the Bell Jar
Vacuum Technique and Related Topics for the Educator & Amateur Investigator

Notes from the Vacuum Shack — No. 7 June 2020

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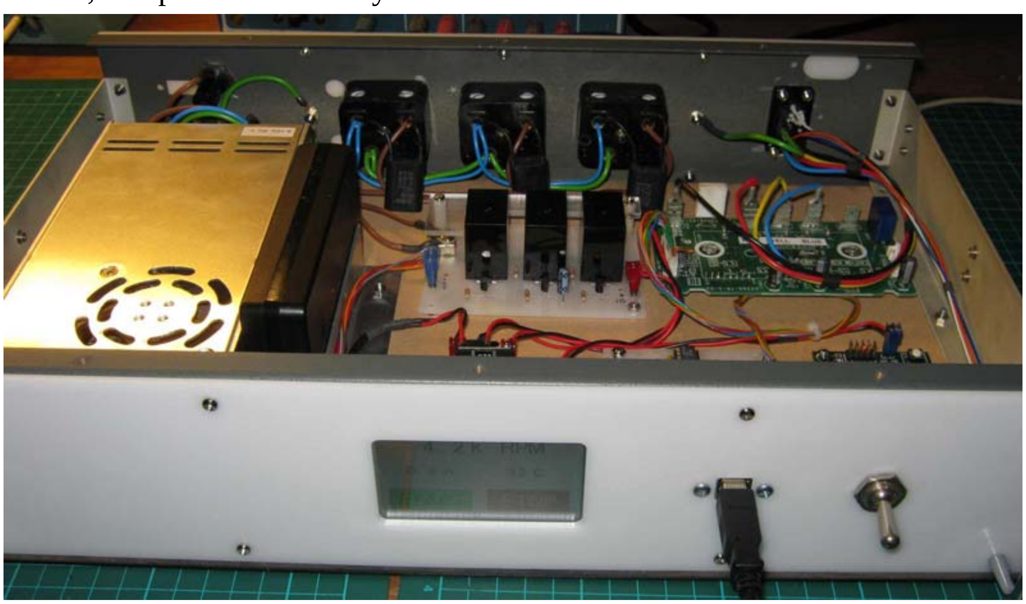
Adventures with a Turbo Molecular Pump during the Lockdown

Mark Atherton, New Zealand

24th March 2020, and COVID-19 hits New Zealand. We are given 48 hours notice until complete lockdown, so it is time to draw up a list of half a dozen projects that can be tackled during the next six or so weeks, and spend those precious few hours shopping like mad to fill the workshop with material, components and curry.



I had recently taken an interest in high vacuum systems and managed to purchase a pair of turbo pumps from a local online auction house for a very reasonable sum (given that the price did not include controllers). I also managed to get my hands on a couple of the MIL style round connectors from eBay. This latter purchase was based on a single photo on the auction, and a weekend's work learning about MIL-DTL-26482, which was the anticipated connector.

I have written a document that outlines some of the key decisions that were taken associated with the design and construction of a home-made, fully integrated TMP controller, as well as some of the trials and tribulations along the way. The unit implements a contemporary BLDC power controller, along with power supplies, touch-screen, and switched power outlets. This whole unit is microprocessor controlled.

Some of the decisions may appear to be non-optimal, but a complete system was built using parts-in-hand. Along the way, reams of documentation and notes were also created, and masses of stuff were learned (which was the whole point of the project).

The article itself runs to eighteen pages; this is clearly too large for *the Bell Jar*, so Steve Hansen has kindly offered to host the main article on his site. The link to the full PDF document is here: http://www.belljar.net/contributions/atherton_turbo_controller.pdf.

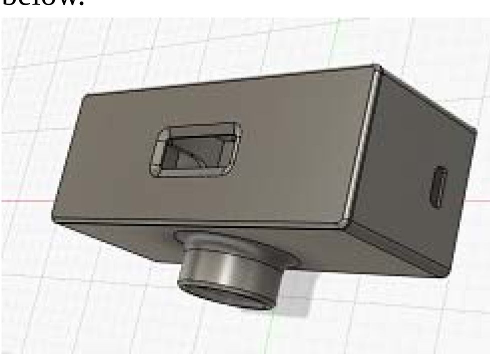
With best wishes from New Zealand,
markaren1@xtra.co.nz

A Proposal for an Open Source Fore-Pressure Vacuum Gauge Project
Robert Clarke (Robert Clarke Modelmaking), Ireland

I am looking for a collaborator to help me finish this little project. I'd like to build a self contained backing line pressure gauge. I would prefer to have the gauge self contained, without external power connections or readout. This would allow ease of mounting anywhere on the vacuum system.

