Semiconductors @ Home.

COMPENDIUM!

A book on how to build 1960-ish semiconductors tooling at home.

Nixie.

Hello, and welcome to this guide.

Before we start, you should know this is not the usual manual that will handhold you through an easy, step by step, process towards the final goal.

The odds that you will find exactly the same base material sizes I used are slim at best. Of course all easily obtainable overseas components will be referenced, and 3D printed STL's will be avaliable too, but that is not the point.

You need the knowledge, not the Ikea manual, because there are no kits to assemble, yet... ;)

Be prepared to get creative.

Altough this compendium will display the story as a more or less continuous and well organized build log/ story for ease of readability and comprehension, that is a bit far from the truth.

I did what I could, with what I had. Made bits here and there, and all in all, worked on more than one thing at a time. Should you want the true story, begin at the blog, then follow up at Hackaday.io's project page and end at the twitter feed. That will represent the true evolution of the project, with its ups and downs.

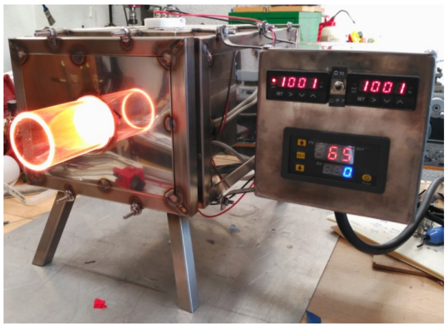
That can become confusing, fast. In any case, enjoy the reading!

Index

(all page numeration is a link to it's chapter)

The Basics

Heat:

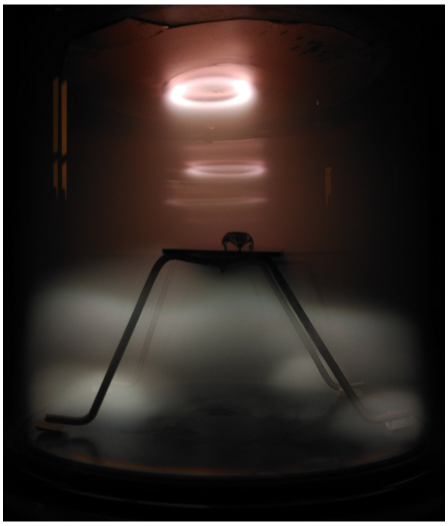


In it's most simple iteration, an oven capable of reaching 1000ºC is all you need. (and some chemicals, but that's for later).

With it you will be able to oxidize Silicon and drive the impurities into it.

Go to: *Oven Build*

Pressure:



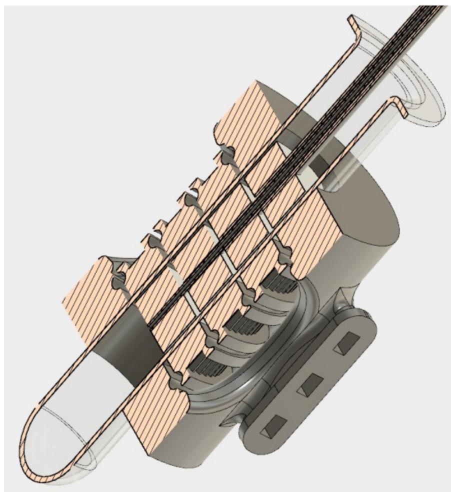
The longer you dive into this rabbit hole, the fancier the equipment goes (always in homemade terms).

To interconnect the various devices and perform other functions, what you want is to deposit metal in vacuum.

Either evaporation, or a magnetron sputtering machine, the later being the simplest of the two in some ways, will be able to diposit aluminium on top of of the silicon, making connections.

Go to: *Vacuum chamber build*   Go to: *HV power supply build*

Push & Poke:



A small vacuum chamber has benefits and drawbacks.

Pros:

- Quick vacuum, because of small volume to evacuate
- Easy to mantain and clean.

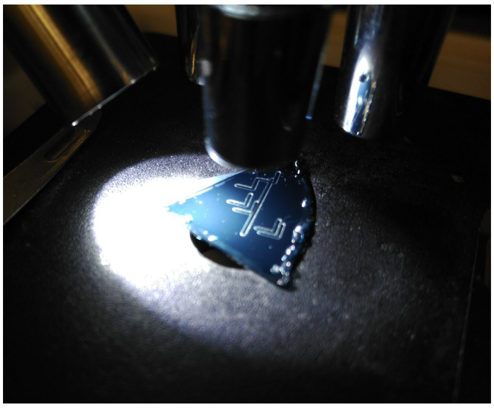
Cons:

- Limited space.
- One experiment at a time, posible contamination between changes of target.

With that in mind, it would come in handy to have some way of interacting with the world within.

Go to: Magnetic Feedthrough Manipulator

Light:

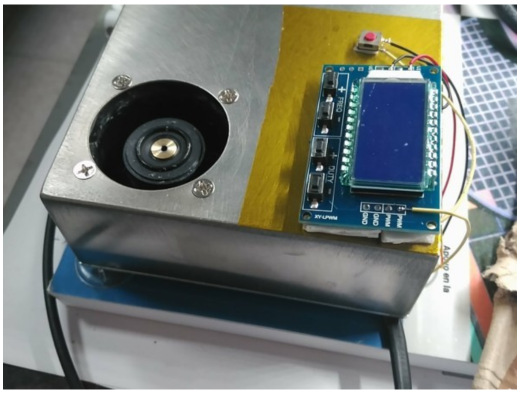


You will want to also pattern both the silicon oxide and the metal layer, otherwise, you will have a shiny shortcircuited silicon shard.

There are plenty of options for that, but then, my brain farted and thought that, since I wanted to use PMMA (acrylic), I might be able to use my K40 laser cutter to just mill it.

Go to: Photolitography

Spin and cook.



Paterning also has a hidden face, wich might not be immediately obvious.

It requires for some form of resist to be put on top of the wafer. As mentioned before, PMMA was chosen because of avaliability. To turn that into resist, it first has to be dissolved in a suitable chemical, then, coated on the surface and finally, cooked to drive out all the solvent and properly cristallize it, leaving a good, uniform surface.

Go to: *Spin Coater*

Go to: *Hot Plate*

Danger:

The "last" thing you need, are chemicals.

We're not going to mislead anyone here, making semiconductors requires dangerous and extremely dangerous chemicals.

-HOWEVER-

Chemical danger is inversely proportional to the precautions you take minus the concentration of said chemicals. (completely made up rule)

And that's why I would include a benchtop fume hood in the project. I deemed it absolutely necessary. Also a hermetic HDPE bottle to safely store everything.

Go to: *Safety!*

Overseas materials reference:

All 3D printed and machined part files are avaliable in the Hackaday.io project page.

Oven Parts:

- Kanthal 220V 2000W.
- Temperature controller.
- Temperature sensors.
- SSR's.
- SSR radiator.
- Timer relay module.
- Double shielded high temp wiring.
- High temp wiring.
- Ceramic terminals.
- Fused Quartz tube.
- Viton O-rings 50mm OD

Vacuum chamber:

- Vacuum grease.
- KF16 corrugated pipe.
- KF16 T-fitting.
- KF16 weld ferrule.
- KF16 centering ring + filter.
- KF16 clamp + centering ring.
- Glass chamber.
- Flip-up 9V battery holder.
- Ring magnet.
- Inside magnet.
- HVAC grease.
- Liquid Refrigeration O-ring 98OD*2mmØ.
- Liquid Refigeration O-ring 55OD*2mmØ .

Acid containers and safety:

- Calcium gluconate gel.
- 20x50Ml HDPE bottles.
- Long sleeved nitrile gloves.

Feedthrough and hand controller:

- 6*4mm stainless tube.
- 4*3mm stainless tube.
- 3*2mm stainless tube.
- PTFE block sheet.
- 9mm*100mm linear rail.
- 15mm*150mm linear rail.
- 3Mmm ceramic balls.
- 14*21*28 linear bearing.
- PTFE tube 2*1mm.
- 0,8mm Braided steel cable.
- 5*2mm magnets.

Alumina machining parts:

- 5mm linear bearing LM5LUU.
- 5mm linear axle.
- 6mm diamond hole saw.
- 61mm diamond hole saw.
- 48mm diamond hole saw.
- 45mm diamond hole saw.

Glassworking:

- Oxy-acetylene miniature torch.
- Graphite rod.
- 15mm borosilicate test tube.
- 19mm borosilicate tube.

Miscellaneous:

- micro usb camera.

Vacuum chamber:

Let's talk about pressure levels:

Microns	Torr	Atm	
760.000	760	1	Your everyday life.
600.000	600	0,78	Vacuum cleaner.
380.000	380	0,5	Vacuum bagging food.
76.000	76	0,1	Resin difusion vacuum bagging.
500	0,5	0,00065	Freeze drying.
200	0,2	0,00026	Vacuum for freezer repair.
50	0,05	0,000065	Incandescent lightbulb.
1	0,001	0,0000013	Thermos bottle.
0,00001	0,0000001	0,000000000013	Vacuum tube/triode.

Numbers have been rounded up a bit for ease of visualization.

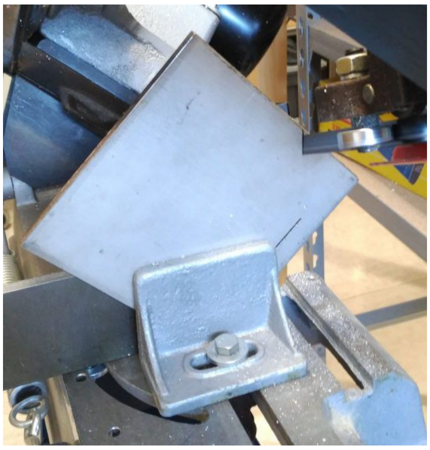
Beyond the vacuum tube, that's ultra high vacuum, wich is a completely different can of worms. Everything outgases, you have to use weird materials, take into consideration the surfaces of the chambers/funnels, etc...not where I want to go.

As Vacuum chambers go, I think I can safely say there are infinite shapes to choose from. They must withstand the pressure that you are going to put on them. They have to withstand relatively high tempeatures and allow for, at least, some form of electrical connection with the inside.

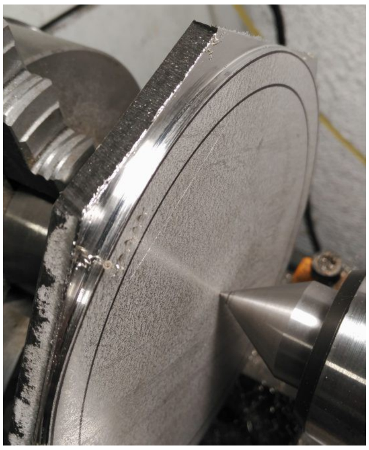
I am not a real fan of electrical feedthroughs, they are a hole wich passes a metal through, usually, another metal and that it is always troublesome, since you want isolation too. So, when I saw the desktop commercial sputtering machines that have a simple glass cylinder as wall, and a top and bottom electrodes wich also happen to be the endplates of the chamber, I said to myself: "I have to have it like that!"

My first idea was to make the endplates from aluminium, and it worked for a little while. However, as I later found out, at least one "should" be made out of stainless.

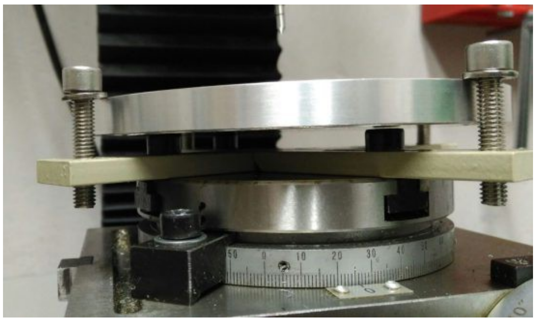
Rough cut:

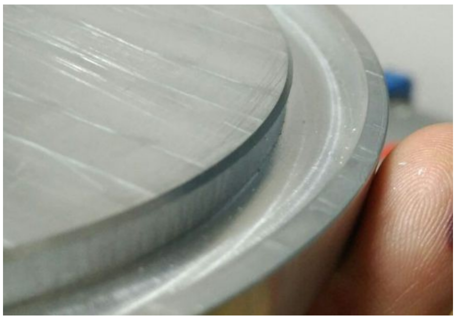


Interrupted cut:



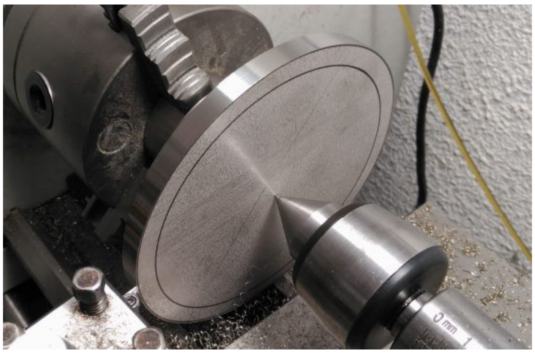
I machined a groove in the mill, as I thought that keeping the seals captive was the best option. However, as good as the milling looks, it wasn't as mirror finish as I would like, leading to leakage problems.

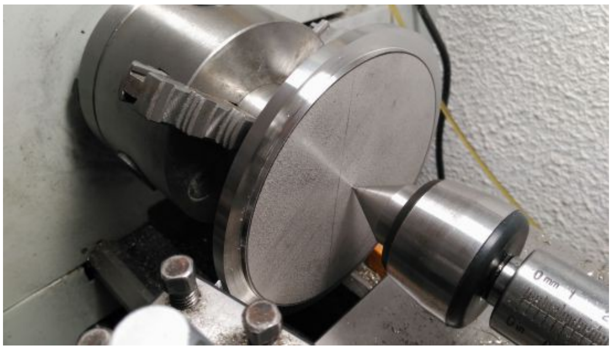




After thinking a lot about how to polish it, I came to the conclusion that the outside lip was just giving me problems, so I ended removing it, wich also made polishing the resulting flange surface a breeze. Before you wonder, why not just use a flat plate? Simply put, vacuum will suck the seal in, even if the rubber is quite rigid. It's highly improbable that the clamping force provided by the plates against the glass will hold it, leading to sealing problems and/or crashes.

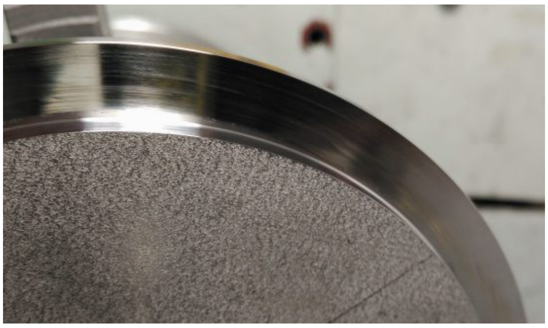
Once the disc was at size (125mm, just 2mm wider than the seals), the side flange was cut and polished.

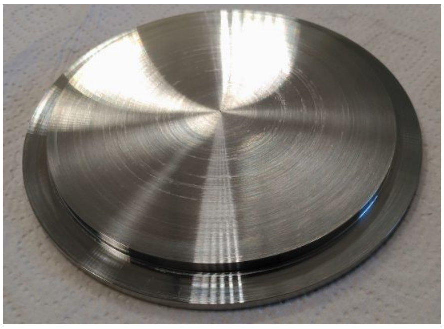




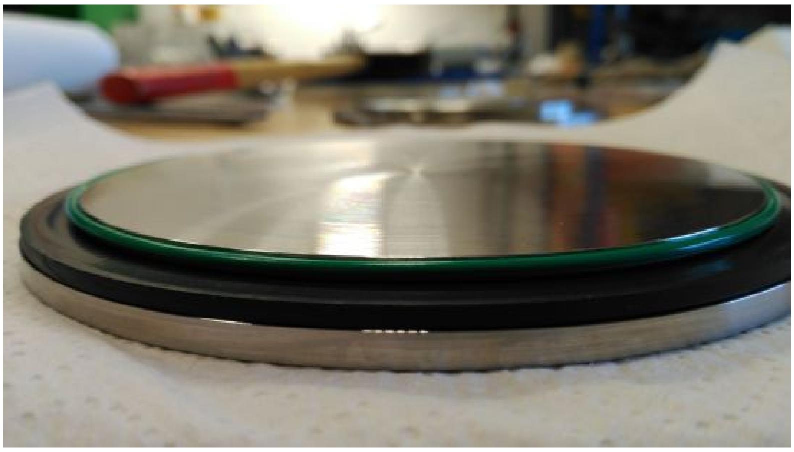
At this point, the disc is finished, but a rough surface is really not desirable for the inside of a vacuum chamber.

Since the disc was held only with double sided tape and tailstock I really, really carefully trimmed the surface (0,02mm passes), then polished.





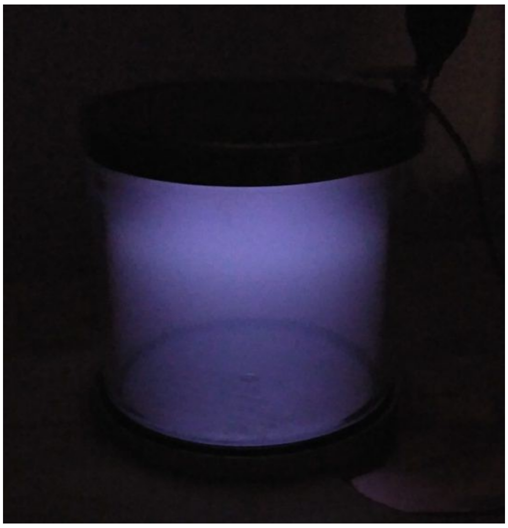
When that was done, some viton rubber seals where cut. Viton is not super flexible, so your chamber walling needs to be fairly flat in the edges (Mine isn't and requires some persuasion to start pumping down, then it goes fine). I also use two viton o-rings to keep the glass bell centered, just in case.



The glass is a 100mm ID borosilicate, 5mm thick, beer machine viewport. I know many people just use canning jars or whatever glass encasings they can find. And at first I considered it too, because I could not find any supplier of borosilicate tube in bigger enough size (that was affordable). One day as I was about to go to sleep, I just gave internet a last go, and lo and behold! I found one homebrew beer supplier that sold them at a decent price.

In the photo they have square edges, but mine came with them flame polished, wich is not bad either.

And where does all that sit? In a BEKVÄM table, of course. It seems to be the go-to support for things like this, and other stuff.



My first bout with vacuum came from the hand of a refrigeration repairman pump.

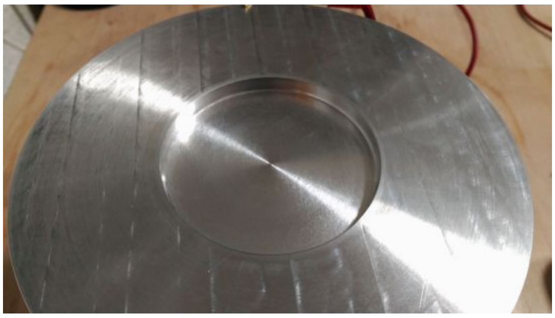
As far as I understood, being two stage, it would take a while, but it would attain a decent vacuum level. So there I went, built a nice, fancy vacuum chamber and connected it to the pump through a custom adapter (1/4SAE to M8 with o-ring seat). Once 500V where applied, I was greeted by a nice purple glow, so, there I was, staring at my first plasma ever!

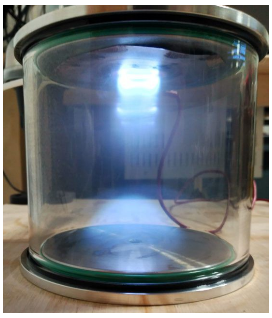
But the vacuum was not low enough, wich allowed sparks to form with the leftover ionized gas.

When that happens, it`s a short circuit inside the chamber that will fuck up your power supply, like a coil discharge, and also vaporizes chamber wall material wich will deposit elsewhere.

Applying a magnetic trap to it, focused the plasma, but after thinking about it, I realized the magnet was too far from the chamber (10mm thick plate), making for a weak plasma trap:

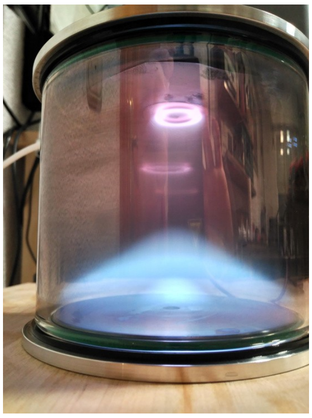
So, a recess was machined in the plate to decrease the gap to 4mm, wich did the trick:





After poking around, If I started with a cool pump (room temperature), I managed a vacuum wich I guess was about 500/300 microns or whereabouts. After a while, the pump performance decreased noticeably (in terms of plasma quality), trying to help by coupling my vacuum bagging pump to it's exhaust, made absolutely no difference.

Next day's plasma, looking redish from copper deposited in the chamber walls. Good enough for what the pump was built, it didn`t work for what I wanted to do.



I could probably have managed with an Argon atmosphere, but damn, loosing power to just make gas glow (in the rest of the chamber) well...that doesn`t cut it fo me.

Best result with that setup?

A copper oxide layer with 100 ohm resistance. Not good, I'm afraid.

It became clear that this wasn't going to get much better, and having to wait a month for SAE pieces to try an Argon atmosphere, I just decided it wasn't worth, so fuck it, I went and sold the pump in a pawn store. There was no much point in saving it, because I already had one wich doesn't use oil, wich is less messier than those "cheap" refrigeration pumps.

Upon thinking my frustration out, I looked for secondhand pumps on wallapop, because you know, sometimes if one digs, finds glod.

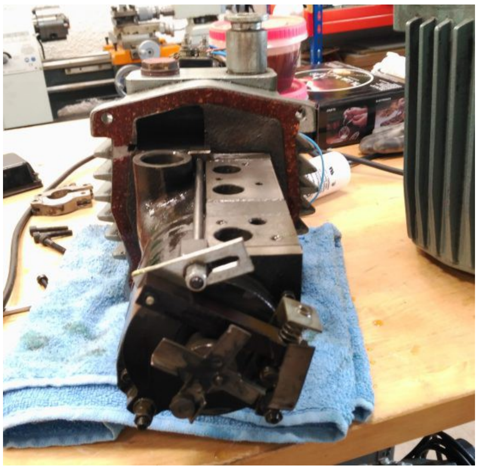
An ad gave me good vibes. The pump had KF-16 high vacuum flanges, not 1\4 SAE fittings, wich was a good sign. Also, whoever had stored it, had had the provision of covering both flanges (inlet and exhaust) with proper KF seals, not just leave them open or covered with film. @ 150€, (175 with shipping) it looked like a well mantained bargain. Upon contacting the seller, he commented it had been used to make Neon signs, wich require a good vacuum. With that, I decided I had to have it. (also, the next best thing was in the 500€ range)

Once I got it, I immediately changed it`s oil, wich, in the pantone chart of degradation, looked bad, but not *dead pump* bad.

