

Design and Construction of a Multiplate Chamber

By

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Abstract

Multiplate chambers can be used as a source for high current, high voltage ion beams via pseudo-spark discharge. A five gap, untriggered multiplate chamber has been constructed at Houghton College, which operates at voltages up to -25 kV and pressures between 25 and 80 mtorr. The discharge occurs when the voltage across a 2.7 pF capacitor, which is charged through a 400 M Ω current limiting resistor, reaches the breakdown voltage of the air in the device. The discharge voltage at several operating pressures has been measured by monitoring the current flowing into the capacitor, and the beam current as a function of time has been measured with an oscilloscope across a 10 Ω resistor to ground. The shape of the beam spot has been observed using a phosphor screen.

Thesis Supervisor: Dr. Mark Yuly

Title: Professor of Physics, Chair

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Chapter 1

WHAT IS A MULTIPLATE CHAMBER?

1.1 Introduction to Multiplate Chambers

Over the past four decades, numerous experiments have been conducted with pseudo-spark devices, or multiplate chambers (MPC). These experiments were started after 1979 when Christiansen and Schultheiss first used multiplate chambers to trigger thermonuclear fusion using their high energy ion beam output [1]. Such devices can create discharge currents in the kiloamp range with an accelerating voltage over 100 kV. It is important to note, however, that these currents occur during pulses lasting only 50 ns.

As shown in Figure 1, a multiplate chamber consists of an aligned series of parallel conducting electrode disks separated by larger insulating disks with the gaps around the electrodes and between the insulators being sealed by o-rings. After the chamber pressure is reduced to its operating pressure, usually between 20 to 80 mTorr, a large potential difference is built up across the chamber as a high negative voltage power supply charges a small value capacitance in parallel with the chamber. This potential difference increases until the breakdown voltage of the chamber is reached, at which point the negative charge that has been built up on the capacitor is discharged in the form of a high current electron beam along the axis of the chamber. At the same time, a positively charged ion beam is discharged in the opposite direction.

1.2 History

After Christiansen and Schultheiss first published their work in 1979 [1], many other experiments were conducted using multiplate chambers. Many were solely interested in using this new pulsed electron beam source, and further studied the specific characteristics of the electron and ion beams produced by MPCs. Cross et al. [2] investigated the discharge characteristics of a triple gap chamber with the discharge current and voltage shown in the figure below along with the beam current. Nistor and Mandache's [3] measurements, on the other hand, were focused on the beam characteristics concerning target ablation in the process of thin film creation. Using an argon filled chamber

connected to a power supply set between 14-17 kV, Nistor measured the electron beam's current with a faraday cup connected to ground via a 0.3Ω resistor with results similar to Cross [3].

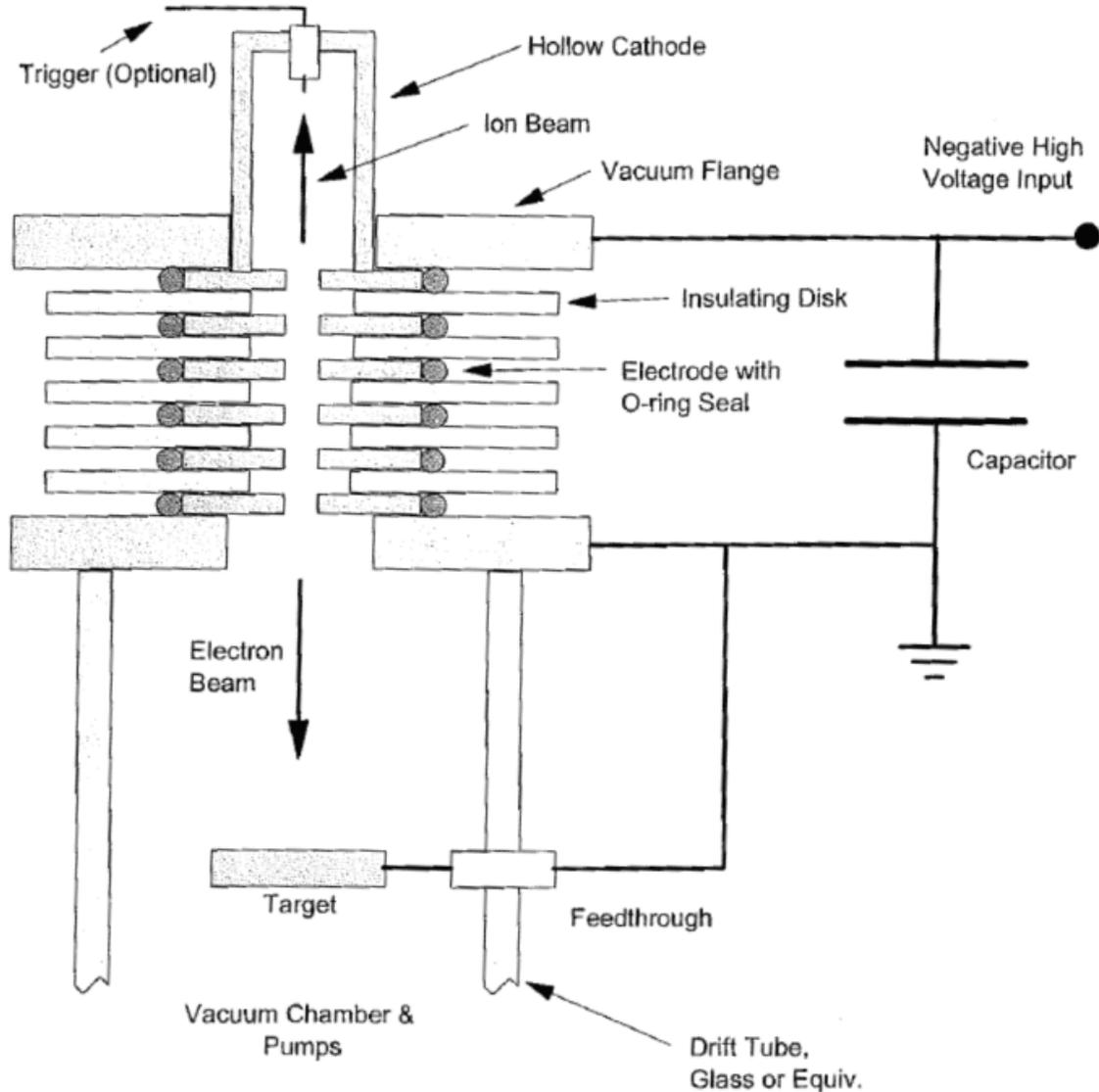


Figure 1. Diagram of a basic setup of a multiplate chamber with labeled parts including an external triggering mechanism. The negative high voltage input causes a charge to build up across the chamber due to the capacitor connected in parallel to it. Once this charge reaches a critical level, a high current electron pulse is discharged toward whatever target is placed at the anode of the chamber. A charging resistor is required between the high voltage supply and the capacitor in order to limit the charging current to the power supply's maximum current output. Figure taken from Ref [4].