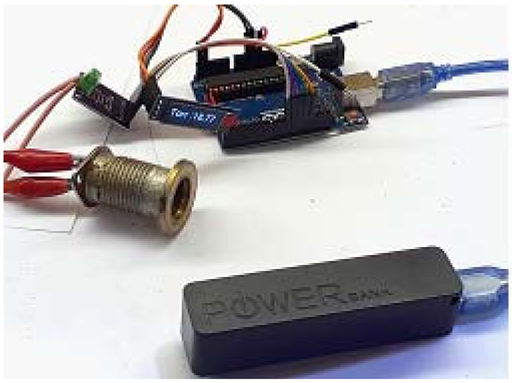
I intend for this to be an open source project, so that the community might benefit. Especially needed are those with knowledge in the area of electronics and the Arduino.

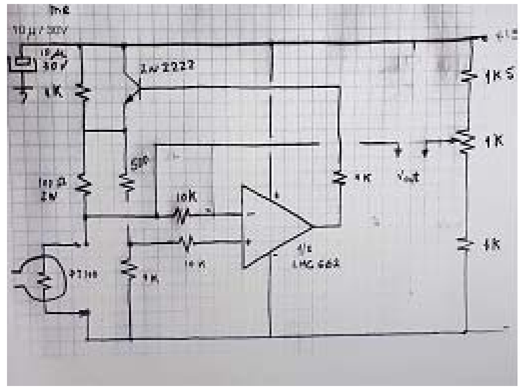
Work done so far includes the CAD files to allow for the 3D printing for the case. See the image below.



The vacuum connection would have two options e.g. KF16 flange and perhaps a silicone tabulation. My prototypes are constructed from t4 fluorescent tube to which a PT100 RTD sensor attached, mounted in a modified brass tank fitting and the other from a TO-3 transistor can soldered to the same style of tank fitting.

There is already wonderful work done here:
http://www.cientificosaficionados.com/tbo/medidores%20vacio/medidor%20de%20vacio.htm.





It seems the constant temperature configuration is the most sensitive for this type of sensor but this requires using an opamp to keep an eye on the current. This is where it gets above my head. I could build the circuit attached but my aim here is to use off the shelf components as much as possible to allow replication by anyone who has access to purchasing these parts. Arduino related break-out boards are widely available, very reasonably priced and easy to mount and assemble. If the PT100 drive/sense circuit could be built from one of these it would be ideal, even if it is slightly modified.

And after we've done this could we build a high vacuum gauge from an ionisation fire alarm...?

If interested, please contact me at robertwclarke@gmail.com

Rob's CO_2 Laser (MK 1)

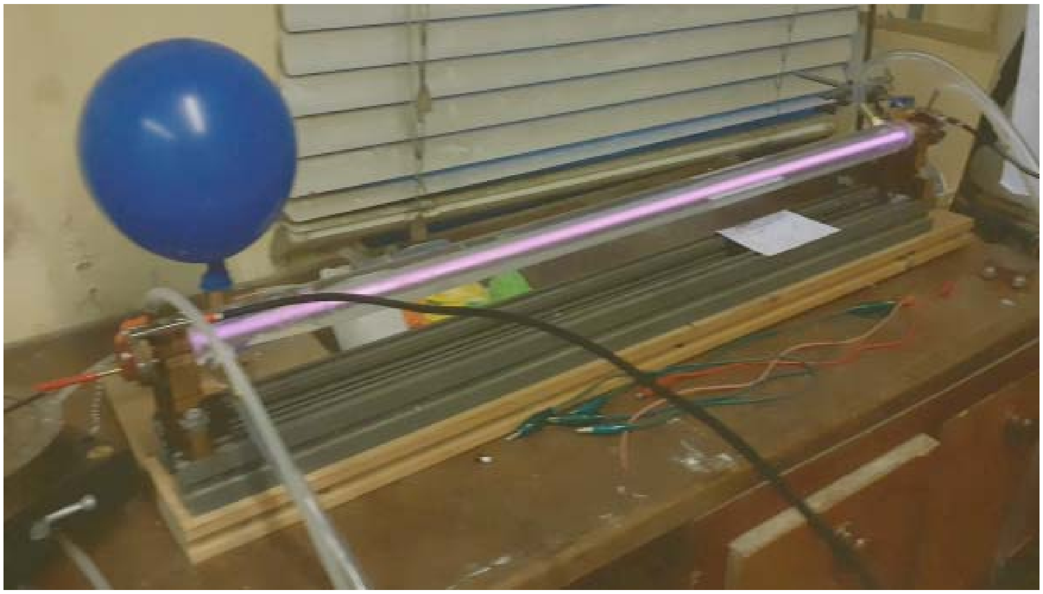
Robert Clarke (Robert Clarke Modelmaking), Ireland

What could be better than building a laser!? I started this flowing gas CO_2 laser quite a few years ago but for various reasons it kept being put on the back burner. Happily with the lockdown due to COVID-19 it was resurrected with renewed gusto and a blank diary.