With new oil, the pump started, but after a couple seconds, it would stall. Thinking about denser residues from storage, I charged the pump with a 50\50 kerosene-oil mix, to try to clean it up a bit, and ran the pump. It ran fine for a few moments, then disliked it even more than just oil. Maybe I had a dud, altough the seller, who seemed confiable enough, told me the pump ran fine.

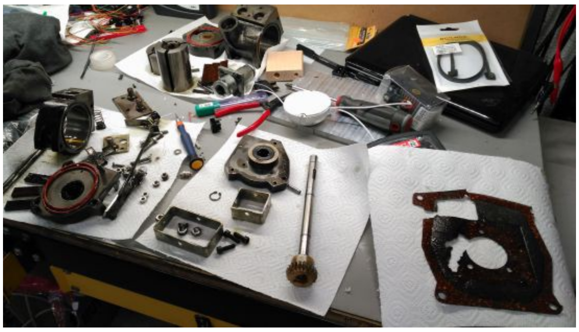
Altough the pump was rated for 220\380v three-phase, the motor came, by the looks of it, wired for a cheater capacitor to go from sigle phase to three pase. At that point, and nothing to loose, I decided to dismantle the pump completely.

I didn`t know what to expect, so I just went along, loosing bolts, carefully poking around trying to not break anything, and using a nylon mallet if I had to push harder.



To my amazement, it came apart easily enough, and looked deceptively simple. While doing it, I found the pump was completely drenched in oil on the inside, and thought that that was what stalled the motor. After all, the pump is a compressor, and oil is not compressible, right?

The pump was so old, it still used cork seals for vibration dampening (not the high vacuum seals)



So, once the pump was completely apart, it was given an all nigher in a KH7 bath, (except the pieces with plastic seals, wich where given like a three hour rinse.

Note how the rotors and rotor howsings are either empty or not towching anything, to prevent damage.

Then, proceeded to reassembly it, wich, to my delight, was absolutely uneventful.

Oil was painted on each sealant ring and metal sliding surface (it has bronze bearings backed with plastic oil seals, and also, everything is sumbersed in an oil bath), and the pump looked fantastic.

So, with the pump completely clean and reassembled, I charged it`s oil bath and...BAM...stalled motor again.

DAMMIT!

I had either reassembled it wrong (highly doubted that) or had some problem, OR, most likely, the motor could only run on three pase, or was a dud. Just for the heck of it, I decided to connect the pump to the lathe in some perilious yet controlled way (with a flexible coupling! don't worry). But, upon starting the lathe...

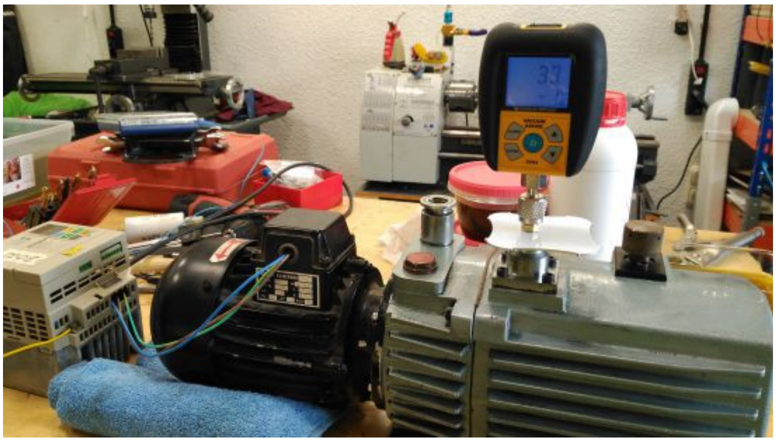
It went to 60 microns right out of the bat! A-Mazeing!!! (pump is designed to run at 1400 rpm, however, my lathe just does 1100). So the pump worked fine, I just had to replace the motor.

To the shop I went, ready to buy a motor. However, you know when a shop owner really, I mean, REALLY listens to you and your problem? I could see his brain trying to work a solution for me. And indeed he worked it out. The motor was fine, however, using a capacitor to cheat a three-phase motor, reduces it's performance dramatically. Once that was established, he raised the "wait for it finger" and came back with a Variable Frequency Driver.

Went home, looked at the manual, scratched my head, looked at the manual some more, understood it has codes and such, programmed it to run at 50Hz, (55 max.), tried the motor without pump to confirm direction of rotation was good, and crossed my fingers:

That's a fantastic vacuum! (for such an old pump) On further tests, the pump settled between 40 and 50 microns, wich is an awesome vacuum, nonetheless.

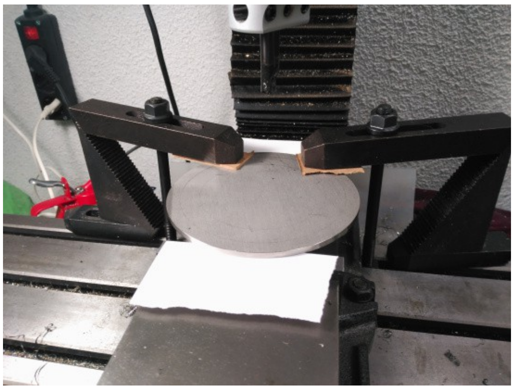
Mind you, at 700 microns you can already start a turbomolecular and at 200 microns, you can start an oil diffusion pump, both for very high vacuum, so, I was ecstatic.



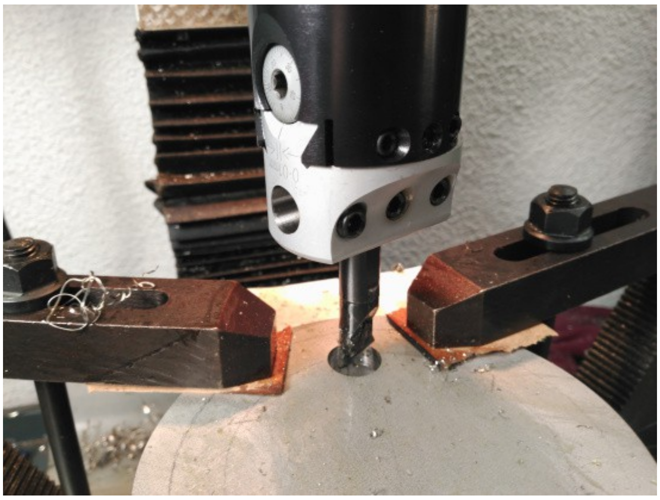
In this moment I also made a stainless endplate. But, why change from aluminium to stainless? KF16 weldable flanges like these (and all other KF joints, for that matter) come mostly in stainless steel. At this point, it is worth mentioning that altough these flanges can work dry, it is highly recommendable to use HVAC grease in them, so they seal even better. Remember, high vacuums are tricky and deceiving. XD

I bought one before finding a stainless supplier, but even then, for the cost (I think it was 8€) I much prefer to just buy and save machining time/inserts/material. Altough I have material from wich I could have machined an aluminium adaptor, welding aluminium is a pain in the ass, compared to stainless, iron and similar, so, even if having found a cheap place to buy stainless stock, I just went for that (buying the piece).

Plate holding and drillset. 7-10-13-15-16mm and then the boring head up to 19mm



Finishing the hole, TIG welded the nipple and began assembling the vacuum lines.

At this point, I realized that, unlike the SAE fittings, the whole plumbing was metal. That meant trouble if I wanted to use the end plates as electrodes, because they could put the pump at potential, making it risky at best, ot damaging the pump at worst.

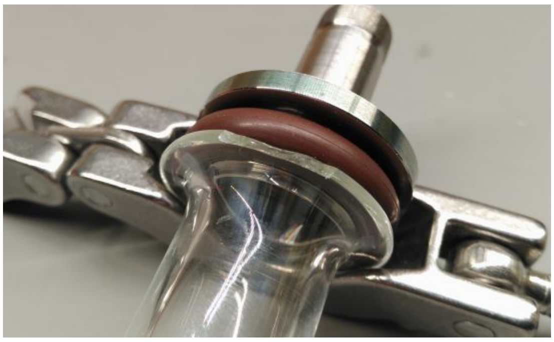
I looked for KF isolators, but ceramic ones where unaffordable and glass made where not cheap either, not counting that probably the sellers would not even do business with an individual.

So, I bought borosilicate tube and set my lathe to slow cooking.

Hmmm, looks like the part, doesn't it? Also, It fits.

It closes:

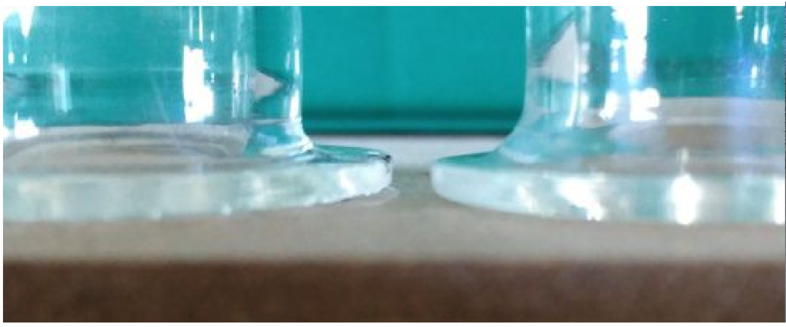



Aaaaand...it breaks. (WAS expected, it doesn't have the proper 15º slope, for starters)This was done with absolutely ZERO effort, just heating the glass and poking it with a graphite rod.

So, I went a bit further and bought some graphite board, to try to best form the shape.

Once I had cleaned the mess that it is to work with graphite, I decided to try it out...and at first it worked. You can see a definite improvement in lip straightness, and a sharper edge.

So, a more advanced tool was made, again, making a real mess, and was tried out.



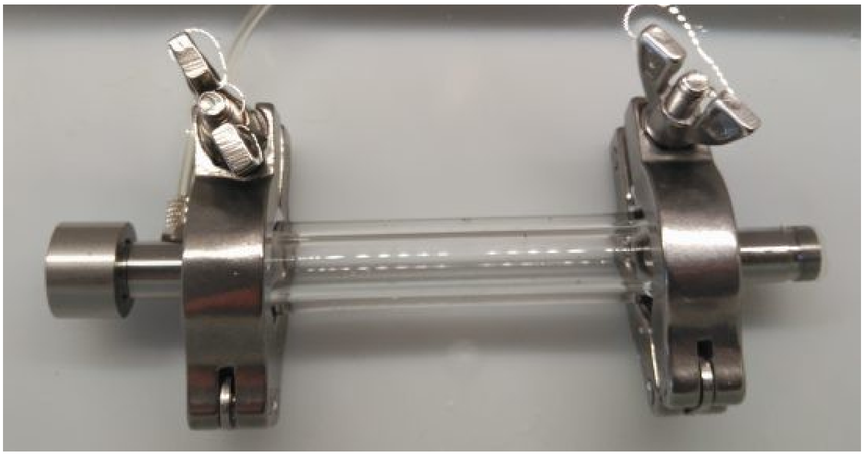

Aaaaand I messed up.

I managed to break or deform all four extra tubes (19*100*2.5mm, borosilicate). I could not even cut the tubes to try to salvage them, they just broke (tried scoring as I don't have a diamond saw)

However not everything was lost!

I picked up the first trial tube, wich had broken a bit, and flamed the edges so they where not sharp. Also, added a 0.5mm teflon gasket so the glass didn't rub directly on the stainless steel clamp.

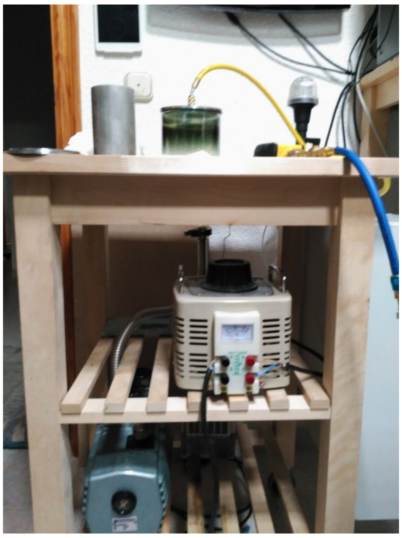
And luckily, it seems to work good enough! I submerged with a small vacuum inside the tube, and there where no detectable leaks. Phew! ^^U



Lessons learned:

1. I think I am working in the plastic zone, as the blowtorch didn't seem to have enough oomph as to really fuse the glass. Since I was not properly fusing it, molding a specific shape was not possible, hence my problems. Also, it made repairs impossible. I should upgrade my setup to an Oxy-something flame.
2. A Blowtorch will only work with *relatively* thick glass, thin glass will heat too much and deform easily. Either use a very small blowtorch or a miniature Oxy-whatever torch.
3. If just a simple lip works, it's better than trying to make a full shape with my basic tools. Next tubes will be made simpler, then, I might try to mold them if I have spares.
4. Still, having to buy 5 new tubes and trying again, is way cheaper (as a whole) than buying a brand name tube. (as of now, I might have spent like 30€)
5. Cutting glass with the simple scoring method only works with the Oxy-something torch because it is almost a point source of heat. A Blowtorch heats too much zone.

Crudely put everything together and quickly reached 160 microns and drove up the voltage...but past 1000V no plasma was to be seen. I verified connections in case a cable was loose (highly doubted that, but one must check everything). and finally, tried increasing Ar pressure to 1000/1200 microns, wich obviously arced. Then decreased the vacuum again...and had to go waaay up (voltage wise) than before (with the cheap pump) to get some plasma glow.

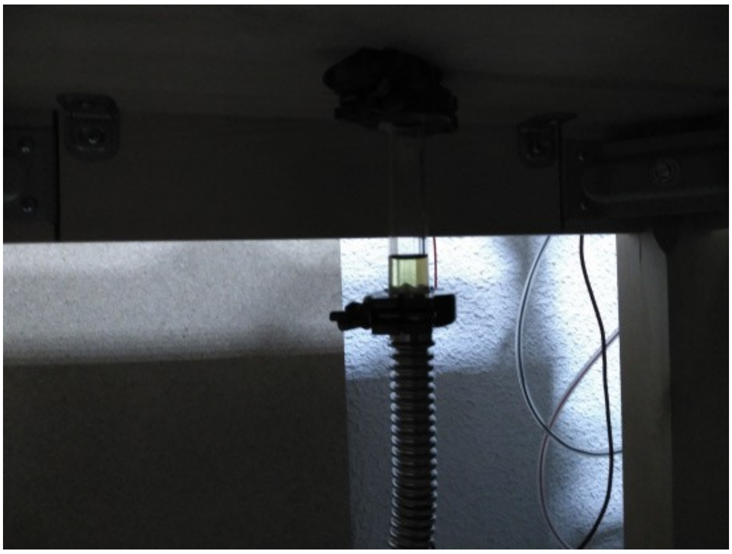


With my cheap multimeter maxed out, an arc current spike fried it out, so I don't really know what voltage this thing required to light up at 160/140 microns. All I can say is that my guesstimate on the cheap pump's ultimate vacuum was probably waay out, more in the range of 500/800 microns (can't know for sure).

In the end it was very late and had to stop the pump, so I left it unvented as a test for the integrity of the whole vacuum circuit.

Aaaaaand...

Yup! I forgot this pump doesn't have a non-return valve, so the oil was sucked up the circuit. The whole vacuum chamber was soaked in oil when I arrived from walking the dogs, it must have went up quite far, however, the rest of the circuit hoses apear to be clean, so I guess it bubbled up in the chamber. Well, this is not worse than having a blow-by with an oil difussion pump. Luckily I already bought a vacuum valve, so this shouldn't happen again. ^^U



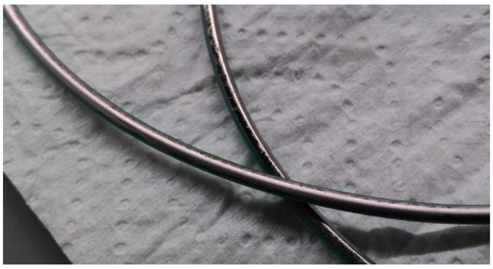
Anyhow, next morning i decided to try some sputtering (yes, without cleaning the oil mess...it was just a quick and *dirty* test).

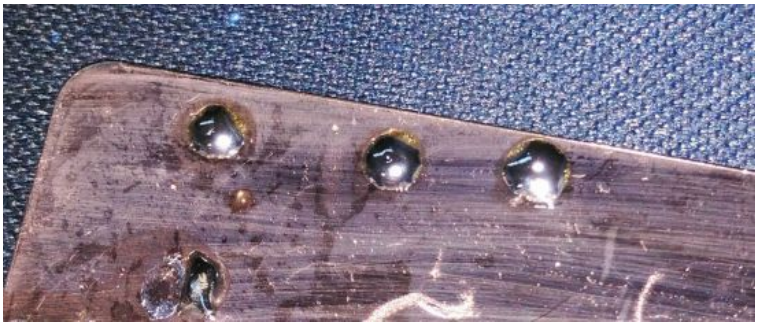
Aaaaaand...

¡¡SUCCESS!!

This was in the adhesive side of a smartwatch glass screen protector, so the copper crackeled, hence the small test point and it was retired from the chamber after a few minutes, so the copper thickness was small.

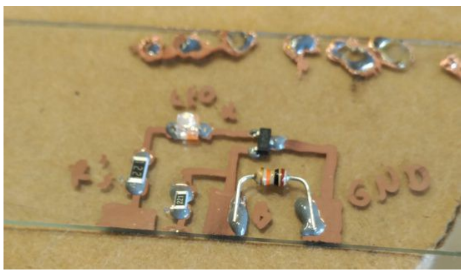
Anyways, definitely good copper. Aplied some Sn/Pb solder with the soldering iron and it wetted perfectly.





Also accidentally deposited copper in the centering seals XD!

For fun, I tried to do a simple circuit on glass. However, the copper film was simply too thin, and the solder paste destroyed it when melting. In any case, that just requires more time in the chamber. I'll have proper deposition figures soon.



So proud!

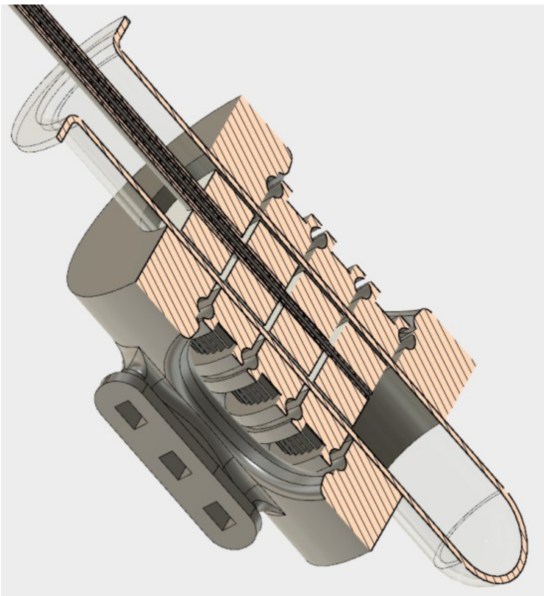
Glass Feedthrough manipulator.

Making feedthroughs for vacuum is no easy task, materials must be taken into consideration because of outgassing, as well as the air-tightness of the interface.

Luckily, normal neodimium magnets with their chromed surface are already vacuum compatible, and so are, glass, stainless steel and teflon. (more on the wikipedia article exactly about materials)

As you might already know from the vacuum chamber, I had started basic glass forming, wich happened to be an ideal skill for the manipulator project, as I could form a test tube end to be compatible with vacuum fittings.

After confirming that I could indeed shape the end of a borosilicate test tube, and that with 10mm separation for 5mm magnets, it's possible to make full turns without stage interference, a quick model was sketched in Fusion.

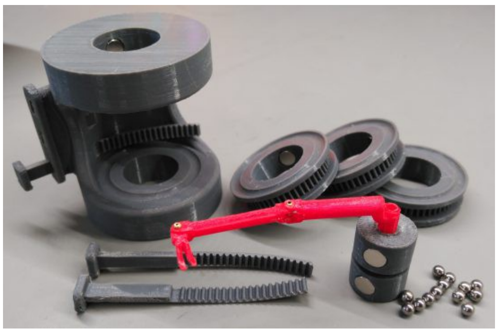


The external means of actuation must provide independent rotation for each axle AND whole assembly vertical displacement.

Each gearwheel holds 2 magnets inside and raceways for 3mm bearings. Individual control is achieved with a pushbutton coupled to a gear rack.

It should look like this (left).

A test holder was designed and 3D printed in pla. (15 hours later):

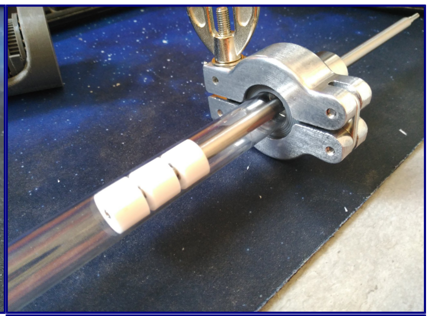


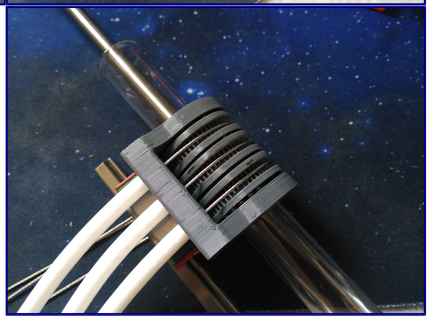
I only had few 3mm balls wich allowed for only three per stage, AND two couplings from the previous test, but it should serve to prove the point.

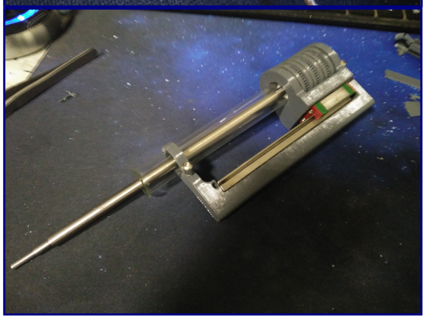
For the final version I got 3mm ceramic balls, as they have become very cheap with the fidget spinner craze.

Once satisfied that it would work, I also made the rest of the vacuum pieces. PTFE guide for the rods and magnet carriers for them.









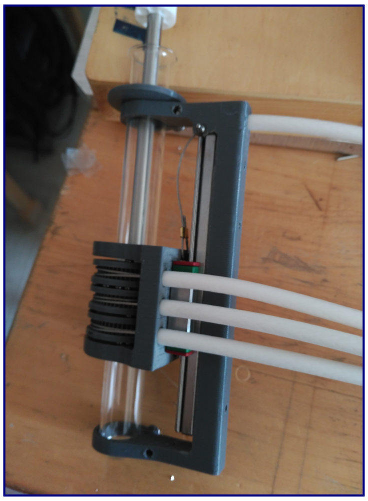
After that, the external actuation needed to be redesigned, as the gear/rack mechanical coupling proved impractical, so I switched to bowden drive:

I had thin braided steel cable in my workshop, for pneumatically pulling things in other projects. What I did not have was bowden tube of any kind!

Coaxial cable, help me!

