CEBAF 200KV INVERTED ELECTRON GUN*

P. Adderley, J. Clark, J. Grames, J. Hansknecht, M. Poelker, M. Stutzman, R. Suleiman#,
K. Surles-Law, Jefferson Lab, Newport News, VA 23606, U.S.A.
J. McCarter, University of Virginia, Charlottesville, VA 22904, U.S.A
M. BastaniNejad, Old Dominion University, Norfolk, VA 23529, U.S.A.

Abstract

Two DC high voltage GaAs photoguns have been built at Jefferson Lab based on a compact inverted insulator design. One photogun provides the polarized electron beam at the Continuous Electron Beam Accelerator Facility (CEBAF) and operates at 130kV bias voltage. The other gun is used for high average current photocathode lifetime studies at a dedicated test facility and has been operated at bias voltage up to 200kV. The advantages of higher DC voltage for CEBAF include reduced space-charge emittance growth and the potential for prolonged photocathode lifetime. However, a consequence of operating at higher voltages is the increased likelihood of field emission or breakdown, both of which are unacceptable. Highlights of the R&D studies leading toward a production 200keV GaAs photogun for CEBAF are presented.

INTRODUCTION

A new nuclear physics experiment, Q_{weak} [1], requires 180μA average current which is roughly twice the current delivered to most high current experiments at CEBAF. This high current requirement poses a problem for the DC high voltage GaAs photogun; namely, even though the CEBAF bunch charge is very small (< 1pC), space charge induced emittance growth causes the beam to expand in space and time, leading to significant beam loss on apertures that define the spatial and temporal acceptance of the injector. As a result, operation at "normal" 100kV bias voltage and at high average current leads to inefficient beam transport and necessitates more frequent heat and reactivation cycles of the photocathode (i.e., accelerator downtime). Equally important, Q_{weak} is a parity-violation experiment. This means it is essential to minimize interception on apertures that introduce unwanted helicity correlated charge and position asymmetries on the delivered beam. By operating the CEBAF DC high voltage GaAs photogun at higher bias voltage, we improve the transmission of the beam through photoinjector apertures, thereby prolonging the operating lifetime of the photogun and preserving beam quality for increasingly demanding parity-violation experiments. Today's CEBAF photoinjector employs a DC high voltage photogun operating at 130kV bias voltage. A planned CEBAF photoinjector upgrade will use a 200kV photogun.

This submission describes the successful commissioning of a new DC high voltage spin-polarized GaAs photogun operating at 200kV with an inverted insulator geometry. The photogun recently delivered 4mA average beam current from a high polarization strained-superlattice GaAs photocathode that was illuminated with light from an RF-pulsed fiber-based drive laser operating at 780nm and with 1500MHz pulse repetition rate. This is a new record [2] and an important development toward realizing some of the requirements for proposed high current accelerators like eRHIC [3].

*Work supported by the U.S. DOE under Contract No. DE-AC05-84ER40150
suleiman@lab.org

DESCRIPTION OF THE PHOTOGUN

The CEBAF load lock DC high voltage GaAs photogun [4] employs an inverted insulator geometry. This describes a photogun with a ceramic insulator that extends into the vacuum chamber, as shown in Figure 1. The primary benefit of this approach is that a large metal structure is not required to support the cathode electrode. As a result, there is significantly less metal biased at high voltage, and consequently there is less metal to generate field emission. Another appealing feature of the design is that the insulator is a common element of medical x-ray sources, and therefore relatively inexpensive compared to cylindrical insulators purchased solely for accelerator electron gun applications. Finally, because there is no exposed high voltage, corona shields and a tank for dry nitrogen gas or SF_6 are not required.