The completed laser is shown in operation in the photograph on the next page.

A note on safety: I have no qualifications in anything I'm doing here. This article is for information only. High voltage can go strange places under a vacuum. Always disconnect your power supply before making any adjustments! Educate yourself; there are plenty of resources available on the internet for free.

A note on credit: Much of what I have here is thanks to the information from Jarrod Kinsey's website and videos. Also Sam's Laser FAQs, an amazing resource. Also the YouTuber “kartopla1982” and last but not least *the Bell Jar*!



The tube measures 800mm long with a 11mm bore. The optics are 3 mm thick solid copper disks punched from a flat bar. The Output Coupler (OC) is located at the end that the laser light exits (hopefully!). The other end of the cavity is the location of the High Reflector (HR). These mirror surfaces should be as close to 100% reflective to the 10.6 μm light as possible. Thankfully bare copper is highly reflective in this wavelength.

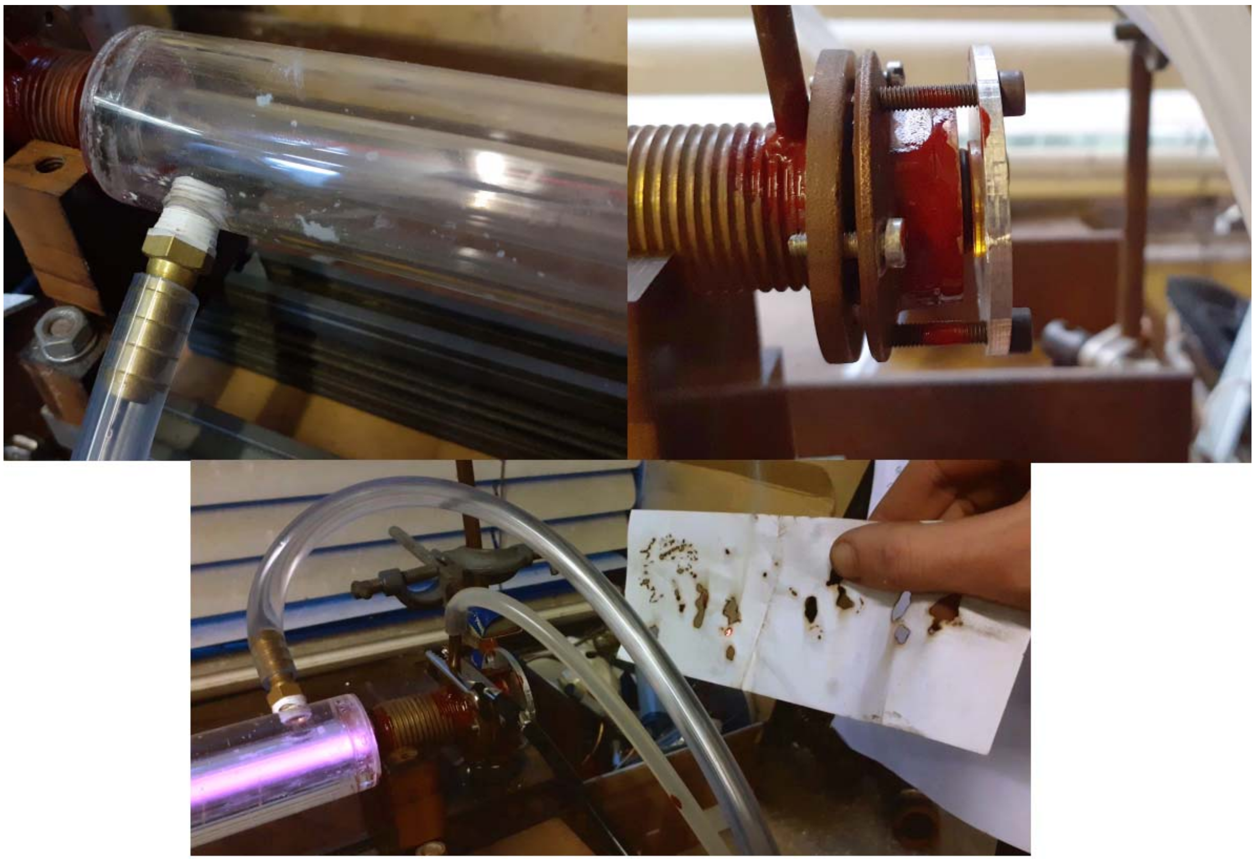
Making the Mirrors

The OC is flat and the HR is slightly concave. To make my mirrors I followed Jarrod Kinsey's penny grinding instructions in spirit, these are detailed on his website. My HR radius turned out to be just about twice the tube length. During the grinding, the dome forms very quickly since the required radius is very large. For the HR I used pitch to fix one of my disks to the top of a dowel and held it in a vise at an appropriate height to work standing up. Then I used 9 micron aluminum oxide grit to impart a mat finish on the disk I was working. I used random overhanging, circular grinding strokes.