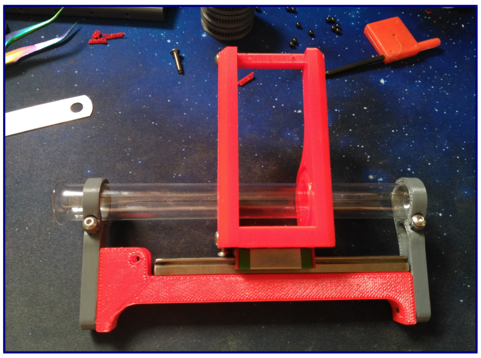
UHF cable core is usually made either of poliethilene foam or, in higher grades, from PTFE. I wasn't as lucky as the second choice, but for short distances and small forces, PU foam would work fine. (for future projects I did order PTFE tubes)

A linear rail was added to the back to attach the motion driver to the test tube and provide Z axis movement/control, wich would also be bowden controlled.



Springs on the other side of the bowdens would provide cable tension.

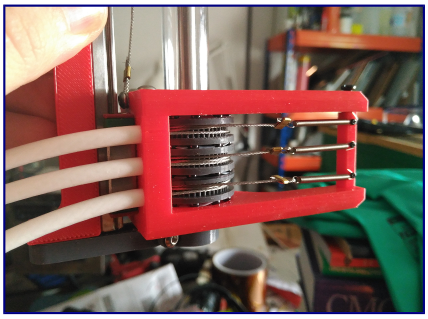
However, altough the bearings could take it, they exerted much lateral force in the pulleys, binding the rotary motion, so, a second version with zero radial net force was implemented.



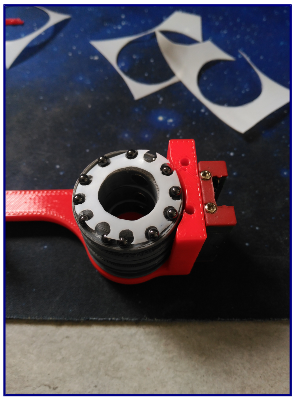
The axis of the push/pull force in the cable sit in the same plane, nullifying the force exerted on the pulley (technically, it generates a twisting motion as the cable does not alignt with itself, but the bearings can cope with that easily)

Also, the fixed test tube holder didn't really work, as each test tube is slightly different, so, the linear guide holder was made as separate pieces, making the tube supports adjustable.

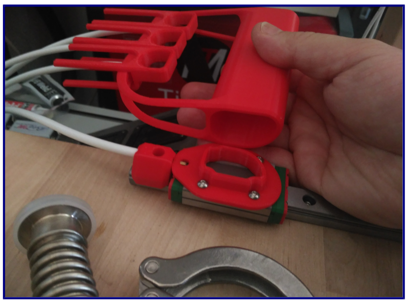
Teflon ball cages where scissor cut so the balls would sit properly in the pulleys.

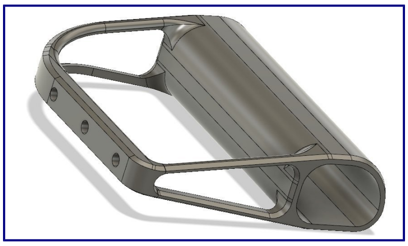


Small sections of brass tube would be flat clamped to the cable to make connections. After that, it was time to make a hand controller for it. So I mostly went nuts with the chamfer tool in fusion 360.



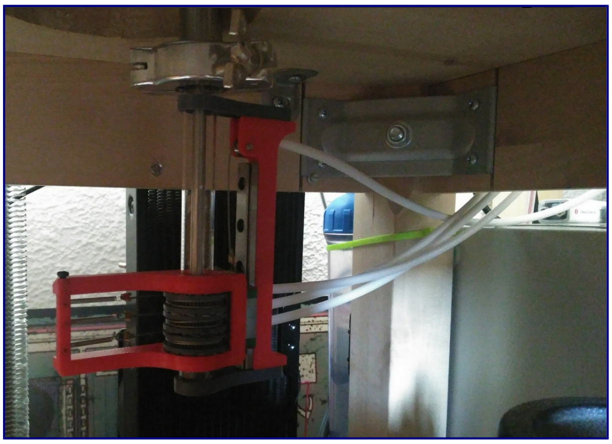
That hand piece would get attached to a linear rail with an adaptor, wich in turn would be directly screwed to the sputtering table.





The whole hand will move the Z axis, whereas each finger will have direct control of one of the pulleys.

Here's a bottom view of the assembly coupled to the vacuum chamber. All the bowdens where cut to the minimal lenght and lubed with silicone oil.



I now have a modular system with 3 coaxial axles with Z movement that I can employ for anything inside the vacuum chamber, WHILE it is operating.

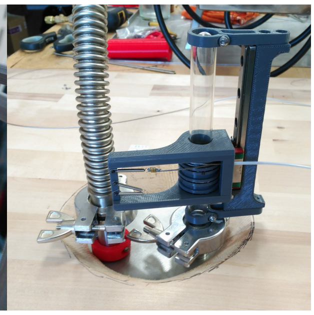
I can have different motion groups for different purposes and all I need to do is remove the internal magnet assembly, wich slides out into the chamber, and put a new one, with different end effectors/holders/targets.

Here, for example. I'm spot welding a small strip of stainless, in provision for the small arm that can move samples around:

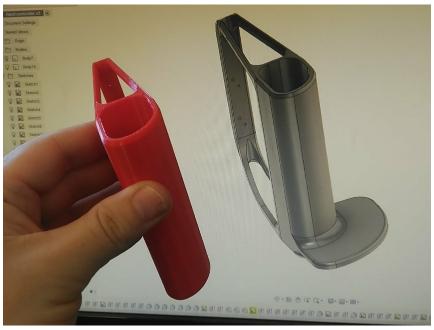
Instead of an arm, I can use it to put a plate over the samples and cover them until the sputtering is stable and clean.

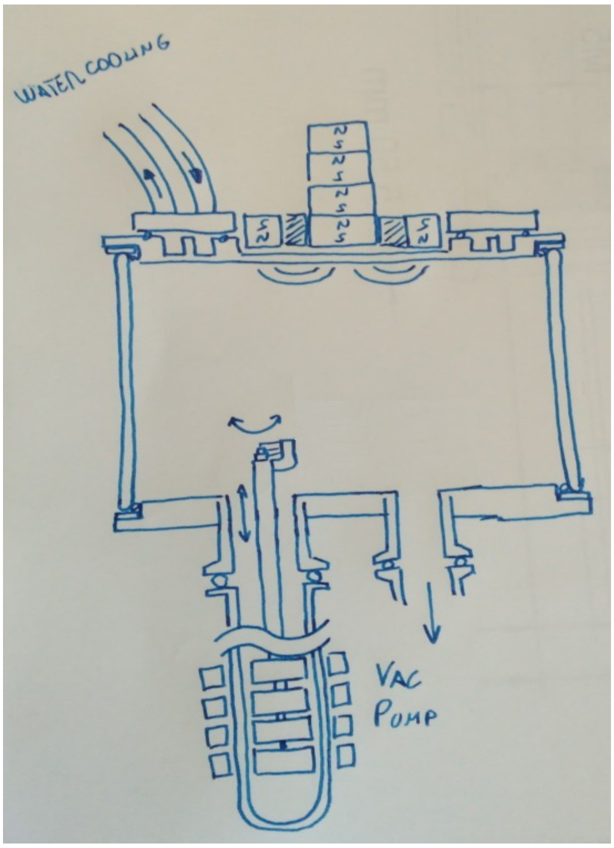
Or, I can have one arm with targets, and switch them at my convenience, while a second arm covers the samples meanwhile the changes (leftover sputter of a different material) stabilize.

There are infinite possibilities for this, It is just a matter of what work I need doing inside the vacuum environment.



For the final version, designs where slightly changed to accept readily avaliable 2mm PTFE tube as bowden and the finger rings lost their guides, as they where no really necessary. Also, the hand actuator was redesigned to have a handrest:





Final Vacuum chamber cutaway with magnetic trap, water cooling and glass feedthrough.

Extras.

In here you will find extra information about chamber refrigeration, vacuum plumbing and cleaning.

Magnet care.

As you know, plasma is a quite hot stuff. Usually it's density is so low that thermal transfer quickly reaches an equilibrium much lower than the melting point of materials. However, in a sputtering machine, you do concentrate plasma in a small area, so, continuous operation requires a bit more than just having a passive aluminium heatsink.

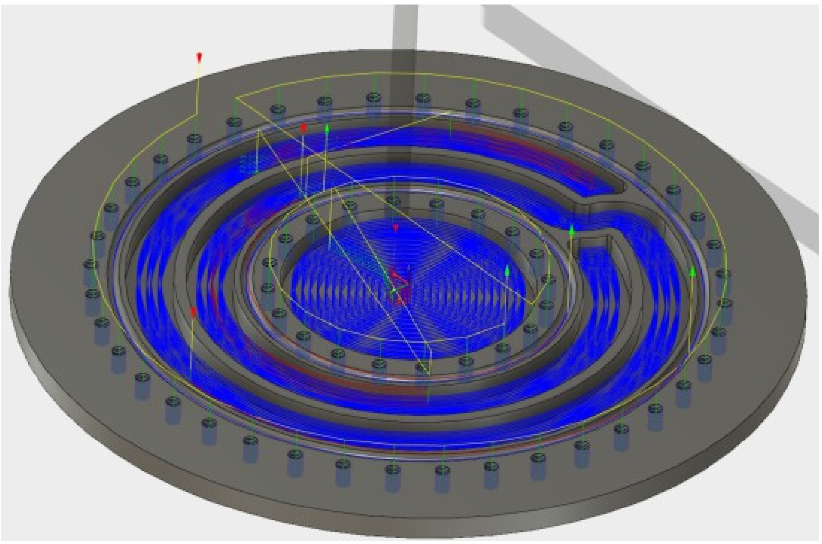
Yes, you can just powermelt the target.

An aluminium plate with concentrated plasma heats quickly, as I have found out. After medium sputtering runs (20/25 minutes, NO Argon), the magnets are so hot you can barely hold them in your hand. That must be around 40/50ºC, wich obviously can only get worse. Normal (cheap) neodimium magnets have a curie point of just 100ºC, so it's better not to risk damaging them. And just because fuck yeah, I want to liquid cool it to allow extended operating time.

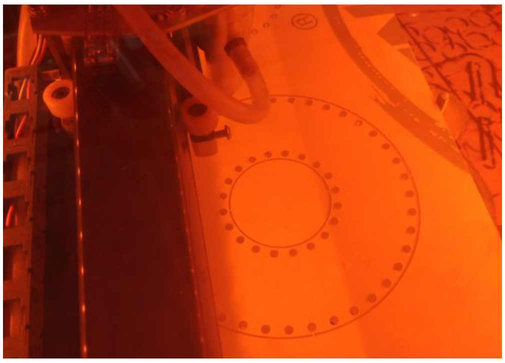
Let's have some water channels cut into the plasma trap plate:

At first I was thinking about machining it by hand in stainless, as having a rotary table makes it a fairly easy task. However, later on, I realized I could simply make it in aluminium wich is a better heat conductor AND my 3020CNC can machine it, if you are patient.

I'll still have to tap all the holes by hand, but that's a minor nuisance.



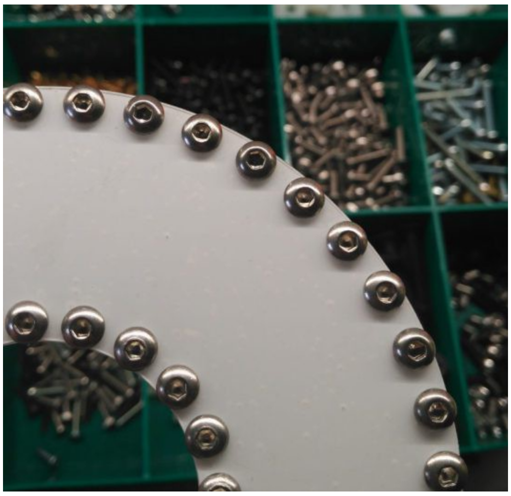
Having a laser cutter helps immensely with reducing waste (milling acrylic is a pain in the ass)

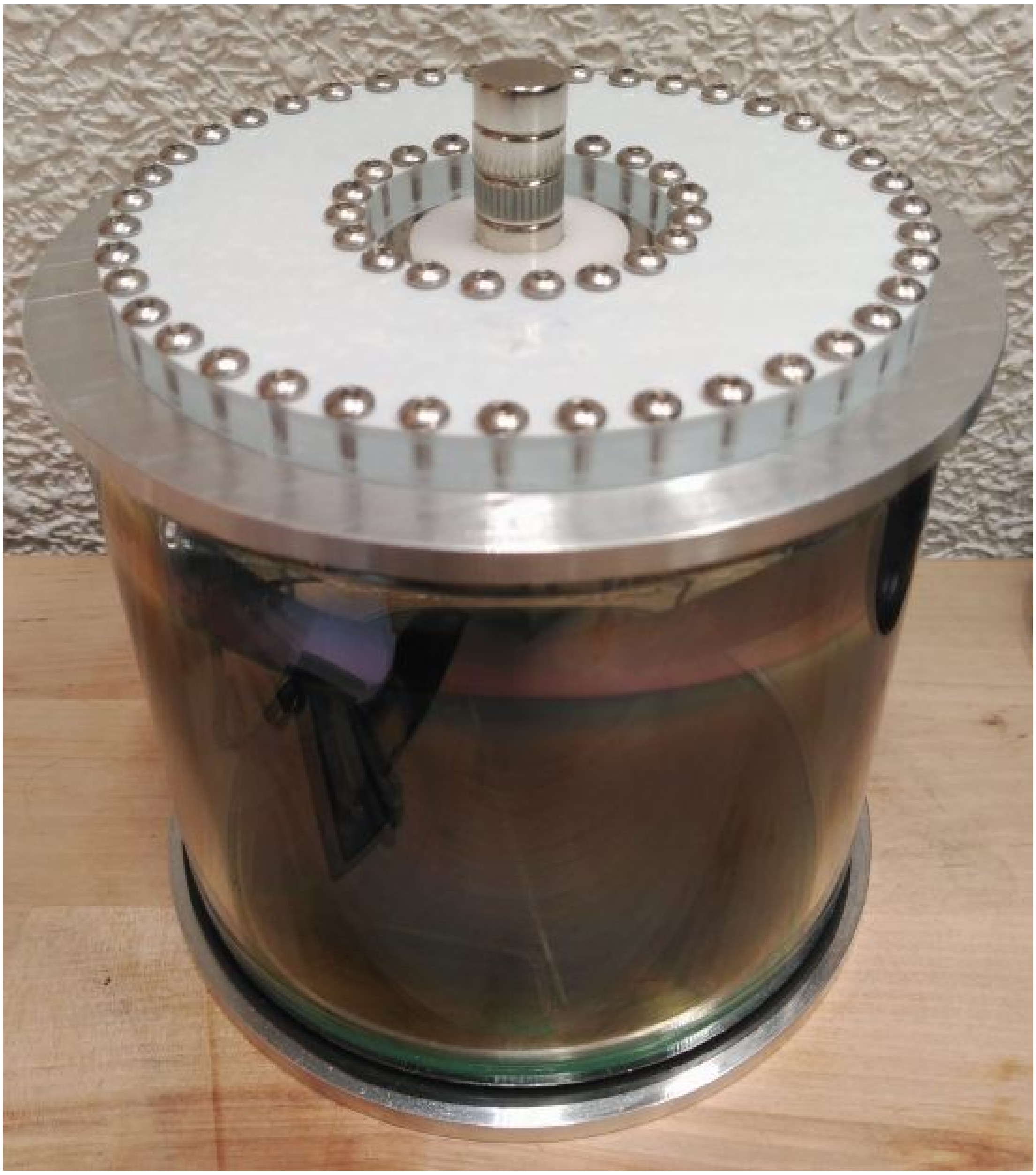


Some might say so many screws are overkill, and might be true, however, given the diameters involved, and that I am using viton O-rings wich are not super flexible either, I have just preferred going all the way. The acrylic is 7mm to ensure minimum deflection.

Yeah, I should have made the utside border a tad larger. (The inside diameter has to fit the magnets, so there's not much room there.)

The screws are stainless steel, so I don't think they will affect the shape of the magnetic trap.

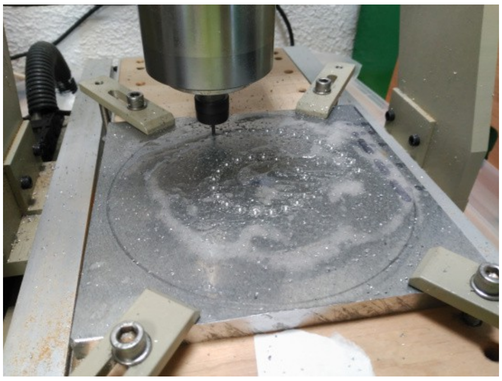




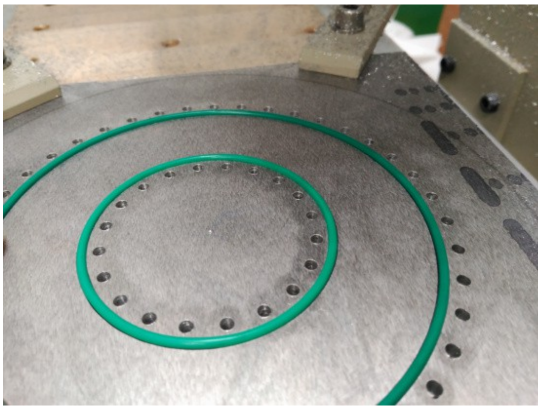
Test fit.

Machining!

I was too lazy to actually make a separate program for spot drilling, so I used the same drilling program, but added a +6.5mm offset so it would only peck 1.5mm with the 90º spot drill, I know, extremely ineficient, but it would have taken longer to start the computer and actually make the program.



After drilling, the o-ring recesses where cut, followed by a quick seal check, just in case y messed up, or the o-rings where wrong.

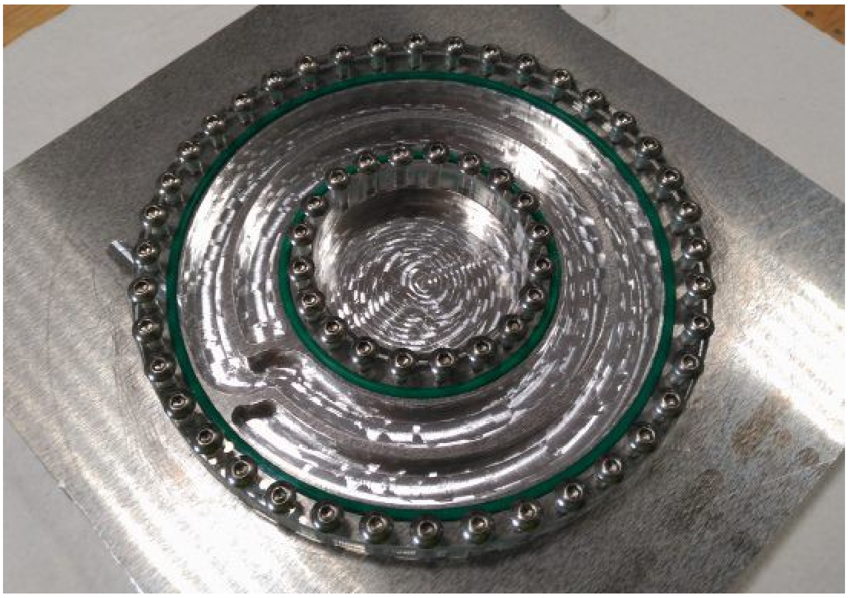
As an afterthought, I could ave made the slots 0,5mm deeper, so the acrylic would fully compress the rings and sit flat against the plate, but well, as I said, an afterthought.

The magnet slot was cut first:Then the water channels:

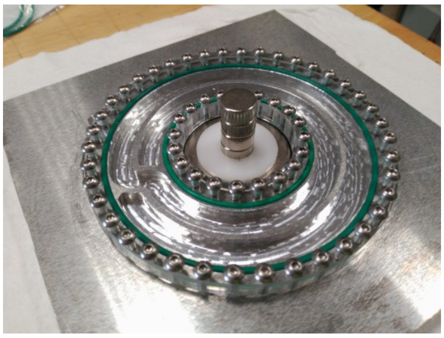
You can observe the little misshap with mach 3 going first to Z-Ø instad of X/Y-Ø, and a not-so-exact Z height setup. Fortunatey, the cut was ony 0,15mm deep, so it doesn't affect the overall performance, just my inner pride. (I tested a newish 2-flute endmill instead of the oldish 4-flute I was using, but it underperformed, so I changed back, and messed with the paper thickness Z height procedure. This part is not critical in the Z axis, so I wasn't particularly worried.

Anyhow, everyone hail the awesome cooling plate:



I accept the fact that there will be some blow-by between inlet and outlet, but most of the water should still flow along the path.

Magnets!



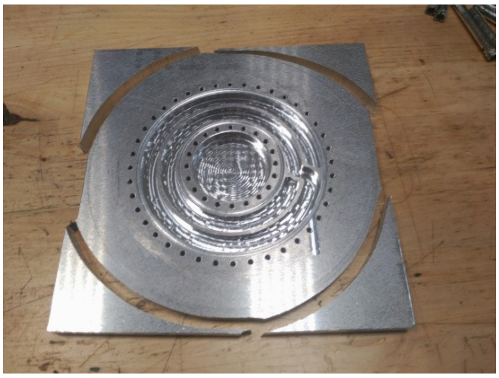
The CNC part took 6.5h to machine in a cheap (ballscrew) 3020CNC router, with the following setup:

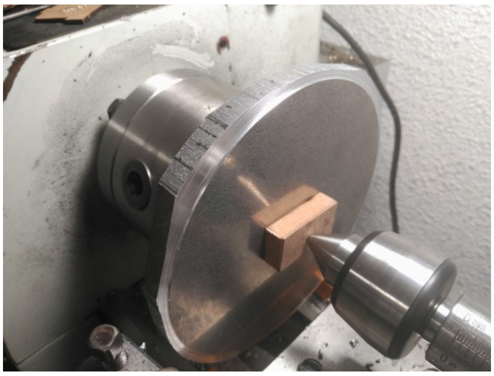
- 2mm carbide 90º spot drill, 2,5mm carbide drill.
- 8mm depth, 0,25 pecking depth. Lube between holes.
- 2mm (R1) carbide ball endmill.
- 4mm-4flute carbide endmill, flat, center cutting.
- 0.5mm depth of cut up to 5mm depth (6mm for magnet), 1.25mm stepover. 75mm/min plunge. 150mm/min feed.
- LUBE as if there was no tomorrow. Also make sure all the router bolts are tight.

These kind of machines are not particularly rigid, so this is the absolute limit of what they can do. If you are patient, tough, you will be able to squeeze it to the very last drop.

Using a locating setup, one could just machine the outside border and flip the part to machine the lip, however, since I have a lathe, I just prefer to do it there and avoid the hassle.