The capacitance dependence of the chamber's x-ray emittance was also determined by scintillator detection of the x-rays using various capacitance values, as well as shielding the scintillators with aluminum foils with varying thicknesses between 20-60 μm [3].

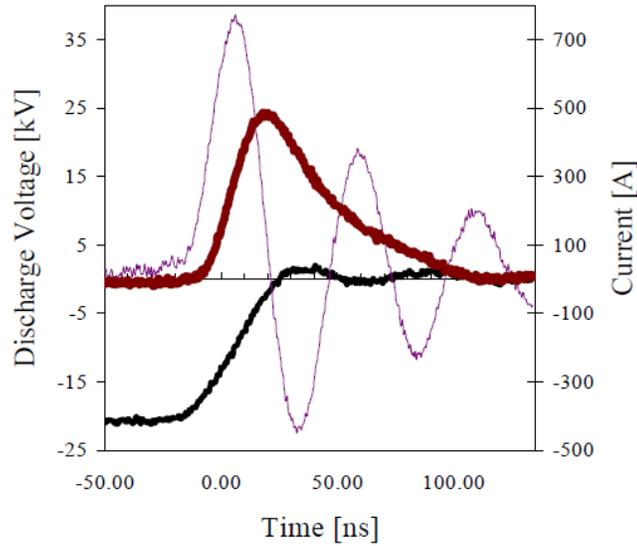


Figure 2. Plot of discharge current (thin red line), discharge voltage (thick black line), and the beam current (thick red line) from Cross' experiment with a three gap chamber. Figure taken from Ref [2].

This work was furthered by Jain et al [5] who in addition to confirming Cross' et al and Nistor's et al results as shown in Figure 5, also measured the rms beam radius, and rms emittance of a 6 gap, argon filled multiplate chamber operated at -30 kV.

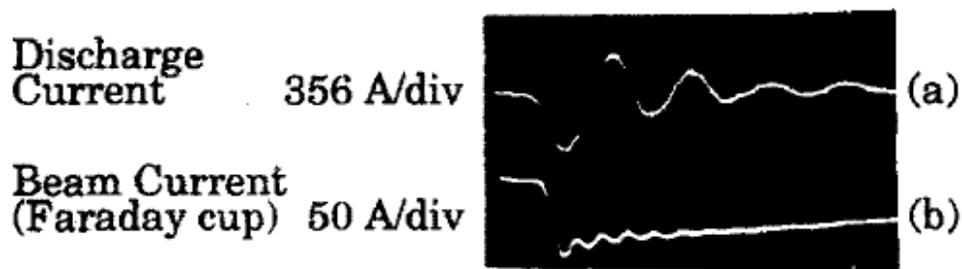


Figure 3. Oscilloscope reading of Nistor et al. multiplate chamber's discharge and beam currents. Note the similarity to Cross et al. results in Figure 4 on the previous page. Figure taken from Ref [3].

The application of multiplate chambers for thin film creation was studied by Jiang and Xu [6] who created ZrO_2 films via pulsed electron beam ablation. An oxygen filled chamber at 10 Pa with a powdered

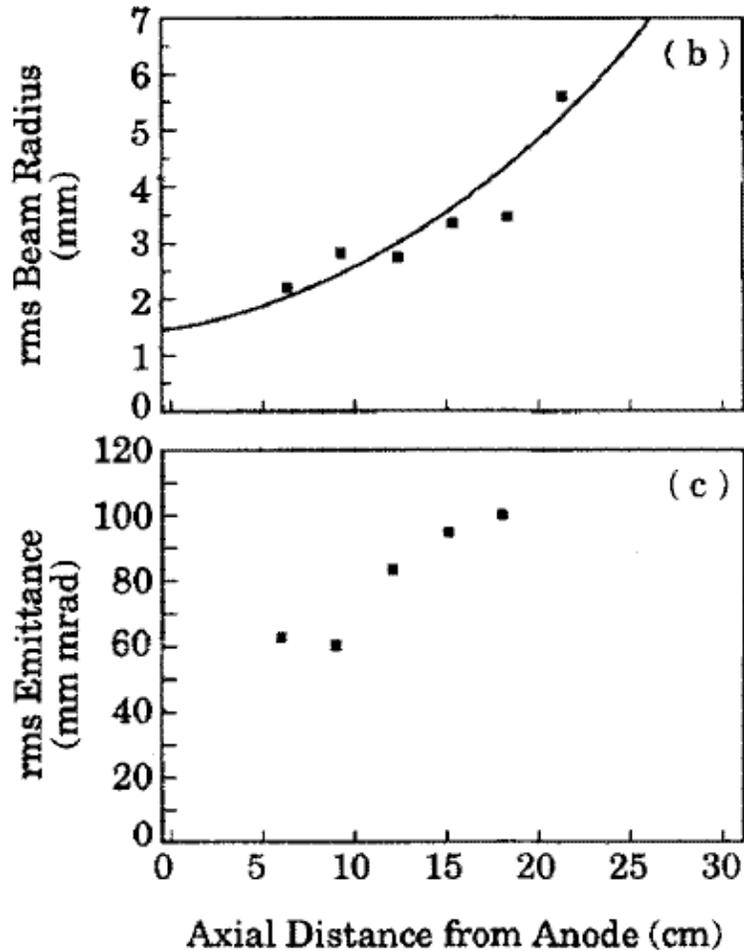


Figure 4. Plots of the rms Beam radius and emittance as a function of the axial distance from the chamber's anode. Note how the beam radius appears to be exponentially related to the distance. Figure taken from Ref [5]

ZrO_2 target, had Si or NaCl substrates located 2-4 mm above it, but offset such that they were not in the beam path. Thus, the ZrO_2 powder was evaporated by the pulsed electron beam discharge of the chamber, and then deposited on the substrate. Films were also successfully produced using pure Zr targets. Substrates farther from the targets produced films with more uniformity and larger surface areas, but at a lesser rate of deposition. Benker et al [7] explored another application of multiplate

chambers by using an Argon filled 30 gap chamber to drill holes metal sheets. Each pulse carves deeper into the target as shown in the figure below.