Once the blank was matted all the way to the edge it was polishing time. I simply cleaned up carefully (tool, blank and hands!) and put some pitch on top of my copper tool. Before this cooled I pressed the wetted blank on to impose the curve. Then the pitch is smeared with a little Cerite and water. I polished in a similar way to the grinding. This causes the polish to appear starting from the centre, however this means that the centre is actually being worked more than the edge, which is bad in terms of time. To compensate for this you simply reverse your set-up. Make the blank the tool, and vice versa. This is practice is only appropriate at the polishing stage, during grinding it will flatten your curve.

I must confess I got impatient and used Brasso. The result was overtly shiny but with an orange peel texture on close inspection.

The coherent light must exit the tube for it to be any fun. In my case this happens through a small hole in the OC which is sealed with a zinc selenide window sitting on an o-ring. This is simply clamped against the outer face of the OC. I drilled a 3mm hole in the centre of the OC disk with a new drill bit. I wanted the edges of the hole to be as tidy as possible. The copper is very soft and distorts easily. Solid support below is not a bad idea during drilling, e.g. acrylic or hardwood. You can superglue it on and heat it to get it off. The OC was polished using figure 8 strokes on a piece of cotton stretched over a small bit of glass. With Brasso of course.



Clockwise from upper left: Cooling water connection; OC mirror assembly including gas inlet, electrode, copper OC and clamping plate; beam detection using thermal paper.

My power supply is the form of an oil burner ignition transformer which I found dumped by the road side. The voltage is rectified but not smoothed. My rectifier is built from salvaged micro-wave oven diodes. There is no current limiting at this stage. I don't think I will ever be running this for more than a few seconds at a time so overheating is unlikely. My construction philosophy was to allow space between the components to avoid arcing. I would be wary of home done potting or other DIY insulation against these voltages.

I found some ‘underground’ electric fencing wire at my local farm supply shop. This cost me €15 for 25 meters. Though it is not quite rated for the voltages I am using it was a hell of a lot better than the insulation on my croc clips! (These used to arc through their insulation to my wooden workbench.)

Mirror Alignment:

Reflector alignment was achieved by digital camera and by eye. I was delighted with this discovery as it was very effective for reasons you will see below. The output coupler is aligned first. The camera will need 'Live View' for this method. You can use the camera's own display or, as I did, an external monitor (This was mostly because I couldn't see the camera screen due to space limitations). The set up is shown in the picture below.

Begin with the HR removed and align the camera pointing as straight as possible down the bore of the tube. If there is an overlay composition guide available, switch it on and select a crosshair. The crosshair guide should be in theory centre of the camera optic. We want this right in the centre of the hole of the OC. The cavity/tube and any other circular elements visible should be concentric to this. This is important and a bit time consuming to establish, but not impossible. Once this is achieved it should be locked off in this position as the focus ring and digital zoom buttons will need to be used.

Once the camera is aligned and locked off, the focus is changed to show *the reflection* in the OC mirror. Ultimately we want to see the reflection of the open HR end and the camera lens itself. This is easiest observed using the digital zoom option in Live View mode. For me at X10 zoom the screen is filled with just the OC and I see the reflected image with much greater detail. OC mounting screws are adjusted until concentricity is achieved in the reflection in the OC mirror. And that’s your OC aligned!

The HR is easy, eyesight dependant. This is achieved by simply looking through the hole in the OC and adjusting mounting screws of the HR until concentricity is achieved. Assuming your OC hole is well centred, your eye is automatically aligned to the center of the bore and so the HR will be aligning back to your viewpoint. I'm sure my mirrors could be more accurately aligned but my goal was to achieve *any* lasing action rather than efficiency!

Electrodes and Mirror Mounts

Just as with most DIY laser tubes, my electrodes are also my gas inlets/outlets and mirror mount receivers. These parts began their lives a brass ‘tank fittings’. I did modifications on the lathe but I think they could be modified with a few grits of sand paper and lots of patience. The mirror mounts sit on thick o-rings which allow for the adjustment of the mirrors without breaking the vacuum seal. I seated mine in grooves but I don't think this is necessary.