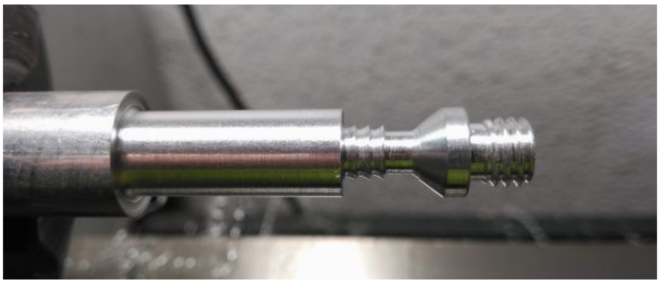
First, bandsaw the corners and chuck the plate from the inside...





...and slowly carve the diameters away.

Oh! Also some custom fittings should be made, amirite?

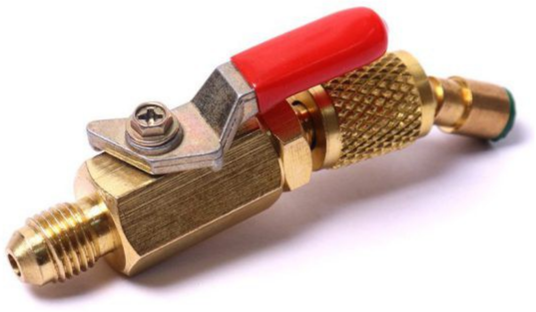


In the heat exchanging department I would like to employ some passive cooling, using a big ass radiator.

I know I could try to hook it up to one of my beer refrigeration units, however I pretty much prefer not to, because the vacuum chamber is at potential, and having liquid wiring around is...well, not my thing. Also it will make for a standalone unit (not that it is going to go anywhere, but hey, what if I want to sputter in the living room?) Should that not suffice, I can always connect it to one of the machines later, or make a heat exchanger or something.

In any case, the particulars of the radiator are irrelevant, any liquid computer cooling setup should work (to some extent). So, pick your poison, as some say.

Valves.

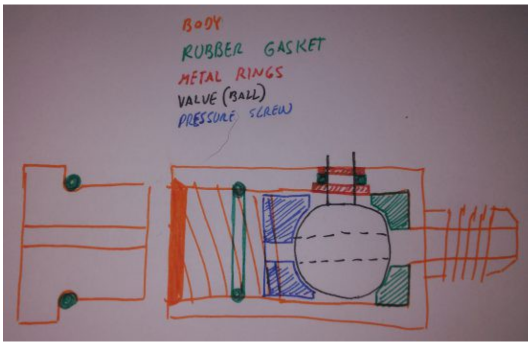


You will probably have started with a refrigeration vacuum pump (we all do, don't be ashamed) and it's interesting, but headachy 1/4SAE connectors. For those, there are not that much range in valves to choose, and the most common is this one:

For sure there should be high quality ones out there, but if you have the money for those, better skip this step and go with KF flanges and a good pump.

For the ones trapped in the 1/4SAE world, be careful. If you must use one of these valves, they WILL NOT seal the same way from one side than the other.

Here's a hand drawn schematic of the insides:



As you can see, the only confiable seal is the rightside. the rubber gasket is under pressure from the ball and the body, so, if any of those seals has to be any good, this one will be. The leftside seals are not especially bad, nor extremely good, they will do, up to a point.

However, the ball actuator o-ring, sitting between two metal plates is something to be aware of. Altough the ball axle itself is polished and nice, the o-ring seat in the body will leave much to be desired, thus, making a less than improbable good seal. Should you have your vacuum chamber connected to the left (vacuum pump to the right) of this valve, I assure you it's vacuum will not last, both open and closed valve.

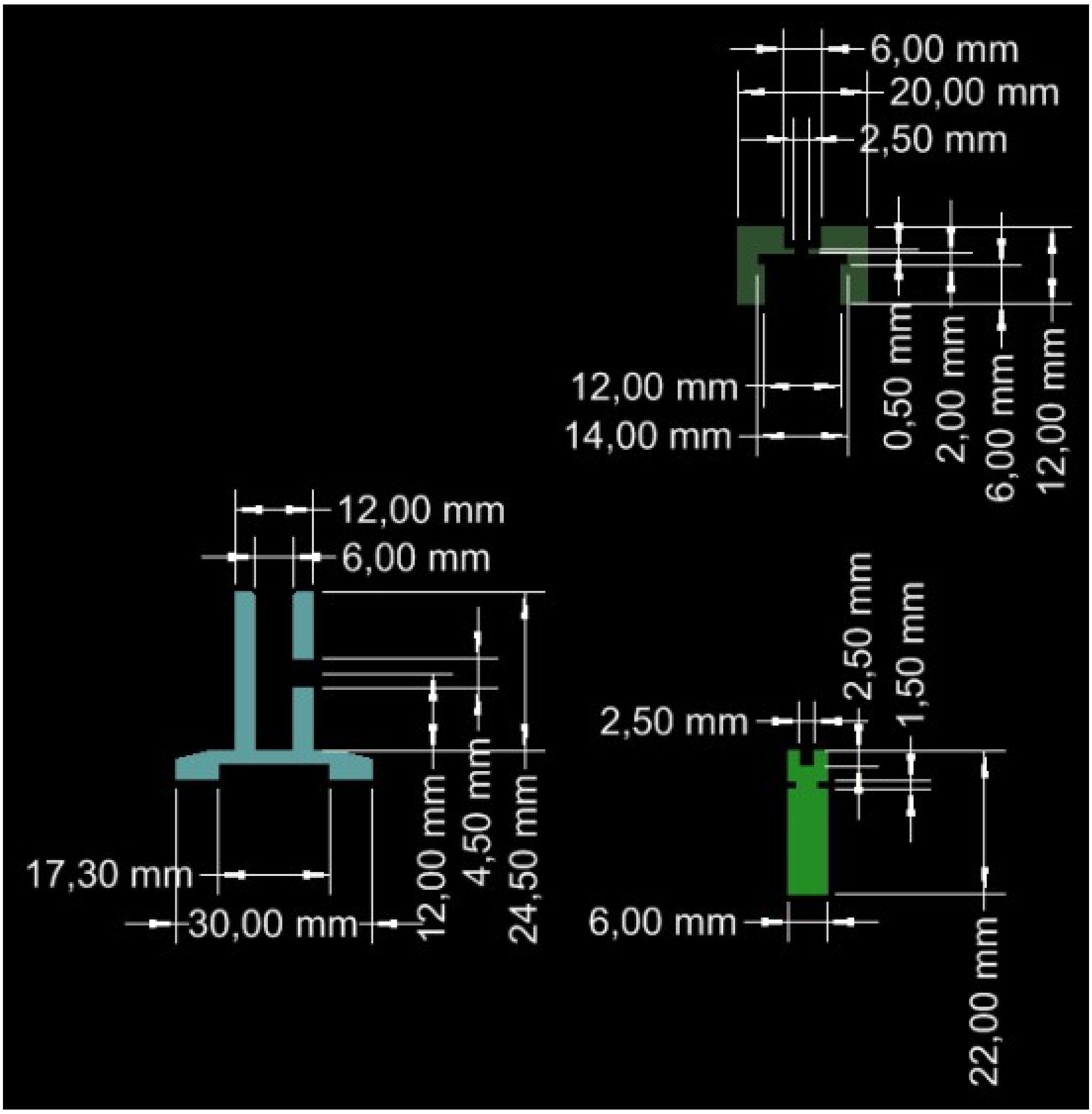
Having it the other way around will not prevent circuit leaks (keeping you from the ultimate vacuum your cheap pump *could* attain) but at least with the valve closed, your chamber stands a chance.

Homemade gas valve.

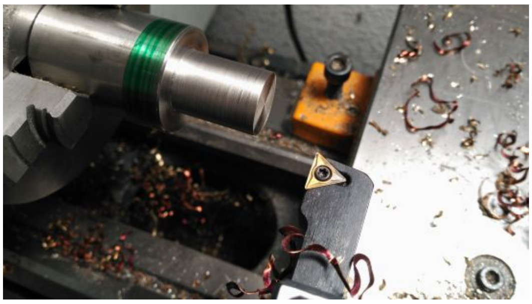
Since we previously established that SAE ball valves aren't the best at keeping high vacuum AND that they won't work well for letting small gas quantities into our devices, some other solution had to be found.

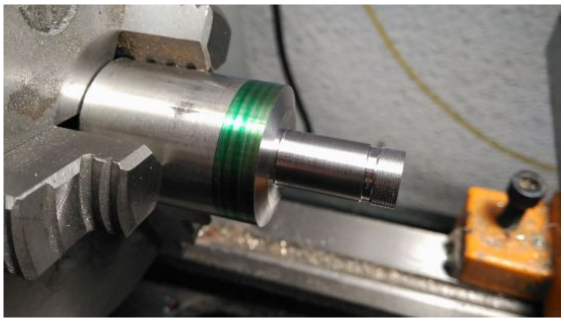
Comercial valves turned out to be extremely expensive, so, it was clear that one more suitable (and affordable) had to be made.

Original plans:



Everything is stainless steel 304 (except the bearings, I know).





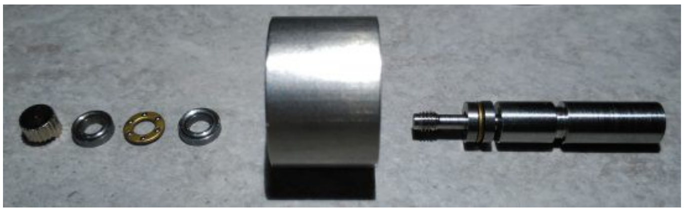
UP: heavy turning (for my lathe), that's 2mm chips.

Unfortunately, I didn't catch all the machining process, I got very busy with it. Here's the final product (minus the o-rings):

Fitting is not critical, but making it a good one, is best practice:

That's some small axial bearings! (3x6x3mm). The knob is smooth because since the plunger rides on bearings, nothing should ever be stiff enough to require knurling. (also, I don't have a knurler :P) As you can see from the timelapse, I changed the screw design into a prong extension, easier to machine and allows for simpler play adjustment.

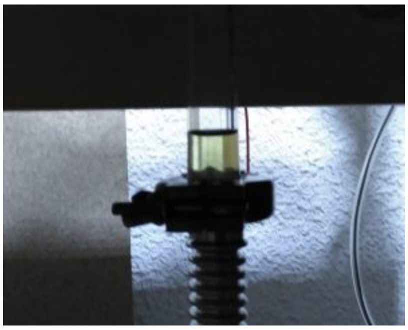
The ball bearings allow the actuation of the plunger without o-ring twist, both up and down. (the up might be a bit overkill, but hey, I already got the bearings, you know).



And most importantly, the gas connection.

It accepts 2mm RC compressed air tubing.

Cleaning.



Remember I previously talked about oil flowback?

When It came the time to clean it up, I could not find much information about it, so I just got it soaking in kerosene all night, ensuring that the tube was well rinsed.

The next day, I gave it a very hot water rinse, followed by a two day drying period.

Aaaand...

Well, that surely wasnt enough, because on the first run, it fucked up my pump's oil. The tube gor freezing cold, the oil got milky white, and the vacuum was only 1300 microns. So, that was not good enough cleaning, I guess.

Obviously, something was evaporating quite vigorously. Being a corrugated tube one should not dismiss it's big surface area and crannies trapping moisture and water. In the end, I figured that whatever was in there, had evaporated into the pump's oil, so it was good to go.

Changed the oil and...

Well, fucked up again. Whatever was in the tube, there still remained a lot AND, being left cold before, probably didn't help. I uttered some NSFW words and then proceeded to evacuate all the oil in the pump, AGAIN.

Before leaving the pump, I filled the vane chamber with clean oil and ran it brefly (2 o 3 seconds), so whatever was left from the oil foam from before, was ejected out with clean oil. I then left the pump alone and concentrated in the culprit (the tube, not me, XD!)

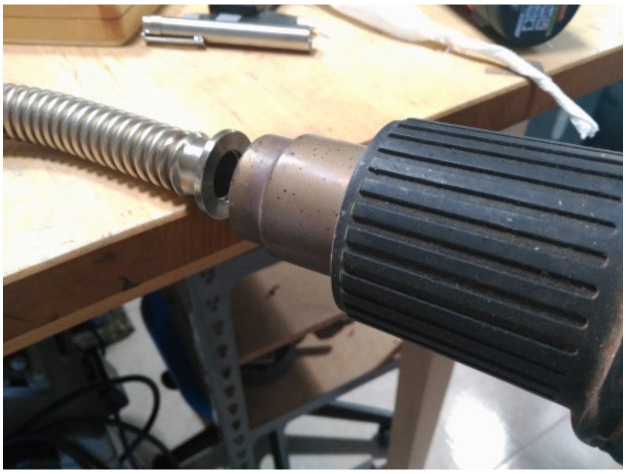
First I gave it a weekend fill with KH7 degreaser with both ends covered.

Afterwards, a hot water cleaning, then a vigorous shake with a half fill of isopropyl alcohol, followed by a blowout with compressed air.

Since I wasn't still sure about it's dryness, I hooked my shopvac to one of it's ends with my hand, more or less like this, with mi fingers closing the gaps:

! WEAR EAR PROTECTION !

Lo and behold, the tube got cold. Not freezing cold, but noticeably nonetheless. So, I alternatively hooked the vacuum on either of it's ends until the tube remained at room temperature.



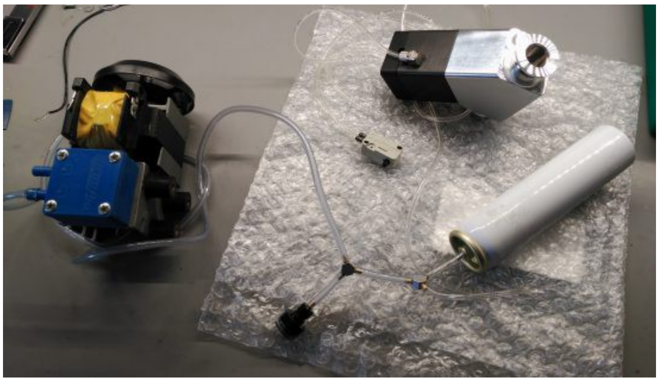
AND then, toasted it a bit with my heat gun at mid power.

I'm sure there are proper written down procedures for this but I haven't found any, altough seriously, If the tube is not clean after this, buy a new one. :S

HVAC valve.

In the aftermath, I finally set myself to give some attention to the pneumatic HVAC valve I had bought. I found this one on ebay for cheap, it was 1/3 the price of any other mechanical valve, and I figured it would not be that difficult to operate.

I also had this cheap diaphragm pneumatic pump, wich, combined with some of the tray elements and spare parts from my RC drawer, amount for a standalone pneumatic system.



Max pressure is 2 BAR, enough to operate the valve. I added a miniature reservoir so the pump only has to run briefly at machine start-up. The valve is a VM1000-4NU-00 pneumatic microswitch.

The Y splitter, reservoir and manometer, are all RC air retract parts.

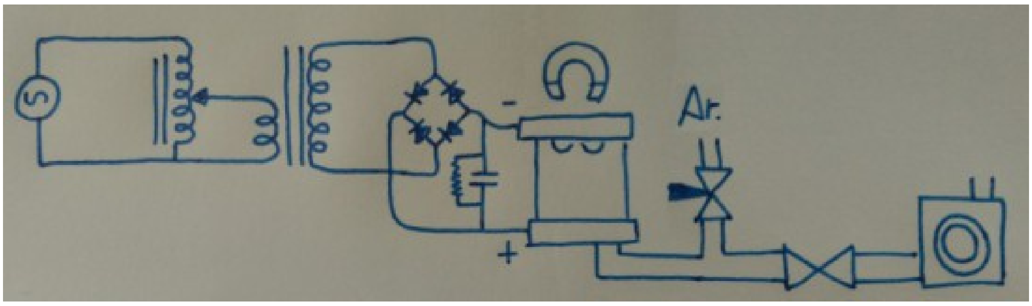
HV Power supply.

To actually deposit metal under vacuum, you can either evaporate it, or magnetron sputerize.

Simple evaporation requires a power supply that can drive very high currents to heat a "boat" made out of tungsten to white hot, so it's contents can evaporate. Besides requiring said single use recipients, that amount of current will heat things a lot, wich has it's own set of problems.

Thus, I decided on the magnetron machine because the power supply can be built with a variabe transformer and leftovers from a microwave oven (and some HV diodes). And depending on the shape of your chamber, not even electric feedthroughs.

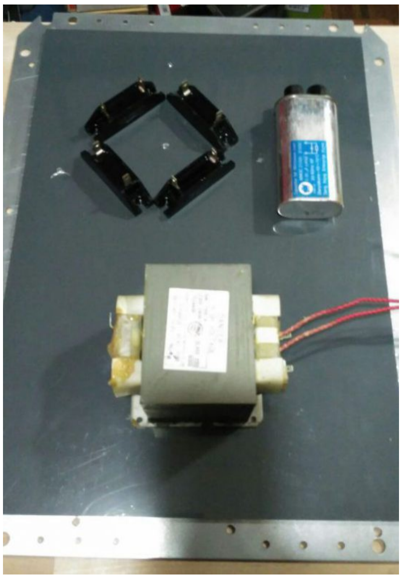
Schematic:



From left to right:

- AC source. (220V wall socket)
- Variac 3000VA. (probably a smaller one works)
- Microwave transformer, stock.
- HV rectifier.
- Microwave capacitor with built-in parallel resistor for self discharge safety.

All components get mounted with nylon screws on top of a PVC plate AND a steel support connected to ground.



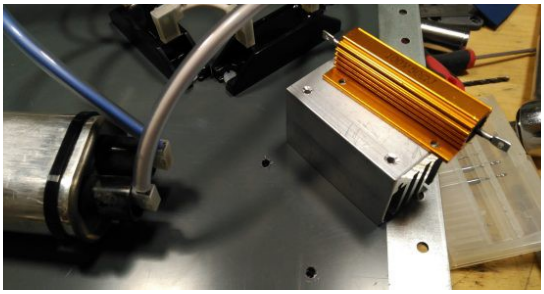
All sputtering I have seen around, reports in their setups about 500V tops, and around 500mA max. Most 2KV diodes I saw in ebay where low power, and I didn't felt like risking a failure there, so instead I looked for power diodes, no matter what the voltage. I ended with 20KV 2A diodes, you can call that overkill, if you want. XD!

Silicone cable was employed everywhere. Long sections were further insulated with transparent PVC tubing.

The capacitor was zip tied to two adhesive nylon stands:

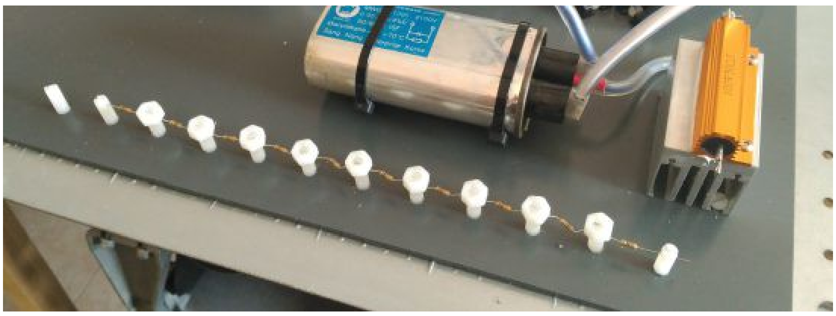
I plan to have dedicated voltage and current meters (I want my multimeters avaliable elsewhere), so I'll use cheap ones from ebay, having them battery powered, to save on the hassle of tapping into the HV line. Or tap into mains line, and risk having spurious currents/voltages deriving from the HV section into the mains section.

There is no point in having a power resistor without a heatsink, right? XD

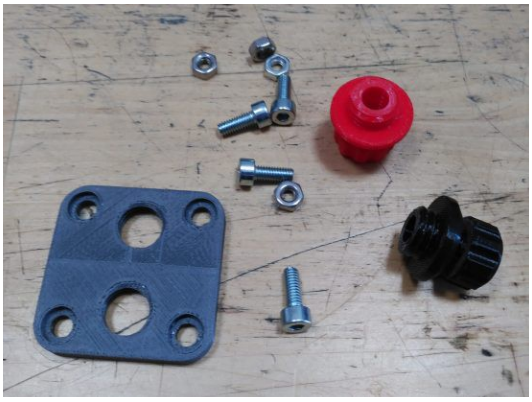


Everything is held down with M6 nylon screws, wich also make good standoffs for the voltage divisor, comprised of 10*1MΩ and 1*100KΩ for a 1/10 reduction.

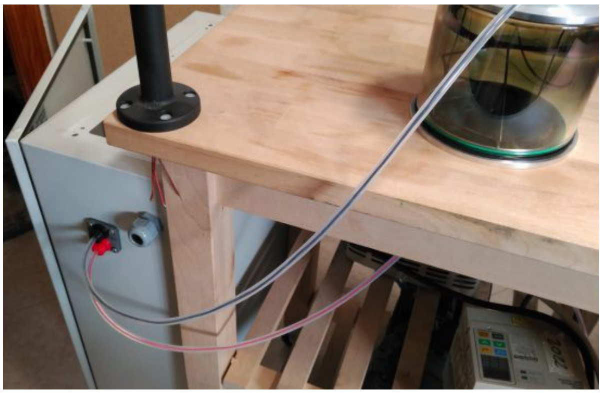
A slot was cut in each screw so the resistor lead would get trapped with a nut, simple but effective.



I also had to deal with the M25 gland and a hole made by the previous owner for a SMEMA connector (SMT line interconexion standard). For the first, I would have preferred to have it at the bottom of the box for the 220V input line, but well, it was free, so I can't complain much, so I just routed the cable on the inside, away from everything to the bottom of the box, to the microwave transformer.



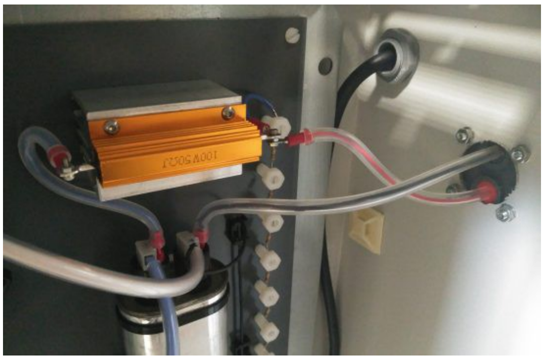
The other hole kinda messed up with my head. I could not realistically leave it there and/or solder something into it to make it disappear, so......I got wild and 3D printed a holder plate and two custom glands.



Since the HV lines also run inside silicone tube, I didn't worry much about PLA dielectric constant and/or conductivity.

For the internal connections I used faston connectors in the capacitor and screw-on terminals for the resistor. The divisor extremes where soldered to silicone cable.