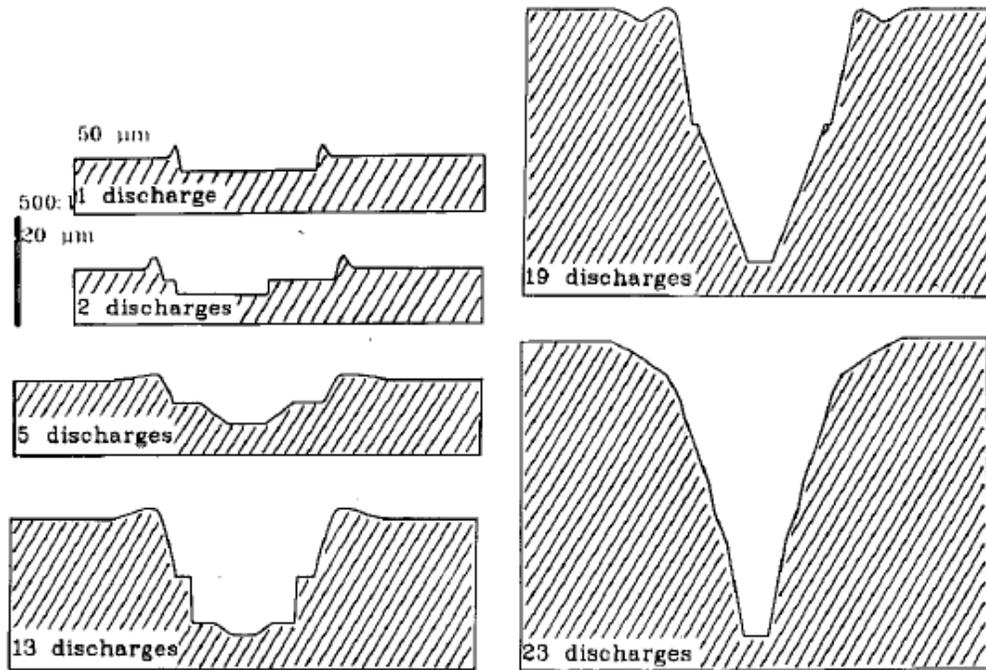


Figure 5. Evolution of a drilled hole created by successive discharges into a 0.5 mm thick sheet of copper. Figure taken from Ref [7]

1.3 Motivation

As seen in the previous section, there are many applications for multiplate chambers. As Jiang and Xu showed, thin films can be created using multiplate chambers while Benker et al showed their ability to drill into metal. Rather than simply drilling holes, it would also be possible to use the electron beam to etch designs into metal sheets by moving the target between each pulse. Multiplate chambers can also be used to study plasmas since within each pseudo-spark discharge a plasma channel is created. This is why Christiansen experimented with multiplate chambers in the first place – to trigger nuclear fusion. Though there are many applications for the multiplate chambers’ pulsed electron and ion beam, it can also be used as an x-ray source. This expands its applications to include use in x-ray diffraction, fluorescence, and flash photography. However, merely constructing a multiplate chamber does not instantly allow these experiments to be done. First, operating capabilities of the chamber such as the beam current and voltage along with its pulse frequency must be measured.

Chapter 2

Theory of Operation

2.1 Introduction

In the operation of a multiplate chamber, there are two possible states for the device: charging or discharging. In the charging state, the potential difference across the capacitor increases at a decreasing rate due to the output current of the high voltage supply. Once the breakdown voltage of the chamber is reached, the charge that has built up across the capacitor is discharged in the form of an electron beam. The frequency of these discharges is controlled by three factors: capacitance, charging resistance, and pressure. Common multiplate chamber capacitance values range from several pF to few nF allowing the device to pulse more rapidly as a lower capacitance yields a smaller time constant, but also lowers the voltage. The required resistance is determined by the maximum current available from the high voltage source. The pressure determines the breakdown voltage according to Paschen's law [1].

2.2 Paschen's Law

In 1889, Friedrich Paschen [8] stated his law describing the breakdown voltage of a gas at pressure “ p ” between two parallel plates separated by a distance “ d ” as

$$V = \frac{Bpd}{\ln\left(\frac{Apd}{\ln\left(1+\frac{1}{\gamma}\right)}\right)} \quad (1)$$

where A and B are physical constants of the gas. In air, for example [8],

$$A = 15 \text{ cm}^{-1} \cdot \text{Torr}^{-1},$$

$$B = 365 \frac{\text{V}}{\text{cm} \cdot \text{Torr}}, \text{ and}$$

$$\gamma = 1.18.$$

Therefore, the voltage required for a an air filled multiplate chamber to discharge can be determined by substituting A , B , and γ into Eq. 1

$$V_B = \frac{365pd \frac{\text{V}}{\text{cm} \cdot \text{Torr}}}{\ln\left(\frac{15pd \text{ cm}^{-1} \cdot \text{Torr}^{-1}}{.614}\right)} \quad (2)$$

where V_B is the breakdown voltage for the chamber.

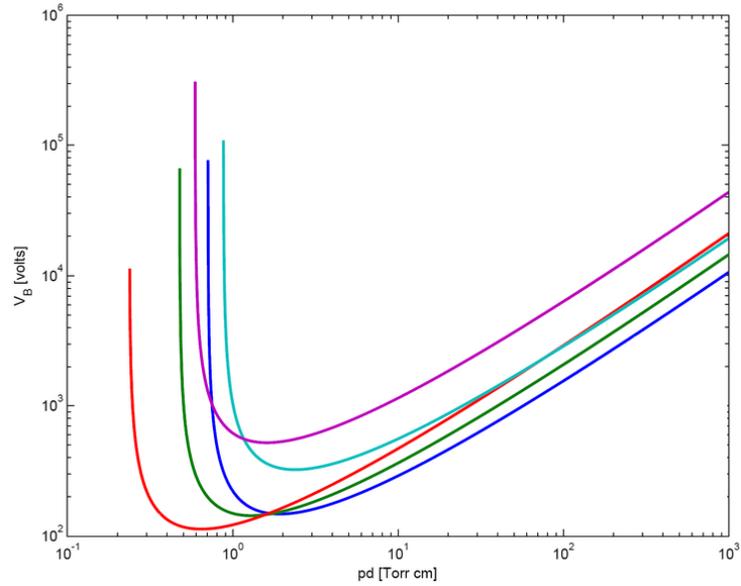


Figure 6. Graph of Paschen's law for Helium (dark blue), Neon (green), Argon (red), Hydrogen (light blue), and Nitrogen (purple). Note the minima occur around 1 torr cm. Multiplate chambers operate at pressures below these minima in order to achieve pseudo-spark discharge. Graph taken from Ref [9].

2.3 Circuit Analysis

Figure 3 depicts the two different circuits representing the charging and discharging states of operation. The switch between these two states occurs when the voltage across the capacitor is equal

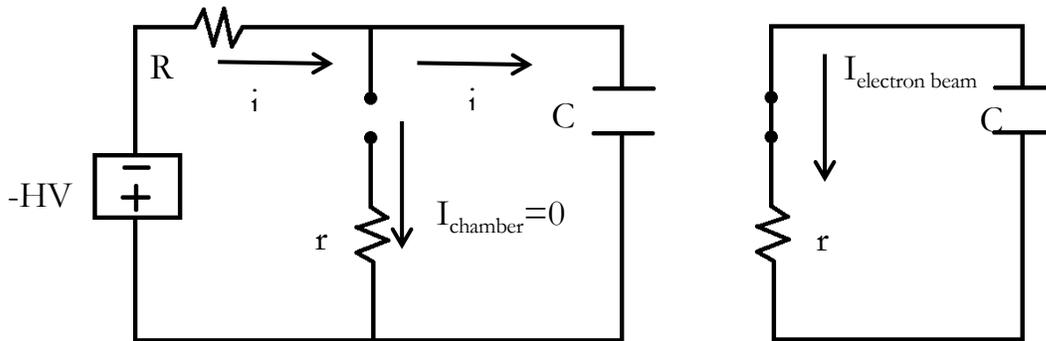


Figure 7. Diagrams of a multiplate chamber while the capacitor is charging (a) and discharging (b). While the capacitor C is being charged by the negative high voltage through a charging resistor R , current does not flow through the chamber represented by the gap in the middle wire. As the capacitor discharges, however, current flows through the chamber in the form of an electron beam, and small resistor r used to calculate the beam current.