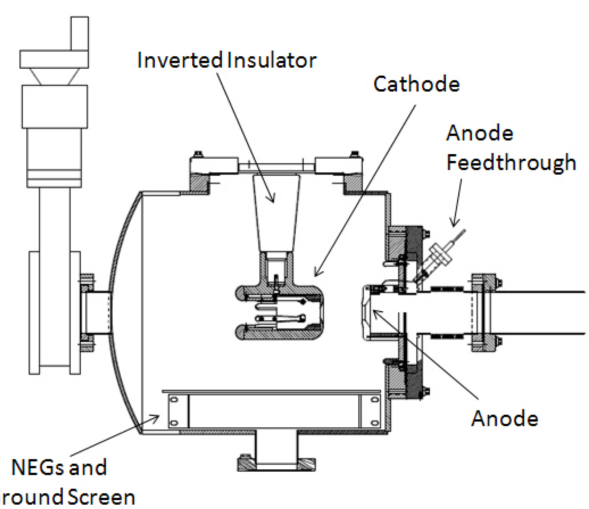

Figure 1: Cross section of the CEBAF inverted gun high voltage chamber.

The polarized GaAs photogun operating at CEBAF uses a tee-shaped cathode electrode made of 316L stainless steel polished to sub-micron finish using diamond grit. It was high voltage processed to 150kV without detectable field emission and now provides beam at 130kV. The success of the CEBAF nuclear physics program depends on this photogun providing beam, so we have been reluctant to increase the bias voltage beyond these values, concerned that field emission sites might be created. A second inverted gun located at an Injector Test Facility is used for more aggressive testing. It employs a similar tee-shaped cathode electrode but made of large-grain niobium.

Large-grain Niobium Cathode Electrode

Niobium is used to make superconducting RF cavities and there are many reports of field emission-free operation at field gradients exceeding 30MV/m. Although these results were obtained at ~ 2K and with RF electric fields, it seemed reasonable to evaluate niobium in a DC high voltage photogun at room temperature [5]. An appealing feature of niobium is that is can be chemically polished, which greatly reduces the preparation time of a new electrode (it took weeks of tedious effort to diamond-paste polish the 316L stainless steel electrode used at CEBAF). The niobium electrode was chemically etched in a mixture of hydrofluoric (49%), nitric (69%) and phosphoric (85%) acid with mixing ratio 1:1:1 at room temperature. This technique is referred to as buffered-chemical polishing (BCP). Besides taking advantage of BCP, other SRF techniques were adopted including high pressure rinsing with ultra pure de-ionized water and 900°C vacuum degassing [6].

The first application of high voltage was disappointing, with field emission detected at voltage > 140kV. By increasing the applied voltage, some field emitters were eliminated (Figure 2, blue data points) but processing was limited to 225kV which was the maximum voltage of the high voltage power supply. Not surprisingly, photocathode lifetime was poor while delivering beam at 200kV due to low level field emission which served to degrade the vacuum within the photogun. And often

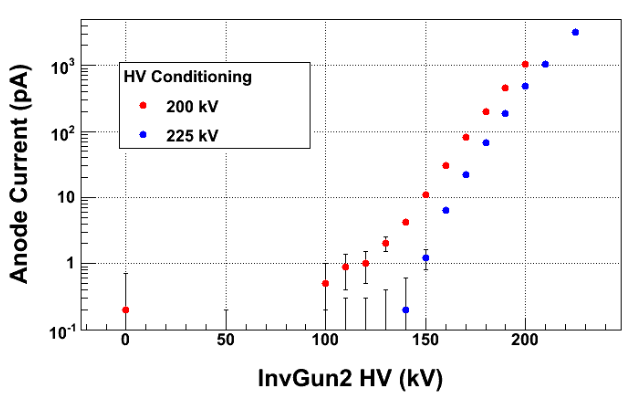

Figure 2: Field emission measurements during the initial high voltage processing of the 200kV inverted photogun. Going to higher voltage served to eliminate some field emitters (blue data points). A subsequent BCP treatment successfully eliminated field emission to 225kV.

there were high voltage discharges that completely eliminated photocathode quantum efficiency (QE).

