Creation of Jefferson Lab 200 kV Electron Gun Upgrade

# Abstract

At Jefferson Lab, electrons are accelerated to near the speed of light using the Continuous Electron Beam Accelerator Facility (CEBAF). The electron beam is generated using an electron gun composed of a highly polarized GaAs/GaAsP superlattice photocathode with an operating voltage of 130kV in an ultra-high vacuum with an internal pressure of approximately 10-12 torr. The electron gun is geometrically designed in such a way to limit the electric field below 10 MV/m at every point in the gun. Our objective is to construct and install an upgraded electron gun capable of running at 200kV in an ultra-high vacuum with zero field emission. We started the design of the gun by focusing on a specific geometry of the electrode to prevent high voltage cable breakdown. We went through a multi-step vacuum creation process that included three different types of pumping, a bake at 250o C, and the activation of the non-evaporable getters (NEGs). Afterwards, we did a high voltage conditioning of the gun where we slowly raised the voltage until we no longer saw electron field emission. Using the vacuum protocols, we achieved a vacuum of 10-11 torr, which is reasonably acceptable, but not quite the desired value. During our high voltage conditioning, we saw slight field emission around the operating voltage of 200 kV, making the gun unfit for installation into CEBAF. This can be improved with further conditioning at higher voltages, but due to the limits of our power supply, we did not feel we had adequate head room to continue voltage conditioning. With this upgraded gun, we can give the accelerator higher beam quality and extended photocathode lifetime.

# Introduction

 Thomas Jefferson National Accelerator Facility is home to the Continuous Electron Beam Accelerator Facility, more commonly known as the CEBAF. Here, electrons are accelerated to almost light speed and collided with targets in order to understand the structure of subatomic particles. The journey of the electrons begin with the electron gun. The electrons start in a highly polarized GaAs/GaAsP superlattice photocathode housed in a metal electrode, which is set at a voltage of 130 kV. The chamber of the electron gun is set in an ultra-high vacuum with an internal pressure of approximately 10-12 torr. The final critical element of the gun is that there is no field emission at running voltage, meaning no radiation is given off by the gun when it is operating. The requested upgrade for the electron gun is that the voltage be increased to 200 kV while having an ultra-high vacuum of approximately 10-12 torr and no field emission at operating voltage.

# Design Philosophy

 There are two main reasons why we want to upgrade the current electron gun. The first is to improve the quality of the electron beam upon exiting the gun. When the laser pulse hits the photocathode, it releases a bundle of electrons. Through electrodynamics, we know that the electrons in the bundle want to repel from one another, causing the beam to spread. However, through quantum effects, if the electrons are travelling at a sufficient speed, the Coulomb interactions of the electrons in the bundle is “ignored” and the beam becomes tighter. The speed of the electrons is dependent on the voltage applied to the gun, so increasing the voltage creates a tighter beam for electrons. Having a higher voltage also improves the signal-to-noise ratio and the statistics for the users of the beam. The second reason for the upgrade is improved photocathode lifetime. If the chamber contained air, the electrons shooting out of the gun would collide with the air particles and ionize them. These ionized particles would travel towards the photocathode and smash into it, creating a hole. This decreases the quantum efficiency of the photocathode, which is just the ratio of the number of emitted electrons to the number of photons sent. Through previous analysis of electron guns and photocathodes, scientists have found that the quantum efficiency tends to drop off with time as 1/e, but this can be improved with a higher vacuum and higher voltage.

 However, having higher voltage does have some drawbacks. Increasing the voltage from 130 kV to 200 kV means that there is a higher risk of breakdown of the high voltage cable-gun interference. With this in mind, we needed to create an environment inside the electron gun chamber where there possibility of electrical arcs is minimized. Through scientific experience alone, researchers have discovered that if the electric field at all points inside the chamber is below 10 MV/m, then the chance for electrical arcs is greatly reduced to almost zero. To do this, we geometrically designed the electrode that would hold the photocathode in such a way to reduce the field at all points in the gun. We constructed it out of stainless steel and finely polished the surface of the electrode by placing it into a barrel of corn cob rotating at 90 rpm to reduce the chance of developing a field emitter. Through our design, the maximum electric field that we calculated through Poisson software at any point in the gun would be about 7.93 MV/m, a value well below our limit.

# Vacuum Protocols

 Once the electron gun is assembled, the vacuum inside the chamber must be prepared. There is a multi-step process that we implemented to prepare the vacuum chamber. The first step involves using a mechanical pump that sucks a good deal of the air molecules out of the gun chamber. This will usually take the pressure from 760 torr to around 0.1 torr. Next is the turbo pump, which has two fans rotating at 90,000 rpm. The primary purpose of this pump is to remove a great deal of all of the helium from the chamber and will ultimately get us down to around 10-8 torr. The ion pump comes next, which is essentially a large capacitor that sucks in any ionized molecules and particles that may be floating around in the chamber. The ion pump cannot begin to work until the pressure inside the gun chamber is approximately 10-6 torr. Finally, we bake the gun at 250o C for about a week to get a lot of the hydrogen and water out of the gun. At the same time, we activate the Non-Evaporable Getters, or NEGs, which are passive pumps that sit in the bottom of the gun chamber and trap residual molecules by way of their internal composition.

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| **Process** | **Estimated Resulting Pressure (torr)** |
| Mechanical Pump | 0.1 |
| Turbo Pump | 10-8 |
| Ion Pump | 10-10 |
| Bake and Full NEG Activation | Low 10-12 |

Table 1: Vacuum preparation process with resulting pressure.

Figure 1. Ion Pump Pressure vs. Time. We started measuring the pressure 19 hours into our bake. Through this method, we saw the gun enter the 10-9 torr range.

# High Voltage Conditioning

 The electron gun needs to be conditioned to operate at 200 kV, meaning that we cannot apply all 200 kV immediately. If we do, we could damage three things: the electrode, the high voltage cable, and/or the insulator.

 When first conditioning the gun, it is necessary to start at lower voltages and slowly move to higher voltages. Through our experience in high voltage conditioning and trust in our design, we felt comfortable in immediately setting the voltage at 50 kV at the start of conditioning. During this process, we monitored the applied voltage, power supply current, vacuum pressure, and radiation off of the gun to make sure that all was going smoothly. At the beginning, we turned up the voltage in increments of about 10 kV until we hit 100 kV, then moved at a slower pace of about 5 kV, still monitoring for signs of field emission and gas desorption. All was clear until we got to 181 kV, when the first significant sign of field emission appeared. At that point, we needed to be very careful about turning up the voltage because we want the field emitter to be eliminated, but we don’t want to damage the gun since the electric field at the tip of the field emitter is very high. After slowly turning up the voltage, we finally eliminated the field emitter at 216 kV, which was almost the limit of our power supply.

 After processing the field emitter and taking the gun up to 216 kV, we decided to let the gun “soak” for a few days at voltages 200 kV and 210 kV to make certain that the gun was able to operate at the desired voltage with no field emission. After about a week, we began to notice that the radiation was very low, but it was non-zero. We did some statistics on the different radiation signals that we were obtaining and found that even though the gun was soaking at operating voltage, we were slowly developing another field emitter. Under normal circumstances, we would simply take the gun to higher voltages and process the field emitter away, but our power supply hindered us from taking the gun to voltages beyond its limit of 225 kV.

# Results

 We did not follow our vacuum protocols as we should have in order to create the desired ultra-high vacuum pressure. We stopped our bake earlier than we would have liked to perform high voltage conditioning and processing, thinking that we would create better vacuum when we installed the gun into the CEBAF. This got our final pressure down to the 10-11 torr range, one order of magnitude off from our desire goal.

Figure 2. Electron Gun Bake Temperature vs. Time. Letting the gun sit at certain temperatures allow for different elements to be removed from the gun.

 Our conditioning was unsuccessful by our required standards. At the 200 kV range, we saw slight signs of field emission that we monitored over the course of a week. We saw that as time progress, the field emission, however slight, was getting worse. This indicated the presence of a field emitter, which is unacceptable to have. The maximum voltage that we applied to the gun was 216 kV, which was not high enough to completely condition the gun. If we had used a power supply that was able to give us higher voltages, we would feel comfortable conditioning the gun to higher voltages

Figure 3. Ch 2 Radiation vs. Voltage and Ch 8 Radiation vs. Voltage. We set up radiation monitors on different points of the gun to get an idea of where we were seeing field emission. The different channels correspond to different locations outside of the gun. In general, we see an increase in field emission at higher voltages and with the passing of time.

Figure 4. Anode Current vs. Voltage. We monitored the current flowing through the anode to make certain that no field emission was coming from the electrode and hitting the anode. The lower this is, the longer the photocathode lifetime will be. There was a general decrease in the current with both time and increasing voltage.

# Conclusion and Further Discussion

 In summary, the electron gun that we created does not meet the requirements necessary to be installed into the accelerator. The vacuum that we achieved was only in the 10-11 torr range and although it is in the range of ultra-high vacuum, it does not meet our requirement of being in the 10-12 torr range. The gun also did not operate at 200 kV without any field emission. Any radiation coming off of the gun is unacceptable and we did not have adequate power to apply high enough voltage to remove any field emitters that may have appeared. At this time, we have decided to condition another gun for the accelerator that has the potential of yielding higher voltages than our original design.