to the breakdown voltage of the chamber according to Paschen's law. The voltage across the capacitor while in the charging state can be found using circuit (a) from Figure 3. Using Kirchoff's voltage law on the outer loop of the charging circuit shows

$$-HV - iR - V_C = 0. \quad (3)$$

Since there is no current through the chamber, the current through the capacitor is equal to the current in the resistor R, and since the current through a capacitor is given by

$$i = C \frac{dV_C}{dt}. \quad (4)$$

Thus, equation 3 becomes

$$-HV - CR \frac{dV_C}{dt} - V_C = 0 \quad (5)$$

which separates into

$$-CR \frac{dV_C}{(V_C + HV)} = dt. \quad (6)$$

Since the power supply voltage HV is constant, the integral of both sides can be taken to show

$$-CR \ln(V_C + HV) + K = t \quad (7)$$

where K is a constant determined by the initial conditions of the circuit. Now the equation can be solved for V_C :

$$V_C = e^{\frac{-t+K}{CR}} - HV. \quad (8)$$

Finally, K can be found using the initial condition that there is no voltage across the capacitor at time $t = 0$. Thus,

$$0 = e^{\frac{K}{CR}} - HV, \text{ or}$$

$$K = \ln(HV^{CR}), \text{ so}$$

$$V_C = HV e^{-\frac{t}{CR}} - HV. \quad (9)$$

This result can be set equal to Eq. 2 order to find the time required to charge the capacitor before the chamber discharges. Thus,

$$HV e^{-\frac{t}{CR}} - HV = \frac{365pd \frac{V}{\text{cm} \cdot \text{torr}}}{\ln\left(\frac{15pd \text{ cm}^1 \cdot \text{torr}^{-1}}{.614}\right)} \quad (10)$$

This can be solved for time t to yield

$$t = -CR \ln \left(\frac{365pd \frac{V}{\text{cm}\cdot\text{torr}}}{HV \cdot \ln \left(\frac{15pd \text{ cm}^1 \cdot \text{torr}^{-1}}{.614} \right)} + 1 \right). \quad (11)$$

Once the capacitor has charged for this amount of time, the chamber breaks down, and discharges the built up charge in the form of an electron beam. Using circuit (b) from figure 3, the expected discharge time and current can be calculated. Applying Kirchoff's Voltage law shows,

$$V_C + i_{beam}(r_{gap} + r) = 0. \quad (12)$$

Since the beam current is equal to the current through the capacitor, and assuming a small gap resistance, this can be rewritten as the differential equation

$$V_C + C \frac{dV_C}{dt} r = 0. \quad (13)$$

This separates to

$$\frac{-dt}{CR} = \frac{dV_C}{V_C}. \quad (14)$$

Thus, the voltage across the capacitor with respect to time spent discharging is

$$V_C = k e^{\frac{-t}{Cr}} \quad (15)$$

where k is a constant that can be found using the initial conditions of when the discharge begins. Because the discharge begins once the voltage across the capacitor is equal to the breakdown voltage of the chamber, at time $t = 0$, $V_C = V_B$, so

$$V_B = k e^{\frac{-0}{Cr}}, \text{ so} \\ k = V_B. \quad (16)$$

Thus, equation 15 becomes

$$V_C = V_B e^{\frac{-t}{Cr}}. \quad (17)$$

The beam current during these discharges can be calculated using Ohm's Law across the small resistor r such that

$$i_{beam} = \frac{V_C}{r} = \frac{V_B}{r} e^{\frac{-t}{Cr}}. \quad (18)$$

These short, high current pulses are unique to pressures below that corresponding to the minimum Paschen's breakdown voltage [1]. At pressures around the minimum breakdown voltage, a glow discharge occurs while at higher pressures, there is a spark breakdown triggered by a single electron avalanche [1]. Though a plasma spark is produced by multiplate chambers operating at low pressures,

the spark is not caused by a single channel electron avalanche causing multiplate chambers to also be called pseudo spark devices. Instead, normal electron impacts ionize the gas within the chamber during a pre-discharge known as a Townsend's glow discharge which has a low current in the microampere range. This small current, however, is enough to begin ionizing the gas. These ions are positively charged, and attracted to the high negatively charged cathode. Upon impact, electrons are emitted from the cathode increasing the current and rate of ionization. Thus, as the electrical field around the cathode increases, this impact mechanism in conjunction with a space charge accumulation enhancing electron emissions causes the multiplate chamber to emit high current pulses.

Chapter 3

CONSTRUCTION AND ASSEMBLY

3.1 Introduction

Multiplate chambers require an alternating stack of electrodes and insulating discs. There must also be endplates for each end of this stack such that the chamber can be sealed in order to reduce the pressure within the chamber. Finally, there must be a mechanism to compress these endplates together securing the seal on the chamber.

The construction of Houghton's multiplate chamber was based on that of Hansen [10] using the same electrodes, insulators, and compressing mechanism, but using 2.75 CF conflat to DN16KF quickflange adapters as our anode and cathode rather than making them ourselves [10]. The chamber was made by stacking polycarbonate insulating disks between welded washers used as electrodes. This stack was then compressed between two 2.75 CF to DN16KF adapters.

3.2 Multiplate Chamber Part Construction

As previously mentioned, two stainless steel washers with an outer diameter of 22.2 mm, inner diameter of 4 mm, and 1.1 mm thick ($7/8''$ OD, $5/32''$ ID, 0.045'' thick) were spot welded together to form the electrodes. Two welds were made approximately equidistant from the center of the washer to the edge, and located on opposite sides of the center hole.

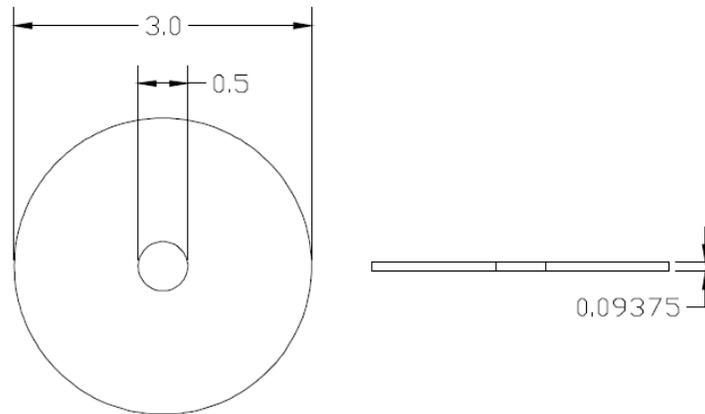


Figure 8. Top (left) and side (right) cross-sections of the insulating discs cut from the Lexan polycarbonate plastic (dimensions given in inches).