The large-grain niobium electrode was removed from the photogun and inspected, whereupon the surface finish was deemed too rough. Another BCP treatment was performed resulting in a cumulative removal of ~ 100µm of surface material (surface roughness < 0.5µm). Upon re-installation of the cathode electrode into the photogun and vacuum chamber bake-out, no field emission was detected at voltage up to 225kV.

PHOTOGUN PERFORMANCE

The 200kV inverted load lock photogun was attached to a dedicated ultra-high vacuum diagnostic beam line (Fig. 3) described in other papers [7]. The electron beam exited the gun through a large bore (2.5") NEG-coated beam pipe and was deflected toward a Faraday cup beam dump using a 15° air-core cosine-theta dipole magnet. The bend allows illumination of the photocathode at normal incidence without needing mirrors inside the vacuum chamber. A large portion of the incident laser power (~ 30%) was reflected from the photocathode due to the high index of refraction of GaAs. To prevent unwanted photoemission from reflections inside the high voltage vacuum chamber the laser and gun were aligned so that the reflected light exits the laser vacuum window within ~ 0.1° of the incident laser beam. There were four focusing solenoid magnets to manage the electron beam envelope and numerous steering magnets to keep the beam centered in the solenoids and to minimize beam loss along the beam line.

To assess the performance of the photogun, charge lifetime measurements were made by illuminating different locations on the photocathode using a tightly focused laser beam ~350µm diameter (Gaussian FWHM). Charge lifetime is defined as the amount of charge that can be extracted from the photocathode until the QE drops to 1/e of the initial value. The current from the photocathode was maintained constant using a generic proportional-integral-derivative software control loop to vary the amount of laser power delivered to the photocathode. Throughout each lifetime "run", ion pump current at seven locations along the beam line was monitored using sensitive current meters within each ion pump high voltage supply. Beam loss as small as 50pA could be detected with these instruments which were used to optimize electron beam steering and beam envelope management.

The drive laser [8] consisted of a low-power, gain-switched fiber-coupled diode laser operating at 1560nm and 1500MHz pulse repetition rate. This light was amplified to 10W using a commercial Er:Yb fiber amplifier. Useful light at 780nm was obtained via second harmonic generation inside a periodically-poled lithium niobate crystal to obtain approximately 0.6W average power and with 50ps pulses.

The photocathode material was identical to that used at CEBAF: strained-superlattice GaAs/GaAsP that provides