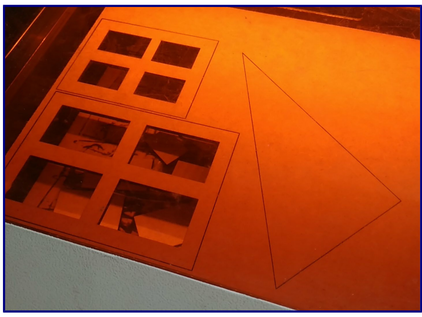
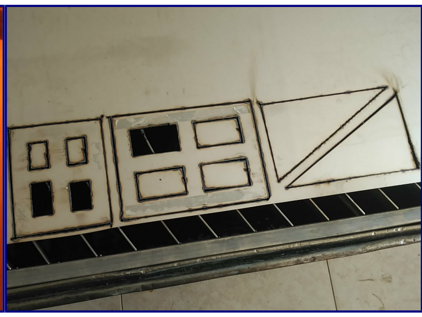
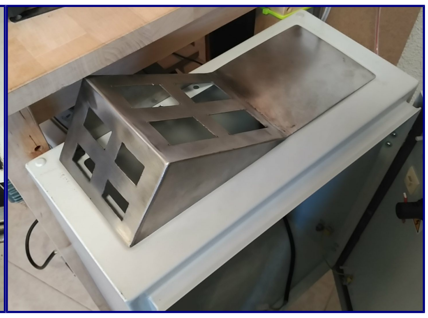
Closeup of the outgoing wiring:



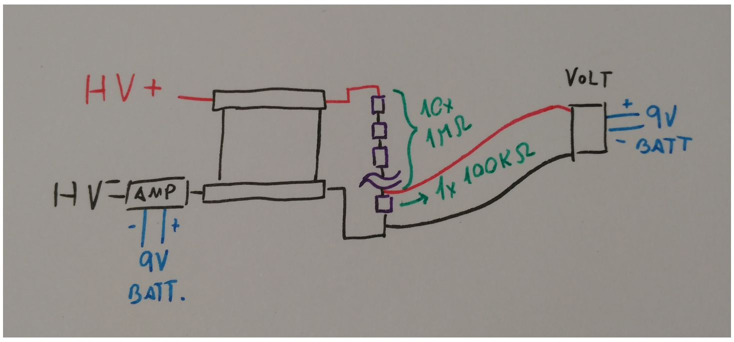
Everything sits nicely and away from everything else, ensuring proper isolation up to the 2Kv+ the system is capable of. Note that the silicone cable was sleeved over the faston connectors, just in case the cable got yanked out, it doesn't hang live on the inside of the case.

Next, the monitor panel.

Current, Voltage, and magnet and oil temperatures. I laser cut some stencils to be used with a cheap handheld plasma cutter, remembering to adjust for the kerf and nozzle width (for my cutter it's 3.375mm/r (1mm kerf)

I have much to learn on plasma cutting, so this was not perfect, but should work.



Since I didn't want to have weird feedback loops between the instruments because of the high voltages, I installed separate battery holders for each one. They are 9V flip-ups from guitar equipment. Also added a high voltage divisor made of 10x1MΏ 1/4W resistors and 1x 100KΏ.

Final setup:

Oven Build.

There are times when I am amazed at what does people find in internet. Like all tubular ovens out there. Well, I was not able to find anything that suited my needs, so had to proceed along the hard route, build it myself.

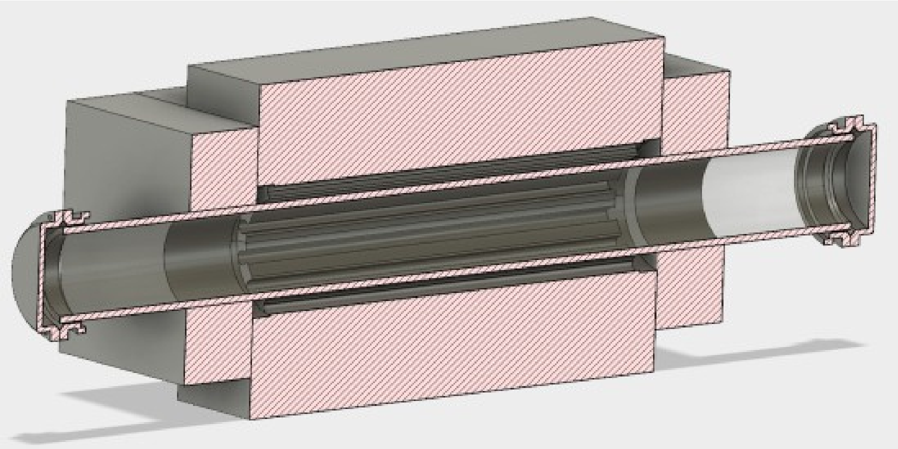
To keep the wafers clean, some form of containment has to be made. In general, semiconductor fab labs and such employ tubular ovens, where a fused quartz tube acts as containment, protection and atmosphere control.

Kilns are not difficult to build, just watch some tutorials on youtube and you are pretty much set, however, a tubular oven has slightly different demands:

1. The glass tube must be Quartz to withstand the working environment, borosilicate won't cut it.
2. The filament is not NiCrom! wich is good for 900ºC max. You have to buy Kanthal, good for 1200ºC and not much more expensive.
3. You want the heat as even as possible, hence the tubular shape of the filament guides/kiln shape.
4. Also, since we're at it, dual temp controllers will ensure that heat rise doesn't generate hot/cold spots.

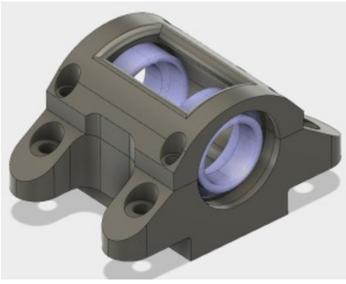
It took me a while to decide on what shape I wanted, but Fusion 360 helped with that, as it became easier for me to just prototype play. I did want a fancy shape that would embrace the quartz tube, but apart from that, building is pretty much straight ->insert filament-join alumina blocks<-.

Once decided, I sourced stainless sheet, square stock and alumina bricks in my country, and then, mainly all the heat pieces elsewhere.

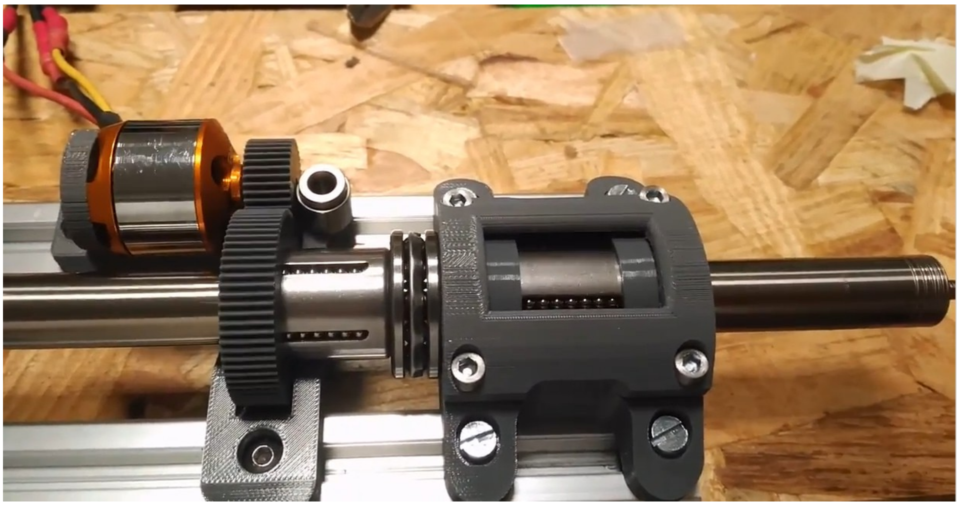


Alumina bricks are easy to saw, but once you want precison shapes, freehand carving is not going to be enough. So, what do you do?

I had lying around a 14mm sliding bar from an old scanner, so I bought some *linear* bearings (14x21x30mm) for it, and encaging those in 20x27x4 radial bearings (via some sleeves), I designed a support for all that (2x) to be anchored into 20mm normalized aluminium extrusions. Since this is a low load, more or less single use tool, I decided to 3D print it instead of make it from a durable material like aluminium.



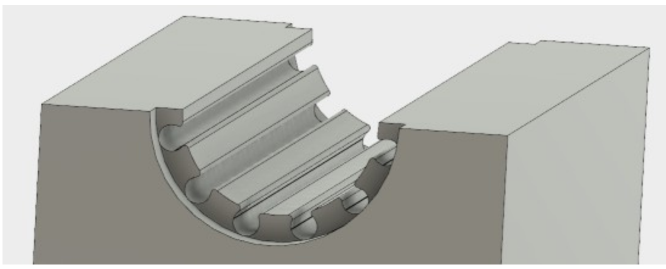
So what does this do?



The *effector* (rod) will have attached some apropriately sized diamond circular saws on it's end. Once the tool and the brick are aligned, you can handfeel the pressure and go as slow as you want on the drilling (because the material is so soft).

I know, I know, I could have used one of the guides as driver with a gear attached to the bearing, however, the motor was an afterthought. I had planned to drill it by hand, but I'm a lazy bastard I guess.

But wait! This only drills the central section and front/back coil recesses but the oven has this shape:



For the coil guides themselves, another machine has to be made, using 6mm drill guide, 6*10mm linear bearings (LM5LUU) and 15*21 ball bearings.

Failed print due to nozzle clog. (dammit, 10h lost)

Since the print failed, I redesigned to be less volumetric and put the printer into another 15h shift (2x):

But each half has six coil guides! how does this work? Magic? No, not really, this adaptor works exploiting the axial simmetry. Once you have drilled three holes, turn it 180º and it will align to drill the other 3.

With all materials gathered (links)

- 6x Alumina bricks. (4 needed, 2 spares/testing)
- 2x SSR 25A+ 2x ssr radiator.
- 2x High temperature K probes.
- 2x Temperature controllers.
- 2x Porcelain connectors.
- 2x Kanthal heating filament 2000W (60cm compressed)
- Quartz tube (45mm OD x 450mm)
- Diamond hole saws (6.5 / 48 / 61mm)
- 3D printed drill guides.
- High temp electric cable.
- Lengths of 15mm square stainless steel tube, screw rod and some washers.

First, a holey test:

If one works slowly, the cores remain intact and you can remove them without having to remove the drill from it's mount.

Big guns. A 48mm drill digs out half of the Quartz tube channel, and a 61mm one cuts the channel to allow the heater to serpentine.

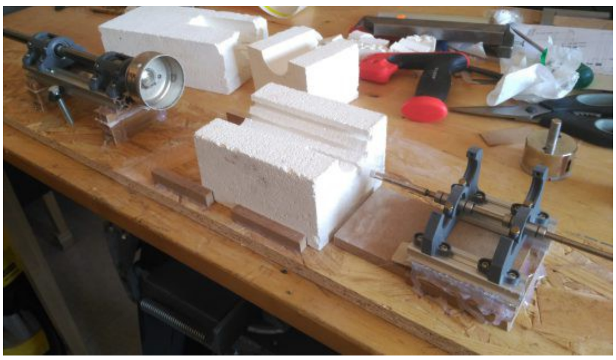
Next, find a way to hold the bricks in place. Justsome press fit wood blocks will do.

This is probably NOT the worst tool in the world. Positioning is within ±0.2mm and angular alignment is good enough.

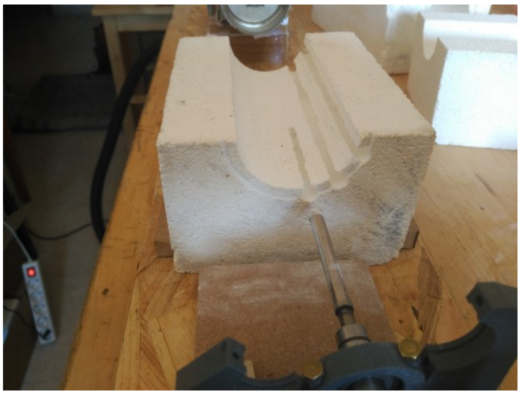
Since this is a single use only (so to speak) tool, I wasn't going to bother doing the mounting perfectly:

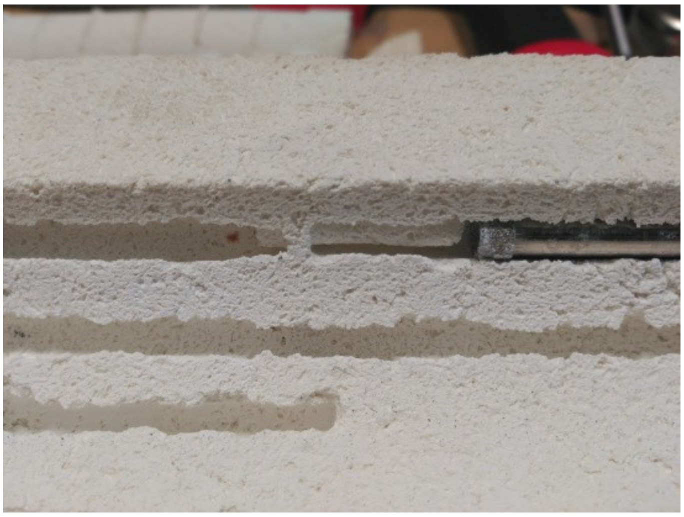
In retrospective, I would make the pieces in such a way that they would fully reach to the base (and also have align markings) instead of this complex centering/mounting technique, but it is done now, and anyone wanting to use them, will have to modify them anyways to suit their blocks.

The complete tool (with short test brick):



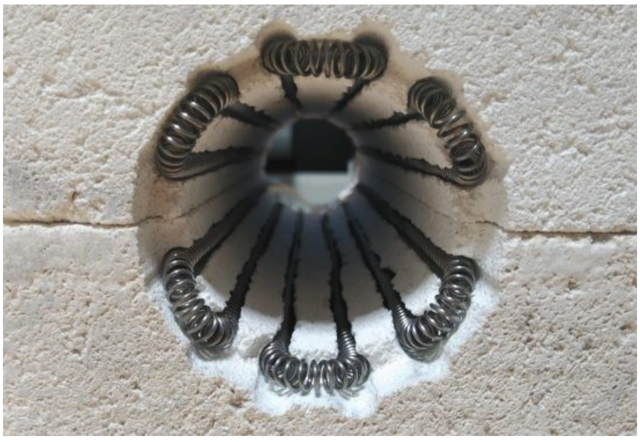
Testing the drill-through capability before commiting with the good bricks. Everything looks nice. The bricks are longer than the reach of the filament saw, so they have to be turned around and drilled from both sides. How good is alignment?





Good enough, I'd say.

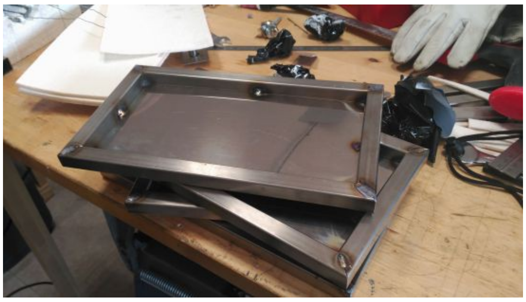
Once that is done, vacuum it good and insert the filaments (pre stretched so there are no shortcircuit between loops)



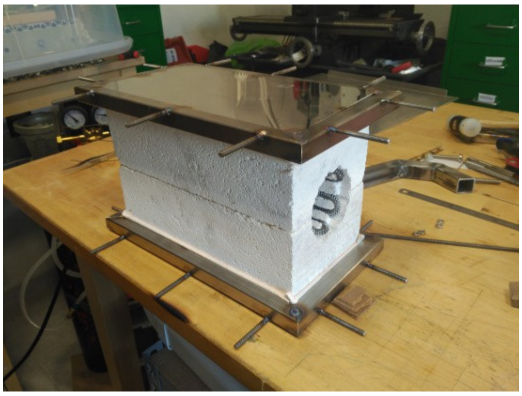
You don't have to straighten much of the filament to make the connection. If you do, you risk burning it (less resistance, more power in the coil than it was designed for.

Now, how should all this get put together? Metal!

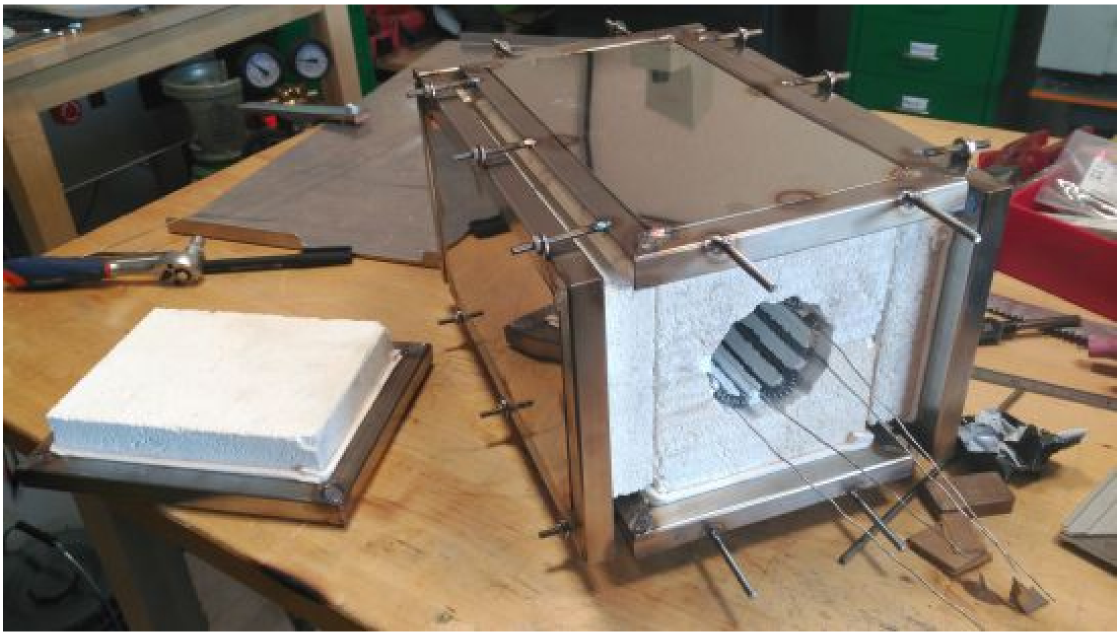
I made some "trays" out of stainless (to avoid oxidation due to temperature cycles), allowing for a small gap between them and the bricks, so I could use a thin ceramic matt (4mm, compressible) this way, I cushion everything, reducing the likelyhood of breaks.



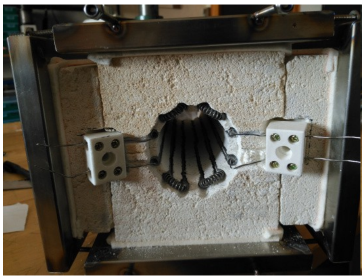
To hold everything some length of stainless screw got soldered to the top and bottom plates, and some washers hold everything together:



Looking good, more screws and washers. The important part is that the oven is fully repairable without hassle.



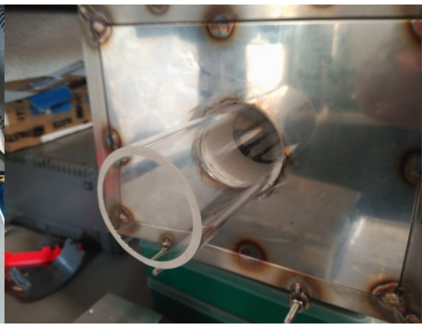
Next, heater connection. Seats are cut into the body and into the back plate. This will make a secure connection AND hide everything.

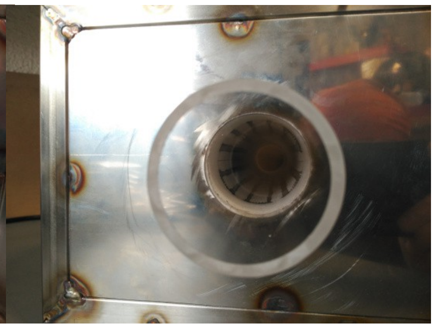


You don't want to clamp the canthal wire directly as a single filament. Instead, you have to bend it a few times to decrease resistance in the clamping point and allow a better connection over time.

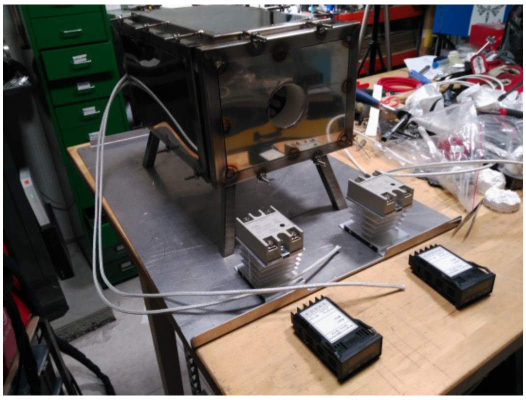
With the same diamond hole saws, you can cut the endplate alumina sections, but you won't be able to cut the metal plate, so find a metal hole saw, or cut it with plasma.

It is also time to test the quartz glass tube fitting:





Now, add some legs and cables:



I'm using duall controllers, one for the top filament and one for the bottom filament, because I'm a control freak, mostly.

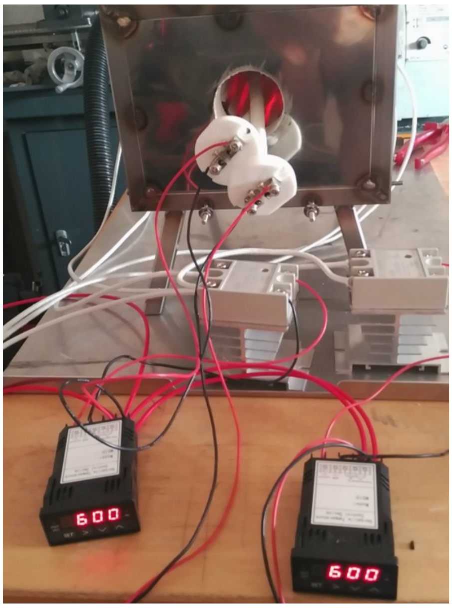
At this point, the oven can be tested by simply inserting the probes inside.

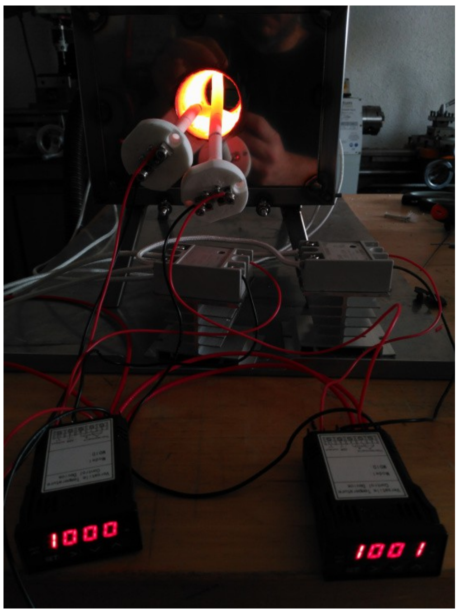
HOWEVER

Never, EVER, put a new oven at top temperature right away. The bricks will have moisture in them from storage and while you are building the oven. Should you put that strain in damp bricks, they are going to break, ruining all your hard work.