A 3.2 mm (1/8") thick Viton 016 o-ring made of flourocarbon with an inner diameter of 22.2 mm (7/8") was placed around each electrode to seal the chamber. The five 7.62 cm (3") diameter insulating discs were cut from a 2.4 mm (3/32") thick sheet of Lexan polycarbonate plastic using fly-cutters on a vertical milling machine. After cutting out eight discs, the 12.7 mm (1/2") diameter center holes were all drilled at once on a drill press by stacking all the discs on top of each other. The two 11.3 cm (4 - 7/16") diameter end plates seen in figure 5 were cut from a 1/4" thick sheet of Lexan polycarbonate. A lathe was used to bore the center 38.1 mm (1 1/2") diameter hole. The center ring of holes to attach the end plates to the conflat to quickflange adapter and the outer ring of holes for compressing the chamber between the endplates were drilled using a 6.35 mm (1/4") bit on the drill press.

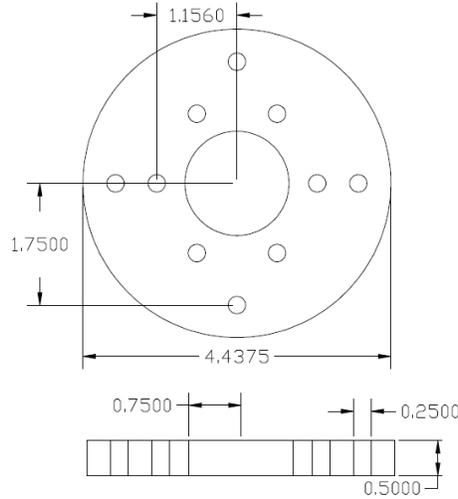


Figure 9. Top and side cross-sections of the endplates cut from the half inch thick Lexan Polycarbonate plastic (dimensions given in inches).

The spacers required for the nylon screws to pull the two endplates together compressing the chamber were cut from a 12.7 mm (1/2") diameter nylon rod using a band saw and lathe to cut them to 33.02 mm (1.3") lengths. Once cut, they were drilled on a lathe, and tapped by hand for 1/4 - 20 nylon screws.

3.3 Multiplate Chamber Assembly

When assembling the multiplate chamber, it was important to align the center holes of the electrodes so their geometry creates a pinching effect on the electron beam. It was also important to keep the

stack of insulators aligned as well since they all needed to fit within the spacers pulling the end plates together.

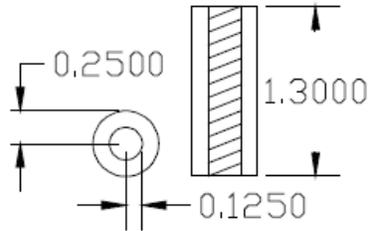


Figure 10. Top and side cross-sections of the nylon spacers used to compress the electrode stack by pulling the two endplates together using nylon screws (dimensions given in inches).

In order to ensure an aligned electrode stack an assembly rig was constructed using a 4 mm (5/32”) diameter steel rod. This was accomplished by cutting two 38.1 mm (1 1/2”) length pieces of 25.4 mm (1”) diameter aluminum rod using a band saw, and then using a lathe to shave down the diameter so they would fit snugly into the center hole of a CF-QF 16 adapter. Then a center hole was drilled and tapped into the two pieces of 25.4 mm (1”) diameter steel rod for the threaded end of the thinner 4 mm (5/32”) diameter steel rod. Using this assembly rig, ensured the electrodes would always be aligned with each other.

To assemble the chamber itself, the assembly rig was inserted into the CF-QF adapter opposite to where the electrodes were to be placed. Before the electrode stack was put into place, one of the endplates was down around the quick flange. Alternating with the insulating disks, the electrodes were stacked using the steel rod assembly rig. Once all the electrodes were in place, the other CF-QF adapter with the other end plate around its quick flange were put into place allowing the assembly rig to be removed.

The spacers were put into place between the end plates after making sure everything was properly aligned. When compressing the electrode stack by tightening the nylon screws into their spacers, one screw could be tightened all the way before tightening the others. This, however, caused the electrode stack to lean to one side as only one side was compressed. Instead, each screw was put into its respective spacer just enough to make it catch the threads so it would not fall out, then each screw

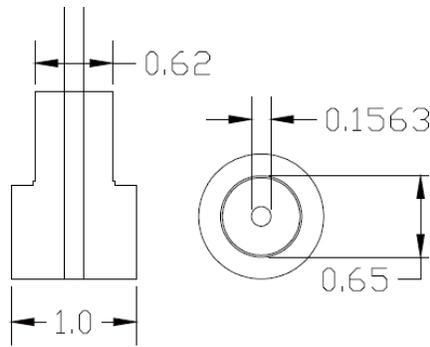


Figure 11. Top and side cross-sections of the assembly rig. The small notch halfway up was cut such that it fit tightly into a QF 16 adapter ensuring the center rod properly aligned the electrodes as they were stacked (dimensions given in inches).

was tightened a couple of turns at a time, rotating between all the screws in order to equally compress each side of the electrode stack.

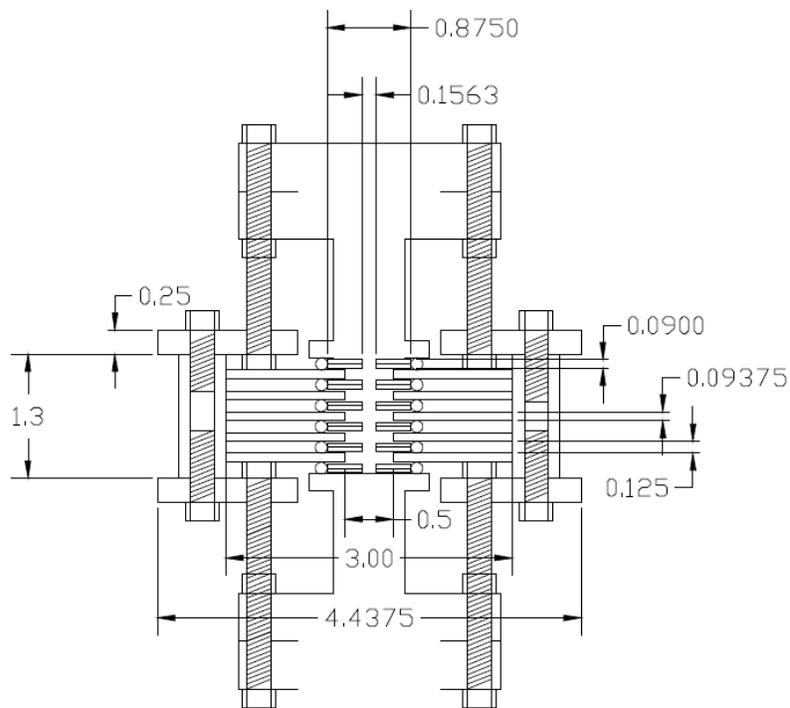


Figure 12. Cross section of the assembled multiplate chamber. Note how the KF-16 end of the CF-KF adapters fit within the center hole of the endplates, while the nylon screws in the 1.3" long spacers pull the endplates, and subsequently CF-KF adapters together. Thereby, compressing the electrode stack (dimensions given in inches).

3.4 Experimental Setup

In order to use the multiplate chamber, a high voltage power supply and low value capacitor were required for the electrical circuit. An EMCO DX250N supply was used to charge a 2.7 nF 30 kV capacitor. An Albia Electronics DM-6 variable power supply was connected to the EMCO power supply's input in order to supply the required 12 V to produce -25 kV. The maximum current of the DX250N is 75 μA , so two 200 M Ω current limiting resistors were put in series between the EMCO power supply and parallel chamber and capacitor. An analog microammeter was also installed on the ground side of the capacitor in order to measure the current flowing into and charging the capacitor allowing the capacitor voltage to be calculated using Eq. 9.

Instead of measuring the beam current directly, the phosphor screen from a 3RP1A cathode ray tube was used as a target for the beam.

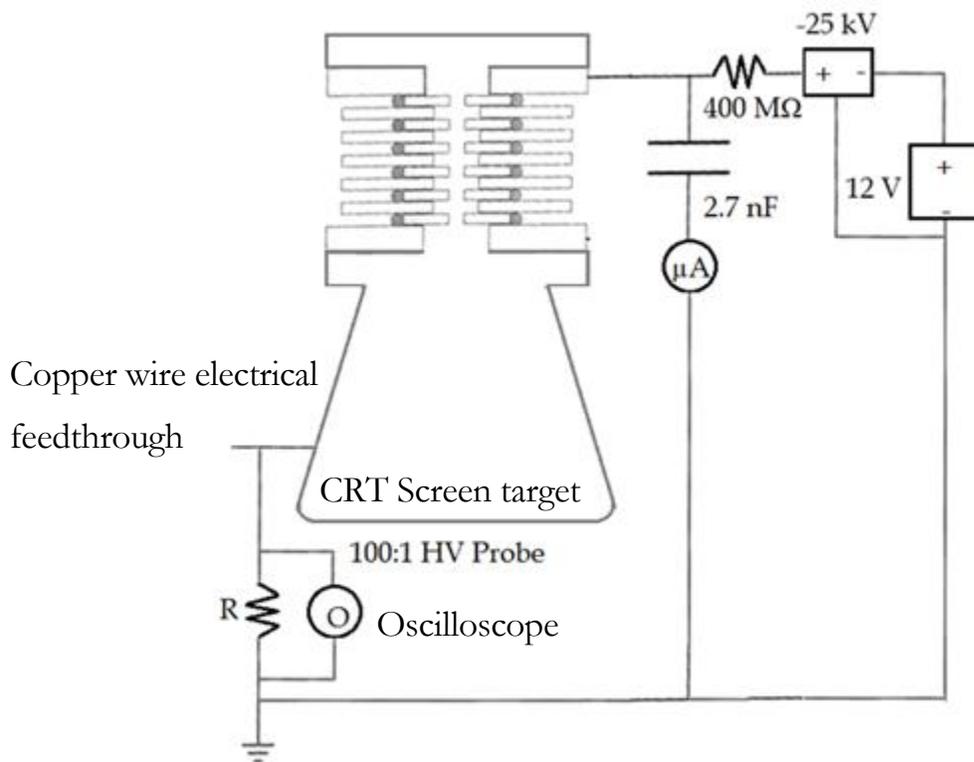


Figure 13. Schematic of the electrical circuit for Houghton College's multiplate chamber using a -25 kV power supply to charge a 2.7 μF capacitor through a 400 M Ω charging resistance. The beam current is found by using a 100:1 high voltage probe to measure the voltage across a small value resistor R during a discharge and using Ohm's law.

To separate the screen from the tube, the vacuum was broken by drilling 1.5 mm hole into the tube with a diamond tipped drill-bit. A file was used to scratch around tube where it was to be cut. Thermal shock caused the tube to break along this line when touched by a glass rod that was heated until molten. Using vacuum epoxy, the screen was sealed to a 2.75 CF conflat flange adapter which was attached to the bottom of the multiplate chamber via a 2.75 CF four way T since a pump, pressure gauge, air leak, and linear motion feed-through were also to be attached. Using the small hole drilled in the side of the tube, a copper wire electrical feedthrough was made by touching a piece of 16 gauge copper wire to the conducting inner surface of the screen, and sealing the hole around the wire with vacuum epoxy. This wire was then connected through a low value (1-10 Ω) resistor to ground and a Tektronix 20424 digital oscilloscope measured the voltage across the low value resistor using a 100:1 high voltage probe. Thus, the voltage across the resistor during a discharge could be measured, and was used to calculate the beam current as a function of time using Ohm's law.

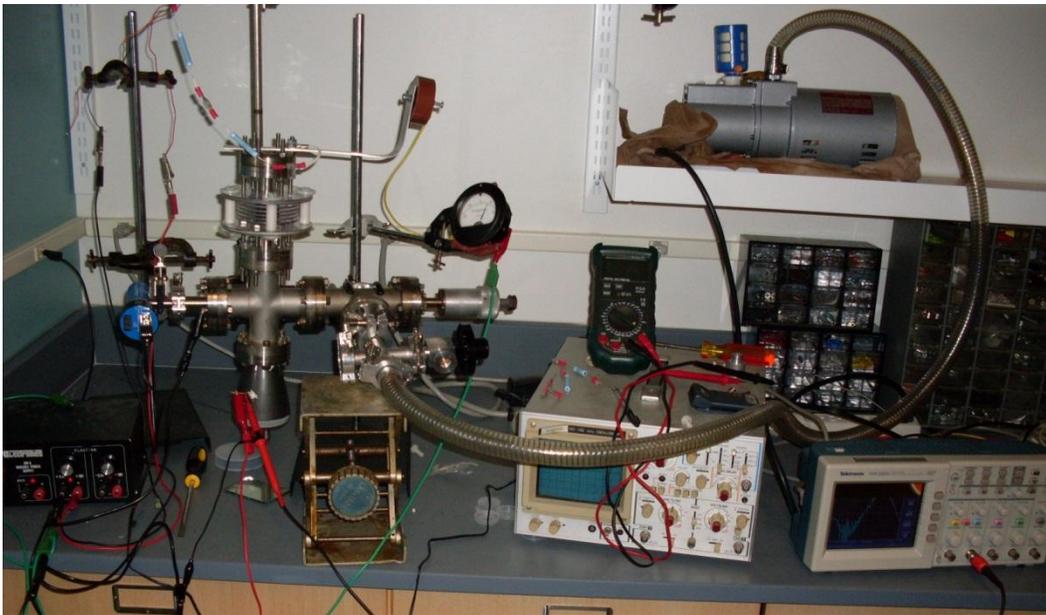


Figure 14. Photograph of Houghton College's multiplate chamber. The assembly is supported by ringstands, but note the HV supply (off top left corner) is kept away from all metal and electronic parts by a Lexan polycarbonate mount.

Since the chamber operates at a pressure around 35 mTorr, an Ulvac G-50D rotary vacuum pump and

Kurt J. Lesker KJL275806 thermocouple pressure gauge were used. The pressure gauge connected to the chamber via a KF16 flange, so 2.75 CF-KF16 adapter attached the gauge to the left side of the 2.75 CF four way T. A 2.75 CF three way T was attached to the final opening of the four way T in order to connect a KF16 4 way T attached to the pump and Edwards adjustable air leak. The final quick flange opening was not required, so it was blanked off. The last opening to the conflat three way T was used to attach a linear motion feedthrough.

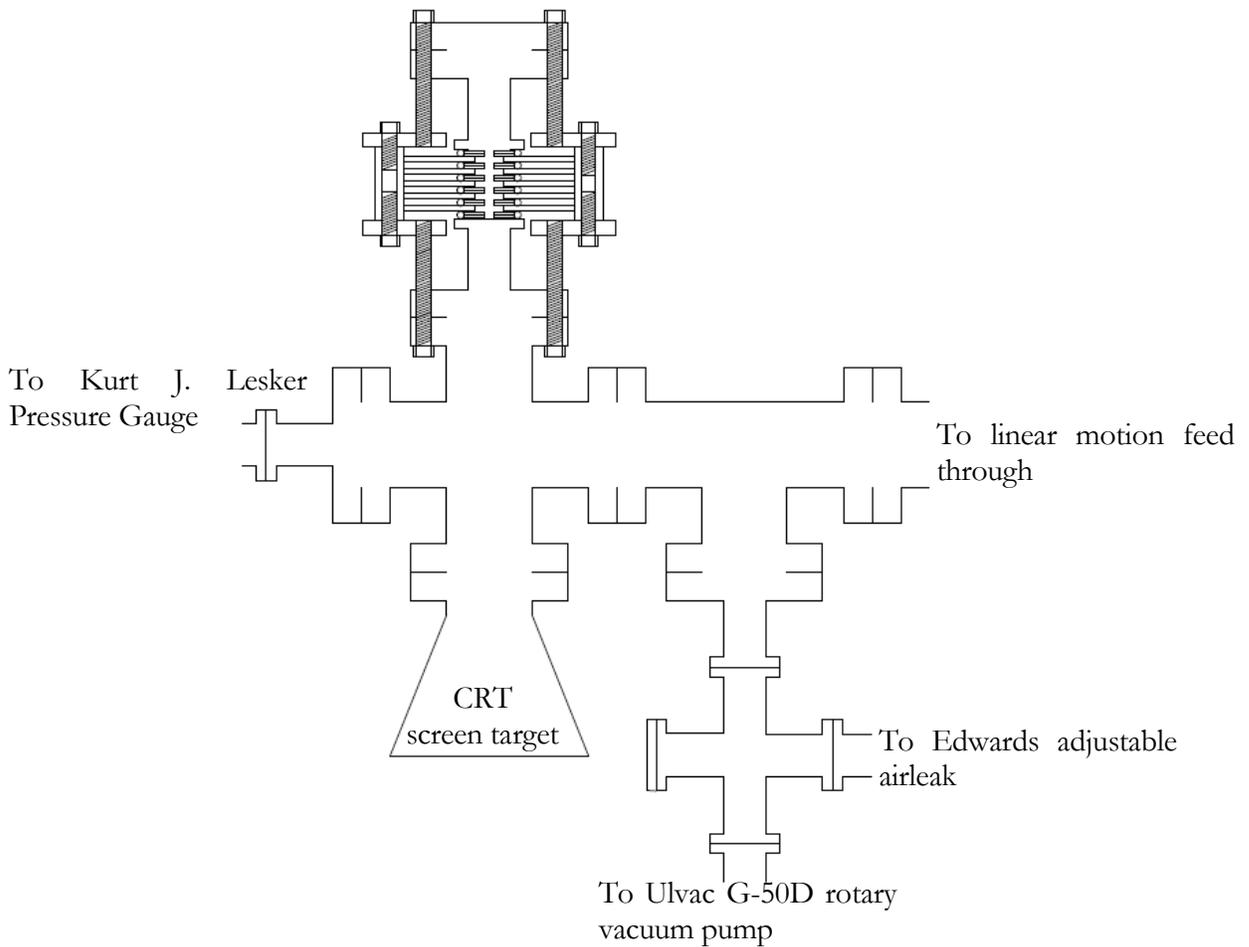


Figure 15. Schematic of the experimental set-up of Houghton's multiplate chamber. The pump connected at the bottom reduces the pressure within the chamber which is monitored by the pressure gauge on the left. The leak to the right of the pump attachment allows this pressure to be controlled. Though currently unused, the linear motion feed through on the right will allow for the beam path and density to be measured.

Chapter 4

Procedure and Results

4.1 Multiplate Chamber Operation

The set-up described in the previous section was used to create, observe, and measure high current electron beam pulse using the following procedure. The chamber was pumped down to 20 mTorr using the Ulvac G-50D rotary pump. Once the pressure was steady, the 12 V power supply was turned on allowing the EMCO high voltage supply to charge the capacitor. Using the Edwards adjustable air leak, the pressure was increased to an operating pressure between 35-45 mTorr. This is an ideal pressure range for the chamber because the breakdown voltage is still less than 25 kV, so there will always be a discharge without an external trigger. The breakdown voltage, however, is still high enough that the capacitor must charge for a couple of seconds as opposed to discharging rapidly at very low voltages.



Figure 16. Reflection of the beam spot seen on the CRT screen during the multiplate chamber discharge. The photograph was taken by putting a mirror beneath the screen at such an angle that the camera could capture the electron beam hitting the CRT screen.

During operation, the micro-ammeter showed the current through the capacitor initially was about 60 μA as expected from a 25 kV power supply running through a 400 M Ω resistor, and would rapidly

decrease to around $10\ \mu\text{A}$ in less than 2 seconds, as the charge on the capacitor increased, at which point the chamber would discharge causing the current to jump back up to $60\ \mu\text{A}$ as the capacitor began to charge again. When the current through the capacitor was $10\ \mu\text{A}$, Eq. 3 can be used to show that the voltage across the capacitor was $-21000\ \text{V}$. Due to the high power discharges occurring in near proximity, the pressure gauge was turned off while the multiplate chamber was operating.

As the original test runs were completed, a geiger muller survey meter was placed beneath CRT screen to confirm the chamber's capability to produce x-rays. Though no specific measurements were taken, the meter detected x-rays everytime the chamber discharged. A pocket dosimeter was also kept next to the multiplate chamber at all times in order to monitor any radiation. Over the course of 4 months of intermitent use, the dosimeter count increased 13 mrem.