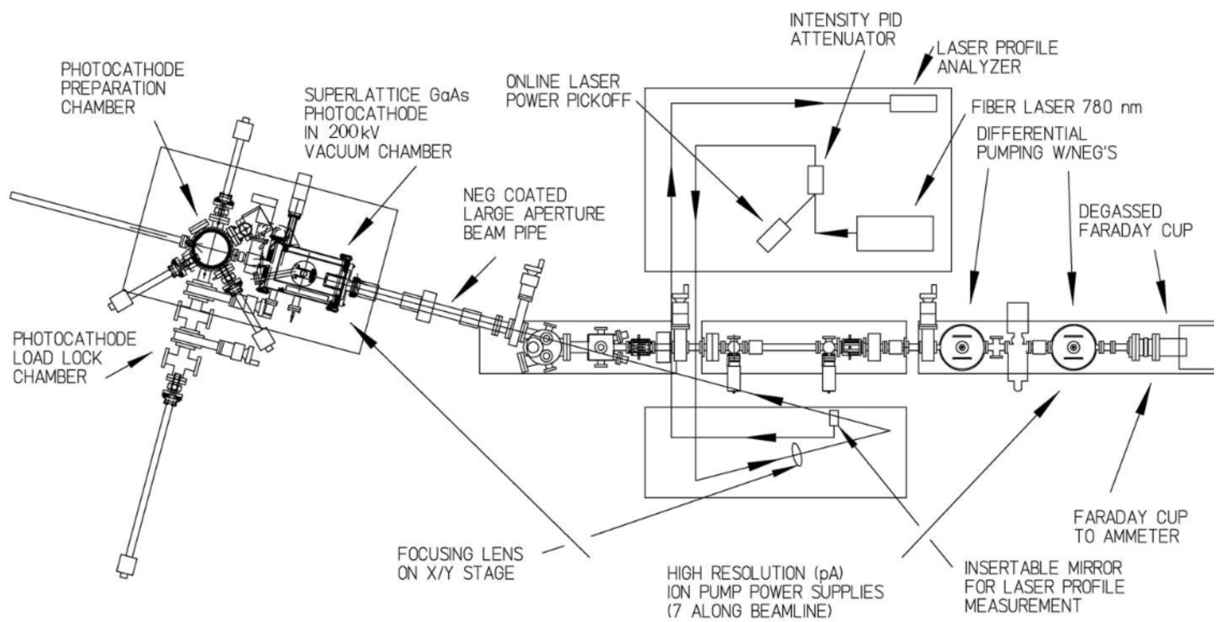

Figure 3: Schematic showing the 200kV load locked inverted photogun, diagnostic beam line and laser table.

polarization > 80% when illuminated with circularly polarized light at 780nm. For these measurements, however, the laser light was linearly polarized and no polarization measurements were performed (there is no polarimeter on the beam line). Only the center portion of the photocathode was activated to negative electron affinity (5mm diameter out of 12.8mm possible). QE degradation across the surface of the photocathode was monitored following each run by extracting about 1μA from the grounded photocathode, with the anode biased at ~ 200V, while scanning the laser across the photocathode using the x/y stepper motor stage.

RESULTS

The initial QE of the strained-superlattice GaAs/GaAsP photocathode was high: ~ 1.5%. This, combined with the maximum available laser power of 0.6W, allowed sustained operation at 4mA for approximately 1.4 hours. A total of 20C was extracted before exhausting QE and laser power headroom. An exponential fit to the QE decay indicates a charge lifetime of 85C. This marks the beginning of a prolonged study of photogun performance at high average current using high polarization photocathode material. One of the primary objectives of near-term study is to evaluate the charge lifetime dependence on photocathode bias voltage. Ion bombardment is the dominant mechanism limiting photocathode charge lifetime. At 200kV bias voltage, there should be 60% fewer ions produced by the extracted beam compared to 100kV bias. As such, charge lifetime at 200kV should be markedly better. In addition, we hope to improve the photocathode lifetime reported in this submission and to demonstrate even higher current operation.

REFERENCES

[1] R. Carlini *et al.*, "The Q_{weak} Experiment: A Search for New Physics at the TeV Scale", JLAB Experiment E02-020, December 6, 2004.

[2] J. Grames, *et al.*, "Lifetime Measurements of High Polarization Strained Gallium Arsenide at Beam Current > 1mA using a new 100kV Load Lock Photogun", Proceedings of the 2007 Particle Accelerator Conference, Albuquerque, NM. THPMS064.

[3] V. Ptitsyn *et al.*, "eRHIC, Future Electron-Ion Collider at BNL" in Proceedings of the 2004 European Particle Accelerator Conference, Lucerne, Switzerland.

[4] P. A. Adderley, J. Clark, J. Grames, *et al.*, Phys. Rev. ST Accel. Beams **13**, 010101 (2010).

[5] P. Kneisel, "Cavity Preparation and Assembly Techniques and Impact on Q, Realistic Q-factors in a Module, Review of Modules", Proceedings of the ERL05 Workshop.

[6] M. BastaniNejad, P. Adderley, J. Clark, *et al.*, "Field Emission measurements from Niobium Electrodes", these proceedings.

[7] J. Grames, R. Suleiman, P. A. Adderley, *et al.*, "Charge and Fluence Lifetime Measurements of a DC High Voltage GaAs Photogun at High Average Current", submitted to PRST-AB.

[8] J. Hansknecht and M. Poelker, Phys. Rev. ST Accel. Beams 9, 063501 (2006).