

DC photogun vacuum characterization through photocathode lifetime studies¹

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Abstract. Excellent vacuum is essential for long photocathode lifetimes in DC high voltage photoelectron guns. Vacuum Research at Thomas Jefferson National Accelerator Facility has focused on characterizing the existing vacuum systems at the CEBAF polarized photoinjector and on quantifying improvements for new systems. Vacuum chamber preprocessing, full activation of NEG pumps and NEG coating the chamber walls should improve the vacuum within the electron gun, however, pressure measurement is difficult at pressures approaching the extreme-high-vacuum (XHV) region and extractor gauge readings are not significantly different between the improved and original systems. The ultimate test of vacuum in a DC high voltage photogun is the photocathode lifetime, which is limited by the ionization and back-bombardment of residual gasses. Discussion will include our new load-locked gun design as well as lifetime measurements in both our operational and new photo-guns, and the correlations between measured vacuum and lifetimes will be investigated.

1. Introduction

The Continuous Beam Electron Accelerator Facility (CEBAF) at Thomas Jefferson National Accelerator Facility (Jefferson Lab) is a US Department of Energy funded nuclear physics research facility which accelerates highly polarized electron beams up to energies of 6 GeV to probe the structure of the nucleus. The electron source for this machine is a 100 kV DC high voltage photoelectron gun, which relies on photoemission from the direct-band-gap semiconductor gallium arsenide illuminated with circularly-polarized infra-red laser light to emit highly polarized electron beams.

With the accelerator operating non-stop for months at a time, maintenance of the electron gun is disruptive to operations. Gun maintenance is typically necessary only when the yield of the photocathode, characterized by a quantity known as quantum efficiency (QE) has degraded due to the ionization of residual gasses in the vacuum and the consequent bombardment of the photocathode by these ionized gasses. A combination of surface chemistry disruption and crystal structure damage is believed to result in the reduction of QE. Long photocathode lifetime, defined as the amount of charge delivered before the QE falls to 1/e of its initial value, is strongly correlated to the vacuum condition of the photo-electron gun and is critical to the successful operation of the CEBAF machine.

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The gun vacuum system consists of a 304 stainless steel vacuum chamber pumped by a combination of NEG modules and ion pumps. Scheduled experiments have very demanding requirements in terms of photocurrent and lifetime, and the manufacturing techniques, characterization, and performance of two different load-locked electron guns to replace the existing “vent and bake” electron gun will be the focus of this discussion.

2. CEBAF photogun vacuum characterizations

With vacuum an essential aspect of photocathode lifetime, we started a characterization of the vacuum system of the existing CEBAF photoguns several years ago [1]. The motivation for these studies was the discrepancy seen between the measured and calculated ultimate pressure in the CEBAF guns. An extractor gauge, with a theoretical (vendor specified?) measurement capability near 1×10^{-12} Torr, was used to measure the pressure of the CEBAF gun chambers as well as test chambers with different numbers of NEG pumps installed, and the measured pressure was consistently higher than the expected value calculated from standard outgassing rates and manufacturer’s pump speed specifications. (see figure 1)

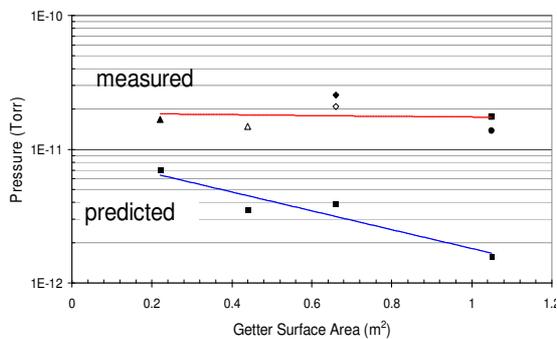


Figure 1 The discrepancy between measured and predicted ultimate pressure in various guns and test chambers served as the motivation for vacuum system characterization of the CEBAF gun systems. From left to right, the chambers are test chambers with 2 and 4 getter modules, respectively, the two tunnel guns and at far right the two load locked guns described in this paper.

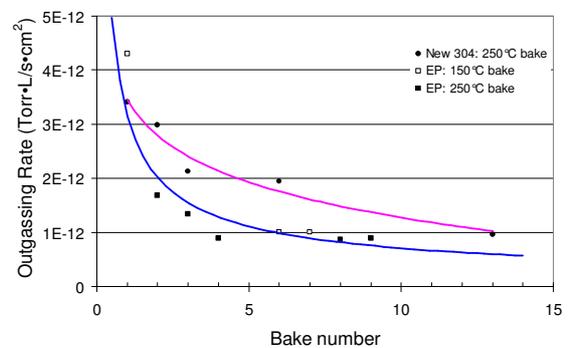


Figure 2 Outgassing rates as a function of bakes for untreated 304 stainless steel (top data set) and electropolished and vacuum fired chamber (lower data set).

2.1. Outgassing measurements

In trying to determine the cause of the discrepancy between calculated and observed ultimate pressure of the CEBAF gun, outgassing rate measurements were made on the 304 stainless steel as installed and on a new chamber constructed using better vacuum techniques. The first chamber was tube 304 steel, machined, welded and cleaned using a degreaser and solvents. The second chamber was electropolished, vacuum fired at 950°C for 4 hours, then the flanges were welded and the chamber cleaned. The outgassing rates of both chambers were measured after a series of vacuum bakes using an accumulation technique with a spinning rotor gauge. The results of these outgassing rates are shown in figure two, and it is evident that the ultimate outgassing rates of both chambers are approximately the same at 1×10^{-12} Torr·L/s·cm², though the chamber that was electropolished and vacuum fired achieved a slightly lower outgassing rate with fewer bakes of the system. Both chambers however exhibit an outgassing rate quite close to the commonly accepted value for 304 stainless steel, meaning that an unexpectedly high outgassing rate is not the cause of the discrepancy between the measured and calculated ultimate pressure.

2.2. Pump speed measurements

The second possibility for higher than expected ultimate pressures is that the pumps are not pumping at the rated speed. To investigate this, we made a series of measurements on the hydrogen pump speed of the commercial NEG modules (ref) as a function of pressure. Pump speed measurements were also made on a Ti/Zr/V NEG coating that was applied to the gun vacuum chamber wall at Jefferson Lab. Measurements were made using a throughput technique with residual gas analyzers on either side of an orifice of known conductance and a conductance limited flow of hydrogen into the test chamber. The results of these pump speed measurements are shown in figures 3 and 4, and it is evident that the pump speed measured at pressures over 5×10^{-11} Torr is quite high, over 1000 L/s, and well over the 430 L/s speed quoted by the manufacturer. The decrease in measured pump speed at the lowest pressures comes from attempting to measure pump speed at the base pressure of the chamber,

following the expected line fit of $S = S_{\max} \left(1 - \frac{P}{P_0} \right)$, where the measured speed falls from its maximum value as the pressure P approaches the base pressure of the chamber, P_0 . The difference between measured and calculated pressure in the chamber is not due to pump speed being significantly less than assumed in the calculations.

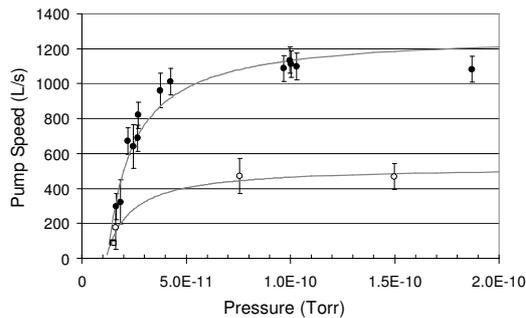


Figure 3 Pump speed for SAES getter modules as a function of pressure, with full resistive activation of pumps in top data set and passive activation of pumps through bake in bottom set. Decrease in pump speed at low pressures follows prediction for drop in measured speed as the base pressure of the chamber is reached, and is not representative of actual decrease in pumping.

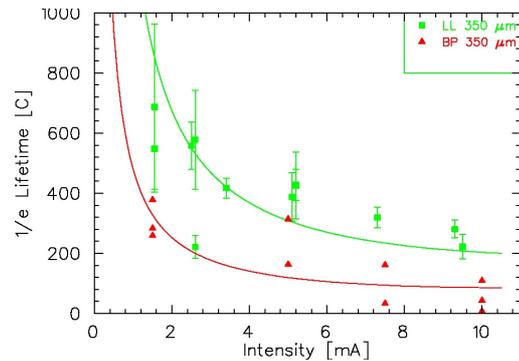


Figure 4 The improved vacuum of the production load locked gun (top data set) manifests itself in higher lifetime measurements compared to the prototype load locked gun (bottom data set).

3. Load-locked gun designs

The vent and bake gun design that has operated in the CEBAF injector for the past 10 years has been quite successful, with photocathode lifetimes up to 100 coulombs for the highly polarized electron beams, however, the single chamber gun design has several significant drawbacks. The three days required to bake the system when a photocathode is changed necessitates that gun maintenance happen only during scheduled accelerator maintenance. In addition, since the photocathode surface preparation, where cesium and nitrogen trifluoride are applied to reduce the surface work function, happens in the same chamber where the electron beam is produced, the vacuum in that chamber is not as low as it might be if this chemistry were separated. In addition, the cesium applied to the cathode also coats the cathode electrode and over time, build-up of cesium will cause field emission from the electrode structure. Finally, with the very sensitive high polarization gallium arsenide/gallium arsenide phosphide quantum well structures that are used to produce highly polarized electron beams, we were quite hesitant to fully activate the NEG modules in the gun while the photocathode material

was present due to the increased heat and pressure in the chamber and possible effects on the QE or lifetime of the photocathode.

Two different load-locked DC electron guns were designed, built and tested at Jefferson Lab over the past several years [2,3]. The first “prototype” design used a 6 way, 10 inch cross as the high voltage chamber. The chamber was constructed of 304 stainless steel and electropolished but not vacuum fired, which would have increased the outgassing rate of the chamber. Cartridge NEG pumps were used in recessed 8 inch ports, and conductance between the chamber and the pump surface may be a limitation in the effective pumping speed of this system. Finally, a large 220 L/s ion pump was used in coordination with the NEG pumps, and though it has large pumping speed, it also has large surface area and the possibility for increased outgassing rate.

The second generation “production” load-locked gun, which will be installed in the CEBAF machine summer 2007, was constructed with better vacuum considerations. The chamber used a 12” tube of 304 stainless steel and a geometry to minimize surface area. The production gun’s chamber was electropolished, vacuum fired then coated with Ti/Zr/V NEG material. Both load locked guns allow full activation of the NEG pumps in the high voltage chamber, eliminate preparation chemicals including cesium from polluting the vacuum and electrodes in the high voltage chamber, and significantly reduce the time required to install new photocathode material in the gun.

The considerable vacuum improvements between the prototype and production load-locked guns should have improved the ultimate pressure: more pumping was installed, surface area was reduced and the HV chamber surfaces were NEG coated to virtually eliminate outgassing. However, as seen in Figure 1, the ultimate pressure measured in both load-locked guns is very similar to the ultimate pressures in the old CEBAF guns and two different test chambers.

3.1. Photocathode Lifetime

The critical metric for a successful gun is not measured pressure but rather the photocathode lifetime during beam delivery. Both the prototype and production guns were run on a test beamline with similar configuration to the CEBAF injector beamline through an extensive series of lifetime measurements [3]. Figure 4 shows the improvement in lifetime as a function of current between the prototype and production guns for unpolarized beam on standard GaAs material for a 350 micron laser spot size. Additional tests in the production gun, generating highly polarized beam from the superlattice material using the wavelength and RF timing structure used in the CEBAF machine, allows direct comparison of lifetime to the old CEBAF electron guns. The best lifetime achieved in CEBAF thus far at operating currents around 100 uA is about 100 coulombs. Lifetimes in the production load-locked gun, which tend to fall with increasing current, were at least 200 coulombs at currents of 250 uA and 1 mA [4]. The improvements in vacuum of the high voltage chamber are manifest in the improvements in photocathode lifetimes although our vacuum diagnostics are insufficient to directly measure the improvement in pressure in the system. We anticipate that the increase in lifetime and ease of photocathode exchange will allow us to meet the needs of the physics program at CEBAF for the coming years.

References

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