The outside face of the flange of the fitting is brought to a good finish. I would recommend 240 grit and down to a polish of 1200 or higher. This surface is a o-ring sealing surface so needs to be pretty good without any substantial radial scratches. These are a sure leak. I normally do my final finish of any o-ring sealing surfaces with a stroke which is concentric to the o-ring's final position.

For the mirror mount, I lead soldered a section of threaded brass (from another plumbing fitting) onto the inner threads. I needed a broader sealing surface for the o-ring and also a larger bonding surface of the mirror. Doing this still left plenty of clearance relative to the bore of the glass tube. This clamping nut/mirror mount also needs to be brought to a similar standard of surface finish on its mating surfaces.

The OC and HR are attached with superglue on the exterior just in one small spot. The real bonding and sealing is done by using Glyptal, I painted on a generous coat at the joint and once this was dry I painted another with vacuum applied. I believe Glyptal works quite well at elevated temperatures where wax or epoxy will soften. Perhaps shellac is another option here.

My gas in and out tubes are 4mm brass tube. K&S brand will have something similar in the U.S. These I lead soldered in place and sealed with Glyptal while under vacuum for good measure. These also work as a good place to clamp the HV croc clips.

The water cooling jacket is an acrylic tube that I had from a job. I turned acrylic spacers to seal the ends. The hose barbs are 8mm x 1/4 BSP, drilled and tapped into place. In retrospect I would leave a gap between the end of the cooling jacket and the electrodes at either end. I did see some voltage 'leaking' that way during a run.

My electrode/mirror mounts receivers were glued over the ends of the carefully cleaned glass tube with slow JB Weld. This adhesive is rare to find in Ireland but it has such a good name in the vacuum world that I made the extra effort to get it. I believe slow epoxies (24h cure) are better for vacuum applications.

Gas Mixing

The gas was mixed to the directions explained by Jarrod Kinsey on his website. I simply reduced the results of his equations to ratios of diameter. Then they are applicable to any balloon size on the fly. The ratios being:

1 He : 1.05 CO_2 : 1.13 N_2.

But to be clear; this only works if you fill your balloon with the gases in the order given. The set up is shown in the picture below.

My gases are from: a party balloon helium tank, a small CO_2 gas welder bottle and, for nitrogen, a pair of spring water bottles containing tap water. The water bottles are connected in series. A reasonable seal on the pipes coming and going through the lids is necessary. The air is pumped in to the first bottle by a bicycle pump where it passes through an aquarium diffusion stone. This is then fed into the second bottle where it diffuses through another stone. The nitrogen exits through the small cut off valve, via the manifold, to the balloon reservoir. In theory the oxygen and CO_2 has been dissolved in to the water and you are only left with nitrogen.

I was lucky to find a real flow control valve on eBay for a few Euros. I recently picked up a couple of pneumatic flow control valves for less than €5 each. They have very fine adjustments;

with some modification I think they might be an alternative to the industrial needle valves for this application.

To fire the laser I first purge the tube. This simply involves pumping down as low as you pump will go and then washing the tube out with laser gas mix. This is followed by pumping down again while choking down the gas flow. With a few adjustments I found a reasonable pressure to operate at. This was just below extinguishing pressure related to the voltage of my power supply. I always switched off my power supply between adjustments. Many parts of this laser are at very high potential. I assume nothing is safe to touch other than the floor. I am pumping with an Edwards E2M5, another eBay find.

There is a short video of the laser on my YouTube channel. It covers briefly what I've written about here and you can see the laser in action! I am conscious that my plan to shoot down spy satellites will not be happen with this laser however I do feel great satisfaction in achieving the output that I have. See https://www.youtube.com/watch?v=FLeMQVq-H_A.

