PROGRESS ON A CRYOGENICALLY COOLED RF GUN POLARIZED ELECTRON SOURCE*

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Abstract

RF guns have proven useful in multiple accelerator applications. An RF gun capable of producing polarized electrons is an attractive electron source for the ILC or an electron-ion collider. Producing such a gun has proven elusive. The NEA GaAs photocathode needed for polarized electron production is damaged by the vacuum environment in an RF gun. Electron and ion back bombardment can also damage the cathode. These problems must be mitigated before producing an RF gun polarized electron source. In this paper we report continuing efforts to improve the vacuum environment in a normal conducting RF gun by cooling it with liquid nitrogen after a high temperature vacuum bake out. We also report on a design of a cathode preparation chamber to produce bulk GaAs photocathodes for testing in such a gun. Future directions are also discussed.

INTRODUCTION

NEA GaAs photocathodes have proven themselves useful for many accelerator applications, either for their high quantum efficiency or the ability to produce highly spin polarized electron beams [1]. Thus far, GaAs photocathodes are used exclusively in DC guns. Tests in an RF gun at BINP resulted in an NEA GaAs photocathode quantum efficiency lifetime of a few tens of RF pulses [2]. This was likely due to a combination of bad vacuum in the RF gun, ion bombardment, and electron bombardment.

Multiple groups are researching ways to improve the lifetime of such cathodes in an RF gun. Such ideas include an SRF gun [3], HOM mode gun [4], a PWT gun [5] and our cryogenically cooled gun [6]. These experiments aim to improve the pumping speed available in the cathode region of the gun to reduce the pressure and ion bombardment. In this paper we report on the results of cooling an RF gun with liquid nitrogen in order to improve the vacuum pressure. We also report on our progress in building a cathode preparation chamber to start producing bulk NEA GaAs photocathodes to use in future tests.

GUN TEST STAND

Figure 1 shows a block diagram of the test stand. The gun is a 1.6 cell copper RF gun similar to the one in operation at the Fermi/NICADD Photoinjector Laboratory. The gun is cooled by flowing liquid nitrogen through the water cooling pipes of the gun. Faraday cups at both ends are used to measure the dark current.

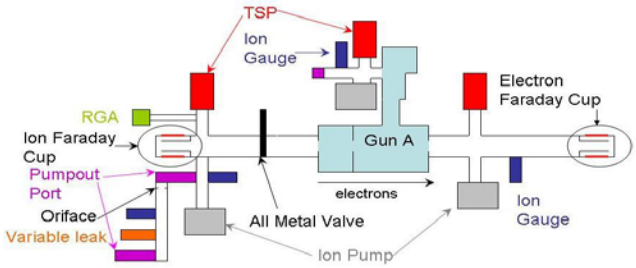

Figure 1:RF gun vacuum test stand

This test stand has various improvements over our previous setup [6]. The ion gauges at each station were cross calibrated on a common volume. The pumping speed of each station can be individually measured because of the ion gauge placement. The valve is an all metal valve to reduce possible outgassing inside of the system. The pumping orifice, used for some preliminary measurements, was moved to a section that could be valved out of the system so the system would not need to be opened to remove it. The cathode port was manufactured with sharp edges, so a cathode plug with a small rounded hole was fit to mitigate the effect of these sharp edges.

The most significant change to the system was to bake most of the vacuum components, including the gun, at 450°C for three days at low pressure (less that 10^{-4} torr). This was found in previous measurements to reduce the amount of outgassing from the bulk material [7]. This was done at a local vendor; all components were baked in the same oven, at the same time. The bake ended with a nitrogen quench.

Upon return from the bake out, we noticed that although the copper and some stainless steel parts were clean (mostly flanges) and others had a blue or brown layer on the surface. This layer could be removed by a wire brush with some effort. We decided to leave this layer in place for the measurements because of time and manpower restrictions.

We believe that the difference between the discolored and clean stainless is a difference in the type of stainless used. Most of the flanges are likely 316 stainless and most of the remaining parts are likely 304 stainless. If the parts were hot then the oven door was opened, 304 stainless is expected to oxidize while 316 may not.

After assembly, the chamber was baked at 150°C for 4 days to remove the water in the system. The ion gauges, TSP filaments, and RGA were degassed during the bake out. The ions pumps were turned on during the last day of the bake.

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VACUUM TESTS

The outgassing rate of the gun was measured by pumping only through the cathode port of the gun with the orifice section valved out. The total outgassing rate was 1.3×10^{-9} torr-L/s. The estimated outgassing per unit area is 1.3×10^{-13} torr-L/s/cm^2 which is a typical value for stainless steel [7]. The RGA shows that hydrogen is main source of outgassing with small contributions from carbon monoxide and methane.

This is in contrast to the previous result of 8.7×10^{-9} torr-L/s [6]. We believe that the 450°C bake of the components is responsible for the six fold decrease in outgassing.

Pumping is provided by three pumping stations consisting of a TSP and 30 L/s ion pump. The pumping speed of each station was measured by flowing nitrogen gas into the chamber and measuring the gas flow into the system and the pressure at the pumps. Two of the pumping stations have pumping speeds greater than 120 L/s when the TSP was not saturated. The third station has a speed of 47 L/s. The reason for the low pumping speed of this station is not understood but may be due to low titanium deposition from the filament in the TSP.

The TSPs are assumed to be at 80% of capacity for calculations of pressure in the gun volume. This is based on the time that the vacuum system is left to reach its equilibrium pressure.

Pressure measurements were made under four conditions, room temperature with and without RF and cryogenic temperature with and without RF. During RF measurements at room temperature the gun was uncooled for the duration of the measurement and the RF frequency was adjusted manually to stay on resonance. The RF was applied with parameters typical at the FNPL, 30 μs pulse width, 1 Hz rep rate, and 35 MV/m cathode field. Table 1 summarizes the results.

Table 1: Gun Pressure under various conditions. The improvement column lists the fractional change from previous results in Reference 6.

RF	Temperature (K)	Pressure (torr)	Improvement
off	300	9.8E-11	72%
off	98	4.4E-11	75%
on	300	1.1E-09	34%
on	98	2.0E-10	31%

As Table 1 shows, there is a significant improvement in the vacuum pressure from the results obtained one year ago. This is likely due to the high temperature bake of the components prior to assembly. We also note that the improvement is less when the RF is on than when it is off. This is a disappointing result showing that the outgassing from the RF was not mitigated by the baking. The pressure at 98K is a factor of 2.2 lower than the 300K case. This result agrees with the prior measurement and was initially not understood. Further investigation revealed the explanation and will be discussed below.

RGA analysis shows that the dominant species are hydrogen, methane, carbon monoxide, carbon dioxide, oxygen, and argon. Figure 2 shows a comparison of the RGA spectra when the gun is at 300K and at 98K. There is no significant change in the spectra when the gun is cooled. All gases except hydrogen and water show increased outgassing when RF is applied to the gun at room temperature. This is not the case for when the gun cooled with liquid nitrogen, as only methane shows increased outgassing.

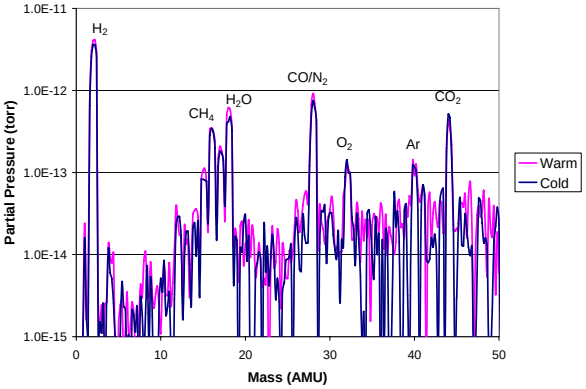

Figure 2: RGA spectra of a 300K (pink) and 92K (blue) RF gun without RF.

Many of these results can be explained by considering what happens to an ideal gas in adjoining chambers of the same volume, one colder than the other, which are separated by an aperture. An equilibrium will result when the net flux though the aperture is zero. If the chambers are at the same temperature, this equilibrium results in equal pressures and densities in each chamber. However, for the case where one chamber is colder than the other, flux from the colder chamber to the warmer is reduced because of the lower gas velocity. This results in the gas migrating to the colder chamber forming a colder, lower pressure, denser gas in the colder chamber at equilibrium. The ratio of the pressures and densities in the two chambers is

$$p_c / p_h = \sqrt{T_c / T_h}\,, \quad \rho_c / \rho_h = T_h / T_c\,,$$

where the subscripts denote the "cold" and "hot" temperatures (T), pressures (p), and densities (ρ) [8]. For our case, the pressure ratio is predicted to be 0.57, and we measure 0.45. We have not taken into account the difference in volume between the warm and cold sections.

Ions which can bombard the cathode are generated in the gun from collisional ionization with dark current and beam. The increased gas density at these temperatures can actually lead to a worse situation than at room temperature.

In order to explain the outgassing at 98 K, we note that methane's melting point is 111 K [9]. The only gases present with melting points lower than 98K are hydrogen, helium and carbon monoxide. The other gases have melting points significantly above this. We theorize that

gases with melting points higher than 98K stick to the walls of the cold gun. The surface heating of the RF is likely enough to evaporate some of the methane back into the chamber, but not the other gases since they have higher melting points.

Significant reductions in the pressure and density in the gun volume can only be obtained when the vapor pressure of the residual gas drops below the ambient pressure in the cold volume. Vapor pressures of the gases involved do not go below 10^{-10} torr until approximately 20 K is reached, except for hydrogen which requires 3 K. This involves using liquid helium at a coolant. In this case, superconducting guns become more attractive. Our cryostat is not able to support such a low temperature and we decided to try a different approach.

It may be possible to reduce the vacuum pressure in the gun volume by cleaning the inside of gun using a thermionic emitter positioned on the axis of the gun [10]. We expect that this will remove the remaining outgassing sources and result in a lower gun pressure when RF is applied to the gun. This experiment is currently in the design stage.

CATHODE PREPARATION CHAMBER

Fermilab received a cathode preparation chamber as part of a phase I SBIR with Advanced Energy Systems in 2005 [6]. This chamber is based a chamber used at Cornell for their GaAs cathode preparation system. Our chamber is being designed to mount behind an RF gun to re-cesiate, reactivate, and hydrogen clean an NEA GaAs photocathode. Though in-situ cesiation can be done in a DC gun, this is not practical in an RF gun [1]. Figure 3 shows the design of the chamber.

The chamber is pumped with a turbomolecular pump and a 300 L/s diode ion pump. Cesium is available through a getter. We will use nitrogen trifloride for the oxidizer. A thermal gas cracker will be used for the hydrogen cleaning. The stalk is designed to hold a heater and provide the opportunity to measure the current photoemitted from the cathode. Since the current focus of the chamber is to gain experience with making NEA GaAs photocathodes, the stalk does not have the ability to be inserted into a gun, however the design is such that extending the stalk and adding a bellows actuator can be done easily.

The GaAs wafer is held in a molybdenum cup and soldered in place with indium foil. It is further secured with a molybdenum cap which is held to the stalk with a bayonet arraignment.

Construction of the chamber is in progress and commissioning is expected to follow shortly.

CONCLUSION

We have measured the vacuum performance of a cryogenically cooled normal conducting gun. Cooling the gun with liquid nitrogen lowers the pressure inside of the gun at the expense of filling it with a colder denser gas. This denser gas can be a source of ions that can bombard a GaAs photocathode causing damage. Cooling with liquid helium is necessary to achieve extremely low pressures. We plan to attempt to reduce the outgassing from the surface by cleaning the gun interior with electrons.

We are also constructing a cathode preparation chamber than can be mounted to an RF gun that will be capable of cleaning, reactivating, and recesiating NEA GaAs photocathodes.

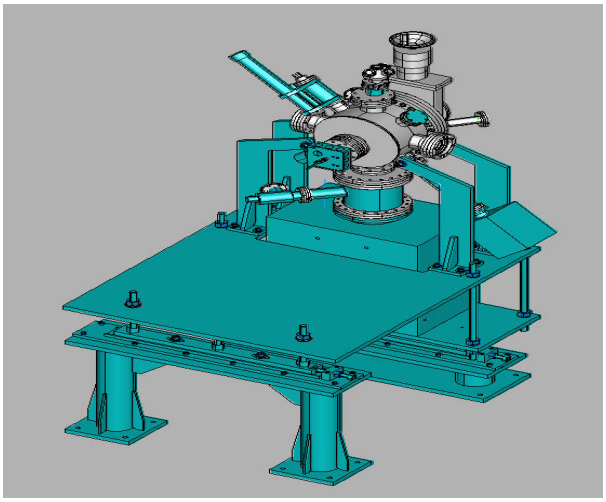

Figure 3: Preparation Chamber for NEA GaAs photocathodes. Gun attaches on far side of picture.

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