Heat cycle I used:

One hour @300ºC followed by 20 minutes at 600ºC. Let it "cool down" for an hour, and then, ramp it up to 1000ºC



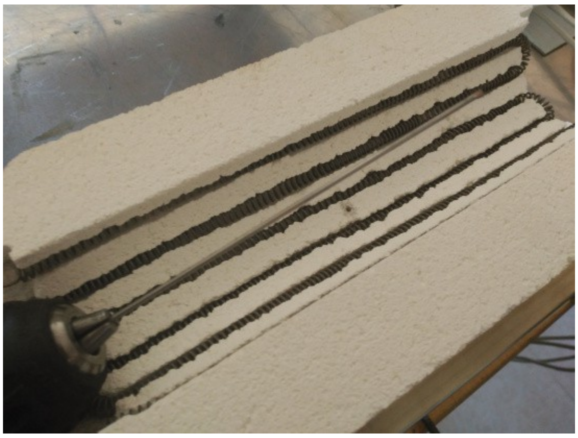


Closeup of the inferno:

Make sure you don't have the probes swapped, it can lead to weird temperature readings (one coil heating the other to keep temperature).

Don't ask me how I know. XD

To install the temperature probes, I began by drilling/reaming a vertical hole from the heat face, so even if it was crooked, the start point was correct.

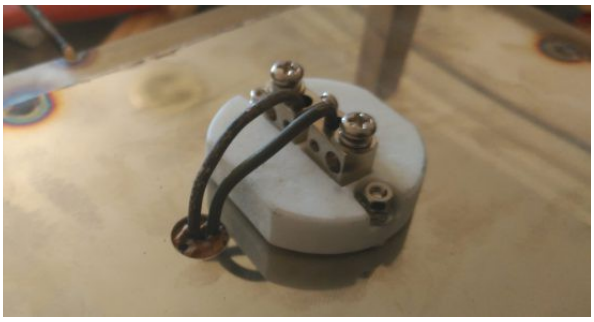


For that, I flat sharpened a tig welding rod and coupled it to the cordless drill.

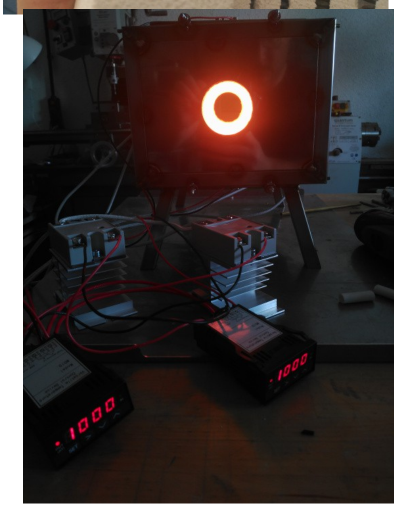
After that, a bigger hole was drilled on the other side to accept a ceramic separator that came with the probe.

To make space for the probe dome and cables, a sharp scrapper was used.

The ceramic retainer is attached to the metal plate with screws, with their head on the inside, so they can't work loose. Also, dual nuts where used:

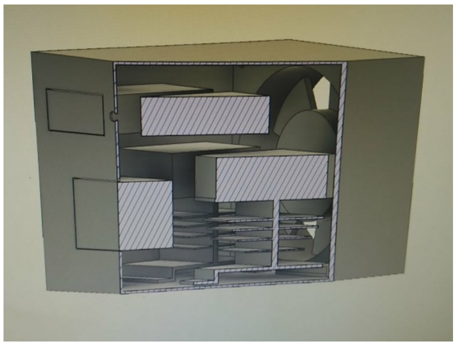


Now looks like a partial eclipse:



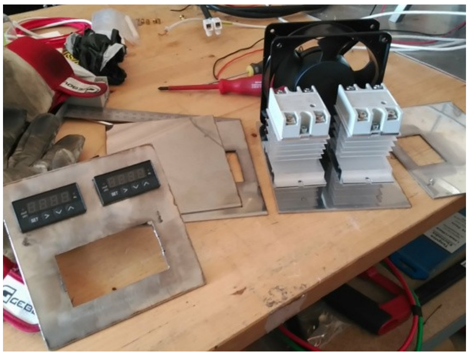
To encase all the electronics, a separate case is needed. Putting it in direct contact with the oven is not really a good idea. Even if we have used good and thick insulation, the body itself is going to get hot eventually, affecting the electronics.

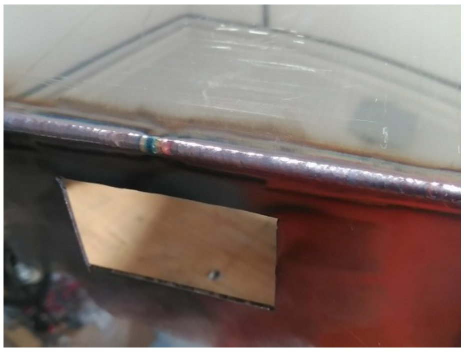
So, a 3D model was made:



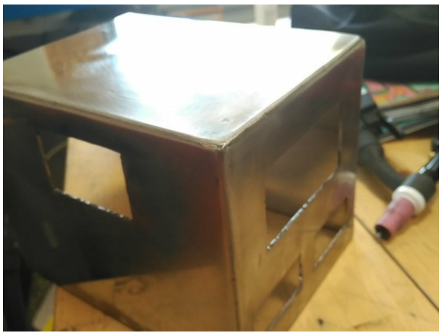
That was transferred to CAD, and then lasercut some MDF stencils to gide the plasma torch.

Plasma cutting by hand (with stencils) is tricky for internal shapes, and thus, all holes had to be tweaked with a file for the modules to fit.



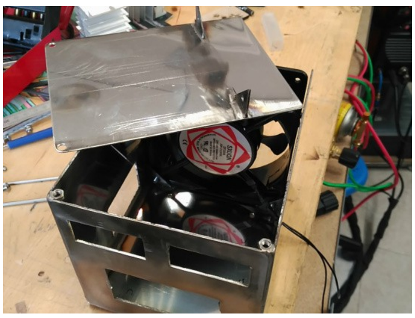


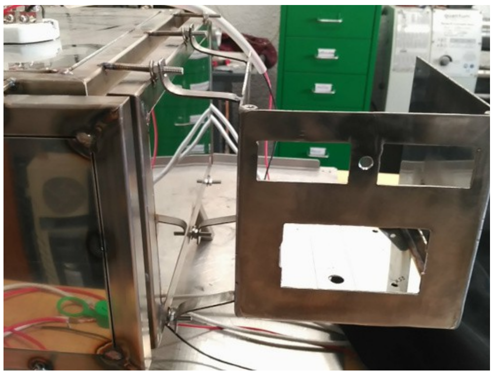
After power sanding and handheld alongside the oven:



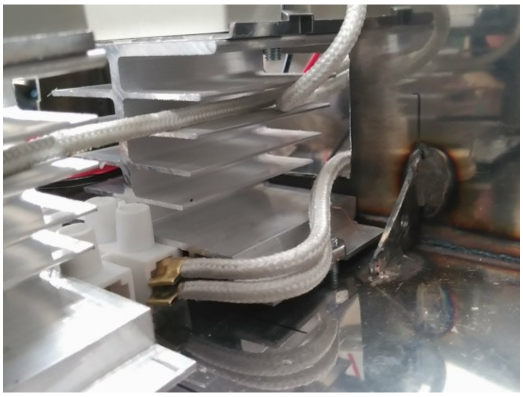
The control box is upside down. XD

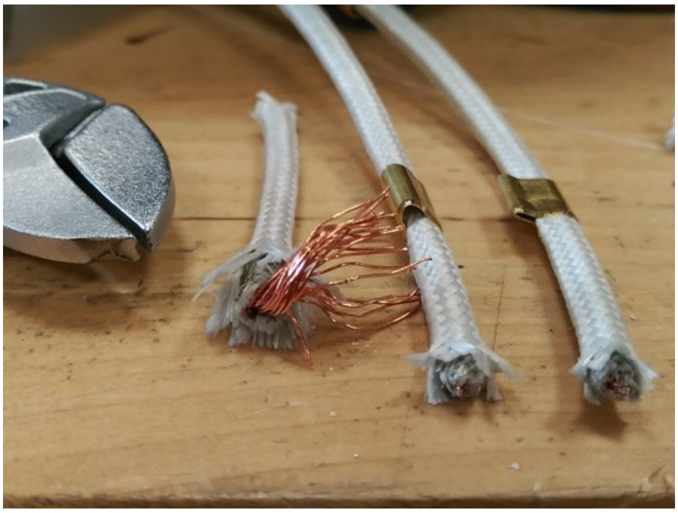
Nuts where welded to hold the cover, and tabs where added to hold the box away enough from the oven side:





And then the integration began:



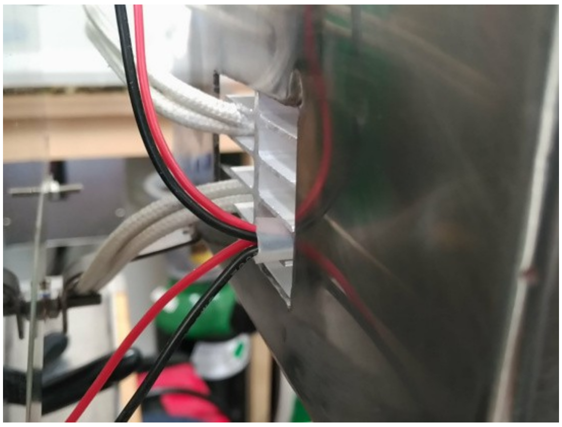


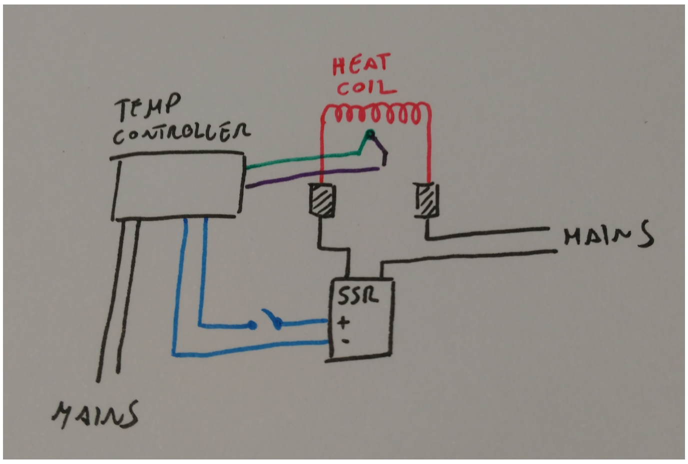
A quick note on fiberglass covered power cable. You MUST crimp the ends before cutting the fiberglass, or it will unravel and create isolation issues. I did mine with some brass tube and parallel pliers.

Since I was not in the mood to make more holes in the box, I opted for the easy cable routing:

And no, the heatsinks can't get hot enough to damage the fiberglass cable or the silicone cable, altough the second one might get sleeved up to the probes at some point.

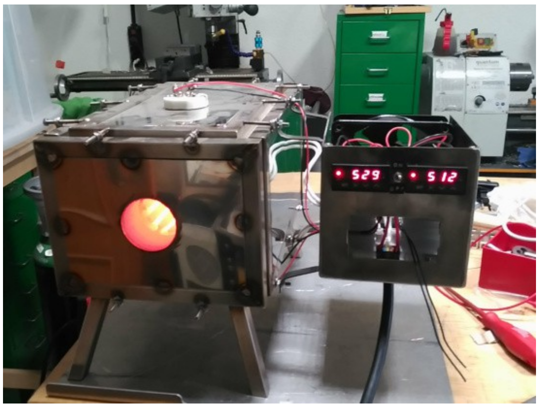
Let's say it is workshop friendly as long as there are no kids around. XD

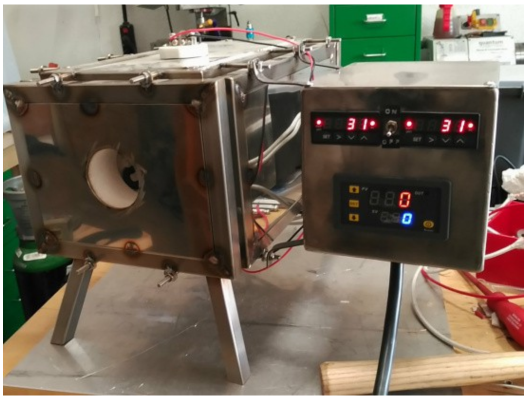




Electrical schematic for one half of the oven. Extremely simple, but just in case someone wants it.
Green and purple wires represent the K-probe.

Testing the power section to ensure everything is ok, before installing the timer. It is NOT connected to the power section, it's just a convenient place to have a programable clock/alarm.

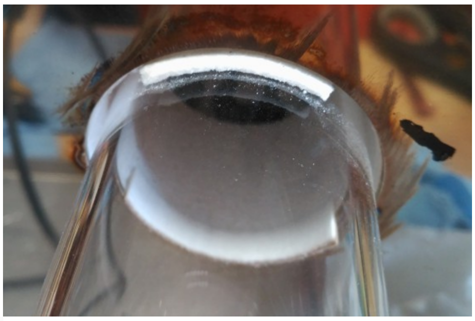


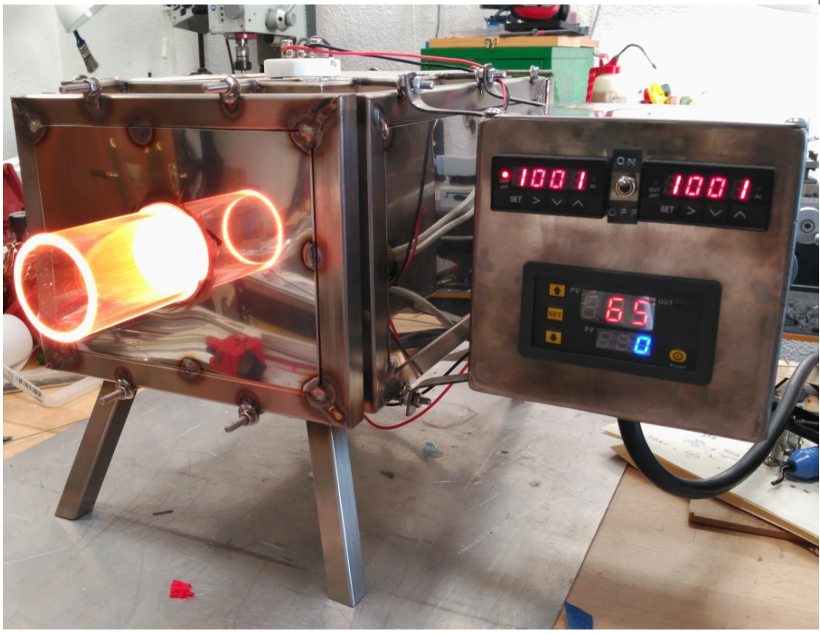


The controller also has a double circuit switch to deactivate the SSR's, just by cutting the "+" from the SSR 3-32V input , so the oven power is OFF but I can still monitor the temperature.

Keep in mind that just disconnecting the power to the SSR's, will affect the settings of the "smart" controllers, so on next power up, ALWAYS decrease the starting temperature, so even if it overshoots a lot, it won't damage anything.

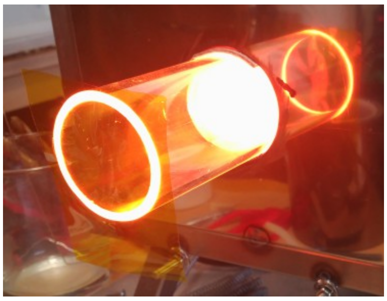
You don't want to rest the quartz tube directly on top of the hot sections. Instead some kind of support has to be added. In my case, I cut strips of ceramic insulating matt and put them top and bottom of the tube, aligning and supporting it at the same time.



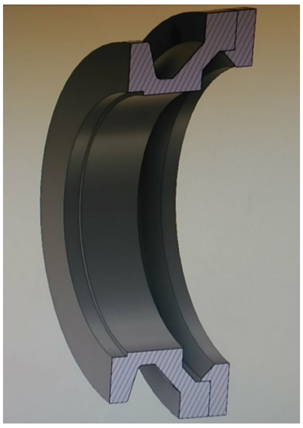


Final result. ^^

Controlled atmosphere:



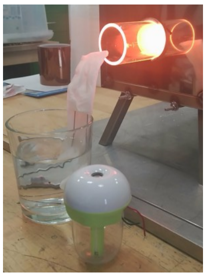
Certain processes require an inert atmosphere to be made inside the tube. In extreme conditions, if the tube is long enough, the ends can be covered with Kapton, and the tube just be flushed with Argon, but that's really impractical and should be used only as a last resort.



In any case, some endcaps should be made for the oven. In my case, given the diameter of the quartz tube, it almost matched the inner diameter of KF 40 flanges, so I simply inspired some O-ring retained endcaps on their measurements.

These must be made of metal (altough in the photo we see a 3D printed mockup) as both the glass temperature and radiant heat will be considerable.

Steam generator:



Using a glass of water with a towel to generate the steam required for wet growth of SiO_2, is the simplest of solutions you can get. However, it can catch dust and it is not sealed to the quartz tube. Using stainless tri-clamp pieces (similar to KF vacuum plumbing, but cheaper), we can assemble a modular water container.

It will interface with the KF40 endcaps previously made for the controlled atmosphere. Instead of a paper towel, fiberglass matt should be used as evaporation carrier, to avoid charring (carbon) contamination.

DO NOT close the other end, as it will risk explosion!

Spin Coater:

Thin film deposition consists of two tools, a spin coater and a hot plate.

The first allows you to make consistent films over the silicon pieces. It is a rather simple tool, just a motor with some form of holding down the piece.

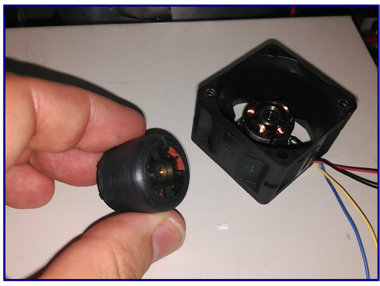
- Mechanical hold downs can get messy, as the rotation will spread the extra amount everywhere.
- Double sided tape can work, but again, picking up the silicon will be messy, and you don't really want to fight the adhesive power of the tape.
- The best option really is to have a vacuum chuck. It holds down the piece as long as vacuum is applied, and then releases easily when it stops.

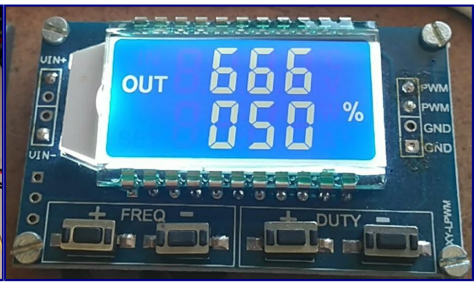
I have to confess that I was going to go for the easier double sided tape option, but as it turns out, I have the weirdest things in my workshop that allowed for an improvised (but excellent) miniature vacuum chuck, on a very cheap homemade spin coater.

I started with a powerful 40*40mm brushless fan from Delta I had around. It has ball bearings for smooth operation and also it's directly PWM controllable and has smooth start built in.

The fins where removed to reduce current consumption and I picked up a simple lcd pwm controller from ebay and hooked it up.

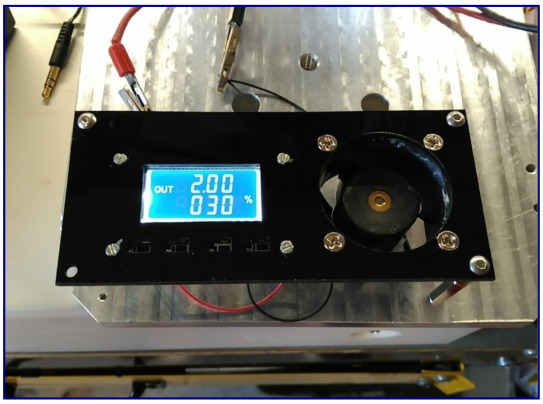
Afterwards the rotor was faced in the lathe.

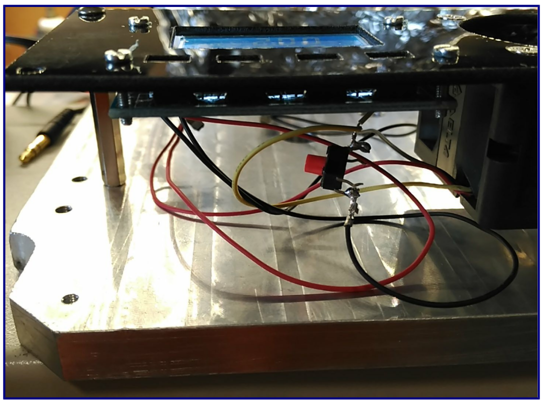




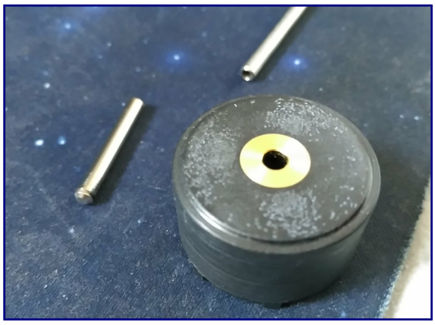
A quick test using double sided tape and a mix of PMMA and acetone, worked well enough, so I quickly cut an acrylic panel and bolted everything together.

This is a bad moment to discover that you have absolutely ZERO panel pushbuttons and you have to leave the start button dangling underneath ^^U





With this, you already have a functioning spin coater. It can easily be made fancier (and more practical).



I had some metal capillary tubes I ordered for the manipulator. Coincidentally, one of them had the right diameter (3mm) wich was totally interchangeable with the motor axle.

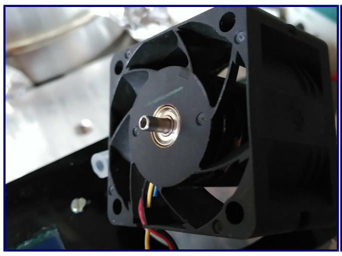
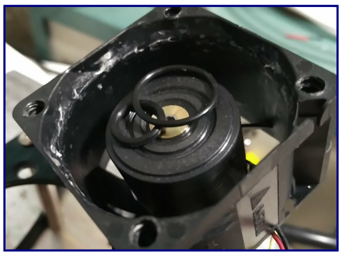
I also happened to have a simple vacuum pump in my "junk" drawers. So, I pretty much was good to go and try the vacuum chuck thingy.

The axle was changed by simply hammering it in, no need to remachine anything.

I left it longer than the original to try to protect the ball bearing from any coating that could seep in and a vacuum tube adapter was machined from scrap aluminium.

The adapter is just held with double sided tape, as it does not sustain any mechanical stress, and, in case of coating absorption, it is easier to rip apart, clean and put together back again. Using screws would difficult that task quite a lot.

Some grooves where machined to hold two standard 10 and 16mm OD o-rings.

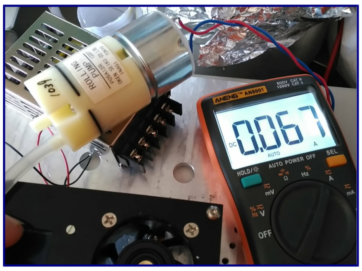
  

But...does it work? Hell yeah it does!