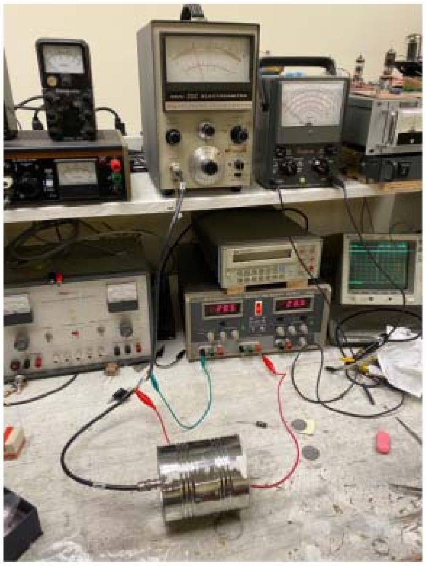
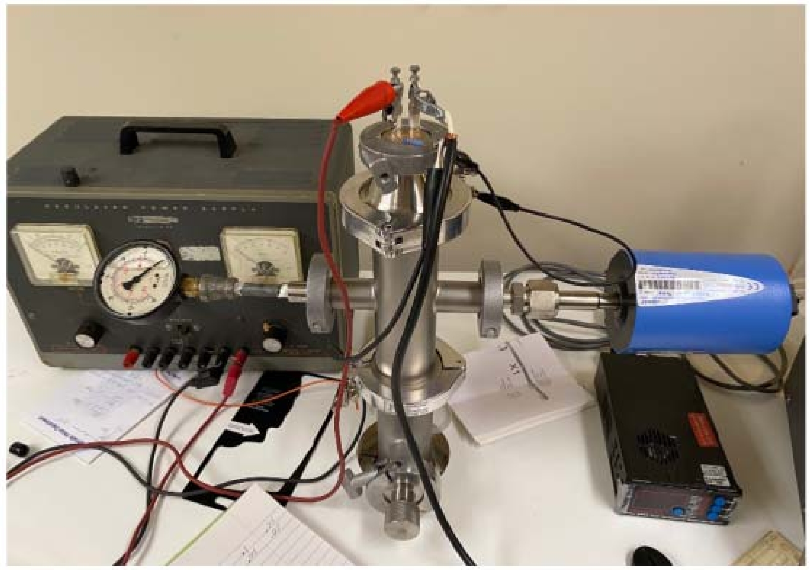
Alpha Particle Pressure Sensors

Those who are familiar with the history of vacuum gauges will be aware of the "Alphatron" gauge from the mid-20th century by Downing and Mellen [1] The sensor basically consisted of an alpha particle source and a detector in the form of an electrometer. They used a high voltage (kV) bias and a fairly large source. Older vacuum texts contain information on the Alphatron and information may also be obtained via an internet search.

Chuck Sherwood (chuck1024@wowway.com) has been doing some experimenting using ^{241}Am sources. (Note, these can be obtained from smoke detectors but in some jurisdictions it is now illegal to dismantle a smoke detector. There are check sources that can be obtained separately. Also, don't work with radiation sources unless you are familiar with proper handling and safety measures.)

The photograph below left shows his basic atmospheric pressure ion chamber set up using 4 sources. At atmospheric pressure the ion current ranges from 50-100 pA per source.

The photograph to the right shows a vacuum version with a dozen sources mounted to a brass tube and KF nipple. The brass tube is biased at about 75 volts. Five 9 volt batteries can be used in lieu of a mains connected power supply. The ion current is very close to 2 pA per Torr, i.e. 1 Torr equals 2 pA and 10 Torr equals 20 pA. While measuring a few pA may seem difficult, it is quite trivial with a electrometer. Chuck uses a vintage Keithley electrometer model 602 and is currently testing some modern electrometer op-amps.

The alpha gauge lived on in a different form as detailed in a 1996 article by Buehler, *et al*. [2] of the Center for Space Microelectronics Technology, Jet Propulsion Laboratory, California Institute of Technology. The purpose of the work was to develop a rugged sensor for measuring the pressure of the Martian atmosphere. To model the atmosphere, many gauges would have to be distributed over the Martian surface. The sensors would have to survive a hard landing (7400 g's), be small and light and be able to operate at 150 K. From the abstract and introduction:

> The sensor is useful in the pressure range between 0.1 and 1000 mb using a 1-µCi ^{241}Am source. Experimental results, taken between 1 and up to 200 mb, show the sensor operates with an anode voltage of 5 V and a sensitivity of 20 fA/mb in nitrogen.
>
> The prototype device described here is the first ionization pressure gage to operate from a 5 V supply. This attribute is very important for low power operation.

Conclusion

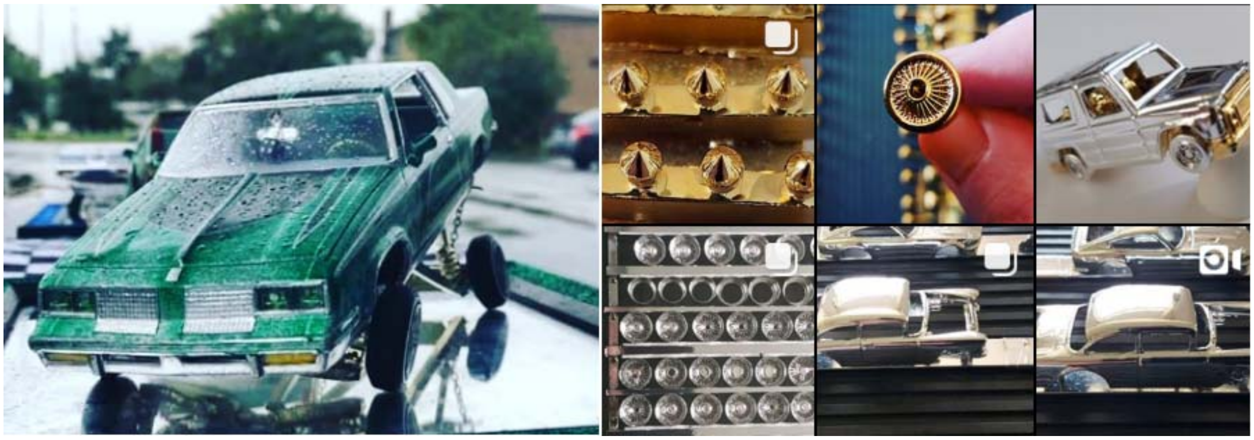
Chuck notes that this is a work in progress and updates will be provided. Any one that's interested in the work is welcome to contact him via his email.

