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

Notes from the Vacuum Shack **No. 20 August 2021**

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A Homemade Electron Gun

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Summary

Having ready access to a small vacuum pumping station and an electron-gun opens up the possibility of all manner of previously unimagined experiments mainly associated with particle physics. This document reports on a rather protracted project to develop a small electron gun (EG), along with some of the associated design decisions.

A great deal of effort was initially put into trying to unearth prior-art on the subject of home-made EG design and fabrication. Only two sources could be found; Ben Krasnow, creator of the YouTube channel 'Applied Science' [1], and Robert Hunt, creator of the Teralab website [2] in the UK. Both of these sources provided significant levels of encouragement, but it was hoped that a simpler mechanical design might be possible. One other interesting source was published by Tektronix in the 1960s [3]. Also, Murray Clarke (a local vacuum-valve wizard) acted as a very useful sounding board for some of my design decisions.

Vacuum Friendly Materials

One of the continuing problems during this project was being able to identify and gather vacuum-friendly materials. The final list included JB Weld epoxy, brass and copper stock, gold-plated brass electrical contacts, stainless fasteners, PTFE covered copper wire, and mica sheet, the latter being able to be shaped using a laser-cutter.

Lots of samples were bought from eBay, including nickel sheet, tungsten wire, and the most elusive of things and some vials of scanning-electron-microscope tungsten filaments (AGA054, photograph on the next page).

AGA054 SEM filament, 12 mm dia base,
70 micron tungsten wire and 250 micron tip-width

Simplicity

Right from the onset of the project, efforts were made to reduce the complexity of the electrical system. The construction of a constant-current source to drive the filament as well as an adjustable bias for G1 (with respect to the cathode) turned out to be time well spent. Both outputs are able to float within ±2.5kV with respect to ground. [4]

Homemade floating filament and grid supply

Oxygen Poisoning

Early experiments indicated that the thoriated tungsten filaments of commercial electron valves (tubes) were very sensitive to oxygen poisoning. Clearly, once the assembly had been exposed to air, this class of electron source was no longer viable. This realisation lead to the idea that the EG from a large-necked CRT could be reworked by replacing its Wehnelt cylinder with a custom fabricated assembly using a tungsten filament.

CRT Investigations

After considerable investigation and dismantling of several newer (1960s) CRTs, the VCR97 CRT was chosen as a suitable donor due to its large EG assembly size. I was lucky enough to acquire several of these devices 'brand new', complete with unopened packing, and markings indicating a 1940 manufacture date.

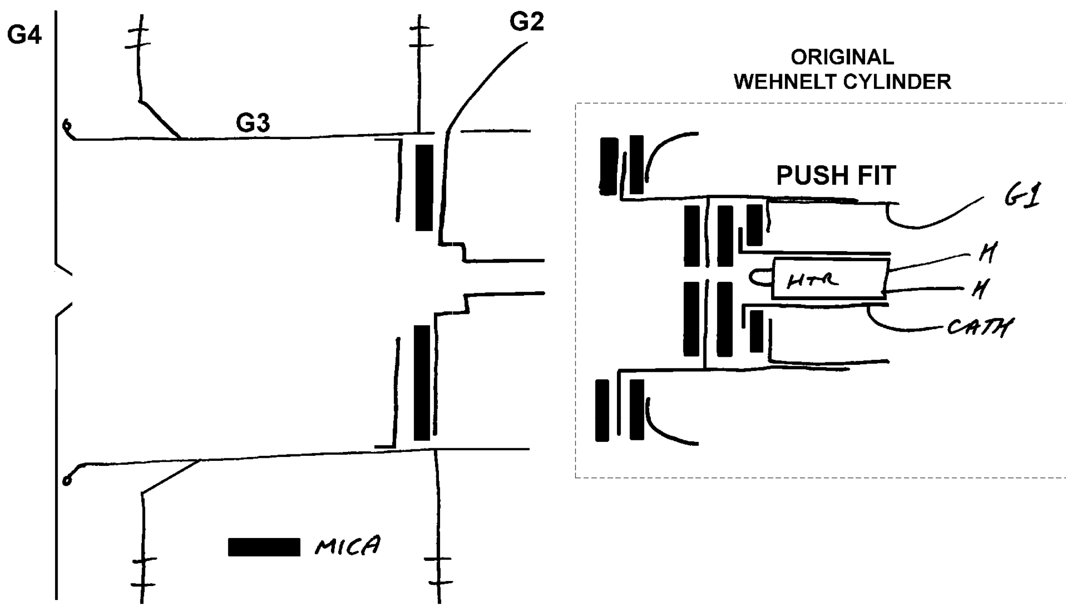
VCR97 CRT, overall 420 x 160 mm

The disassembly process started by placing the CRT screen first inside a thick (100 um) plastic bag. The rear-plate was unscrewed, and the glass sealing tip cut using a large pair of pliers. The vented assembly was then gently beaten with a large hammer at the neck. The screen was removed, and in a well-ventilated area the phosphor was gently scraped off and stored for later use. The e-gun assembly was slowly removed as further glass was chipped away. All of the scrap glass was placed back in the plastic bag, which was sealed with duct-tape before being placed in the bin for disposal. Care was taken to ensure that disposal bag could be handled safely by the disposal workers.

VCR97 e-gun and deflection assembly, 250 mm long including leads

It was interesting to handle a nickel assembly that had never been touched for over 80 years. The whole unit was in the same condition as had been manufactured.

The assembly had a mass of welded electrical connections (many sleeved in glass tubing) heading back to the base of the unit. Again, nickel appeared to be the conductor of choice. All welded connections were peeled back with pliers until the bare e-gun and deflection assembly was visible. Welded nickel clips held the electrodes onto four 4 mm ceramic posts. A minimum number of these clips were removed so that the e-gun and focus assembly could be withdrawn for examination.

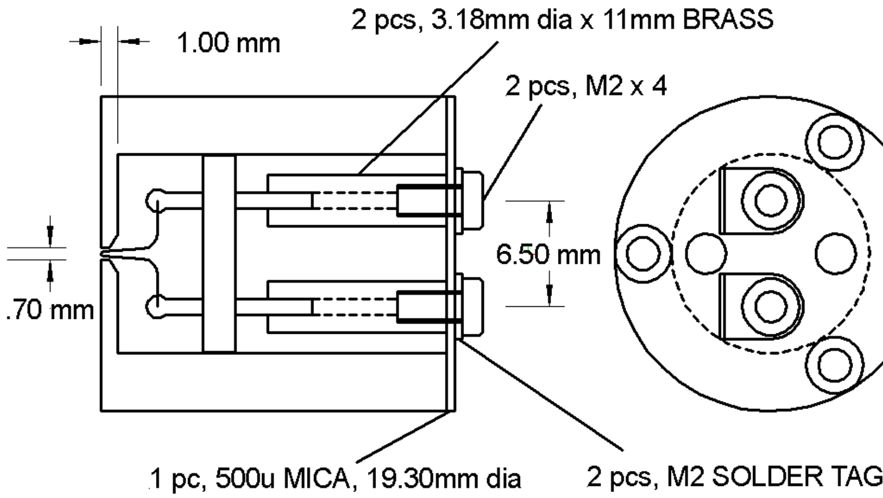


Original Wehnelt cylinder, and focus assembly

It was surprising that the cathode and Wehnelt cylinder were basically a push fit with mica insulation between electrodes. Also, right from the start, it was clear that the assembly did not appear to conform to the expected traditional electrode sequence. The main area of confusion was a tube projecting from the focus assembly into the Wehnelt cylinder. Quite some time was spent drawing a cross section of the assembly before function became obvious.

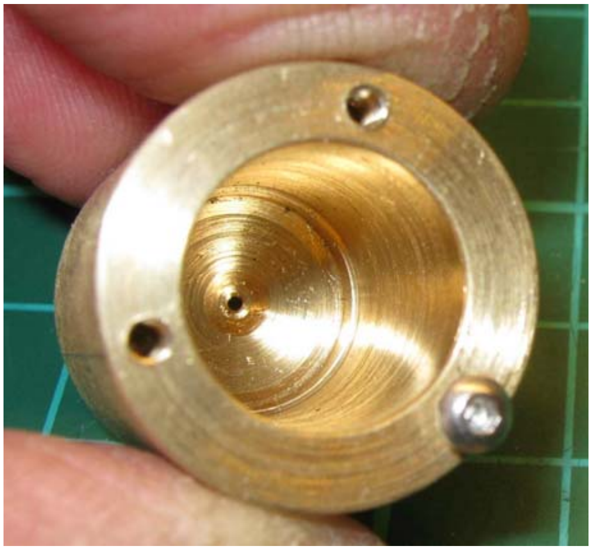
Replacement Wehnelt Cylinder

So having acquired the candidate filament assemblies, as well as a serviceable focus and deflection assembly from the VCR97, it was time to move to integrating the two. The ceramic filament base was 12 mm dia, and the chosen M2 fasteners had 3.5 mm dia heads, so overall diameter for the new Wehnelt cylinder was going to be in the order of 19 mm. More by luck than judgment, this was likely to be an excellent fit with the VCR97 components.



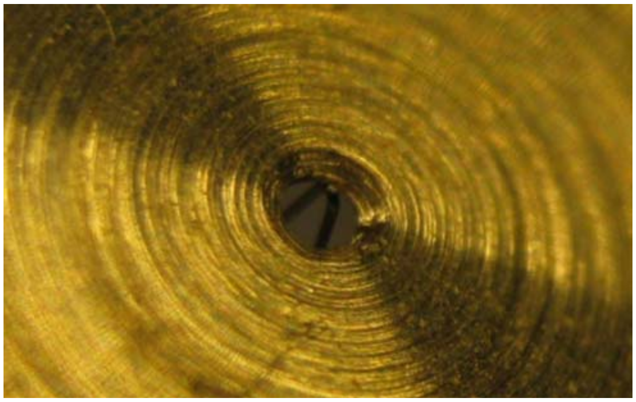
Initial Wehnelt cylinder design

A couple of significant changes were made to this design in due course. Three 3 mm vents were machined in the filament side of the cylinder. As shown, the filament assembly acts as an excellent piston during changes in surrounding pressure. The second update was to put 250 micron slots across the filament holders, then gently squeeze the slots so that the filament became a very snug fit when pressed home. The main bore was cut using a tailstock mounted 12.2 mm drill in the lathe, but this did not result in a square bore at the bottom. To fix this, a sacrificial 11.5 mm drill was ground completely flat and used to bore out the final few mm until the desired 1.0 mm wall-depth was achieved. This was not a fine piece of engineering, but it did the job.



700 micron electron aperture at the base of the new Wehnelt cylinder

With the filament inserted, it was possible to see the nose of the assembly centered, and just poking through the hole.

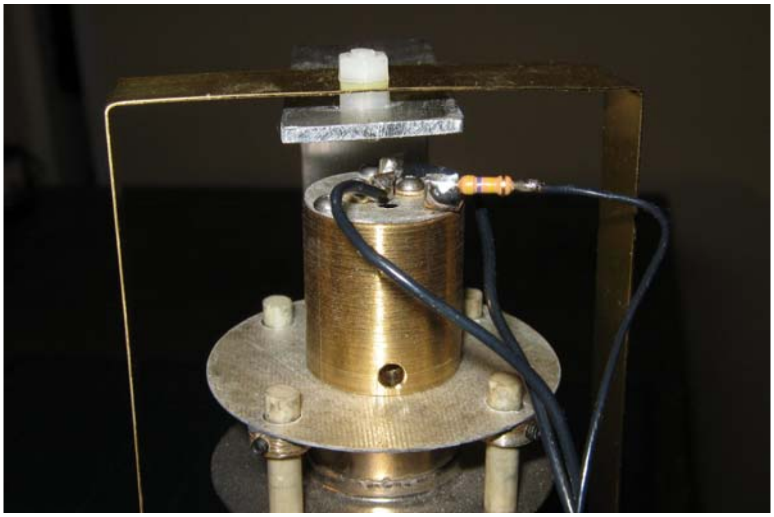


250 micron filament sitting slightly proud in a 700 micron hole.

It was around this time I was discovering the 'lightness of touch'. The huge gouge to the right of the picture was a first attempt to de-burr the hole lightly using a 3 mm drill. Bear in mind that this photo is just over 5 mm wide. The rough finish of the brass was caused due to the use of a wrong lathe tool (steel insert instead of soft-metal); this has since been rectified.

Final Assembly

The brass strap over the top provides mechanical attachment for the whole assembly as well as electrical connectivity to grid G2 and G4 (G24). G24 is connected to the astigmatism-correction potential (around 150V), so need to be electrically isolated from ground, hence the nylon insulator (which thankfully didn't cause any issues with outgassing).



Laser cut front and rear mica disks providing interface to the focus assembly as well as electrical connection to the filament and G1 (with 470k resistor)

Final complete assembly of working unit

One of the final additions was a copper cylinder to imitate the behaviour of the Aquadag coating found around the neck of modern CRTs. This was implemented at the recommendation of the RCA publication “AN-92 Operation of the Improved Type 906 CRT at Low Voltages”, published May 1938.

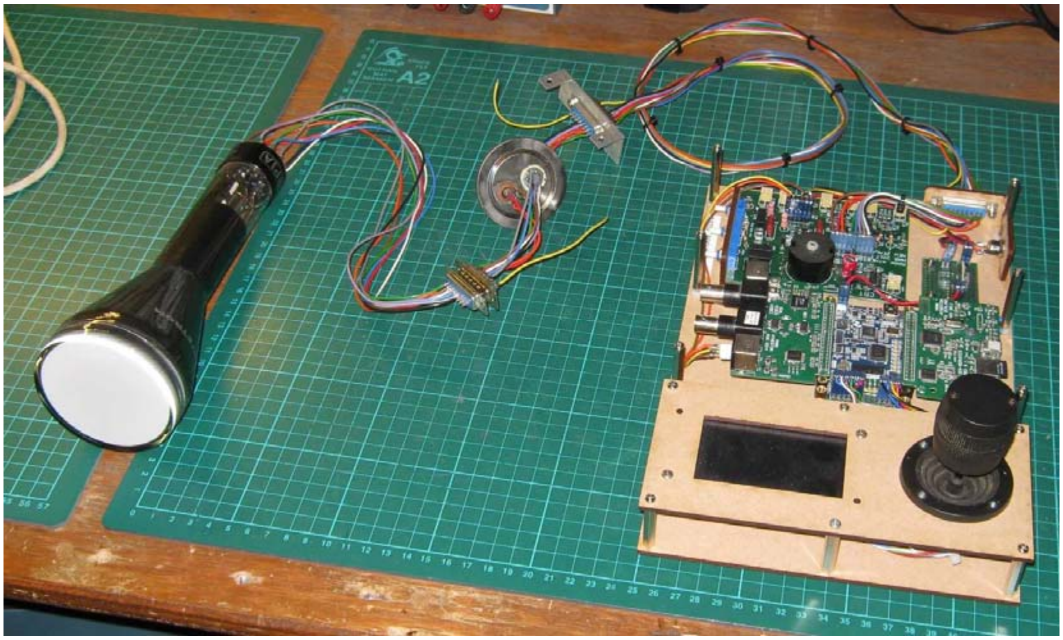
Complete Pumping Station

The pumping station is based on a Pfeiffer turbo-pump, with rotary mechanical pump. Varian instrumentation including cold-ion and thermocouple gauges.

Pumping Station, Bell jar, electron gun,
baseplate [5], and homemade thermocouple gauge [6]

Test Signal Electronics

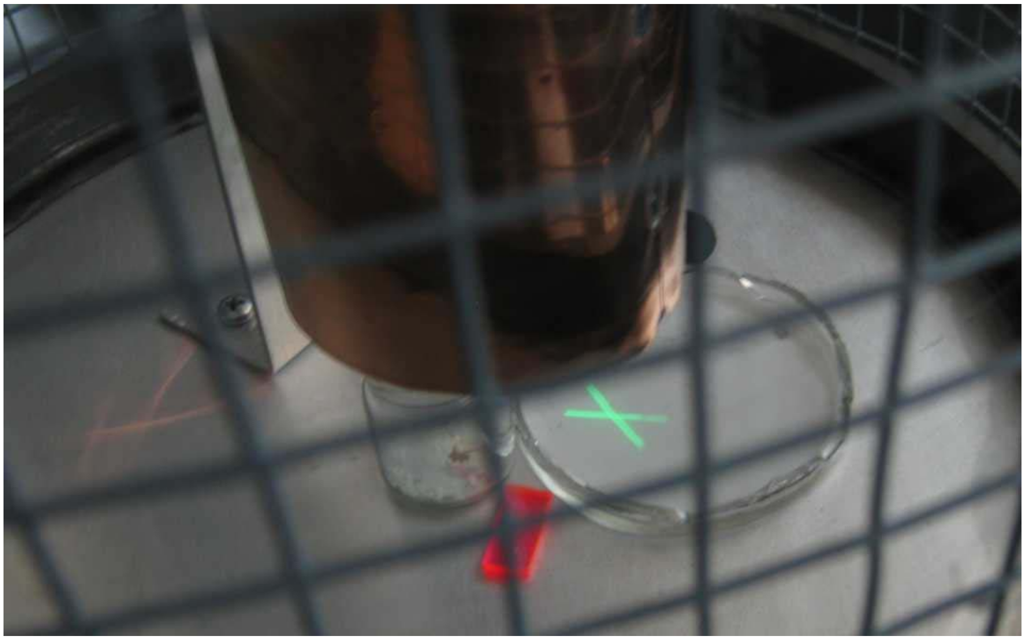
High voltage, deflection and test signal generation was provided care of a home-cooked FPGA based custom unit, assembled on MDF. The FPGA board was a terASIC DE0 nano, with homemade video DAC interface. The HV supplies and deflection were from a previous CRT based vector game 'Vector Drawing Machine number 3'.



Custom test generator [7], with 3RP1A CRT attached

Success

Success at last, with three sample targets: a dismembered CRT faceplate, a 10 ml jar containing CRT phosphor, and a sample of fluorescing acrylic.



Second successful run

Finally

It is difficult to describe the relief associated with getting this test running. I was running out of things to fix, and all previous failures had been isolated, understood, and resolved. This was pretty much the end of almost 12 months of discovery, and learning-things-the-hard-way.

Details of several components associated with this project, along with other interesting vacuum related stuff have been published by Steve Hansen at http://www.belljar.net/articles.html

References

1) DIY Scanning Electron Microscope - Overview
www.youtube.com/watch?v=VdjYVF4a6iU
2) Robert Hunt's physics and science projects
www.teralab.co.uk/Experiments/Electron_Optics/Electron_Optics_Page1.htm
3) Tektronix book 'Cathode-Ray Tubes Circuit Concepts', 062-0852-01
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Page 1, www.belljar.net/tBJ_January_2021.pdf
5) Design and Fabrication of a Vacuum Base Plate, and Associated KF Series Fittings,
Page 1, www.belljar.net/tBJ_June-July_2021.pdf
6) A Simple, Single Supply Thermocouple Gauge,
Page 3, www.belljar.net/tBJ_May_2020.pdf
7) VDM3, Vector Drawing Machine #3
hackaday.io/project/176054-vdm3-vector-drawing-machine-3

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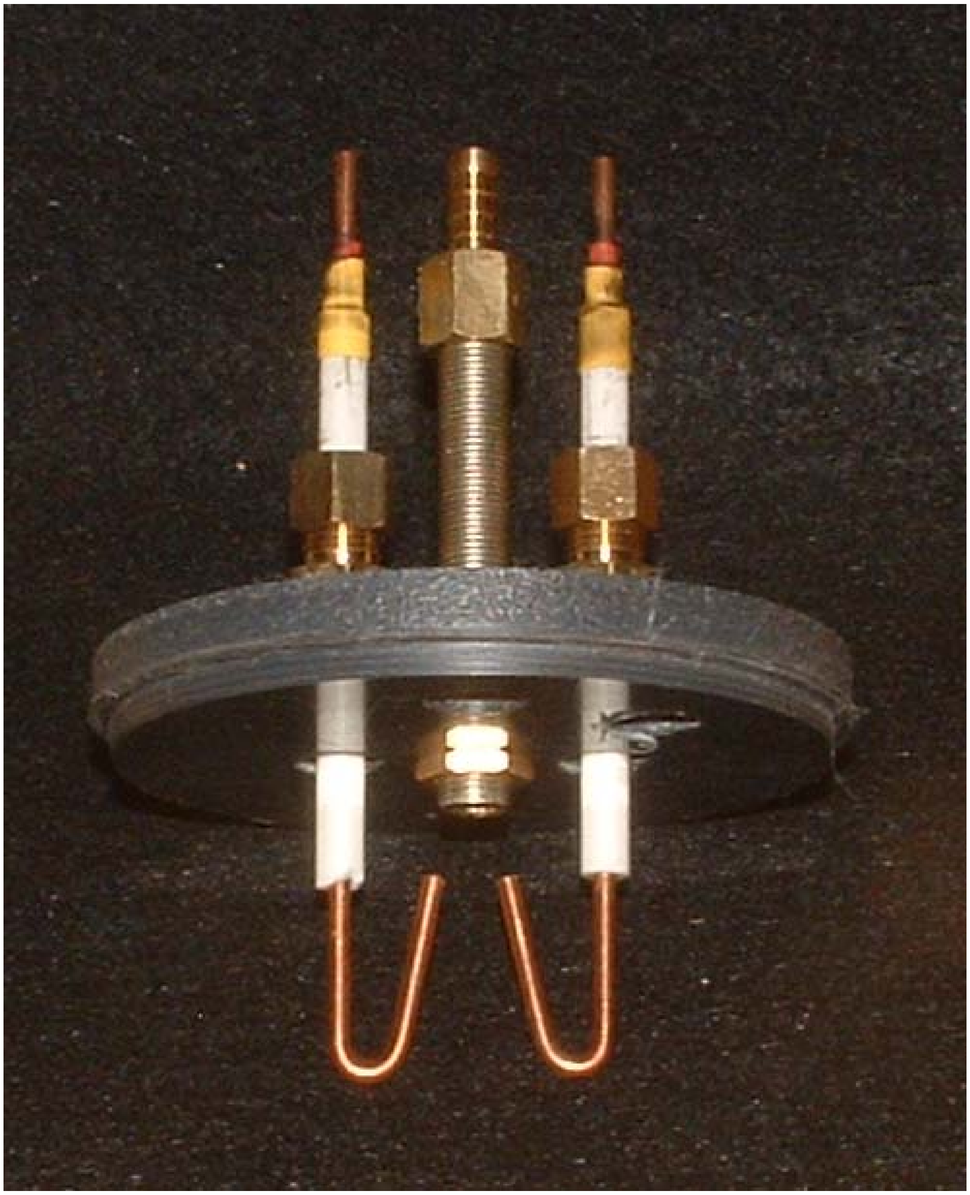
Update on My Plasma Activated Water (PAW) Apparatus

The previous issue contained a brief note on a proposed device for creating plasma activated water using a simple gliding arc discharge (GAD). As of this writing I've fabricated and tested the working mechanism of the device.

Referring to the photo on the next page, the electrodes and gas feed are mounted on the 1/2" PVC disk that I cut with a 4-1/8" hole saw. The resulting disk was just under 4 inches in diameter. The water containing vessel I used is a 4" diameter by 6 inch high acrylic display stand (Azar International #556406, https://azardisplays.com, also available from Amazon). To fit the disk to the vessel, I turned a step in the perimeter to make a loose fit inside the plastic container.



The port for the gas inlet is placed at the center. This was drilled and tapped for 1/8” pipe thread. In line and outboard of this are two holes for the electrode assemblies. These were drilled and tapped for 1/4” pipe thread with centers at 1-3/8” separation. I used ¼ M-NPT x 1/4” brass compression fittings with Teflon inserts to hold the electrode assemblies.

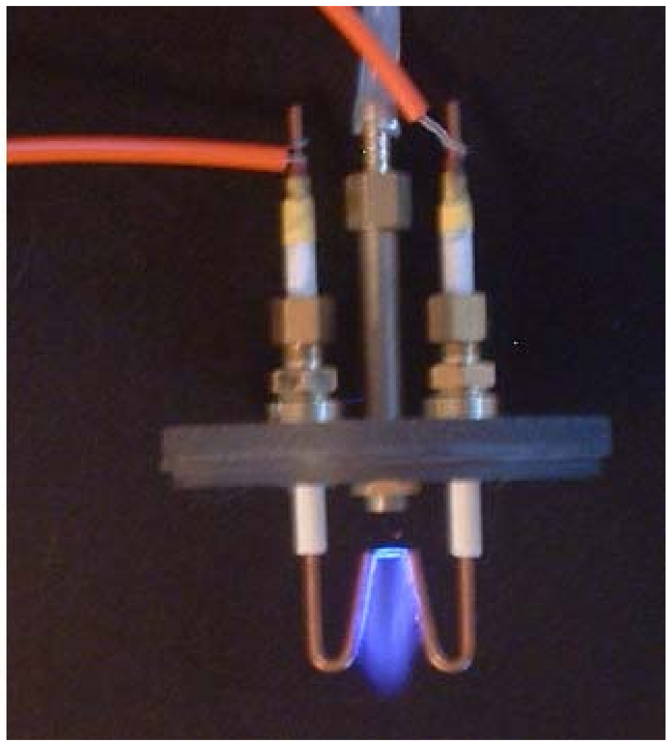
The electrodes were made from 3 mm diameter hard copper rod. These are held in 1/8” ID x 1/4” OD alumina ceramic tubes. Both of these were obtained from McMaster-Carr. The metric rods make a nice sliding fit with the ceramic.

The gap was fashioned by bending the end of each rod around a 1/4” diameter mandrel using a simple bending jig. After getting the correct amount of bend, the electrodes were inserted into the ceramic tubes. Since the fit is a bit sloppy, the upper ends of the rods were secured with some shrink tubing.

The smaller electrode gap is just under 1/4”. The gap widens to about 5/8” before the radius. The length of the straight section is 1”.

The gas feed tube is a piece of straight threaded 1/8” NPT tube stock, the type used in making electric lamps.

Three other holes were added to the disk. Two, at right angles to the electrode/gas feed holes are 1/2” in diameter and can be used with Vernier pH and conductivity probes. The idea here is to data log the changes in these parameters while the device is running. The third hole is positioned away from the other holes and serves as a vent. I threaded this with a 1/4—NPT tap in case I wanted to be able to conduct the activated gas to some other apparatus. The photo below on the left below shows the complete assembly. The photo to the right shows the discharge using an electronic oil burner transformer with me blowing into the tubing. My lungs will be replaced by a diaphragm air compressor.



The next steps will be to integrate everything onto a base (a bamboo cutting board of course) with flow meter, transformer, magnetic stirrer and Vernier sensor probes.

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

September 2014
Intentional Leaks
Various ways of admitting tiny flows of gas into a system

April 2015
Stress and Strain
Gauges that measure pressure based on strain and resonant structures

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

End Notes

I'm curious if anyone has used one of the many inexpensive zero voltage switching (ZVS) induction heaters for vacuum applications. These could include vacuum melting, degassing of electrodes and maybe even the preparation of targets by infusing deuterium into a suitable metal. Many examples of these devices may be found on eBay with prices ranging from under $20 to over $100. To the right is a photo of one offering in the $80 class. This includes the oscillator, induction coil, water pump (for cooling the coil) and a crucible.

Current plans for next month include the finished GAD device and a progress report on my saddle field source.

As usual, contributions of any complexity are welcome.