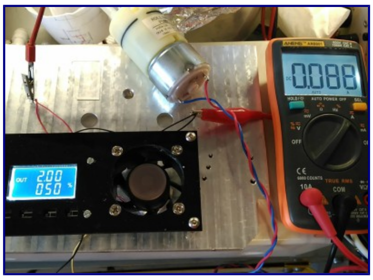
5500 RPM's : https://www.youtube.com/watch?v=tQGquc5nP2Y
Odd Shaped glass: https://www.youtube.com/watch?v=hg0MBisj12A

Initially I was going to power the pump with a 24V supply and look for a 12V unit for the spin motor, but a quick measurement of the consumptions later:

(choked vacuum pump)



(spin motor with chuck ON)



With those kinds of powers, I can just simply throw a 7812 to the 24V supply, heatsinked for the lulz, and call it a day. Also remember that the smooth start prevents the spin motor from drawing lots of current, killing two birds with one stone.

As final note, let's talk about speeds. This motor is not a normal computer fan. This is a high power, 18500 rpm nominal, 800mA brushless motor. Usually, the final RPM's @ 100% power depend on the density of the air and many other variables, so using it without modifications would require direct measurement and/or characterization.

HOWEVER...

Since all the fins have been removed, all the power goes to only mantain the speed, as there is almost no drag (compared to the fan sucking air) so we can be pretty sure that 50% speed will be very near half rpm's and any other divisions we can come up with.

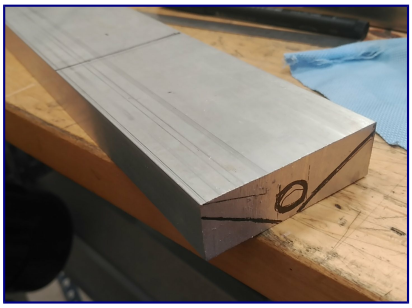
On the funy side, the chuck can't hold anything that is not super centered past 50% rpms. That sounds bad, right? Well, 50% is 9250rpm, much, much faster tan any spin-on coat I have heard of. The highest I have ever heard is 7000rpm for super fine coatings (nm) and this coater will do tat at 38%. So, unless I need something really, REALLY weird, I think it will be good.

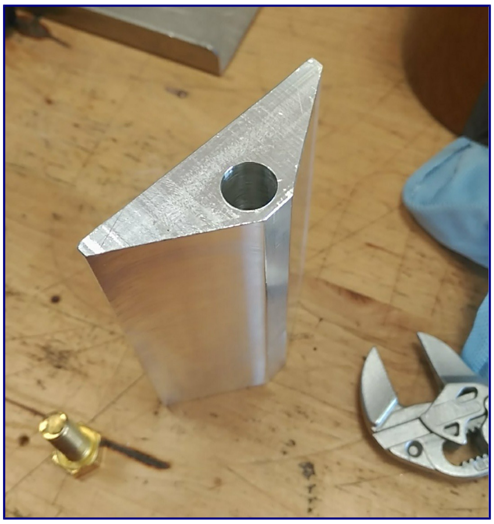
Hot Plate.

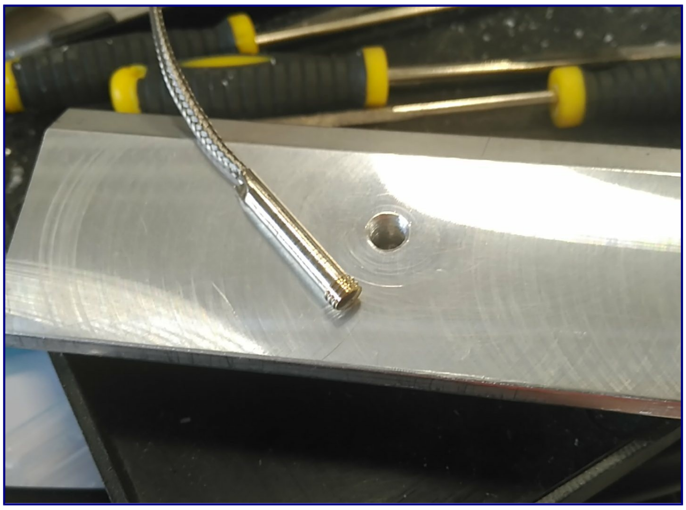
Altough it might be tempting to use the oven as hot plate, and I have done it, it is not really a practical option. As you begin to use the oven for it's intended purpose (growing SiO2 and difussion) it becomes very counterproductive to use it for other things. Also, it is especially a nuisance if some of the coating falls on the quartz tube.

I knew I wanted to work with multiple pieces of silicon at a time, so I made my hotplate quite big, but keep in mind that you could use a 3D printer nozzle block with it's probe and heater cartridge for the same purpose.

A suitable chunk of aluminium was procured from the workshop, wich offered enough space for multiple pieces and could hold in itself the heating cartridge I had around, then it was drilled and milled.

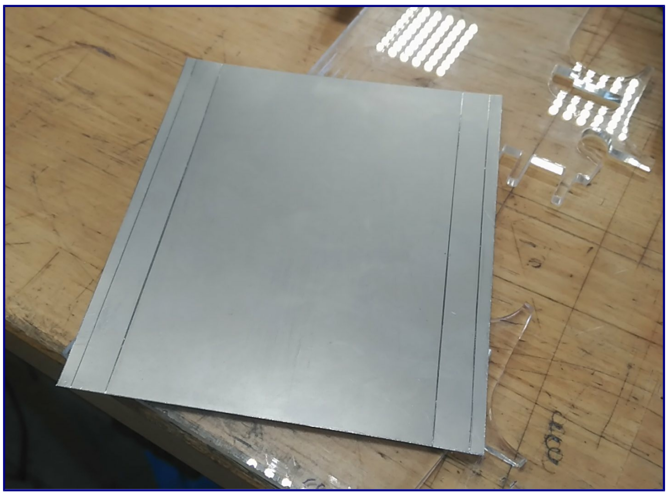






For the K probe, the retention screw had a weird thread I didn't had a matching tap for, so I ended threading the probe itself to M5 and screwing that into the aluminium block, having it's head sitting just 3mm below the surface of the plate.

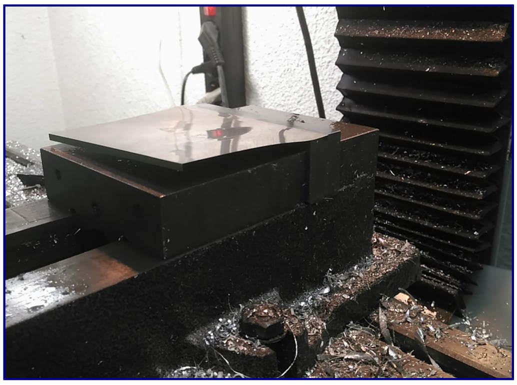
Plenty of thermal compound was employed on both probe and cartridge, the later being held in position with a screw and washer.

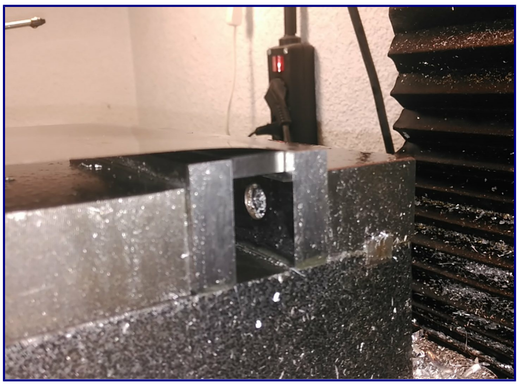


Finally, I wanted to add some termic isolation to the bottom, so the assembly could be made compact. Ceramic matt tends to be fragile, so mechanical subjection (just screws) is not recomendable.

Instead, I scissor cut a piece of solder paste stencil and scored it with a cutter in multiple passes.

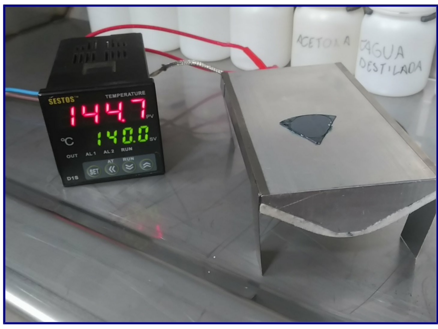
Clamping it into a vice with sharp and square jaws, it was first hand bent and then shaped with a nylon mallet, bending the inside corners using a spacer.





With that and careful measurement, a super nice bracket for the ceramic matt was done. To further isolate the electronics from the plate, sheet metal legs where spot welded to the plate.

With that, but pending a different temperature controller with SSR capabilities, I connected it to an old controller I had around, and for now, I have a sketchy, but working hot plate!



At some point, the controller will be substituted and an SSR will be added.

Laser photolitography.

Jeri Ellsworth used vinyl for simple patterning, for example, but it implies physical contact with the wafer, and I would preferably avoid it. Fab labs use photolitography with sensitive chemicals that are, if possibe at all, quite hard to obtain.

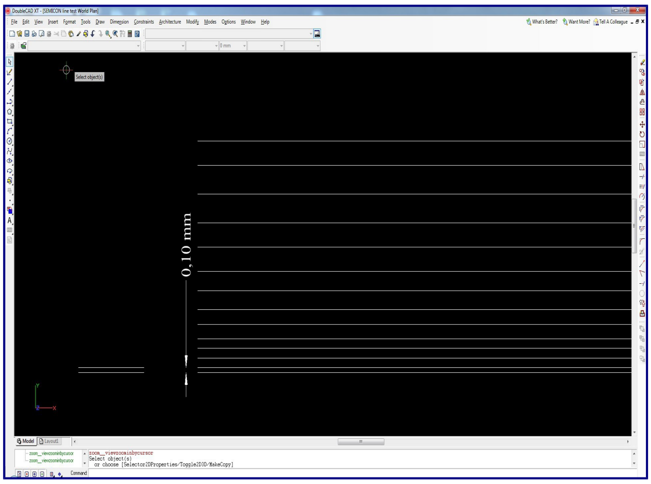
I want to avoid anything that is really difficult to get hold of.

While looking for resists online, I found out that there is a trend to use acrylic (PMMA from now on) dissolved in various chemicals, wich themselves where more or less avaliable, so I was set on the resist, but, how to pattern it?

I myself had a few ideas, but time constraints meant I had to choose one that would allow to test the tools quickly.

Trying e-beam litography with a repurposed oscilloscope CRT tube required too much time and a fair bit more resources than I was able to procure, so it had to be put on hold.

SLA resin was also considered, but I could not get hold of what components make it or if is it resistant enough to the various chemicals to be used on it, so it was also put on hold.

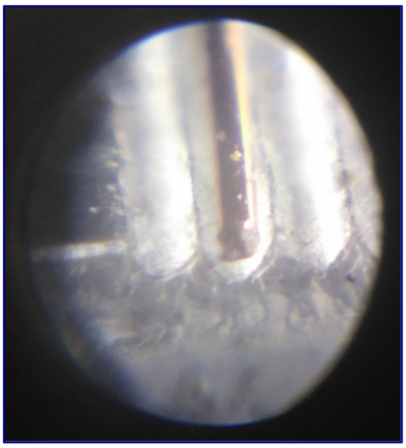


If Silicon is sort of transparent to 10600nm laser light...but PMMA is not... can't I just use laser etching to patern low resolution features on my test wafers?

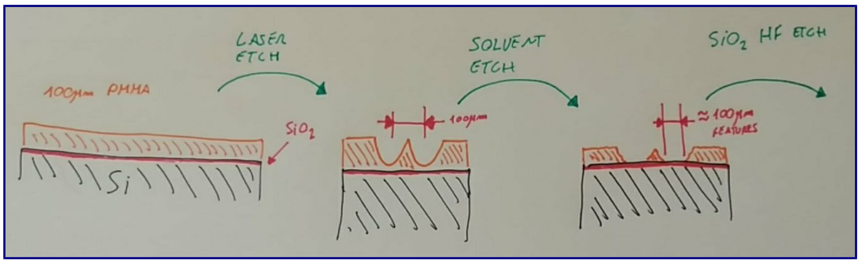
With that thought, I prepared a test vector file with lines separated 100µm - 200µm - 300µm for the laser cutter:

After lasing that, I mcgyvered a microscope to see the tiny details, and here's what I saw:

The trench etch looks fairly constant. Also, with a 110µm copper wire for scale.



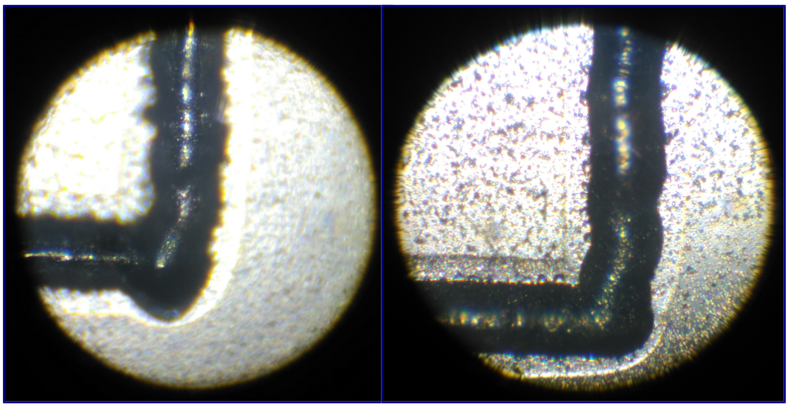
The plan is as follows:



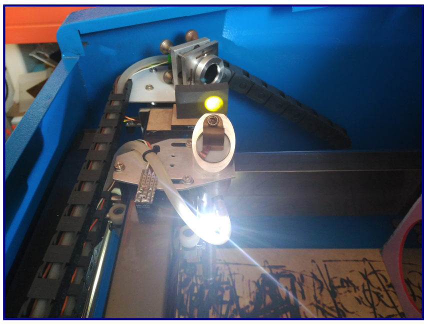
You first etch the PMMA with the laser, but not trying to go all the way, just to the top of the silicon wafer. Then, using PMMA solvant, you eat away some thickness from the leftover PMMA, revealing the silicon on the bottom of the trenches.

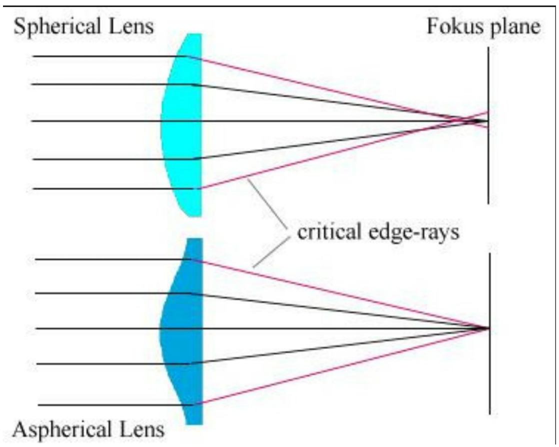
After that, an anneal step and you can etch the wafer. This should enable 100µm features, with 100µm spacing.

After actually trying to draw, it was revealed that some spacing (50µm) had to be added in between starts and stops, otherwise, the laser would overetch in the corners because of stepover.



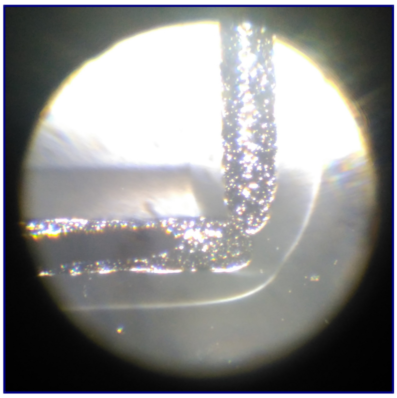
While thinking about the whole laser shenanigan, I started wondering about getting rid of the useless parts of the laser beam, and concentrating on the etching, using a graphite "Hot Trap" as iris. That way, I could increase the power in the laser tube to have more consistency (lowest amperages behave a bit erratically), but not burn through the PMMA layer.





You can call it the poor mans Aspherical lens. What you are actually doing is eliminating the more astray rays for a better focused beam, but at the cost of enormous ineficiency.

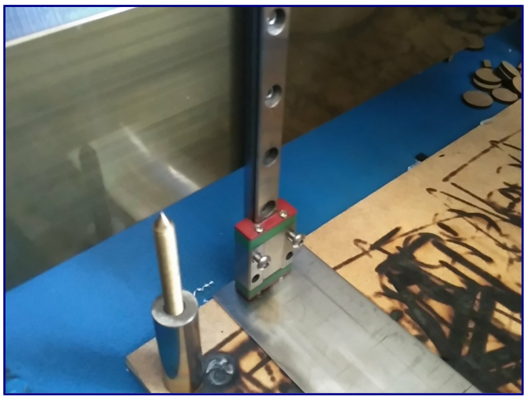
Result: Smaller and much more defined trenches!

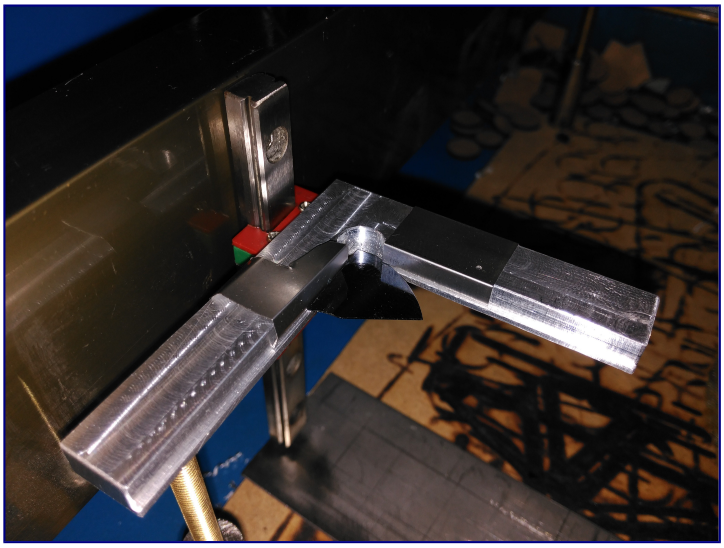


About 2/3 the width of previous tests and 50% shallower depth of trench (aout 50µm deep). Good enough as to have rendered the previous 50µm spacing obsolete.

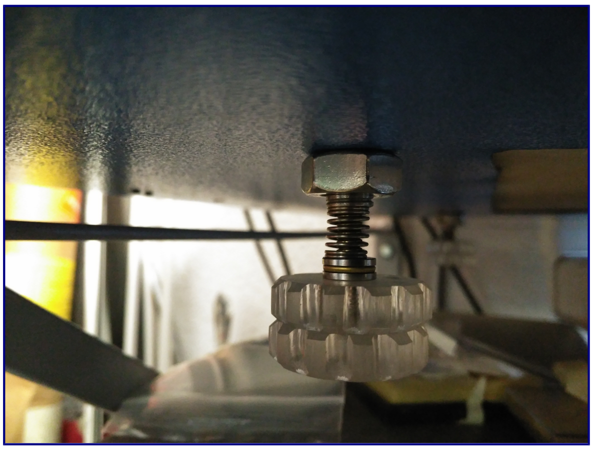
This should enable higher precision in the mask, requiring a gap of 25µm between endpoints, and closer spacing between trenches.

At this point, a better focusing tool should be made. So, holes where drilled...and a vertical linear rail was added:



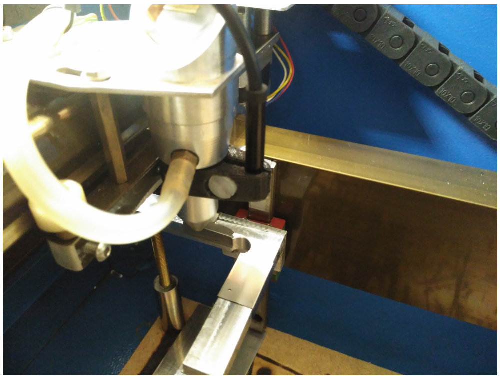


The design requirements dictated the shape, edges and lengths, so there wasn't much to the design. Just an L with recesses for the silicon, and holes for the linear rail guide. Holding is done through flat springs, sitting against the small 1mm ledges in the piece, and made pretty much like the cover in the hot plate.



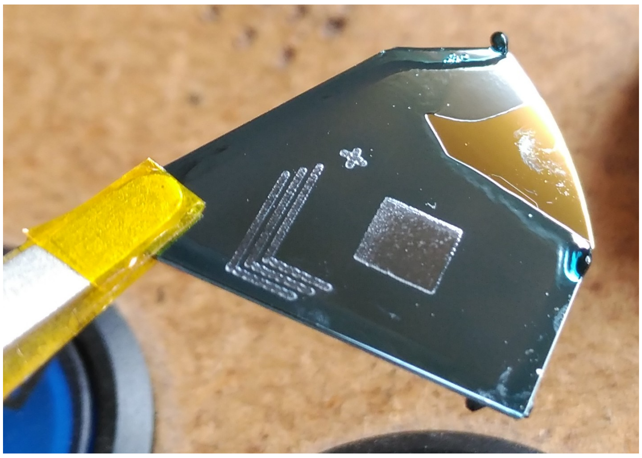
The cutting height adjusters, however, just as they are, could probe flimsy for precision height adjustment, so the screw is preloaded with a spring and an axial bearing to prevent twist resistance.

But having a good way of focusing the laser isn't enough. The process of making semiconductors requires multiple passes of photolitography wich, in turn, should be superimposed with some degree of accuracy to be able to make and interconnect devices.



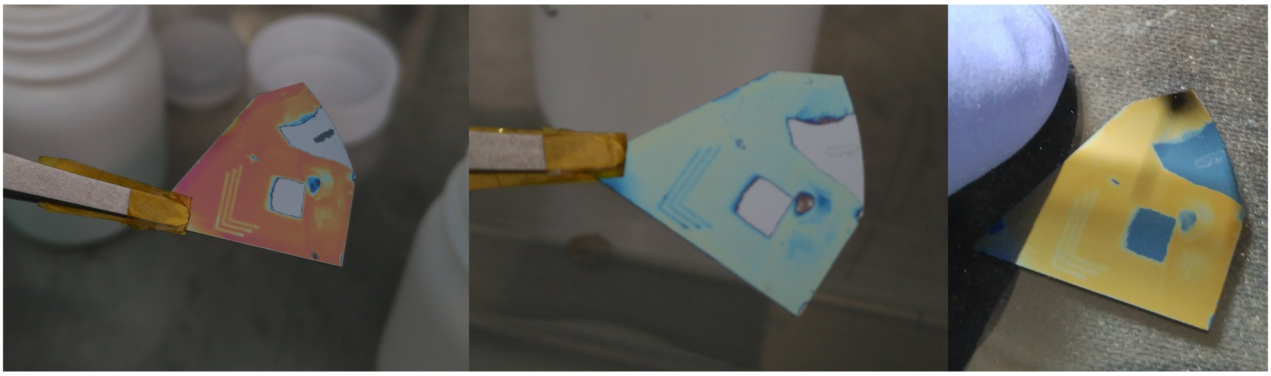
To achieve that repeatable alignment, some form of fiducial marking has to be implemented. In my case, I picked up a simple micro usb camera, and attached it to the laser air assist:

Adding a cross or a point to any vector drawing for the features to be drawn, will carry on into the first etching, allowing for further location of subsequent resist layers.