References

1. J.R. Downing and G. Mellen, *A sensitive vacuum gauge with linear response*, Rev. Sci. Instrum., 17, 218–223, 1946.
2. M. G. Buehler, L. D. Bell, and M. H. Hecht, *Alpha-particle gas-pressure sensor*, J. Vac. Sci. Technol. A 14(3), May/Jun 1996.

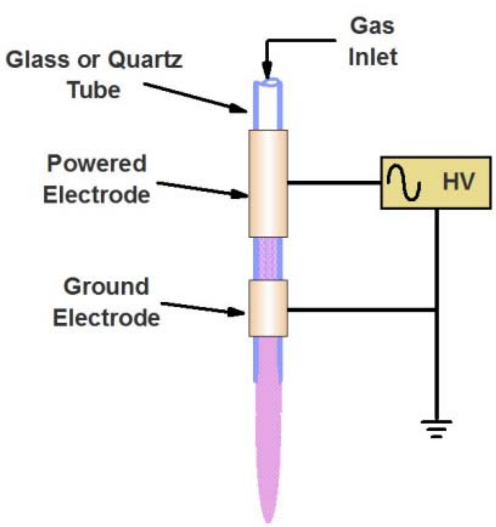
Vacuum Metallization of Plastic Scale Model Parts?

Sean Muldrew makes working 1/24 scale models of custom lowrider cars. These include many resin casted parts that are subsequently chromed using a spray chrome process. He inquired about setting up a simple vacuum process for depositing a chrome film. This is a fairly complex question as the parts are 3D with many hard-to-reach places. Below are some photographs of some examples. If anyone has any bright ideas, please contact Sean at yngstylezdaboss@gmail.com



The Atmospheric Pressure Plasma Jet (APPJ)

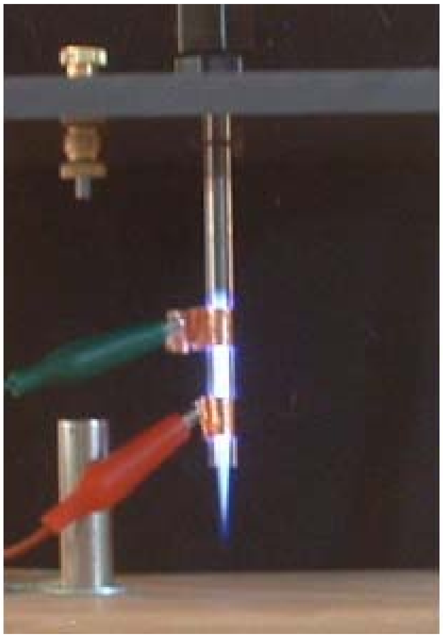
This article is a follow-on to my notes on atmospheric pressure dielectric barrier discharge (DBD) plasmas from the May 2020 issue. A cousin to the planar DBD configuration is the APPJ. In its most basic form, an APPJ is simply a DBD with gas flowing between and parallel to the electrodes. This produces a plume of plasma that extends for a few cm outside of the inter-electrode space. My puttering with these devices has followed my series on low-temperature atmospheric pressure plasmas that has been appearing in *Vacuum Technology & Coating*. Part 3 (June) covers some basic APPJ configurations and Part 4 (July) deals with a variety of applications in materials treatment and coating along with some biomedical applications.



The first device that I have constructed is a very simple coaxial APPJ. This is shown schematically in the figure to the left. My device consists of a quartz tube (borosilicate could also be used) of 6 mm OD and 3 mm ID. The two copper electrodes are made using 10 mm wide self-adhesive copper foil. This is wound around the tube with about a 12 mm space between the electrodes. A tab was left on each electrode for attaching the electrical leads.

This assembly was then inserted into a plastic compression fitting (Parker P4MC4 polypropylene compression fitting 1/4 tube to 1/4 M-NPT) which was then installed on the stand shown in the May issue.. The quartz is a bit undersized for the common ¼” brass hardware store plumbing fittings that use plastic ferrules. The Parker fitting uses an o-ring. This clamps the tube securely. Since this type of compression fitting has an internal stop, they must be drilled with a 1/4” bit to allow the tube to pass through.

Below are photographs of the device. From left to right are the basic assembly, the APPJ working with argon and the obligatory photo of the jet impinging on my finger tip. The last one is a bit blurry as it was hard to keep the camera still while inserting my finger into the plume. Also, I couldn’t reach in any further using this stand, hence the impingement on the very tip of the finger. Neon produces quite a spectacular plume and I found it to be a bit warm. The next step is to adapt an old microscope stand to hold the APPJ.


High Frequency Pulse Power Supplies for DBD and APPJ

In the March 2020 issue I briefly mentioned powering a CloudRay flyback transformer (rectified output) with an electronic transformer of the type that’s used to power 12 volt halogen lamps. These output 12 volts RMS at about 20 kHz. Since a DBD requires an alternating output (sine, pulse, square), I used the same transformer (Amax HD150-120, 150 watts) to drive a small non-rectified flyback (TR-301H) from Information Unlimited. The transformer page is at https://www.amazing1.com/transformers-high-voltage-high-frequency.html.

Over the past few weeks I’ve experimented with a number of other inexpensive off-the-shelf modules for use as flyback drivers. These have included motor pulse width modulation (PWM) drivers and some zero voltage switching (ZVS) devices. There’s a huge variety of these available on outlets such as Amazon and eBay. I’ll defer any discussion of these for the moment but, in general, the results have been variable.

With regard to the lamp transformer, I found that a variable transformer could be used to adjust the output voltage. With the Amax transformer, the unit would start to work at about 30 volts to the input. A deficiency of this type of circuit is that the output consists of the desired 50% duty cycle square wave at around 20 kHz but it is modulated at 120 Hz because of the unfiltered full wave bridge rectifier that is placed at the input of the unit. Other than that, the square wave is reasonably clean. This site has some example waveforms for electronic transformers: http://www.ledbenchmark.com/faq/Transformers-Output-and-Compatibility.html.

The good news is that the unit will work quite nicely with DC. Since cheap 0-100 volt DC power supplies with a 10 amp output are not easy to find, I dug into my bin of modules and found a Drok DR-US200150 DC to DC boost module that I had left over from a ham radio project. I use boosters to maintain the output of a lead-acid battery bank at 13.8 volts. This is the value that keeps radios happy. This booster takes an input of 8-60 volts and converts that to any voltage above the input in the range of 10-120 volts at up to 10 amps. I've fed it with 14 and 24 volts and it works fine. Another booster that works is one from Hyuduo. This is 10-60 volts to 12-97 volts at 30 amps. Both of these boosters are available from Amazon for about $30 each.

With the APPJ I found it best to start the gas flow (a few liters/minute) and then raise the voltage until a stable discharge is achieved. Too high a voltage and you will get sparks on the outside of the tube between the electrodes.

In Search of a Better Driver

One device that I plan to try is a module from a British company, RM Cybernetics (https://www.rmcybernetics.com/). This is their Power Pulse Modulator OCXi v2.2. It is a PWM device with independently variable frequency and duty cycle. The module is designed specifically for driving inductive loads such as flyback transformers and includes a number of protection and monitoring features. The nominal ratings are 9 A current and a switching voltage up to 340 volts using an IGBT. The price is about $90. Unfortunately, the company is closed at the present due to the COVID-19 virus. The company does have a useful page on protection schemes when driving inductive loads. I'm using a simple snubber (series resistor and capacitor across the transformer primary). The direct link is https://www.rmcybernetics.com/product-guides/driving-inductive-loads.

Hopefully I'll be able to report on this device next month.

Articles of Possible Interest in *Vacuum Technology & Coating* Magazine

I just finished up my 4-part series *Low-Temperature Atmospheric Pressure Plasmas***.** They are as follows:

April 2020: The properties of low-temperature plasmas and applications of corona discharges
May 2020: Dielectric barrier discharges
June 2020: The atmospheric pressure plasma jet
July 2020: The atmospheric pressure plasma jet - applications and diagnostic methods

Articles may be accessed at http://vtcmag.com/. Scroll to the bottom of the page to the back issue selection box. Looks for my columns and you can probably find other articles of interest in each issue.

End Notes

It's gratifying to see the contributions of content coming in. In fact, there was more than I could put in this issue. If you are working on something that is vacuum related that may be of interest to others, please contact me. The material on refurbishing vacuum gauges will appear next month along with more on atmospheric pressure plasmas. I've also revived some work on the use of fuel injectors for pulsed gas introduction (see *the Bell Jar* Vol. 10, Nos. 1&2 – also the *Second Five Years* compilation).

That's it for this month. Stay healthy!

Steve