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Characterization of the CEBAF 100 kV DC GaAs photoelectron gun vacuum system

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Abstract

A vacuum system with pressure in the low ultra-high vacuum (UHV) range is essential for long photocathode lifetimes in DC high voltage GaAs photoguns. A discrepancy between predicted and measured base pressure in the CEBAF photoguns motivated this study of outgassing rates of three 304 stainless steel chambers with different pretreatments and pump speed measurements of non-evaporable getter (NEG) pumps. Outgassing rates were measured using two independent techniques. Lower outgassing rates were achieved by electropolishing and vacuum firing the chamber. The second part of the paper describes NEG pump speed measurements as a function of pressure through the lower part of the UHV range. Measured NEG pump speed is high at pressures above 5×10^{-11} Torr, but may decrease at lower pressures depending on the interpretation of the data. The final section investigates the pump speed of a locally produced NEG coating applied to the vacuum chamber walls. These studies represent the first detailed vacuum measurements of CEBAF photogun vacuum chambers.

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Keywords: Polarized electron source; Photoinjector; Electron gun; Non-evaporable getter (NEG); Pump speed; Outgassing

1. Introduction

Electron beams with polarization up to 85% are used to probe nuclear structure at three independent experimental halls at the Continuous Electron Beam Accelerator Facility (CEBAF) at Thomas Jefferson National Accelerator Facility (Jefferson Lab). The electron beams for each hall originate from the same gallium arsenide (GaAs) photocathode that sits in a 100 kV DC high voltage photogun [1]. Residual gasses in the gun chamber are ionized and degrade photoelectron yield (quantum efficiency, QE) when ions are accelerated into the photocathode, damaging the crystal structure or sputtering away the chemicals used to create the negative electron affinity condition.

Photocathode operational lifetime falls as average beam current extracted from the photocathode rises. At lower currents ($<100\,\mu$A), the photogun can operate uninterrupted for months before the QE and laser power are insufficient to provide the required beam. At high currents, the gun can provide uninterrupted beam for one to two weeks before the focused laser beam must be moved to a new location on the photocathode where the QE is still high. After exhausting the usable laser spot locations, the photocathode must be heated and reactivated in situ. This process restores photocathode QE and beam delivery can resume.

There are two identical photoguns at the CEBAF injector, with one providing beam to the accelerator and the other serving as a spare. The single-chamber design (Fig. 1a) requires venting to atmospheric pressure to replace the photocathode. After venting, the photogun must be baked to achieve a suitable vacuum condition by

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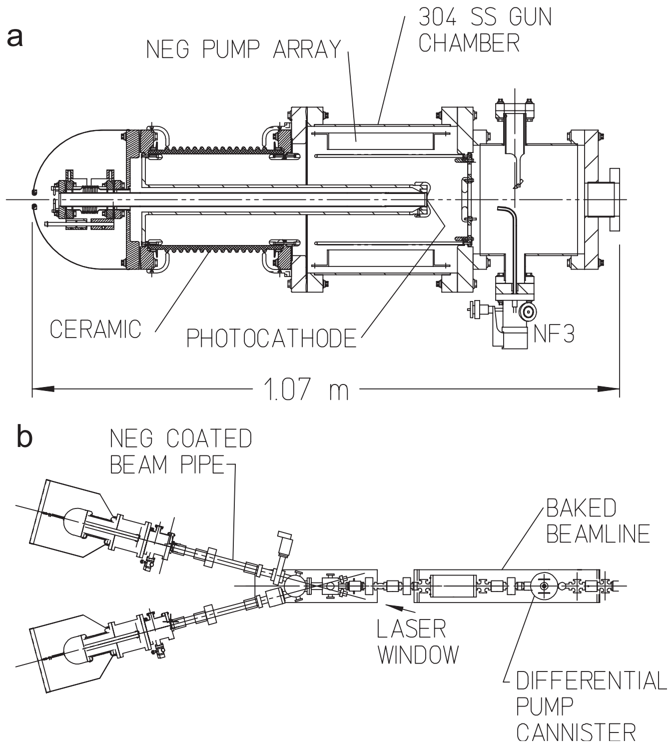

Fig. 1. (a) The CEBAF 100 kV DC high voltage GaAs polarized photogun and (b) the CEBAF 100 kV photoinjector.

removing adsorbed water vapor and activating the NEG pumps. Bakeouts are conducted using a thermally insulated oven and forced hot air to achieve a bake temperature of 250 °C with a typical duration of 30 h. Two types of bakes are performed: an initial bake with an inexpensive sacrificial photocathode following extensive vacuum work where the NEG modules have been exposed to atmosphere, and routine bakes following venting to dry nitrogen and installation of high polarization photocathode material. During the initial bake, maximum pressure, deduced from ion pump current, is $\sim 5\times10^{-6}$ Torr and QE of the sacrificial GaAs wafer is typically less than optimal. Routine changes of photocathode material take place by venting with dry nitrogen and using a glove bag with a dry nitrogen purge around the opened flange to prevent water vapor from entering the vacuum chamber. During bakeout, following a routine photocathode change, maximum pressure is typically 5×10^{-9} Torr and QE is high (up to 1% QE at the bandgap of 780 nm for high polarization superlattice material [2]).

Following a routine bakeout, the photocathode is activated to a negative electron affinity condition using Cs and an oxidant, NF_3 [3]. Activation occurs within the chamber, and the deposition of the chemicals introduces temporary vacuum excursions in the gun. The vacuum recovers within an hour following cathode activation and beam delivery takes place with the gun at base pressure.

The photoguns are connected to the accelerator using large bore (6.35 cm diameter) beampipes coated with NEG material (Fig. 1b). A 15° bend eliminates line of sight between the photogun and the accelerator beamline, and provides means to illuminate the photocathode at normal incidence, which is desirable for high polarization guns. The first 3 m of beamline downstream of the guns was baked to ~220 °C and a differential pump station isolates the baked beamline from the unbaked portion of the accelerator. These features of the injector ensure that the dominant gas load at the photoguns originates from the gun chamber outgassing rather than from the accelerator.

Ten NEG modules [4] surround the cathode/anode gap in the gun vacuum chamber providing extensive pumping of hydrogen gas, which is the dominant gas species in steel UHV systems [5]. A differential ion (DI) pump [6] located downstream of the anode pumps gasses that are poorly pumped by the NEG pumps, such as noble gasses and methane. There are also two GP100 NEG pumps [7] on ports downstream of the anode plate. An extractor gauge [8] and residual gas analyzer (RGA) [9] can be used to monitor pressure within the photogun. These hot filament gauges produce light and gas when energized, so they cannot be left powered during photogun operation since the light could be a source of uncontrolled and unpolarized photoemission and optimal vacuum conditions are achieved with the gauges off. Consequently, pressure is measured only during long accelerator maintenance periods. The best recorded pressures for the gun are shown in Fig. 2, as well as pressure values from test chambers also using NEG and DI pumps. The measured pressure in all chambers is significantly higher than predicted values, assuming typical outgassing rate for 304 SS of 1×10^{-12} Torr L/(s cm^2) and the vendor's stated NEG and DI pump speeds. These observations provided motivation for the outgassing and NEG pump speed studies presented here.

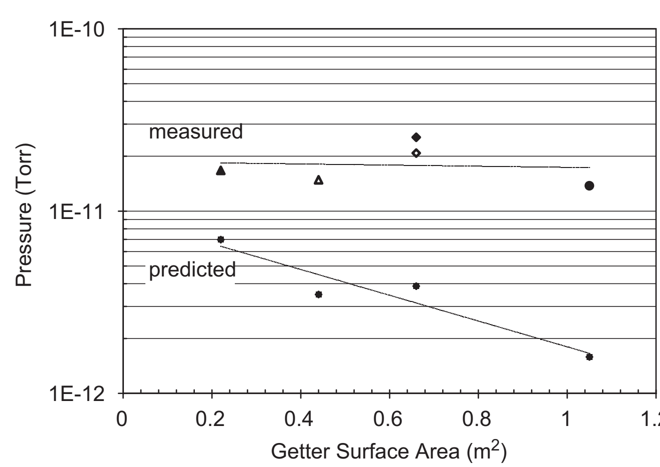

Fig. 2. Measured versus predicted pressure inside CEBAF photoguns and test stands. Closed and open triangles represent best pressure achieved in test stands with two and four fully activated SAES WP950 getter modules. Closed and open diamonds represent CEBAF photogun vacuum chambers, each with ten WP950 modules passively activated. Circle represents a new load-locked vacuum chamber with six fully activated SAES WP1250 modules. Lower data set represents values predicted from calculations based on chamber surface area, assuming an outgassing rate of 1×10^{-12} Torr L/s cm^2 and using manufacturers quoted pump speed.