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

Notes from the Vacuum Shack **No. 22 October 2021**

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Naked CDD Imager under Electron Illumination

Mark Atherton, New Zealand, markaren1@xtra.co.nz

This project was an experiment to see how a CMOS imager behaves under electron illumination. This project could lead to a useful method allowing real-time focusing of an electron beam as well as a means to assess focused electron cluster-size. This is the continuation of a series of experiments associated with a previously described home-made electron gun and test signal generator [1].

Having acquired a tube of single-chip PAL imagers [2], I wondered what might happen if the top layer silicon were exposed directly to a steerable stream of electrons. A small custom PCB was designed for the job, but before the experiment could proceed, the glass window needed to be removed.

The first attempt to remove the glass from the imager was done by applying enough hot air to soften the associated epoxy. Unfortunately this process appeared to cause enough heat damage that the unit stopped working. Attempt two started by scraping the epoxy that was bonding the glass to the ceramic package. Eventually a scalpel blade could be wedged between the glass and ceramic body, and the glass could be twisted off with minimal stress. At one point, the blade did slip and scrape the surface of the device.

The imager was placed under the electron gun (copper cylinder in photograph on the next page), and perched on a dismembered faceplate from a small oscilloscope CRT. Electrical connection to the outside world was via three wires; 5 volts, ground, and video. The CRT faceplate was used as a means to locate the electron stream, allowing it to be steered in the general direction of the imager using the joystick on the test signal generator.

The custom test generator provides EHT supplies, HV supplies, beam deflection and test patterns for the electron gun. Signal generation is from a Field Programmable Gate Array, which subsumes user interface (touch screen, colour graphics LCD, and joystick) as well as high-speed test signal generation and a soft-core 32 bit micro-controller. Various test patterns are available including dot, circle, cross, and a video-compatible raster-scan [3].

Imager assembly, next to the dismembered CRT faceplate

With the bell jar pulled down to a healthy vacuum (5×10^{-6} Torr), a video monitor attached to the imager output and the test generator powered up, it was easy to illuminate part of the CRT screen with a stream of unfocussed electrons using the ‘dot’ test pattern.

The green blob was then steered from the CRT in the general direction of the imaging board where a faint pattern was visible on video from the imager. Even by focusing the stream of electrons, it was barely possible to improve detection using the imager. Damage to the imager due to the scalpel slipping is very obvious. See image below.

Obvious slash-damage to imaging IC.
Much less obvious is the electron illumination within the circle.

As a side note, it was interesting to note the electron heating of the G24 electrode that separates the deflection plates of the e-gun. This could indicator that there are some alignment issues associated with the Wehnelt cylinder, or that G24 was struck with out of focus high-energy electrons. If the latter were true, then heating on both sides of the slot might be expected.

Electron heating of G24 electrode within the electron gun

While the outcome of the imaging experiment was not quite as was initially hoped for, the heating associated with possible misalignment of the e-gun is something which requires further follow up.

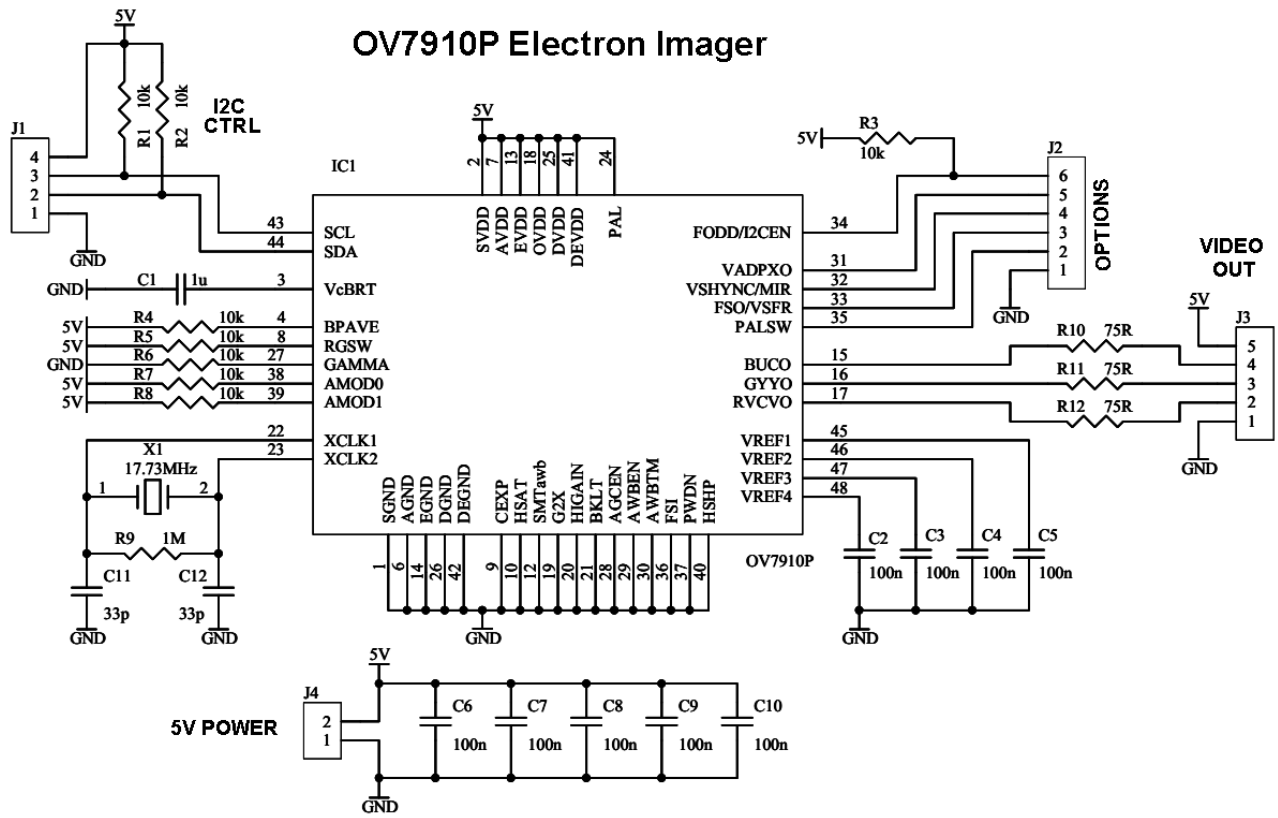
Not all experiments go as planned or are successful. I am a firm believer that there is value to be had by reporting these kinds of projects for the benefit of others.

Mark Atherton
3 Oct 2021
New Zealand

References

1. *A Homemade Electron Gun*, Page 1, http://www.belljar.net/tBJ_August_2021.pdf
2. http://www.datasheetbank.com/datasheet-download/885652/1/Omnivison/OV7910P
3. *Custom Test Generator*, Page 9, http://www.belljar.net/tBJ_August_2021.pdf

Appendix A: Imager schematic



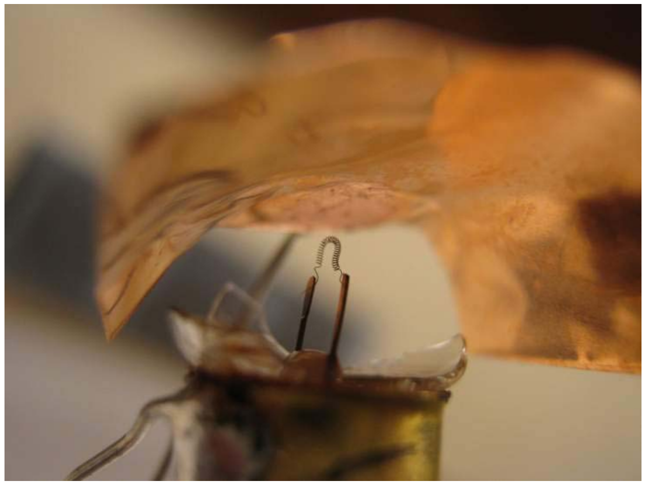
Homemade Vacuum Diode

Mark Atherton, New Zealand, markaren1@xtra.co.nz

A diode is an electronic device that only allows current to flow in one direction. The majority of modern low current devices are now solid-state. This article describes how a vacuum version can be constructed using only a high vacuum chamber and some readily available material. It also lays the foundation for more sophisticated electron(ic) projects downstream [1].

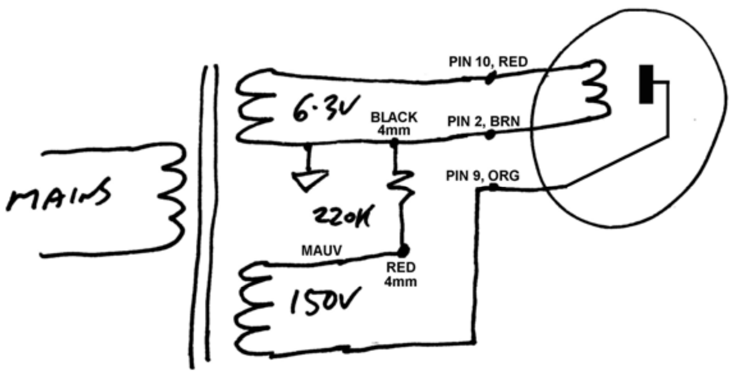
Back in the dawn of history, long before LED lighting was just the merest twinkle in someone's eye, incandescent lighting populated the landscape, including the ever-popular handheld flashlight (torch). The basic emitter of such technology was a very, very fine tungsten wire that had been coiled, the coiled again. When suspended in an inert atmosphere, this tightly bound structure was able to generate immense localised heat (and light) with only a few hundreds of milliamps of current passing through it. One of the other possible uses for such a component is that if the inert atmosphere were replaced with a high vacuum, a cloud of electrons would surround the heated filament. This becomes known as a 'bright emitter', and can be used a directly-heated cathode for various vacuum tube (valve) applications.

An anode structure can be fabricated using a small piece of copper foil (any conductive material can be used, within the constraints of outgassing, and electrical attachment). By placing this electrode a few millimetres away from the bright emitter, a simple thermionic diode can be constructed.



Tungsten filament and copper anode

For the purposes of this experiment, a means of heating the filament and a low power high voltage AC are required. Also required is a means of detecting rectified AC.

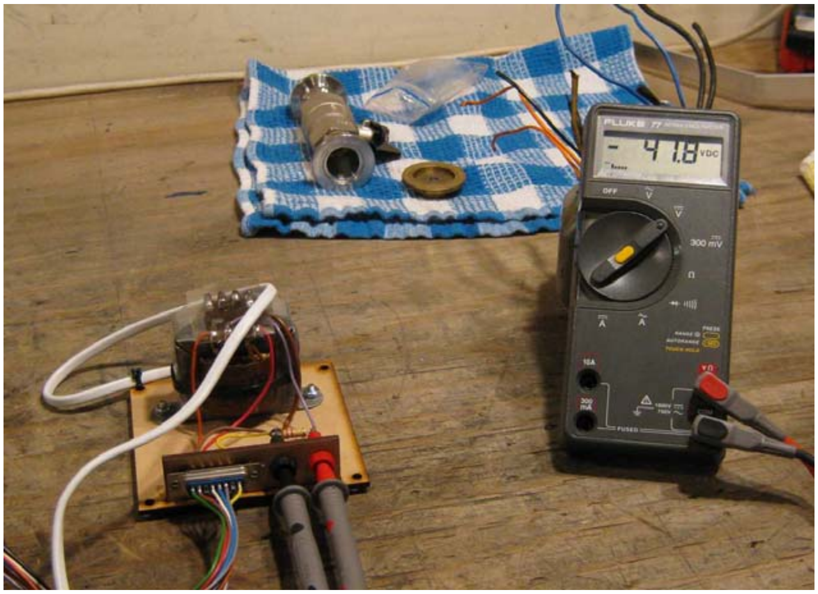


Thermionic Diode test fixture

Red and black 4 mm sockets are connected across the 220k load, and are attached to a DC voltmeter.

Bright emitter and anode in evacuated bell jar

The complete set of parts is shown in the photograph on the next page. It was with some delight that the experiment worked first time. It is worth noting that the meter is insensitive to AC on the DC range; this had previously been tested. Also, for the record, a piece of acetate sheet has been laser cut into a large ‘+’, and tie-wrapped over the exposed terminals on the top of the transformer in an attempt to provide at least some form of safety to me from hazardous voltages.



Test in progress

Mark Atherton
15 Oct 2021
New Zealand

Reference

1. *A Homemade Electron Gun*, Page 1, http://www.belljar.net/tBJ_August_2021.pdf

Vacuum Coating by Evaporation

Chuck Sherwood, chuck1024@wowway.com

I did some experiments with vacuum coatings and thought maybe a basic write up might be of interest. I wanted to keep things very simple so I started with a 6 inch glass bell jar with a hole is the top purchased online.

The base plate was a piece of ¾-inch aluminum plate. A photograph is on the next page. Vacuum connection to the base plate was implemented with a KF-25 bulkhead flange. Two holes were drilled about 2.5 inches apart to fit #1 rubber stoppers. The holes were tapered for a reasonable fit with a hand reamer. One-hole stoppers were used and fitted with ¼-inch brass rods for conductors. Each end of the brass rod was drilled and tapped for a screw. The rods were cross drilled with a 0.11” drill to fit the wires.

The rods support a tungsten filament composed of 3 wires twisted together. Initially I started with three 0.3 mm wires. My second filament was made from 0.5 mm wires twisted together and then wound around a ¼-inch wood dowel to form a coil as shown on the next page. Note this filament has been loaded with aluminum by crimping small pieces of 1100 aluminum sheet metal to the filament and heating under vacuum with just enough current to melt the metal and make it wet the wire. This required about 12 amps.

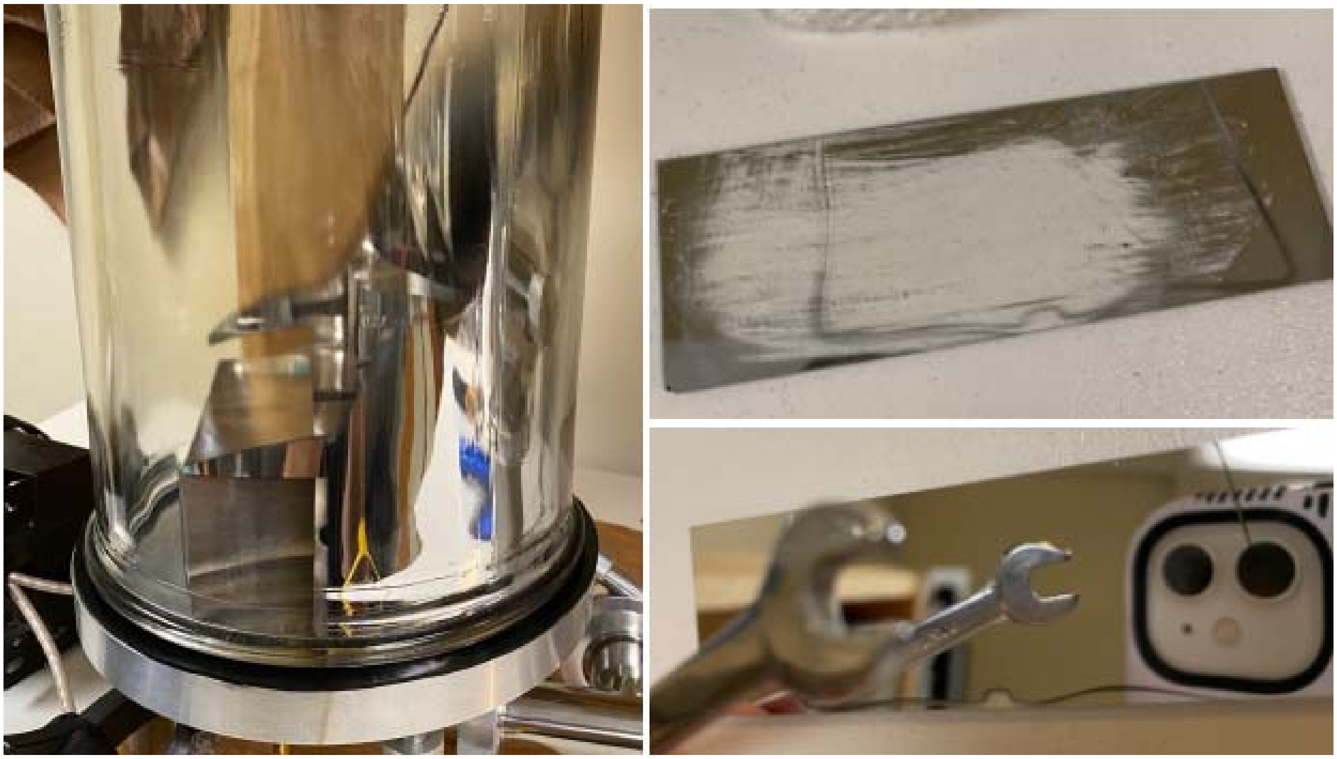
A gasket for the bell jar was cut from sheet rubber, believed to be EPDM. Silicon grease was used on both sides of the gasket because EPDM does not tolerate petroleum based products. A #5 stopper was used in the top hole with a ¼-inch brass rod and aluminum disk to attempt some plasma cleaning. A 10 kV oil burner ignition transformer was used as a power source for plasma cleaning.

I modified an old transformer to power the filament by removing the burned out HV winding and replacing it with 4-5 turns of very heavy gauge wire. Shown at the right, this transformer will produce about 2.5 volts at 50 amps but this is far more than I needed. This filament needs about 2 volts and 15 amps which can easily be supplied by some old tube filament transformers.

I think a 5 volt, 20 amp tube transformer would work well. A Variac is needed to control the filament temperature.

The bell jar is pumped down to about 100 mTorr and the HV is applied for a while. The voltage is slowly increased using a Variac transformer until a glow appears. I used several 30 second intervals to avoid heating anything up. During this time the diffusion pump is warming up, but isolated from the jar. When the DP was ready, I slowly opened the gate valve and pumped the chamber down. When the pressure was close to 10^{-5} Torr, I slowly applied current to the coil to melt the pieces of aluminum crimped to the wire. Heating too fast will just melt the metal and it falls off in balls. Slowly heating it allows it to wet the tungsten wire and wick into the coil. This required several minutes with the coils medium red at about 12 amps.

Filament current is now increased to evaporate the aluminum. This happens quickly and you can see the metal deposited on the inside of the bell jar. It goes from clear to semi-transparent to opaque in 10 to15 seconds. I let it go for another 15 seconds to be sure. Filament current was about 15 amps for this phase.



The photograph above left shows the coating on the inside of the bell jar. To the right are two photographs of microscope slides that have been coated. The top right photograph was done at 10^{-4} Torr with no plasma cleaning. It did not adhere well and the coating rubbed off with a paper towel.
The one below was coated at 10^{-5} Torr with plasma cleaning. It made a perfect mirror coating.

The Capillary Spark

My pseudospark device has been covered in several previous issues of this newsletter. It had its origins soon after I read an article on these devices in *Review of Scientific Instruments* back in the early 1990s. Last month's issue discussed the work ongoing at Strathclyde University in Glascow, Scotland. Their focus has generally been on the optimization of the electron beam energy from the devices and the use of the beam for the generation of high power microwave (THz) energy.

A companion device is the capillary spark. From a 1999 paper by Dediu *et al*. [1]:

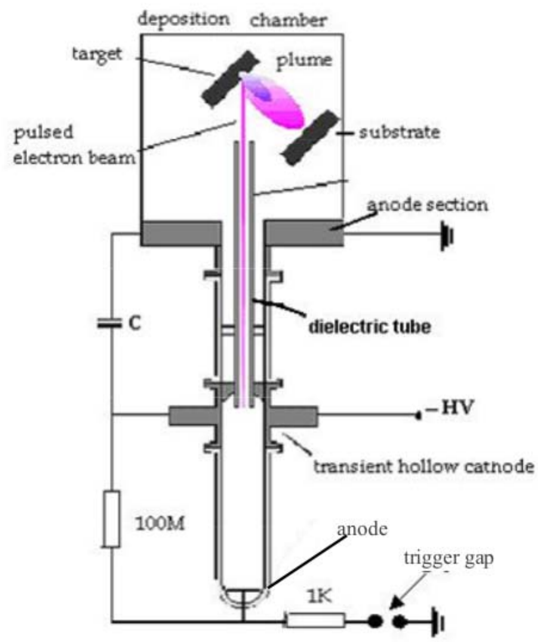
> *"The channel-spark is a type of hollow cathode glow discharge similar to pseudo-spark discharge. The pulsed electron beams in both channel-spark (CS) and pseudo-spark (PS) processes are generated from similar hollow cathodes, they are magnetically self-pinched and accelerated through specially designed gradient electrodes (a stack of insulating and metal rings in the PS system and a simple insulating narrow pipes in the CS system) towards a stoichiometric target placed in the deposition chamber.*
>
> *"Both these e-beam deposition processes are similar to laser pulsed deposition, providing a good stoichiometry transfer from the target and similar surface roughness of the films. The main*

advantage of the methods based on pulsed electron beams lies in their simplicity and very low price of installation, while a disadvantage is the narrow useful pressure interval (about 1-3 Pa).”

For thin film deposition purposes, the pseudospark has the disadvantage of electrode oxidation and erosion.

Earlier this month I happened upon the Ph.D. thesis [2] of Dr. Patrizio Graziosi, a research scientist with the Institute of Nanostructured Materials (ISMN), part of the National Research Council of Italy. The work done for the thesis was conducted between 2007 and 2009. I sent him an email and he graciously replied with some commentary and photographs of the device he is using for the ablative deposition of compounds with impossible to pronounce names. The term for the process is channel spark ablation or CSA. The basic process involves hitting the target material with a high current pulse of electrons. This ablates the target material which is then deposited on a substrate that is placed a short distance away.

The figure to the right is from the thesis. (There are similar figures in [1] and [3]. With some variations in the triggering method and other details, the patent of Mattacotta [4] shows a very similar device.) The thesis explains the general operation as follows:



“Plasma originates in the discharge between the bottom electrode and the transient hollow cathode. The negative high voltage power supply is directly connected to the capacitor which is charged up and to the bottom circuit containing anode electrode, a charging resistor (100 MΩ in the figure) and a floating electrode of the spark gap. At a certain voltage a spark closes the air gap and it resistance becomes zero. As a consequence a rapid variation of the electric field occurs in the trigger bulb. The fast electric field variation ionizes the gas molecules (or atoms) and originates plasma, providing electrons in the hollow cathode cavity, where the discharge amplification happens, ... Because the charging resistor decouples the capacitors and the anode plate, the capacitors discharge on the cathode in the top part of the circuit (the hollow cathode, the grounded chamber, the capacitors) through the low impedance electron beam. The low impedance discharge cannot be sustained (since the power supply is limited in current) and it extinguishes. The current supplied to charge the capacitors defines the charging time and, hence, the operating frequency.”