Being put to use on homemade chloroform-PMMA resist.

(top) Top left cross is fiducial. (bottom) fiducial after first + second etches and after diffusion:



The only detail you have to remember, is to make a pointer in the CNC program so you can backtrace from the camera view to a single point etched, allowing for perfect location everytime.

Safety!

Safety is a relative term here. To be safe, one should not be attempting to build semiconductors at home in the first place.

Having said that. The first thing that should come to your mind, is that any chemical that you are going to use, will emanate toxic vapors, even if it is only isopropyl alcohol.

Think about it. You are going to make thin films based on PMMA-Solvent, wich will require the solvent to be evaporated at some point. The residues on the spin coater will also emanate solvent. You also are going to etch metal film with sulphuric chlorhidric and phosphoric acid, wich result in toxic gases most of the time.

And, of course, when etching silicon oxide, you will be working with Hydrogen Fluoride. All in all, the motto "work in a well ventilated area", to my mind, just falls short.

For fucks sake, just work in a forcefully ventilated area, got it? All labs do it, why wouldn't you? (besides, with the right people, sounds cool to say you have a Fume Hood at home)

Now, what are you going to be working with? Something along these lines:

TABLE 5.1 Etchants for Insulators and Conductors

Material	Etchant Composition	Etch Rate (nm/min)
SiO_2	28 ml HF, 170 ml HF, 113 g NH_4F (Buffered HF)	100
	15 ml HF, 10 ml HNO_3, 300 ml H_2O (P etch)	12
Si_3N_4	Buffered HF	0.5
Al	H_3PO_4	10
	4 ml HNO_3, 3.5 ml CH_3COOH, 73 ml H_3PO_4, 19.5 ml H_2O	30

From the book: Fundamentals of Semiconductor Fabrication (Gary S. May)

So, what is the worst we have to deal with?

Hydrofluoric Acid

At high concentrations it is not a matter that it CAN kill you, it's that it WILL do it. It's an accident waiting to happen.

Go read HF's safety sheet, and let me know if you did NOT have to change your underwear.

My clash with HF, came from the hand of trying to be cheap. While looking for it, I came by a few options:

- Buying cleaners containing HF, with slightly unpredictable results.
- Lab bottle of 20% concentration HF, at about 150€ + shipping.
- Drugstore bottle of 72% concentration at 30€ + cheap shipping.

Guess what I bought.

Yup.

> *The bottle, never opened, managed to attack the glass in a bottle s sitting beside. (all in an hermetic container).*

That's not very safe.

The day I went to dilute 5ml of it, after taking all the precautions possible, once I opened the bottle, it started to heavily release fumes (deadly, remember?) Of course I had the Fume Hood, but it was scary as hell.

> *After that, it still attacked the paper labels in other bottles.*

That made me psicosomatically sick and sleepless. In the end, I paid a company to get rid of the 1L bottle, wich had a cost of 200€.

Moral? I paid more in the long run, because I tried to be cheap.

I will not say that my 50ml bottle of 2% HF is safe to handle, but it is certainly safer-ish than having a 72% anywhere near.

CALCIUM GLUCONATE should be at hand all the time. It is the first aid treatment for HF, prior to going to hospital.

And no, I don't know how on earth they sell it like a common chemical. ¬¬U

After that ordeal, handling the rest of chemicals becomes easier. H2O2 30%, Chlorhidric acid, Phosphoric acid, Sulphuric acid, Boric acid, Acetone, isopropyl alcohol and Chloroform.

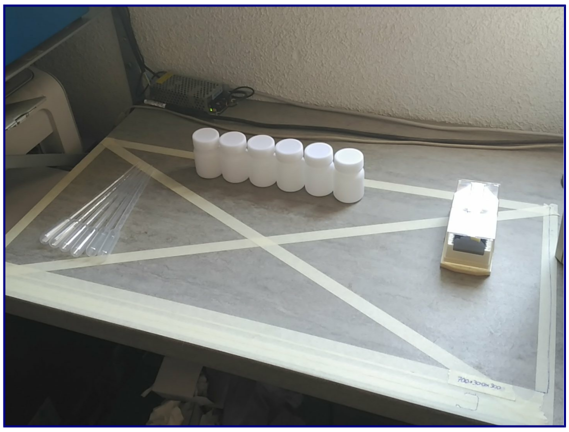
In any case, you NEED a fume hood if you are going to take this seriously. Probably your long term longevity depends on it.

You have a few options, you can either buy new, buy secondhand or build.

I would have preferred to buy, as the scope of this project was mainly the semiconductor tools. However, in the end, it was cheaper to build it myself, and as an extra, I would have lots of spare material to do other things.

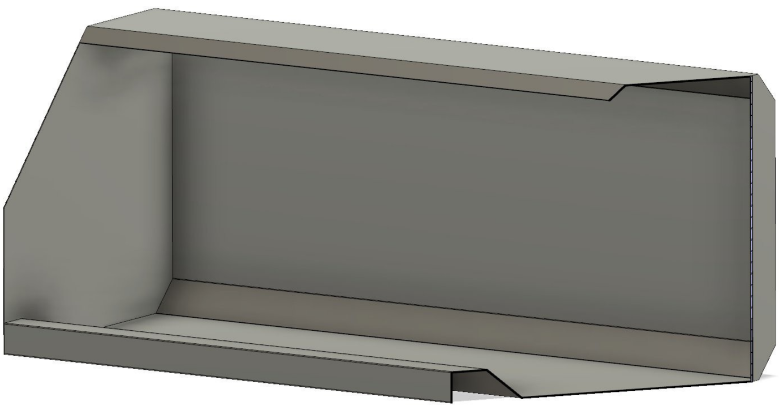
By the way, there are desktop fume hoods, not that expensive, completely made out of HDPE, (resistant to HF)

So, I marked the avaliable space in my workshop (70x30x30cm.)



Once I clearly saw the boundaries, the design quickly came to my mind. It had to have a closed bottom so any small spills where contained. Be easily fabricated, because, why would I want something complicated?

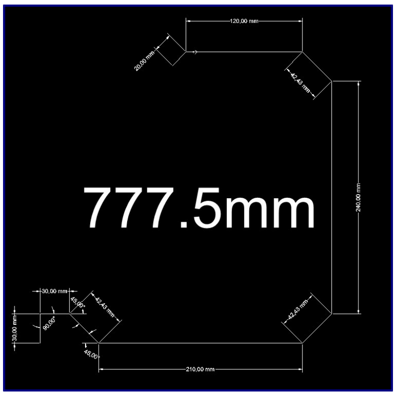
And, most importantly, it had to have a small spill border/arm rest, Just-In-Case.

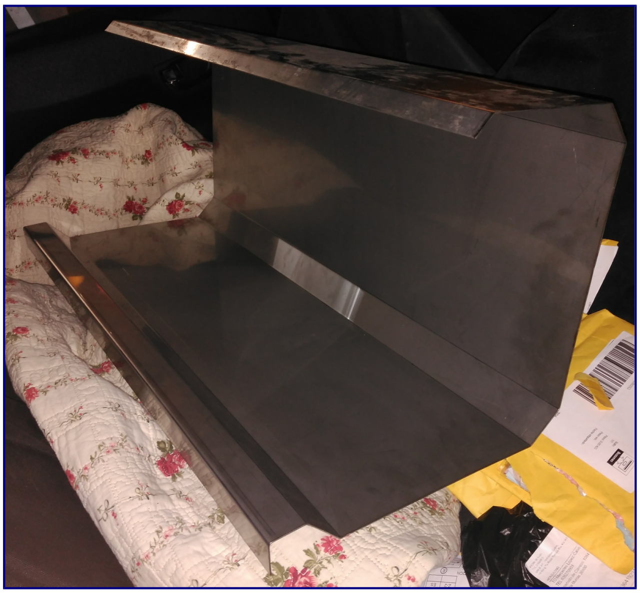


A simple C shape with 30mm height arm rest, and two side plates.

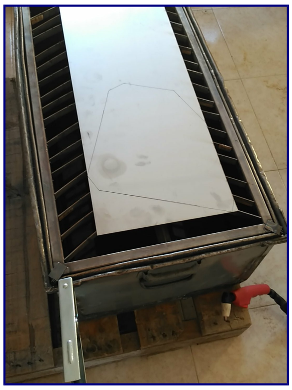
At first I thought I could half cut the sheet with an angle grinder and bend it by hand, but for 700mm width, that was not feasible, nor weldable with the experience I have.

After asking in a metal workshop, bending was so cheap, I opted to have it profesionally done instead.





I was very satisfied, so the sideplates where traced in a leftover piece, and cut by hand with a cheap plasma cutter.



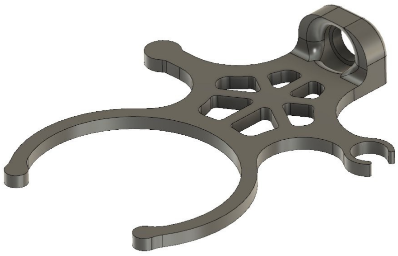
Some welding later, and the famous armrest:

Extraction in itself is done with a super powerful 24V 4A fan with PWM control. So even without the whole transparent cover, the airflow will always be drawn in.

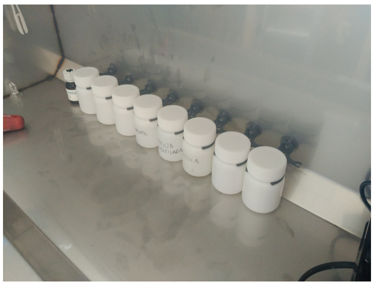
An airflow test was made with the smoke from a slow burning paper towel.

But wait, there's more.

Safety also means avoiding spills in the first place, both on your person, and in the work area, so I designed some interconnectable bottle holders, so the fluids where harder to spill in the fume hood.



The hole in the back is designed for suction cups with 5.5mm shaft and 6.5mm retainer ring. They are designed to hold 50ml HDPE bottles. (link in references)



While dealing with the high concentration acids, long sleeved nitrile gloves, long apron and resistant boots should always be worn, as a face shield too, we are not joking here.

For normal operation, you can substitute the heavy duty gloves with normal nitrile rubber gloves (the cool blue ones, XD) and DO NOT TOUCH YOUR FACE, EVER!

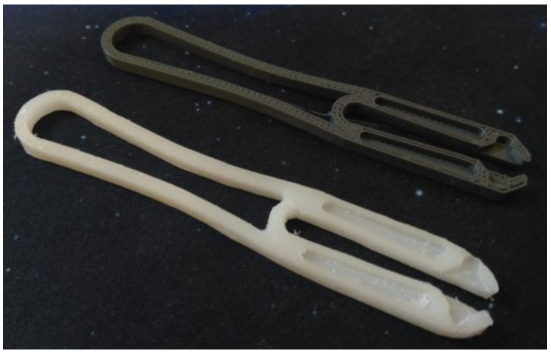
The chemicals should be sealed in an hermetic vessel, preferably HDPE made, and stored in a dry, cold area.

I found mine in a camping store, as an hermetic container with broad throat, and added proper danger stickers, because I could. XD

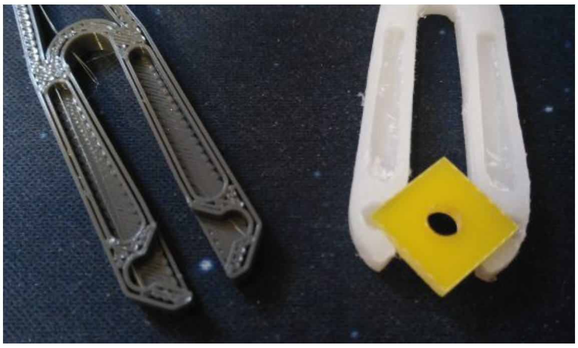
Tooling Extras

In here you will find details about everything else that had to be made but doesn't fit elsewhere. That includes a HF resistant tweezers, spot welder, plasma cutter bed and a bit more about glassworking.

HF tweezers.



As mentioned, high density poliethilene is about the only thing resistant to HF. To handle the wafer sections, you will use tweezers, but HF will eat away any metal ones, and I would not trust much else other than HDPE plastic that can withstand it. However, I did not find accesible (cheap) ones, so I decided to make them, it's funnier and cheaper.



It picks the wafer square by the edges, allowing it to rest in the ledge, making for a very secure hold, no need for double sided tape or other feeble methods.Too thick stock coupled to a short endmill marred the edges a bit, but it proves the point. I'll make some more later.

Spot welder.

Think about all the tools you have, how many are for removing bits and how many can actually join them again?

Stretching my funds I was able to get a decent, cheap, TIG welder, however, even that is overkill or not apropriate sometimes.

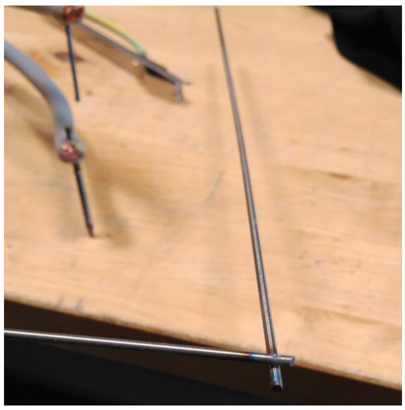
So I went and tackled the spot welder I had long pending.

First, remove high voltage windings from the microwave transformer. Most people saw those and then hammer the shit out of them, however, I do not have an anvil, nor a table capable of withstanding such blows (the coils are resin bonded to the casing). So I tried to just drill the center and wait to see what happened.

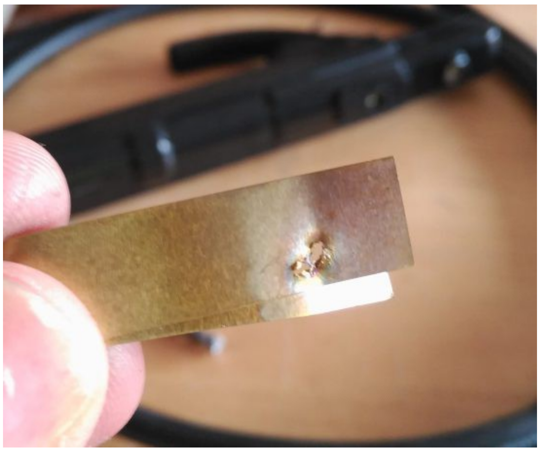
Easy enough, once you have went through, you can just chisel flocks of wires with a screwdriver, with not much force at all. Keep in mind tough that to drill it, you must peck a lot. Going full blast with a drill will jam everything and possibly cause harm to the low voltage coil, wich is not that much protected. (Note I was working over some neoprene rubber matt).

Once freed from the wires, it's time to wind some heavy duty cable in there. It will put up a fight, and if you are not careful, it will scrape the wire lining. I managed to do it without shorts, however, for the final version, I changed the cable and went much more slowly and carefully, even using some leather to slide the wire under the sharp metal corners.

To test it out, some carbide pieces (broken endmill at bottom, TIG electrode on top) and a test on titanium rod.



As I was using a foot pedal, power control was not the greatest, wich lent some *interesting* results on brass.



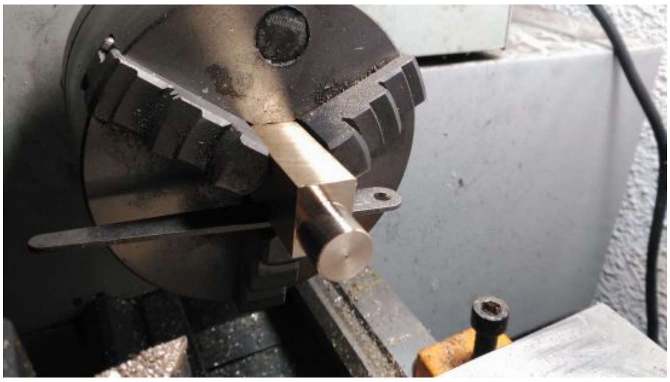
Add a timer for good 'ol control:

Yep, MUCH better:

ATTENTION:

Altough good for TIG and some other uses, tungsten electrodes are not the best option for spot welding, they have the bad habit of welding themselves into the pieces, leaving sharp bits and broken tips. You should use copper electrodes, more or less sharp, depending on the amount of area you want to heat.

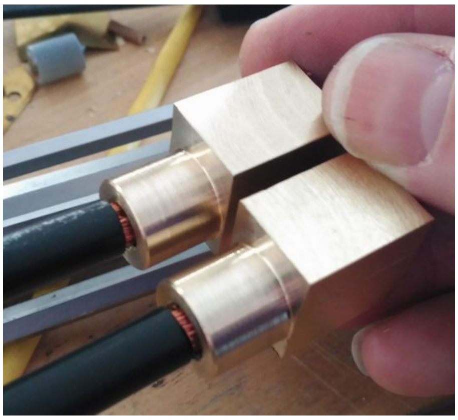
Having the electrodes nailed into the cables doesn't make for a very practical setup, so I dived into some support making:



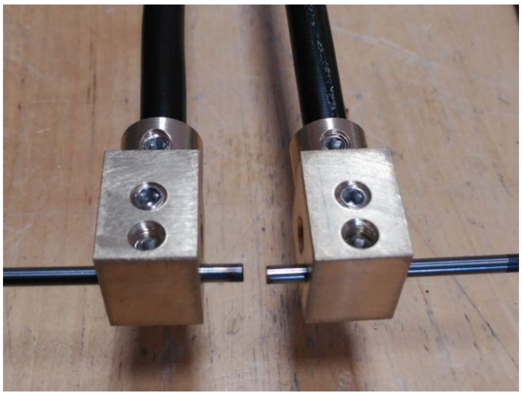
Niiiiiice...
Do they come in pairs?

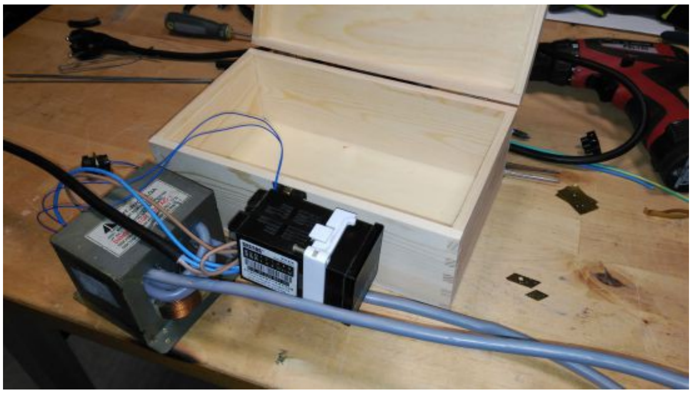
Yes, they do!

Drilling holes for 3 and 6mm electrodes.



Sweet electrode holders IMO.



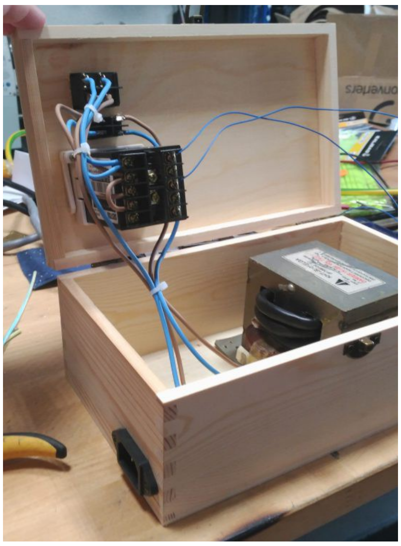


Time to put your ~~dick~~ *junk* in a box:

Blue switch is main power (cutting mains and return). Black switch is enable (connected to just one wire in the mains coil).
The enable serves two purposes:

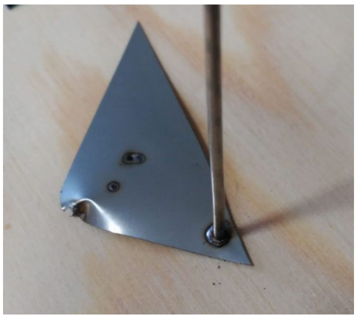
1. On power up, the timer activates itself once, wich is an undesirable behaviour that must be bypassed.
2. Preventing unwanted activation of the welding core, either because "1", or other causes (missteped on the pedal, for example).

Wiring:



First practical use, smt tweezer repair.

If you switch one of the electrodes for some rod, you can spot weld some fancy legs to steel sheet.



Also, welding cage style supports for your fancy vacuum chamber is now super easy.

Plasma cutting water bed.

While building all the tools, I found hard to do some metalworking where sheet metal was used. A hand saw can only get you so far, and a bandsaw will carry you only so much futher. And a fret saw...well, no, thanks.

Then I saw that nowadays, there are extremely cheap plasma cutters (200-ish €) and I thouht...Hell, why not?

The thing is, plasma cutting produces sparks. LOTS of sparks. Unless you have a good workshop with concrete floor (and good shoes), you will damage something.

To counteract that, a water bed is the easiest solution. It will cool and catch all the sparks, and anyways, you need a replaceable cutting support, as it will get slowly eaten away as you use it.

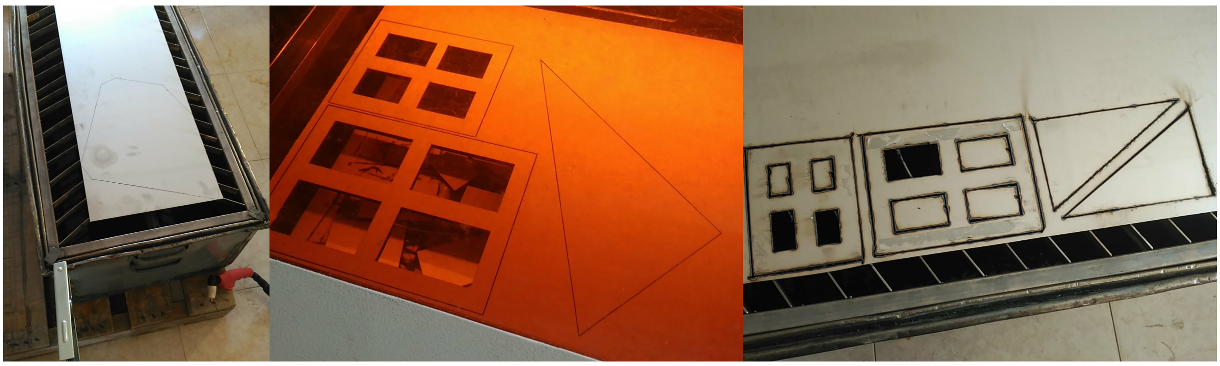
A cheap and tattered metal box was bought, welded shut and anti rust painted.

After that, a metal frame that would sit inside the box was welded, wich would hold bent metal strips, wich are actually the consumable support for cutting. A brace was added so the strips would not fall down. :P

Note that said brace was welded at an angle, so the sparks can't bounce back on a flat surface, but get deflected sideways.

Best thing is that the hotest part is actually a few millimetres away from the outside of the cutter, so you can use wood guides and stencils for the cuts (always taking into account the width of the cutter head!)

In use:



And after welding: