to re-seat your glass slide. See the troubleshooting section if the problem persists.
If a seal does form, remove your hand and place the magnets on top. Adjust the center rod if it's off-kilter. Once the pressure is below 37.5 torr, close the water ballast (This should happen within a few seconds).

Ensuring that the argon is closed at the tank, open the knobs between that and the vacuum chamber all the way by turning them counter-clockwise.

Once the pressure gets reasonably low, say under 100 mtorr, briefly open and then close the argon tank to flush out the chamber. This helps lower the pressure and may need to be repeated.

While waiting for the pressure to drop, connect the alligator clips from the power supply onto the magnetron sputterer. The red, negative wire should be clipped onto the metal to be sputtered (Such as copper or nickel), and the black, positive wire should be clipped onto the steel flange.

Once the pressure has dropped low enough (roughly 15 mtorr), close the knobs between the argon and chamber almost all the way, leave them just barely open. You should notice the pressure drop a little bit as there's now less area to be cleared.

Open the argon tank the minimum amount possible to get gas flow. Adjust flow using the flowmeter knob to reach the desired argon pressure. Between 60 and 100 mtorr is a good pressure.

The next step is turning the electricity on. <u>CHECK THE FOLLOWING:</u>

+ Are the alligator clips attached to the flange and sputtering target?
+ Does everything appear correct in the power supply?
+ Is the general area cleared of any possible dangers?
+ Is the variable transformer turned off?
+ Is the variable transformer set to 0 V?

The answer to all those questions should be yes.

If you have a fan set up for the power supply, turn it on now.

After checking and fixing whatever needs fixing, plug the variable transformer into the wall (it's okay if it was plugged in before, leaving it unplugged is just an extra safety measure.

With your fingers and other body parts well away from the junction box, turn on the variable power supply. Use one hand to hold down the dead man's switch and use the other to slowly turn up the power on the variable transformer. You should expect plasma between 40 and 70 V.

Once plasma has formed, continue increasing power until you reach 70 V. That's a good value to sputter.

Let the deposition run for between 30 seconds and 2 minutes. When the allotted time has passed, slowly turn down the variable transformer to 0 V, then release the dead man's switch and turn off the variable transformer.

Immediately discharge any capacitance in the system by first bridging the flange to the sputtering target with a screwdriver. Open the junction box and bridge the microwave capacitors with a pair of needle-nose pliers.

Remove the magnets from the vacuum chamber. Careful! The sputtering target will be hot, do not touch.

Turn off the vacuum pump and close the argon flow at the tank. Unclamp the bellows from the pump inlet and lightly pry them off the pump to restore the chamber to atmosphere.

Remove the sputtering target from the top of the jar with pilers and set it somewhere it won't be accidentally brushed. Take off the jar, and you should have easy access to whatever was being sputtered.

Congratulations! You have just used a magnetron sputterer. Celebrate briefly, and then begin to clean parts as described previously.

Section II: Troubleshooting

Vacuum Issues

The cornerstone of the entire system is th vacuum within the sputtering chamber. If you can't get a vacuum, you can't sputter. There are two different sorts of vacuum errors: The vacuum won't form at all, and the vacuum won't get low enough for sputtering purposes. The vacuum not forming at all is typically an easy fix with an obvious culprit, but the vacuum not getting low can be more difficult to pin down.

Vacuum not Forming

If a vacuum isn't forming, the likely culprit is a leak. These kinds of leaks are usually obvious, marked by a hissing of air. Nonetheless, here's some of the most common places for a leak to be, and ways to fix it.

Check the top and bottom of the glass jar. The O-ring should form a seal with the glass. The top of the jar especially can be tricky to get aligned and may take multiple tries. If the top O-ring is slipping down, remove the O-ring and ensure both it and the flange are dry. A wet ring has a greater chance of slipping down and breaking the seal.

Make sure the bellows are clamped to the pump and not just sitting on the inlet.

Sometimes the knob on the flowmeter can get attached to the nut sealing the flowmeter. This means that when you're opening the flowmeter to argon flow, you're also opening the system to atmosphere. To fix this, tighten the knob all the way and really crank it down at the end. This seats the nut into its spot on the flowmeter and should break it from the knob. If that doesn't work, loosen the knob, and use a crescent wrench to tighten the nut down while leaving the knob out. Don't tighten it much further than finger tight, the last thing you want is to break your flowmeter.

The Oil Mist Eliminator attaches to the outlet of the pump, not the inlet. This sounds silly, but this mistake prevented us from achieving vacuum for two days.

Not Pulling a Vacuum

Sometimes the vacuum forming but not getting low is the result of a smaller leak. These can be harder to find and are more annoying in general.

If you think there's a leak somewhere, put some soapy water on the area. If it bubbles, it means there's a leak. If you don't even know where to begin, try these areas:

A leak may form in one of the threaded connections between hoses and parts of the regulator system. To prevent these, wrap the threads with Teflon tape before screwing them in to better seal the connection. There are many guides to applying Teflon tape online, but as a rule, you want to wrap the tape opposite to the direction you would screw it in. This prevents the tape from bunching up on itself as you tighten.

Check the jar for any thin cracks. These may form if you bump the glass, breaking the vacuum but not outright shattering the jar. If this happens, you'll need a new jar. You may be able to fix the crack, but it's just a better practice to start again.

There may not be a leak at all, sometimes the system is fickle. Turning everything off and setting things up a second time can often improve the results even though it seems like nothing has changed. When the system is running, flushing the system with some argon can also lower the pressure after it resets.

Another possibility is that the pump is struggling. Make sure there's nothing blocking the inlet to the pump. Also check the oil levels and quality with the gauge at the front. It should reach the top marking on the window and should be a mostly clear liquid. If it isn't you may need to top up or change the oil. The pump uses Kurt J. Lesker Premium Semi-Synthetic Vacuum Oil (KJLSS19).

Vacuum Gauge Issues

For reasons unbeknownst to me, the vacuum gauge sometimes reads a different atmospheric pressure after a deposition. Sometimes this is a simple fix, sometimes it's slightly more convoluted.

Improper Reading

If the vacuum gauge is reading the incorrect pressure at atmosphere (it should be roughly 760 mtorr), there's a simple button combination to reset.

With the gauge exposed to atmosphere, press the switch on the side in and hold for 3 seconds. This will cause the screen to read 100 torr. Press the button 3 times to reach the display reading 760 torr. Pressing the button in and holding for 3 seconds on this screen will cause the gauge to read its current pressure as 760 torr (Note: Adjusting the 760 value will allow you to change what the gauge considers atmospheric pressure. For example, you may want a lower pressure if you're in the Rocky Mountains). Sometimes the reading won't switch to 760 torr even with this procedure. If that happens, see the next section.

If it Won't Reset

If the pressure won't reset, there's a few things to try. First, try holding the switch in the upwards position for 3 seconds. The screen will read "dEF" before resetting the gauge to factory settings.

If that doesn't work, try pumping the system down to vacuum with the gauge turned on, then bringing it back up to atmosphere. Doing this seems to "shock" the gauge into normalcy. I don't know why it works, but it does.

If none of that works, investigate the gauge. The inlet may be blocked by something, or it may be contaminated.

If nothing works, contact Kurt J. Lesker, you've reached a problem above my paygrade.

Power Supply Issues

The power supply is the area you hope to be issue-free because problems with it can be dangerous. Know where your nearest fire extinguisher is. You hopefully won't need it, but it sure would suck if you did and didn't have it.

Sparking

If the power supply is sparking, it probably means there's metal touching or almost touching that shouldn't be. After making sure everything is off and discharged, carefully go over the whole circuit and see if there's anything that should be better insulated or moved away from other things.

Also make sure you aren't giving any parts shortcuts you don't want them to take. We had an issue where the diodes were bridging between themselves before they actually touched.

Smoking/Burning/Melting

Things in the power supply get hot, especially the power resistor. Some of the consequences of this are unavoidable, some can be tamed a little, bit. If you can, don't rest the resistor directly on the wood. Set it on a silicon gasket or heatsink from an old computer to give the heat somewhere to go that isn't flammable. Using fans in the power supply to bring in cold air and blow out hot air may also assist in cooling the system.

The resistor will get hot, and it will smell like burning rubber. Don't run depositions for much longer than 90 seconds to avoid lasting damage.

Not Working

If the power supply has never worked, reference the circuit diagram and check to make sure your system matches up. Also check every connection to make sure there's no breaks or holes in the circuit.

If the power supply worked at one point and doesn't anymore, the most likely culprit is that something burnt out. Check the fuse in the variable transformer as well as the fuse from the microwave transformer to see if they've been burnt out.

The next likeliest culprit is the diodes. These can be checked by applying a known voltage across them and measuring the voltage difference when the diode is flipped.

If neither one of those was the issue, scan through the whole circuit and see if anything is awry. Some wire or clip may need replacing.

If that doesn't solve the problem, sleep on it, come back, and see if you find the problem the next day or have a midnight epiphany. The solution may be a series of trial and error.

Sputtering Issues

If you've got a vacuum, got a low pressure, have a working power supply, but are still unsatisfied because you're not getting a plasma to spark or not getting high quality depositions, check here.

No Plasma

If there's no plasma, check for the following:

+ Ensure the alligator clips are connected to the vacuum chamber, negative on top, positive on the flange.
+ Make sure you're using a high enough argon pressure, try sparking at around 100 mtorr of argon and going from there.
+ Make sure everything in the power supply is connected properly and that the variable transformer is turned on with the dead man's switch depressed.
+ Make sure you're applying enough power to the system. Try turning up the variable transformer, it may be that your transformer is lower voltage than ours and that you need to run depositions at 90 or 100 V.

If none of that works, sleep on it, come back, and see if you find the problem the next day or have a midnight epiphany. The solution may be a series of trial and error.

Poor Quality Deposition

Getting a high-quality deposition can be one of the most frustrating parts of the process. There was roughly three months between our first plasma and our first high quality deposition. Admittedly there was a lot of prototyping stops not included in this manual, but my point is that this area is where you really need to keep the fight and persevere.

When the plasma sparks, check if the colors are right. A pure argon plasma is purple, nickel is purple, and copper is green. Google should be useful enough to tell you what color to expect for other materials. If you aren't getting the right colors, you might not have enough argon or voltage to be breaking the material's atoms free.

Here's some general tips to improve the quality of your deposition:

- Make sure you're pumping to a low enough pressure in the chamber. Any oxygen in the chamber will oxidize the deposition, this can be especially frustrating with materials like copper.
    - To that end, check for leaks. If there's atmosphere flowing into your chamber, the oxygen in the air will screw up your samples.
- Make sure your sputtering target is clean. If there's gunk on the material, you will sputter gunk. If you only want to sputter pure copper, make sure the target is only pure copper.
    - Really make sure everything is clean. Anything that's in the chamber has a chance of being sputtered. If you don't want it being sputtered, don't have it in the chamber.
- Make sure the magnets are working for you, not against you. The plume should have a beam shape in the middle based off your core. Point that beam at the epoxy table, that's the thickest deposition.
    - Play around with the magnets and the core of the stack. Maybe more or less magnets will help, maybe removing the core will help.

Beyond that, play around with it. You know your system best, and you're the most qualified to be fiddling with it to see what helps.

Phone a Friend

If something is going wrong and you just can't figure out how to fix it, feel free to contact me, and I'll try to help as best as I can.

Email: fidelesdei@live.com

Phone #: 770-508-7661

If I can't be reached, contact Dr. Zachary Lindsey at Berry College

Email: zlindsey@berry.edu

Section III: Parts and Construction

Part Sourcing and General Tips

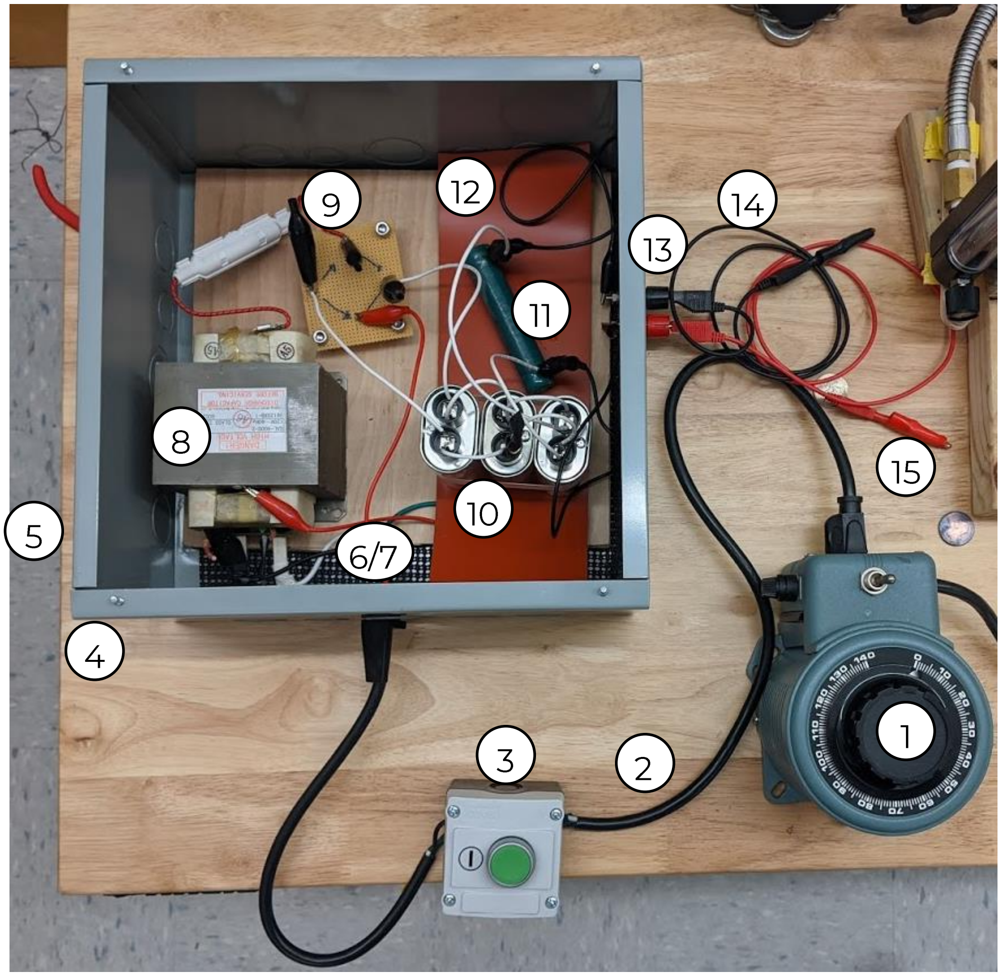
Even if you know what you're looking for, sometimes finding a place to get it is the hardest part. Though there are links with the parts list, I wanted to include a brief section on some general part sourcing and construction tips.

- Microwaves are gold mines. If you find one for cheap or free, grab it. They provide magnets, capacitors, transformers, and an assortment of random junk that may be useful. At $10-$20, they're one of the highest value items you can get, and they don't need to work to be useful
  - Places to look: Goodwill, thrift stores, dorm room common areas (especially at the beginning or end of the year, people give this stuff away), we found one sitting by a dumpster.
- McMaster-Carr is your best bet for specific parts. Their prices are typically fair and their items are high quality. They're usually a good first stop when you're trying to find something.
- For vacuum parts, Kurt J. Lesker is a good place to look, but look elsewhere too. Lesker will almost always have what you want, but they probably aren't the cheapest if other stores are carrying it.
- If you need something soon and quality isn't the number one concern, Amazon is a good bet. It's often the cheapest if you have prime since you don't need to pay for shipping.
- The typical engineer's toolkit is duct tape and WD40. What I would recommend adding to your fanny-pack is the following to truly be ready for anything:
  - A Dremel with cutting and sanding bits
  - Sandpaper
  - Electrical Tape
  - Needle-nose pliers
  - Flathead Screwdriver
- Lastly, jankiness is a tool to be embraced, not something to be feared. Always see if there's a simpler way to do something, and if it can be done with what you already have. Most things don't need CNC-ed parts with high tolerances. Be safe, but don't be a perfectionist.

Parts

My hope is that this portion of the manual contains all the information needed to construct a magnetron sputterer like ours from scratch, or, at the very least, replace parts as needed. If any links are defunct or down, the information about the part is hopefully enough to source out another replacement

Power Supply



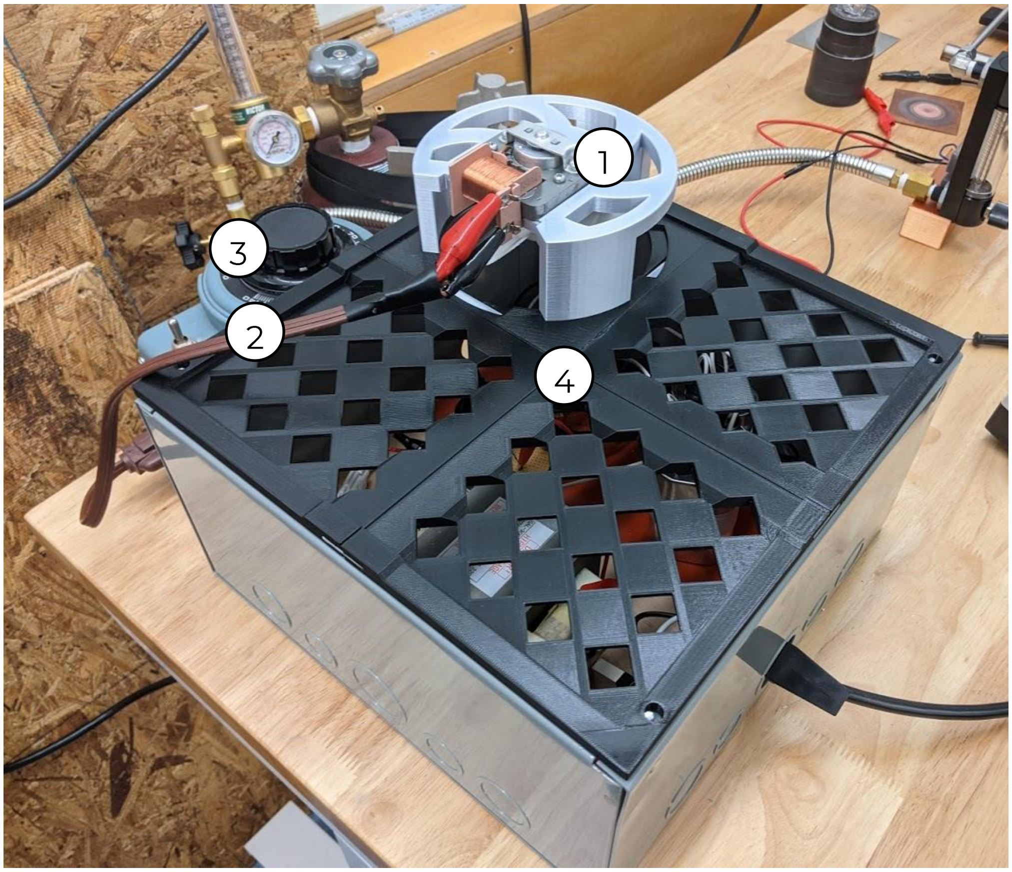
Setup Compressed for Picture

1- Variable Transformer
   i- This is what we had in the lab, there's nothing special about it
   ii- Get a fused transformer, we burnt out the 10A fuse and ended up switching to a 20A

2- Microwave Power Cord
    i- This was looted from one of the many microwaves we took apart for magnets
    ii- The middle was cut to insert our dead man's switch
3- Dead Man's Switch
    i- You want a momentary, normally off switch
    ii- Holes were drilled in the side for wire passthrough
    iii- https://www.mcmaster.com/7546K21/
4- Junction Box with Lift-off cover and Knockouts
    i- 12"x12"x6"
    ii- Keeps our system isolated from the outside world and wandering hands
    iii- Knockouts were used to route microwave cable in and power out
    iv- https://www.mcmaster.com/75065K39/
5- Acrylic Cover (Not pictured)
    i- 12" x 12" x 1/8"
    ii- Keeps the top closed but lets us see what's going on
    iii- https://www.mcmaster.com/8560K239/
6- Piece of plywood
    i- Roughly 10"x10"
    ii- Keeps the electronics off the box
7- Shelf Liner
    i- Prevents the board from sliding around any
8- Microwave transformer
    i- If you use the power cord from a microwave you should be able to connect from your dead man's switch without any soldering
9- 4-diode Full Bridge Rectifier
    i- These are mounted into a scrap piece of breadboard and held in place/connected with alligator clips
    ii- We used screws to keep the diodes and breadboard free-floating
    iii- Diodes can be found for cheap on amazon or other online dealers
10- Capacitors
    i- Like the power cord and transformer, these were taken directly from scrapped microwaves
    ii- We used three, the more you have the smoother your DC power output

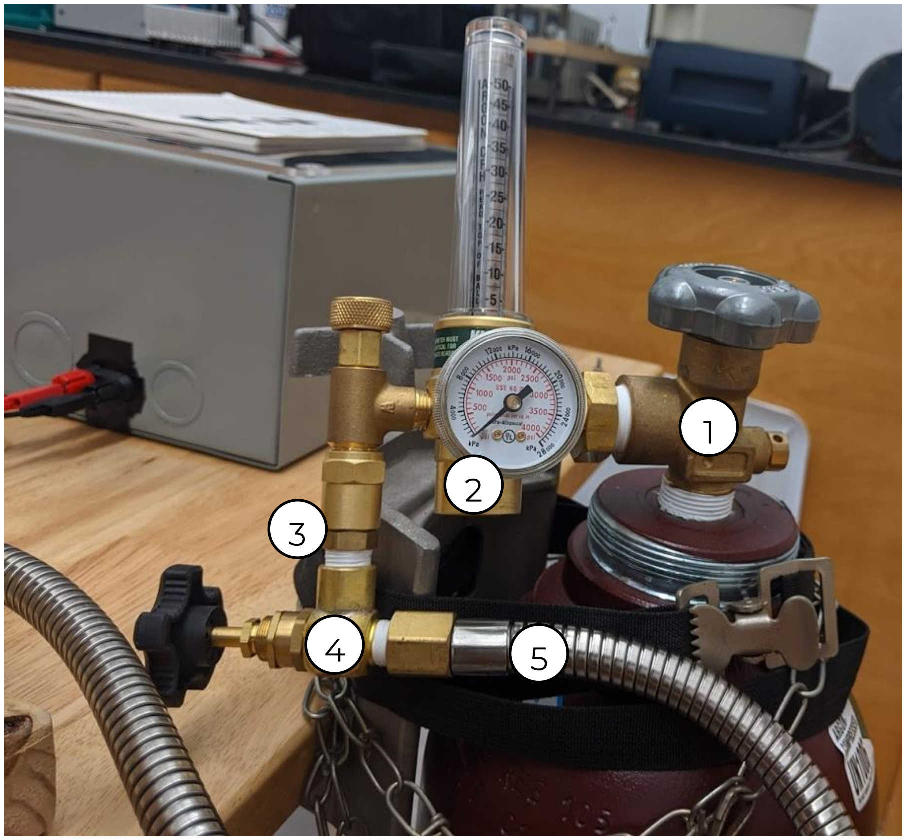
11- Power Resistor
    i- This dispels some of the energy as heat
    ii- Size and shape don't matter, bigger would probably distribute the heat better but is more unwieldy
12- Silicon Gasket
    i- This is just a thick piece of silicon to keep the resistor from burning up the wood base
    ii- Any of these should do: https://www.mcmaster.com/silicone-gaskets/high-temperature-silicone-rubber-sheets-bars-and-strips-6/
13- Panel-Mount Double Banana Jack
    i- These help get our output into more easily and safely managed alligator clips
    ii- https://www.mcmaster.com/7124K42-7124K422/
14- Banana Cables
    i- Standard banana cables
    ii- Ours are 2 or 3 feet long, that's a good length
    iii- You can find these almost anywhere or loot them from a physics classroom if all else fails
15- Banana Jack Alligator Clips
    i- These clips switch from the banana jacks to the alligator clips
    ii- https://www.mcmaster.com/7236K98/

Optional Upgrade: Fan Cover



1- Microwave Fan
    i- This was taken out of a microwave, there's nothing special.
    ii- The 3D printed fan holder was designed specifically for this fan.
2- Power Cord
    i- This was hacked together from an ordinary power cord.
    ii- We found it in a drawer.
3- Variable Transformer
    i- Same model as before, we typically run the fan at 90 V.
    ii- No 20A fuse necessary for this transformer.
4- 3D Printed Cover and Fan Holder
    i- Designed to cover the power supply and allow for a mounted fan.
    ii- Parts were printed in PLA and hot-glued together
    iii- https://sites.berry.edu/lindseylab/research-projects/magnetron-sputtering/resources/

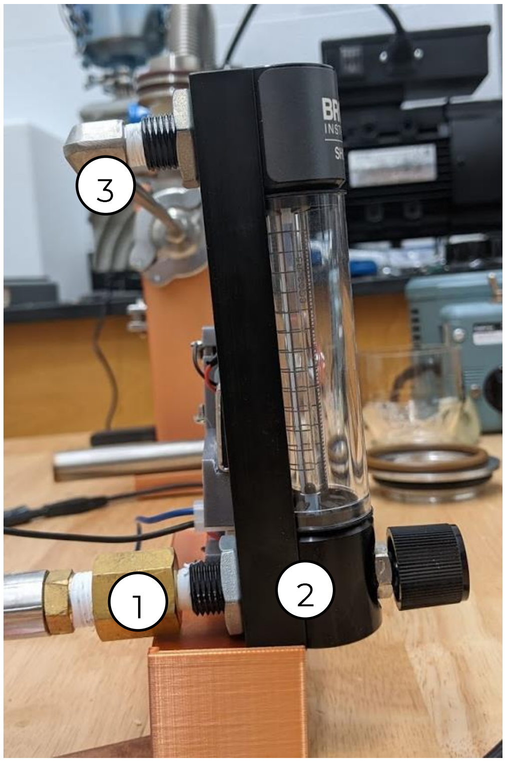
Argon Side

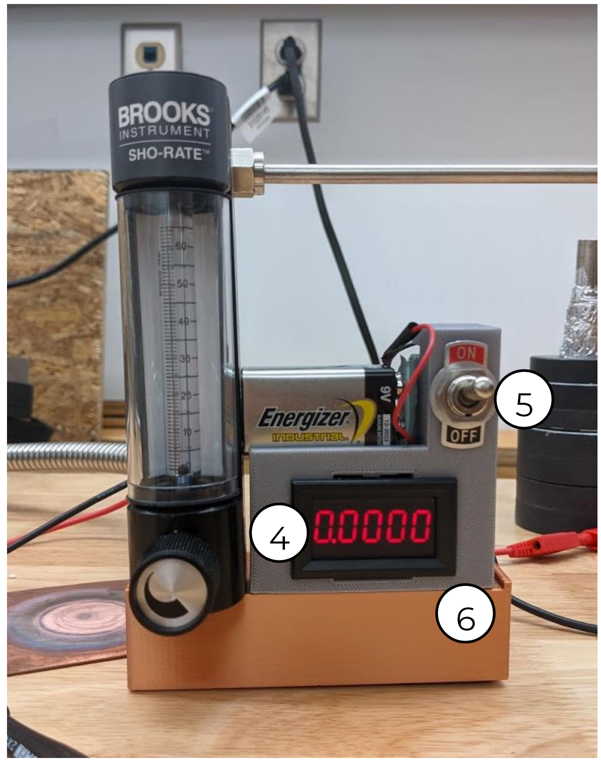


1- Argon Tank
   i- Standard Argon tank. We got ours at the Airgas store in Rome.
2- Argon Regulator
   i- Victor® Model HRF1425-580 Cutskill® Light Duty Argon/Carbon Dioxide Flowmeter Regulator, CGA-580
   ii- Not proprietary, any other regulator should work fine as long as there's a 5/8" - 18 (RH Female) outlet.
   iii- https://www.airgas.com/p/VIC0781-2723
3- 5/8"-18 UNF Right-Hand Male x 1/4 NPT Male Adapter
   i- This piece took forever to get right, and I'm not sure this link is what we've got, but it should work just fine. Just get that configuration of sizes and thread types.
   ii- https://www.mcmaster.com/7919A52/
4- Panel-Mount Precision Flow-Adjustment Valve
   i- Likely redundant, we don't end up using this valve.
   ii- https://www.mcmaster.com/7810K15/

5- Argon, Nitrogen, and Oxygen Hose
   i- Gets the argon from the tank to the chamber. We have a 2 ft long hose.
   ii- If this part needs replacement, I'd get 3 ft to allow some more wiggle room.
   iii- https://www.mcmaster.com/5665K61/

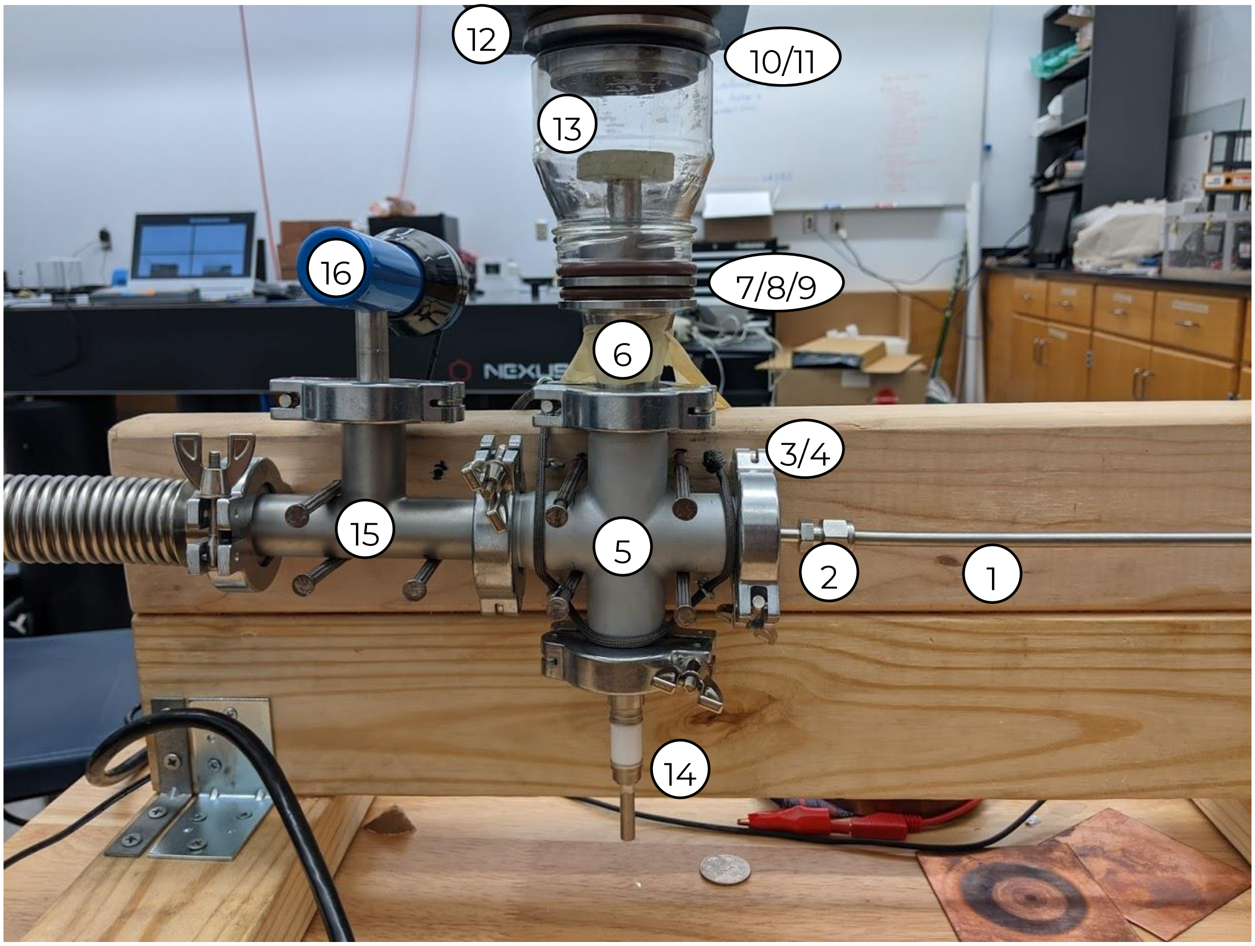
Flowmeter





1- Reducing Adapter,
   - i- 1/4 NPT Female x 1/8 NPT Male
   - ii- The flowmeter has smaller fittings than the hose, thus the adapter
   - iii- https://www.mcmaster.com/9171K62/
2- Flowmeter for Inert Gas
   - i- Primary method of regulating argon flow into the system
   - ii- https://www.mcmaster.com/4112K95/
3- Yor-Lok Fitting for Stainless Steel Tubing
   - i- 90 Degree Elbow Adapter for 1/4" Tube x 1/8 NPT Male
   - ii- Gets our thread connection into a vacuum friendly tube
   - iii- https://www.mcmaster.com/5182K821/
4- Ammeter
   - i- Generic battery powered ammeter
5- Switch
   - i- Generic Switch, prevents the battery being drained
6- 3D printed Flowmeter and Ammeter Stand
   - i- Holds switch and ammeter as well as flowmeter.
   - ii- https://sites.berry.edu/lindseylab/research-projects/magnetron-sputtering/resources/

Central Sputtering Area



1- Smooth-Bore Seamless 304 Stainless Steel Tubing
    i- 1 ft long, ¼" diameter stainless steel tube
    ii- https://www.mcmaster.com/89895K724/
2- KF25 to ¼" Swagelok
    i- KF25 is the measurement of choice for our vacuum chamber, this adapter gets the argon into the proper form-factor for our vacuum chamber
    ii- https://www.lesker.com/newweb/flanges/adapters_fittings_swagelok.cfm?pgid=kf
3- KF25 Aluminum Clamps
    i- These clamps help keep the whole apparatus together. Stainless steel would work fine too.
    ii- https://www.lesker.com/newweb/flanges/hardware_kf_clamps_machined.cfm?pgid=al2&highlight=QF25-100-C

4- KF25 Centering Rings
    i- These O-rings keep a seal between parts of the vacuum chamber. We used Fluorocarbon rings, though I'm sure the Buna-N would work
    ii- https://www.lesker.com/newweb/flanges/hardware_kf_centeringrings.cfm?pgid=ss
5- 4-way KF25 Aluminum Cross
    i- Again, stainless steel should work just as well, aluminum is just cheaper
    ii- https://www.lesker.com/newweb/flanges/fittings_kf_crosses.cfm?pgid=4waystd
6- KF25-KF40 Reducer
    i- This piece prepares the manifold for the larger flange that fits inside the smucker's jar
    ii- https://www.lesker.com/newweb/flanges/fittings_kf_nipples.cfm?pgid=reducer2
7- KF40 Stub
    i- This stub combined with two O-rings forms a seal at the entrance to the smucker's jar.
    ii- https://www.lesker.com/newweb/flanges/flanges_kf_weld.cfm?pgid=weld3
8- KF40 Centering Ring
    i- Only one of these is needed for the connection between the reducer and the stub
    ii- We don't use a clamp here because it prevented our O-rings from forming a good seal with the Smucker's jar
    iii- https://www.lesker.com/newweb/flanges/hardware_kf_centeringrings.cfm?pgid=ss
9- Smucker's Jar O-rings
    i- This is two separate O-rings. The inner ring is a buffer to keep the outer ring in place
    ii- The inner is a no-name ring we found, inner diameter less than 1.5"
    iii- The outer is a Kurt J. Lesker Fluorocarbon O-ring with a 1.6" inner diameter
    iv- https://www.lesker.com/newweb/flanges/hardware_orings_fluorocarbon.cfm?pgid=4

10- KF50 Stub (Metric Tube)
  i- The metric tube is a different size to the imperial or standard size, it's important to get metric to ensure a nice fit.
  ii- The flange is too long at the start, we angle-ground ours down to roughly ½" long
  iii- https://www.lesker.com/newweb/flanges/flanges_kf_weld.cfm?pgid=metricweld3

11- Top Stub O-ring
  i- This is another no-name O-ring from our glass-cutting kit
  ii- A ring with an inner diameter less than 2.2" should ensure a tight fit

12- Stub-Sputtering Target O-ring
  i- 0.210" cross section, 2.35" diameter fluorocarbon O-ring
  ii- https://www.lesker.com/newweb/flanges/hardware_orings_fluorocarbon.cfm?pgid=4

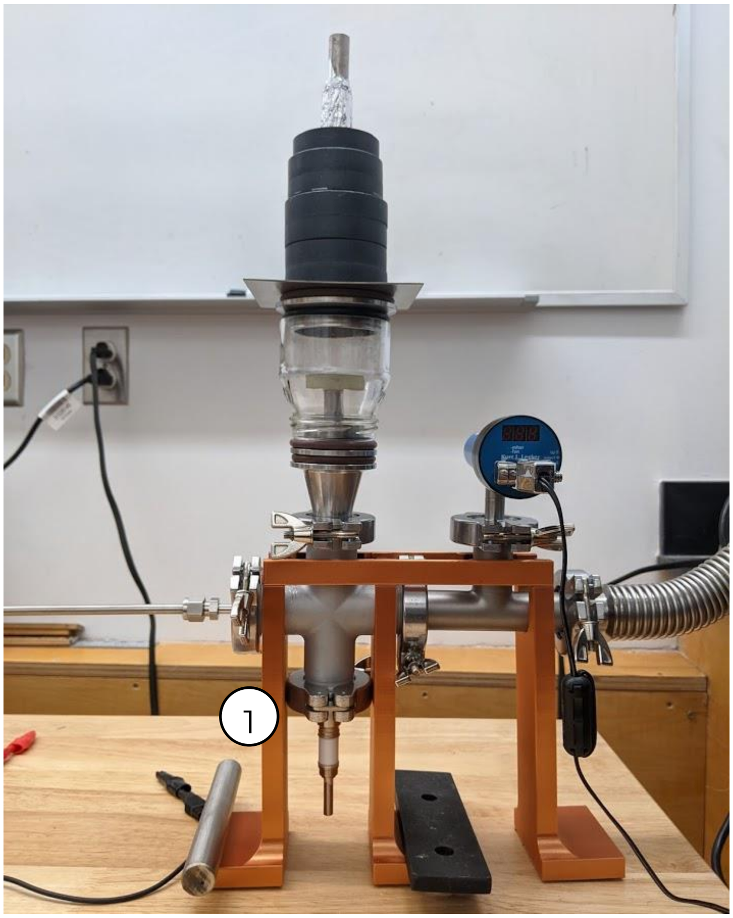
13- Smucker's Sugar-Free Jelly Jar
  i- This is the size to get to fit the flanges. Makes some PBJs
  ii- The bottom was cut off as detailed in the construction section

14- High-voltage Feedthrough
  i- We don't really care about this as a feedthrough, it's more useful for table-mounting purposes
  ii- It's a KF25 mount with a ¼" nickel rod on the inside
  iii- Clearer view in the epoxy table picture
  iv- https://mpfpi.com/shop/power-feedthroughs/voltage-power-feedthrough/12kv-power-feedthrough-voltage/a0118-11-qf/

15- KF25 Stainless Steel Tee
  i- This acts as the vacuum gauge mounting section
  ii- Aluminum would also work, we had the stainless steel
  iii- https://www.lesker.com/newweb/flanges/fittings_kf_tees.cfm?pgid=standardtee

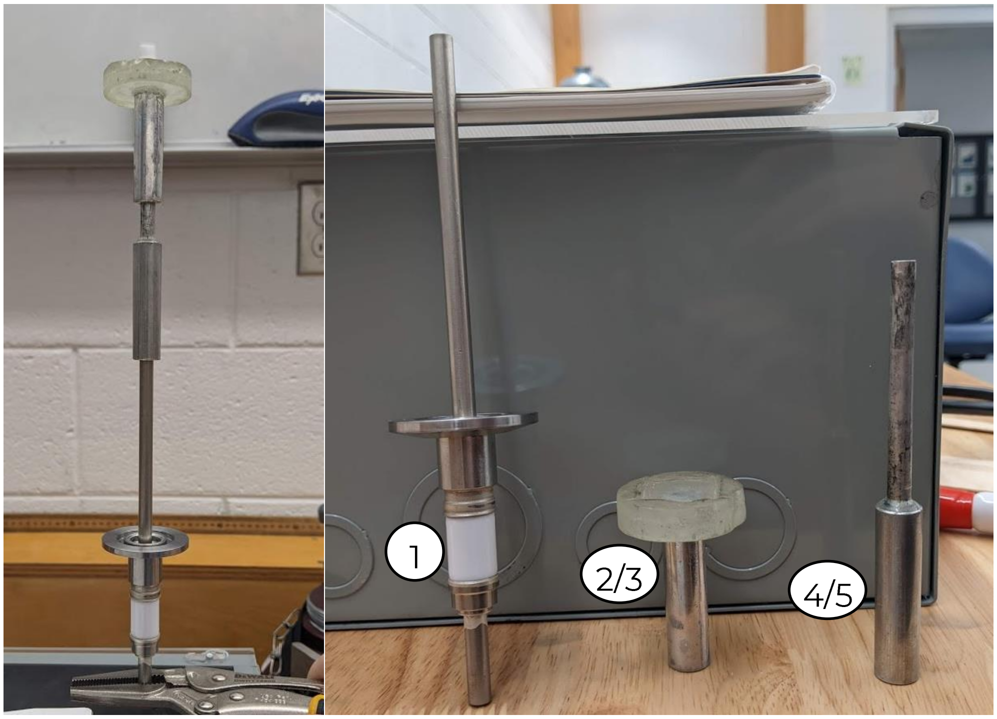
16- Vacuum Gauge
  i- Used to measure the pressure in the chamber
  ii- Model # KJL275807LL
  iii- https://www.lesker.com/newweb/gauges/convection_kjlc_2.cfm

Optional Upgrade: 3D Printed Stand



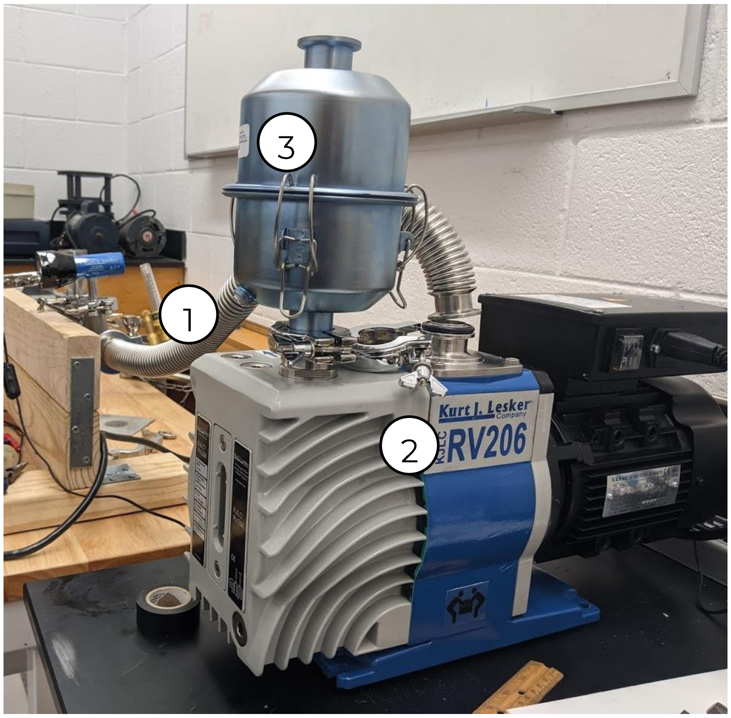
1- 3D Printed Stand
   - i- Designed to hold the system while looking less jank than the 2x4s.
   - ii- I recommend putting shelf liner on the feet to increase grip.
   - iii- May need to be weighed down due to the lower mass.
   - iv- https://sites.berry.edu/lindseylab/research-projects/magnetron-sputtering/resources/

Sputtering Table



1- High-voltage Feedthrough
   - i- Same as above, re-pictured here fer clarity
   - ii- https://mpfpi.com/shop/power-feedthroughs/voltage-power-feedthrough/12kv-power-feedthrough-voltage/a0118-11-qf/
2- Aluminum Unthreaded Spacer
   - i- 2" long, ½" OD, 0.252" ID
   - ii- One side is bound to the epoxy table , the other is open to allow the rod to slide in
   - iii- https://www.mcmaster.com/92511A085/
3- Epoxy Table
   - i- Simple flat area to rest glass slides or other targets on
   - ii- See **Construction** section for how to make it
4- Aluminum Unthreaded Spacer
   - i- 2" long, ½" OD, 0.252" ID
   - ii- One side is epoxied to the aluminum rod , the other is open to allow the high-voltage feedthrough to slide in
   - iii- https://www.mcmaster.com/92511A085/
5- Aluminum Rod
   - i- Roughly 3-4" long, epoxied to the spacer
   - ii- https://www.mcmaster.com/8974K22/

Vacuum Pump

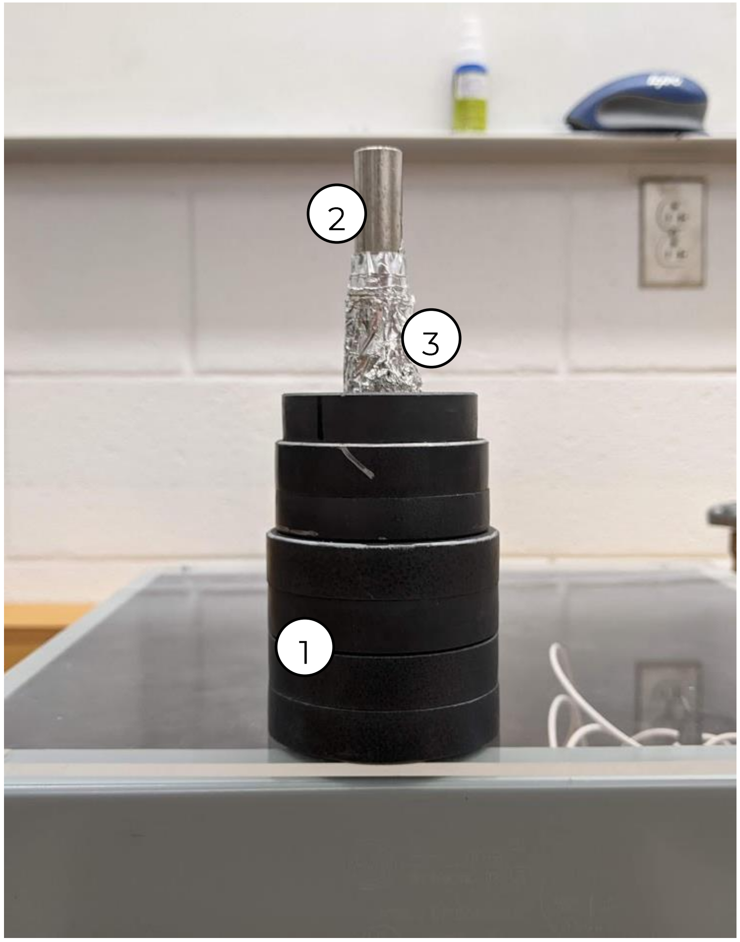


1- Hydraulically Formed Bellows
   - i- Flanged Standard Unbraided Wall
   - ii- KF25, 2 ft long
   - iii- If this part needs replacement, I'd get 3+ ft to allow some more wiggle room.
   - iv- https://www.lesker.com/newweb/flanges/bellows_kf_hydraulically formed.cfm?pgid=standard

2- Kurt J Lesker Rotary Vane Vacuum Pump
   - i- This pump gets us down to about 10mtorr on the best days which is more than good enough for sputtering
   - ii- https://www.lesker.com/vacuum-pumps/rotaryvanepump-kjlc-rvseries/part/kjlc-rv206ssl

3- Regular Duty Oil Mist Eliminator
   - i- Model # PFEGL925QF25
   - ii- https://www.lesker.com/newweb/traps/oilmisteliminators_kjlc_regularduty.cfm?pgid=0

Magnet Pile



1- Magnets
    i- These ring magnets were taken from 4 different microwaves we looted over a month-long period
2- Magnetic Steel Rod
    i- Roughly ½" in diameter and 6" in length
    ii- Use a more magnetic rod if you so desire, this is what we had
3- Aluminum Foil
    i- The rod was wrapped in aluminum foil to center it within the magnets

Construction

Power Supply

In some ways, the power supply is a project of its own. I'll try to make it simple.

The supply starts with a variable power supply. No work is needed here apart from swapping the 10 A fuse with a 20 A one.

Save a microwave power cord from one of your salvage jobs (heck, save them all). One end of the cord should terminate with two connectors that can friction fit onto corresponding inputs on the transformer. Cut the rubber coating to expose the wiring within, you'll need roughly 3" of wire to work with. There should be three wires inside: A ground, positive, and negative. The ground is probably green, the positive and negative are probably black and white or something similar. Cut either the black or white wire and strip it to expose the copper inside. This will connect to your dead man's switch.

Remove the screws in the button housing to get a look at the guts. The guts are just a momentary switch. Drill two holes in the enclosure near where the switch sits to allow your previously cut wire to go into the button housing and be screwed into the switch. After that, close the button housing and tape the three wires back into one cohesive package.

Pop out one of the knockouts in the center of your junction to allow the microwave cable to pass through. This is as simple as setting a flathead screwdriver against the edges of the circle and tapping the back of the screwdriver with a hammer. Set your plywood baseboard inside the junction box to prevent unwanted contact, I recommend using shelf liner between it and the metal to prevent the baseboard from sliding around. Use the included green screw to attach the ground wire to the junction box in the base. Fit the outlets of the microwave cord to the metal tabs on the lowest coil of the transformer.

The transformer has three coils, they are roughly separated by orders of magnitude. The bottom input coil holds a voltage of roughly 100 V. The middle, thick coil holds roughly 2-3 V. The upper, thin-wire coil holds roughly 1000 V. Snip the middle coil and put electrical tape over the ends. You don't need this coil and don't want it getting in the way.

The upper, thin-wire coil has two outputs, but the second might not be obvious. One output is a tab that may or may not have a fuse attached to it. If it does, great, replace the fuse with a 20 A fuse. If it doesn't, that's fine, you'll need to use an alligator clip to get to the rectifier. The other output of the coil is the metal housing of the transformer. This output is technically the ground, and I've labeled it GRD in the circuit diagram. There should be a wire leading from the thin coil to the housing that can be clipped onto . If not, attach a wire securely anywhere on the transformer housing.

The next section is a full-bridge rectifier to convert from AC current to DC current. This is essentially plugging things into a breadboard with a little modification for the diodes. To secure them, we drilled slightly larger holes in a scrap piece of breadboard, then held the diodes in place and connected them with alligator clips. We then drilled even wider holes in the corners to hold screws to prop the board up and away from anything. Diodes have polarity, the white bar indicates direction of current. The top and bottom of our diode holder are shown in Figure 4

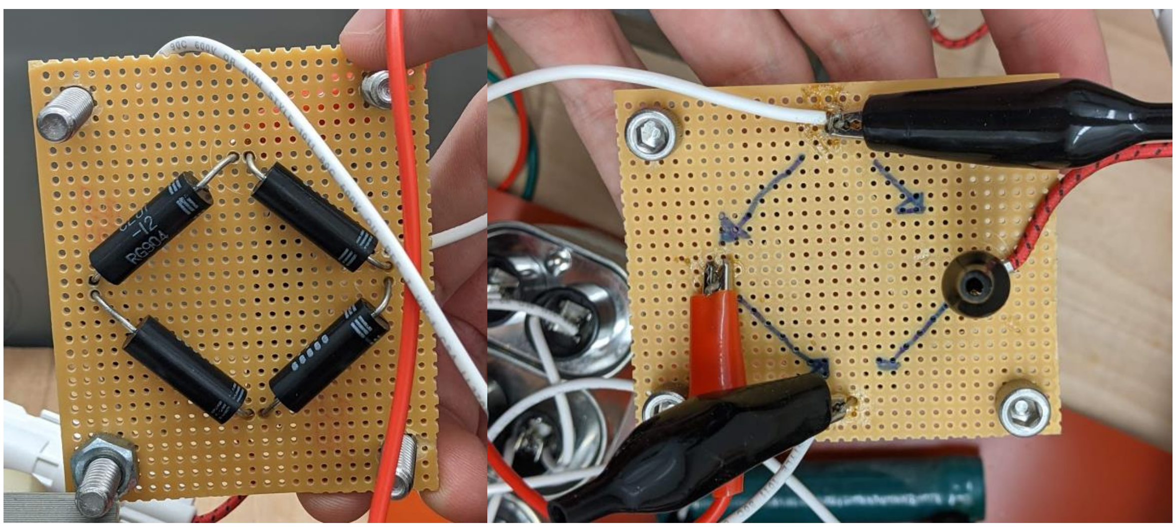


Figure 3: The bottom and top of our diode holder. Arrows can be useful to quickly know orientation

The next step is wiring in the parts of the full bridge rectifier. This may take some soldering, but it's a simple job. I've repasted Figure 1 from the segmented breakdown to showcase the circuit diagram to be achieved. The wires connect to the box-mounted banana jacks which are conveniently the next step in construction.

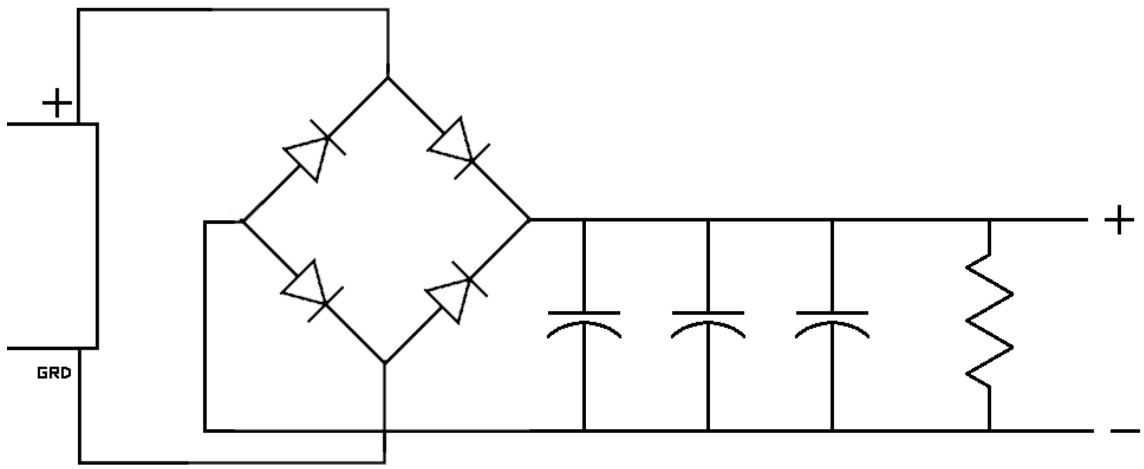


Figure 1: Circuit diagram for the full bridge rectifier. + and – connect to the banana jack in the wall of the junction box.

Knock out another circle in the junction box to the right of your inlet. This can be done using the same screwdriver technique as for the initial knockout. Slot your jacks in. You'll likely have empty space above and below jacks, this can be covered with some electrical tape, though it's more of an aesthetic issue than a safety one.

The final step is the lid. This can either be acrylic or 3D printed.

Acrylic: Use the included steel panel to figure out where to drill into your acrylic sheet. Give yourself pretty big tolerances. Drill into the acrylic, I recommend using pilot holes to not shatter it. Once the holes are drilled, insert the screws into the top of the junction box from the bottom up, you want the threads poking through the top. The acrylic sheet should fit on top nicely and not be at risk of falling off.

3D Printed: Print the parts in PLA or some other plastic, I recommend printing with supports. After cleaning the supports out, slide the joints into the slots on the sides of the corner pieces. I recommend using superglue here, there's a little too much weight for me to feel comfortable with a friction fit.

After connecting your alligator clips to the banana jacks, you should have a working power supply.

Epoxy Table

The table to hold whatever is being sputtered is a fairly simple construction. We used JB Weld ClearWeld Epoxy to make our table.

To begin, get a small, round container of sorts to form the table. Something like a tea candle with all the wax burned out would work great. Pour in an initial layer of epoxy, mixing 1-part resin to 1-part hardener. Immediately blast it with a heat gun or something similar and tap it on a table to reduce bubbles.

After that layer is hardened, place the aluminum spacer on top of the epoxy, roughly centered. Pour in a second layer of epoxy with the same ratio to fix the spacer to the table.

Once that's hardened, remove the table from the container. This may require some cutting or persuasion.

If all you want is a flat table, you're done! If you'd like a slot for a slide, get out your Dremel.

Place a slide on the top of the table and trace it with a marker of some kind so you've got an outline on the epoxy. Using the Dremel with a cutting head, trace the outline to carve a square into the epoxy. Move slowly across the center with repeated carves to form a square divot in the table. As you carve, test the fit with a glass slide to see if any areas need to be more honed down.

The carving doesn't need to be perfect to have a secure hold on the slide, it just needs to be able to stop it from being bumped out or blown out by suction forces.

Glass Cutting

Making the vacuum chamber involves cutting relatively thick glass. This took multiple steps, but the cornerstone is a glass cutting kit like this one: https://www.amazon.com/dp/B07PFV3GMG/ref=cm_sw_em_r_mt_dp_5SCOFb251SZWV?_encoding=UTF8&psc=1

There are many kits on Amazon like this one, the name brand doesn't matter.

Begin the glass cutting process by emptying the Smucker's Sugar-Free Jelly Jar of Jelly and removing the label with a hot water scrub or some acetone.

After that, place the jar on the glass cutter and adjust the brace to the desired length. Our jar is roughly 3" tall, but the height can be played with to affect the plume shape.

Rotate the jar in the glass cutter, pushing firmly downwards and slightly towards the brace to ensure a deep, firm score on the jar.

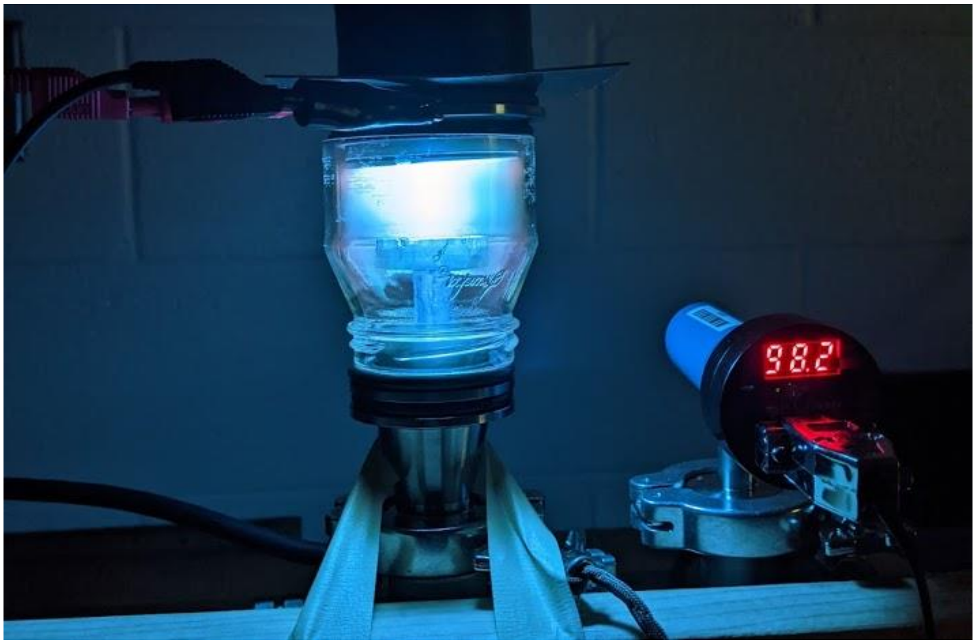
After the line is scored, there's a variety of methods to break the glass. Here's what worked for us:

Heat up a soldering iron as hot as it will go. Hold the iron for a few seconds at points all around the score line to warm it up. Next, hold the iron at one point on the line until you hear a snap/pop/crack. Repeat this process moving around the jar until the bottom breaks free from the top.

Once the jar is in two pieces from whatever method you used, check for cracks. If there's any cracks going into the jar piece that will be used for the vacuum chamber, restart. It's not worth trying to use a broken part.

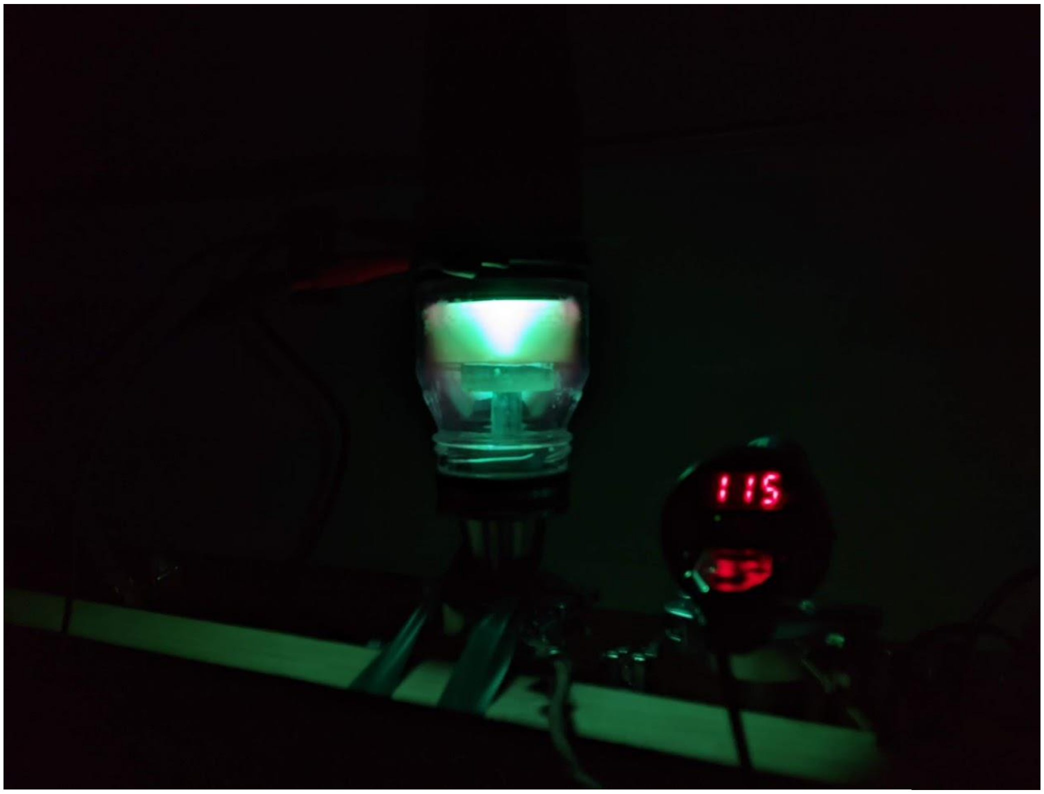
Sand down the edge of the glass so it forms a flat ring with no hills or valleys. This is a long, arduous process that will kill your forearms but build character. Using wet sandpaper can speed it up a little, but it's a marathon.

Section IV: Gallery

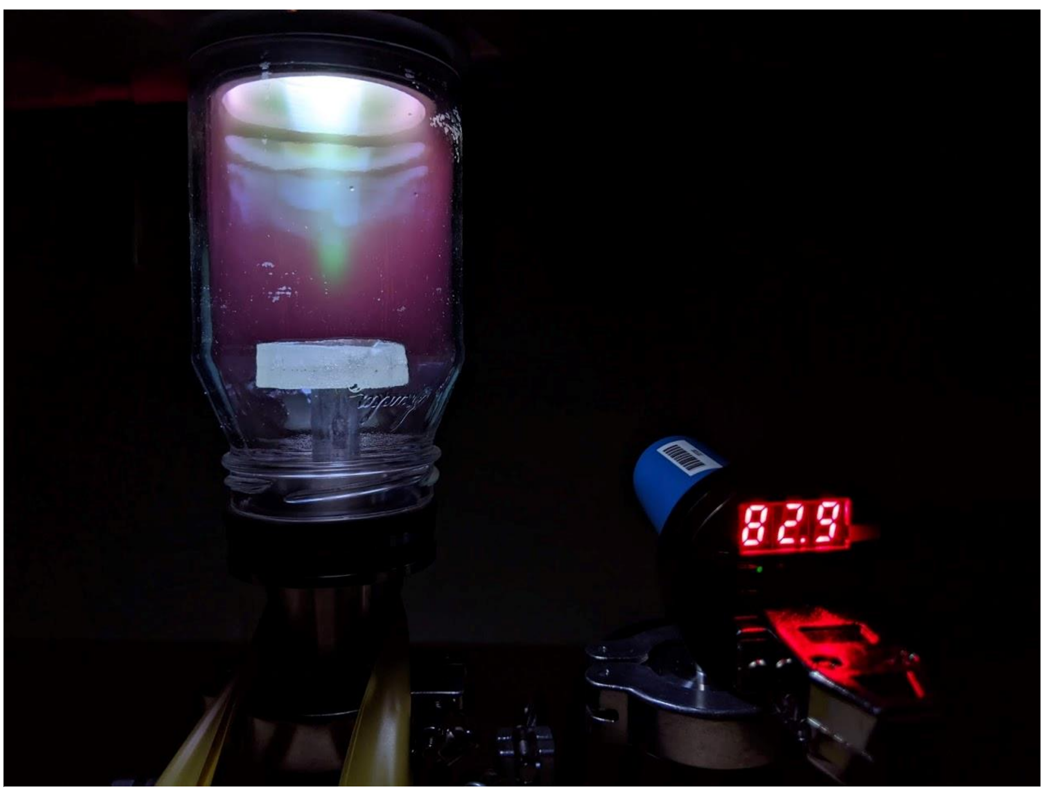


Picture 1: Blue plasma plume with nickel deposition

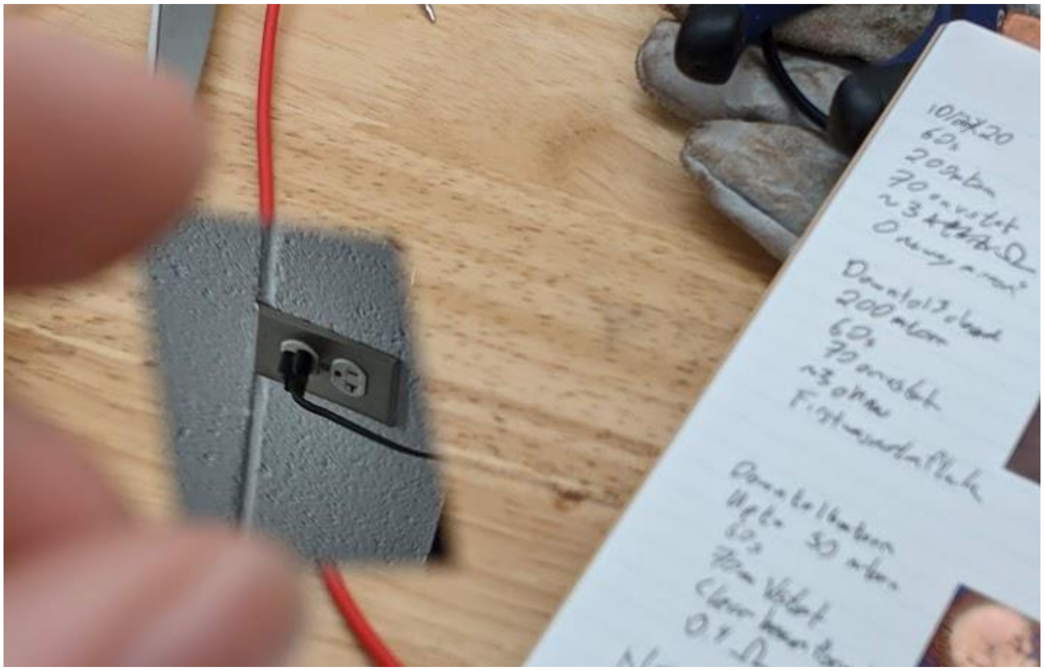
Picture 2: Oxidation on copper plate after a deposition

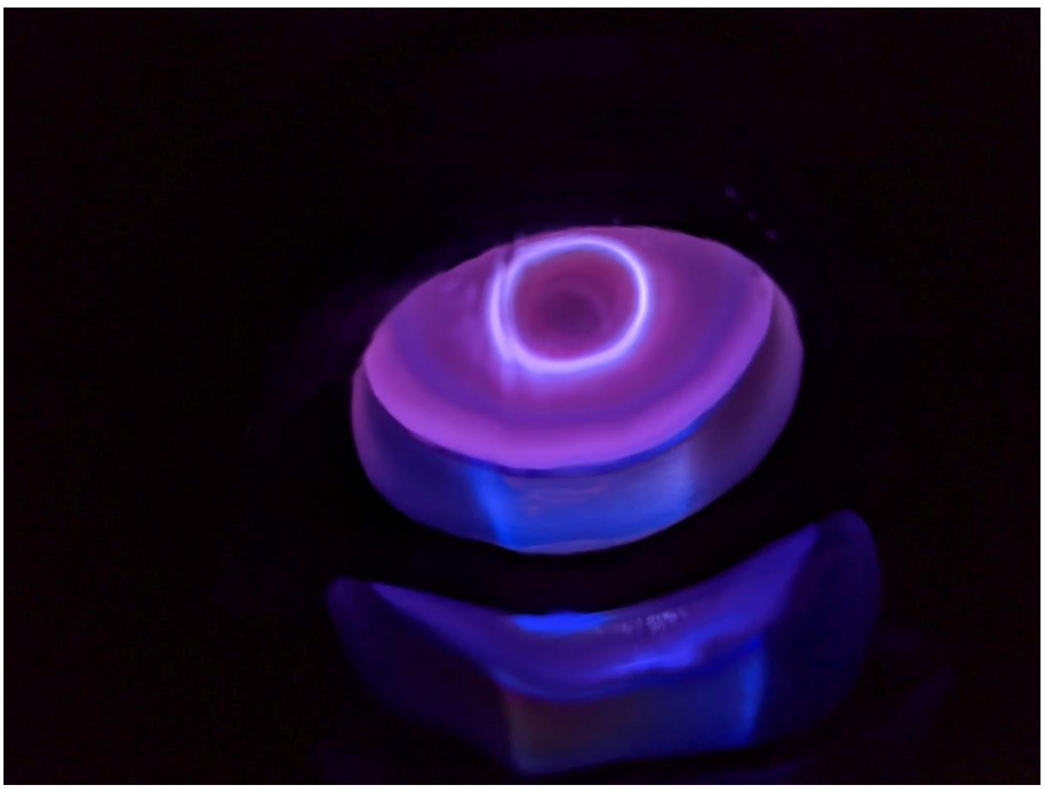


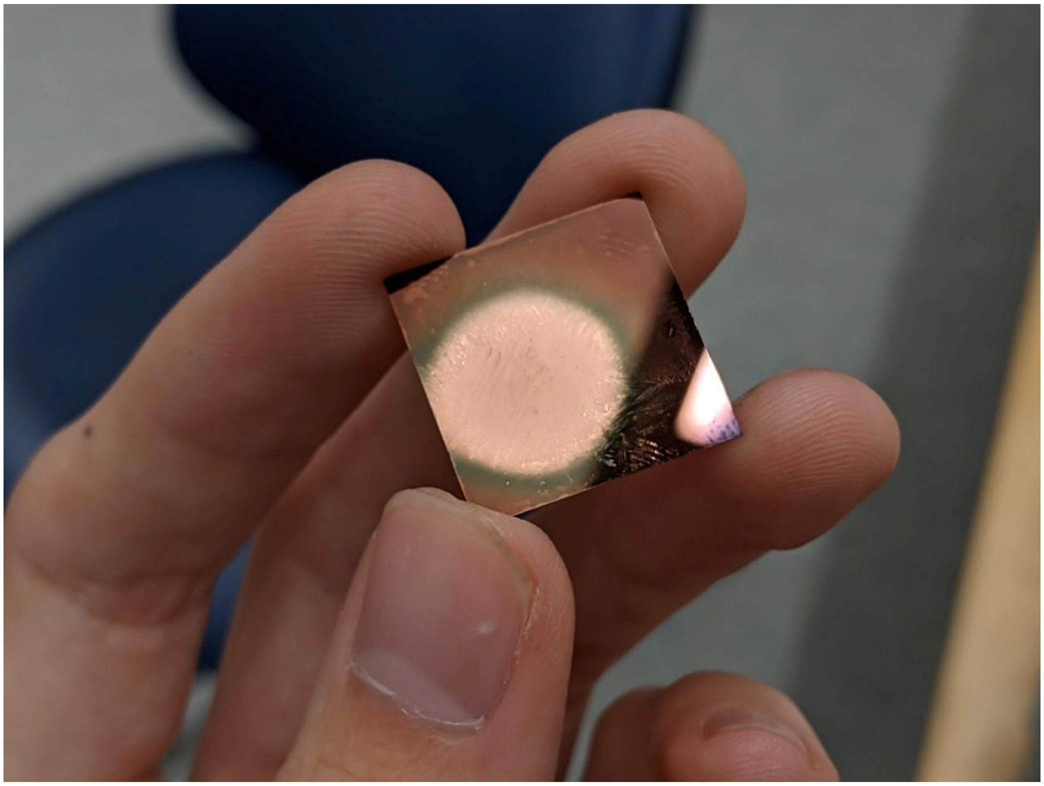
Picture 3: Strong green plasma plume with copper deposition



Picture 4: Weaker green plasma, majority argon with some copper


Picture 5: Highly reflective nickel deposition


Picture 6: Concentrated plasma ring beneath ring magnets


Picture 1: Majority oxide copper deposition with some pure copper

Fin