The voltage across the dielectric section accelerates the electrons escaped from the cathode and the so-called channel discharge occurs.

Some photographs are shown on the next page. Dr. Graziosi humbly stated “The system is home-made so maybe it does not look appealing or fashionable.” He is currently using the device “to deposit complex oxides, i.e. oxides with complex chemical and physical structure with exotic properties, and dielectric thin films.” It goes to show that you don’t necessarily need “fancy pants” equipment to do cutting edge research.

Above left - Vacuum bulb with anode, hollow cathode and connections to the capacitors; top right - The resistor box with cover removed; bottom right – the adjustable spark gap. Photographs courtesy of Dr. Patrizio Graziosi.

The net result of this is that I now have another project on my plate. I have a tentative design based mostly on materials that I have in my inventory of stuff. One of the first tasks will be to modify my chamber (shown to the right) so that it will accommodate both the PS and CS sources. I also plan to shorten the distance of the 1” diameter section between the source and the chamber using a bit of surgery. I will use a 3 mm ID by 6 mm OD quartz capillary (same ID as the Italian device). Details on the PS device itself as it now stands were in issue #3 of this newsletter.

References

1. V I Dediu, Q D Jiang, F C Matacotta, P Scardi, M Lazzarino, G Nieva and L Civale, *Deposition of MBa2Cu307-x thin films by channel-spark method*, Supercond. Sci. Technol. 8(3):160 (1999) DOI: 10.1088/0953-2048/8/3/005 https://www.researchgate.net/publication/231017128_Deposition_of_MBa2Cu3O7-x_thin_films_by_channel-spark_method
2. Patrizio Graziosi, *Material engineering in hybrid spintronic devices*, Ph.D. thesis. https://www.researchgate.net/publication/44221096_Material_engineering_in_hybrid_spintronic_devices
3. P. Graziosi, M. Prezioso, A. Gambardella, C. Kitts, R.K. Rakshit, A. Riminucci, I. Bergenti, F. Borgatti, C. Pernechele, M. Solzi. D. Pullini, D.

Busquets-Mataix and V. A. Dediu, *Conditions for the growth of smooth La0.7Sr0.3MnO3 thin films by pulsed electron ablation*, Thin Solid Films, 2013. https://www.academia.edu/28590510/Conditions_for_the_growth_of_smooth_La0_7Sr0_3MnO3_thin_films_by_pulsed_electron_ablation

4. Francesco Ciuo Matacotta*, Apparatus and process for generating, accelerating and propagating beams of electrons and plasma*, US Patent 7,872,406, issued January 18, 2011.

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

September 2013
Delivering the Vapors - Bubblers and Direct Liquid Injection

October 2013
Solid Source Vapor Delivery Devices - Reverse flow bubblers and ion implant vapor sources

November 2013
Sub-Atmospheric Gas Sources and Delivery Devices

December 2013
Vapor Delivery Systems for Solid and Liquid Sources

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 was going to present some great results with my plasma activated water (PAW) apparatus using a gliding arc discharge (GAD). Well, I fired it up and the conductivity of the distilled water did not change. It could be that the air flow to the GAD is either not high enough (my compressor topped out at 20 slm) or without a high enough velocity. I'll try a better nozzle next. The alternative, that I might pursue regardless, would be a simplified surface micro-discharge device. Preliminary tests show that this would work just fine with the existing electronic oil burner transformer and would be much cheaper and perhaps safer. It would also eliminate the noisy compressor. Stay tuned.

As usual, contributions of any complexity are welcome.