4.2 Beam Spot

Using the procedure described in the previous section, the high current electron beam pulses produced by the multiplate chamber were observed striking the CRT screen. In addition to the green flashes caused by the electron beam striking the phosphor CRT screen, the plasma discharge could also be seen within the chamber. Figure 16 above shows the beam spot of a pulse. Though the whole screen is lit up, the brightest spot can be seen as barely off-centered to the bottom right of the picture. There are a couple of possible causes for the beam spot to not be centered. The endplates to the chamber could have been unevenly compressed causing a slight bend in the electrode stack. Alternatively, a small electrical field across the beam path would cause a deflection.

4.3 Current Measurement

Once large, consistently timed discharges were occurring every couple of seconds, the voltage across the small value resistor was measured using an oscilloscope. Initially, a $10\ \Omega$ resistor was used. Later, this was switched to a $3\ \Omega$, then $2\ \Omega$, and finally a $1\ \Omega$ resistor. As seen in Figure 17, there was a measured voltage of approximately $-2500\ \text{V}$ through the $10\ \Omega$ resistor. Thus, using Ohm's law the maximum discharge current was about $-250\ \text{A}$. This negative current arises since a negatively charged electron beam traveling from the top of the chamber to ground is equivalent to a positively charged current flowing from ground to the top of the chamber. Once the resistance was lowered to $3\ \Omega$, however, the voltage measured was still approximately $-2500\ \text{V}$. This would mean the beam current

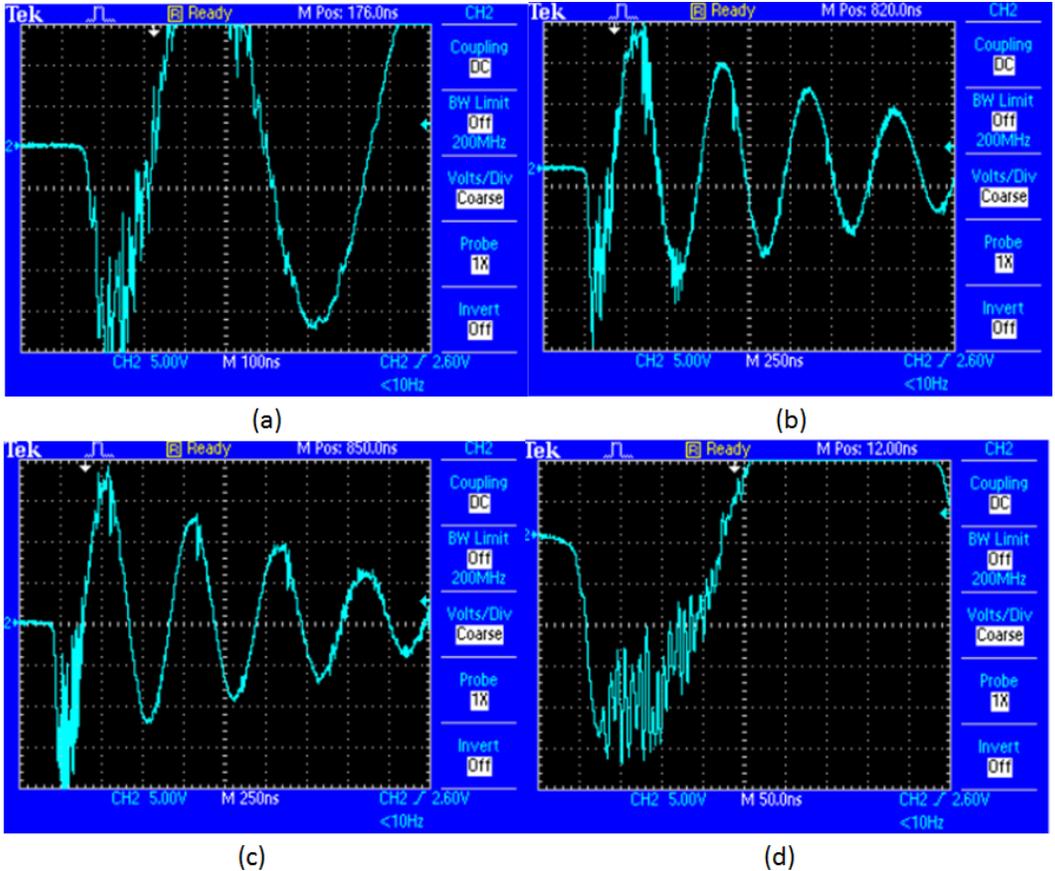


Figure 17. Images captured on the oscilloscope measuring the voltage across the several different resistors between the CRT screen and ground: 10 Ω (a), 3 Ω (b), 2 Ω (c), and 1 Ω (d). Notice the initial voltage drop caused by the chamber's electron beam pulse discharge was approximately 75 ns long. However, there was a ringing effect after this initial voltage drop which was also seen in other experiments such as Cross' and Nistor's. This behaviour is similar to that of an RLC circuit, implying some internal inductance existed within the circuitry.

was over -800 A, three times the current observed with the 10 Ω resistor. This occurred with the 2 Ω resistor as well resulting in a current of -1250 A. The beam current should remain relatively consistent independent of the resistor value. The reason for this behavior is unknown.

Chapter 5

Conclusion

After periodic use of the multiplate chamber constructed at Houghton College over the course of several months, it was found the chamber operated best at pressures ranging from 25-45 mTorr, with the most consistent large pulses occurring around 33-35 mTorr. Unfortunately, due to the inconsistent voltage measurements with the oscilloscope across various resistor values, the beam current could not be confidently established. Hopefully, this problem can be resolved in future work. Other possibilities for future work include locating the electron beam and measuring the current density via the linear motion feed through. Once the operating capabilities of the chamber are well known, it could be used in any number of capacities from being an x-ray source for diffraction or flash photography, to evaporating materials for thin film deposition.

References:

- [1] J. Christiansen and Ch. Schultheiss, *Z. Phys. A* 2990, **290**, 35 (1979).
- [2] Cross *et al.*, Proceedings of EPAC, TUPLS089 (2006), 1711-1713.
- [3] Nistor *et al.*, Romanian Reports in Physics, **60**, 615 (2008).
- [4] Steve Hansen, *The Bell Jar*, **2**, 3-76, (1993).
- [5] Jain *et al.*, *Phys. Fluids*, **2**, 2487, (1990).
- [6] Jiang and Xu, *J. Appl. Phys.* **66**, 5594, (1989).
- [7] Benker *et al.*, IEEE Transactions on Plasma Science, **17**, 754 (1989).
- [8] E.M Bazelayn and Yu. P. Raizer, *Spark Discharge*, CRC Press LLC, (New York, 1998).
- [9] Wikipedia, Paschen's Law, http://en.wikipedia.org/wiki/Paschen's_law.
- [10] Steve Hansen, *The Bell Jar*, **3**, 3-80 (1994).