ISBN: 978-3-95450-227-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2022-THPOMS036

HERACLES: A HIGH AVERAGE CURRENT ELECTRON BEAMLINE FOR LIFETIME TESTING OF NOVEL PHOTOCATHODES

M.B. Andorf*, J.K. Bae, A.C. Bartnik, L. Cultrera, J.M. Maxson, I.V. Bazarov
Cornell University, Ithaca, NY, USA

Abstract

We report on the building and commissioning of a high current beamline dedicated to testing novel photocathodes for high current and spin-polarized electron applications. The main features of the beamline are a 200 keV DC electron gun and a beam dump capable of handling 75 kW of beam power. In this report, a Cs3Sb photocathode is used to demonstrate the facilities high current capabilities.

INTRODUCTION

Numerous accelerator techniques and applications require the ability to produce high-average current ($\geq$ 1 mA) bright electron beams from a photoinjector. Electron-based strong hadron cooling techniques may require average currents as high as 100 mA. A high current Electron Recovery Linac (ERL) is envisioned for LHeC[1]. For EUV lithography with an ERL, 10 mA beam current is needed[2], while it has been estimated that medical isotope production with an ERL requires 100 mA[3]. High average-current spin-polarized electron production is highly desirable for a number of nuclear physics facilities[4, 5] and for polarized positron production[6]. The realization of these applications will push the boundary of what is state-of-the-art in accelerator physics technology; however, ultimately the viability of their use depends on the reliability of the electron source.

Semiconductor based photocathodes are a proven way to generate high average current electron beams. They have quantum efficiencies (QE) on the order of 10% at convenient visible or near infared wavelengths where commercial high power laser sources are available. A major complication of a semiconductor based photocathode is they are extremely sensitive to the vacuum environment and degrade with use more rapidly than metal photocathodes. In particular at high current, in addition to vacuum poisoning, ion back-bombardment[7–10] from the ionization of residual gas in the gun and thermal desorption[11] from exposure to an intense laser beam limit the cathodes operation lifetime.

The High ElectRon Average Current for Lifetime ExperimentS (HERACLES) at Cornell has been recently commissioned at 200 keV with up to 10 mA average beam current. In close proximity to the Photocathode Laboratory at Cornell, HERACLES is a dedicated beamline aimed at improving the robustness of photocathodes operated at high current.

FACILITY

HERACLES Beamline

The start of the HERACLES beamline is a DC electron gun[12] originally designed and fabricated for Cornell's ERL program where it was used to achieve a record high average current from a photoinjector of 65 mA[13]. Currently we operate the gun at 200 keV. The beamline is shown in Fig.1. Outside the gun, the beamline has two solenoids, three independent horizontal/vertical corrector coils, three BeO pneumatically controlled viewscreens, a faraday cup for low current ($\approx$ 100 nA) measurements, a quadrant detector for beam positioning information at high currents. The beamline includes an EMS system which has not been recommissioned[14]. The beamdump is designed for up to 75 kW of beam power. It is cooled via a closed loop heat exchanger. The same heat exchanger also cools the gun's power supply and the main drive laser, a Coherent gas Argon laser. In this work, the laser was operated with a single line at 488 nm. Trapped ions[15] outside the gun are removed by two clearing electrodes. In addition to contributing to cathode damage via ion back-bombardment, trapped ions can cause beam loss leading to a trip off of the machine[16].

Cathodes are transported in HERACLES via a vacuum port. The port interfaces with a vacuum suitcase which is used to transport cathodes grown in the photocathode laboratory. During transport the suitcase is pumped with two non-evaporative getter (NEG) pumps combining in approximately 400 liter/s of pump speed. The vacuum port is pumped with a single 100 liter/s NEG. After attaching the suitcase, it typically takes 20 hours for the vacuum port to pump down to approximately 5×10^{-9} Torr. Given that moving the cathdoe through the vacuum port takes only a few seconds, this vacuum is sufficiently low to avoid degradation from vacuum poisoning.

CATHODE GROWTH AND TRANSPORT

For a high-current demonstration, a Cs_3Sb cathode was grown off center with a Molybdenum puck. After annealing at 500 C for 48 hours, the puck was cooled to 120 C. A metallic mask screens the puck from the Cs and Sb sources, allowing the active area to be grown off center. The active area shape is circular with a radius of approximately 2 mm. An off centered cathode is used to reduce damage from ion back-bomardment[17].

During the growth, initially only Cs was deposited until the QE peaked at which point we started to deposit Sb. A Quartz Microbalance (QCM) was used to monitor the Sb

* mba83@cornell.edu

ISBN: 978-3-95450-227-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2022-THPOMS036

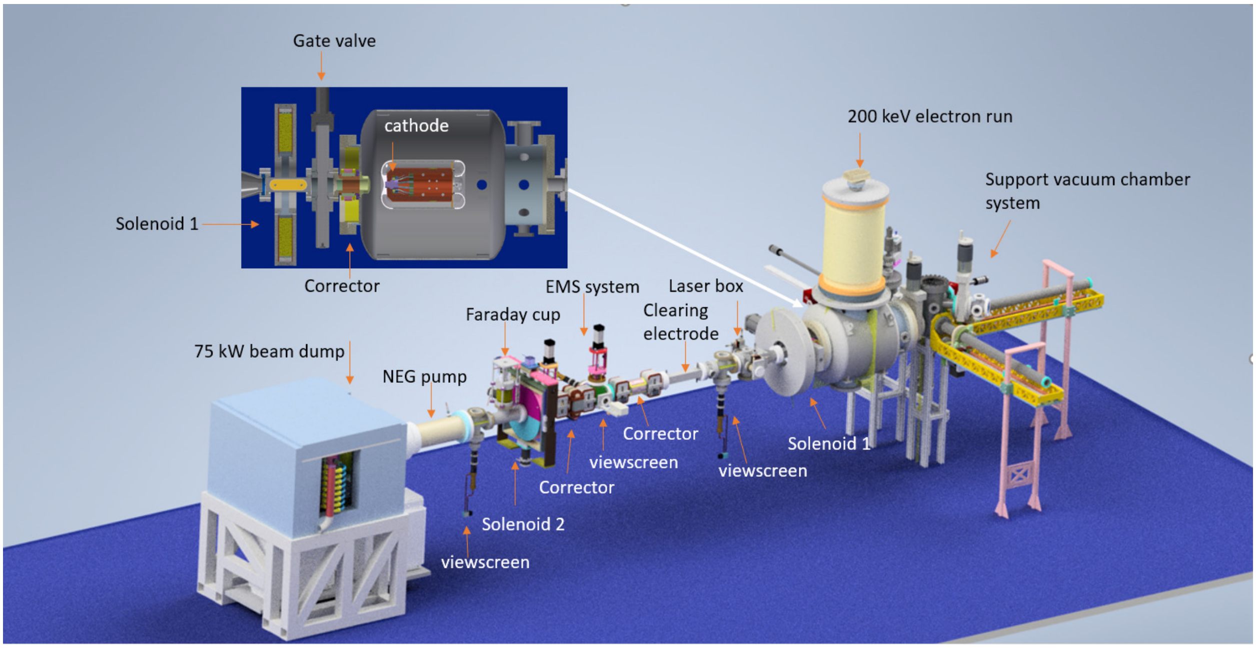

Figure 1: The HERACLES beamline. Lead shielding and SF6 tank are not shown. The floor corresponds to the room dimensions. The inset shows a cross-section of the gun viewed from above.

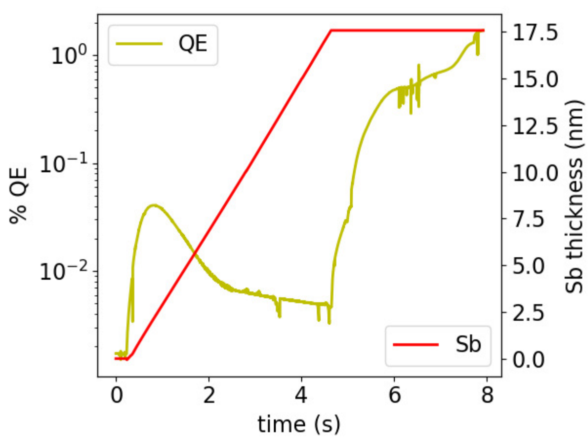

Figure 2: The evolution of the cathode QE (yellow) and Sb thickness (red) during the cathode growth.

deposition. Once 17.5 nm was deposited, the shutter was closed. We continued to deposit Cs until the QE once again peaked and the growth was stopped. The evolution of the QE and deposition are shown in Fig.2.

HIGH AVERAGE CURRENT DEMONSTRATION

The cathode was inserted into HERACLES and the laser aligned to the active area. Variability of the position of the active area from cathode-to-cathode typically requires small corrections to the laser alignment and beam trajectory. At low current (≈ 100 nA), the beam will be inspected for aberrations at each view screen in the beamline. If an abberation occurs, it is likely due to the beam trajectory being off centered in one of the solenoids and correction is straightforward. To facilitate beam transport, linear combinations of the corrector coils are used. In particular, groups were developed so that correctors upstream of solenoid 2 can make horizontal or vertical steerings downstream of the solenoid. Another grouping allows for the horizontal or vertical angle between corrector pairs 2 and 3 to be adjusted without affecting the position upstream.

After satisfactory beam transport to the beam dump is achieved, the current is slowly increased to the target value. During the ramp, vacuum pressure in the beamline, water temperature of the beamdump and radiation levels are monitored closely. Adjustments to the magnet settings are made to minimize pressure and radiation levels. A P-I feedback loop implemented in *Python* maintains the target beam current once it has been reached.

Fig.3 shows the high current demonstration in HERACLES with 8 mA average current. The drops in current (blue line) are due to radiation trips indicating levels exceeded 2 mR/hr inside the room. During this run, the levels were observed to be around 1 mR/hr with the occasional spike of 2 mR/hr causing the trips. The run lasted for a little over 3 hours over which no degradation of the cathodes QE was observed (green line). During the run the pressure near in the gun was stable (red line) and about a factor of 10 higher than the nominal pressure without beam but with the gun gate valve open.

CONCLUSION

HERACLES, a DC electron gun beamline at Cornell University has been commissioned up to 10 mA average current

ISBN: 978-3-95450-227-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2022-THPOMS036

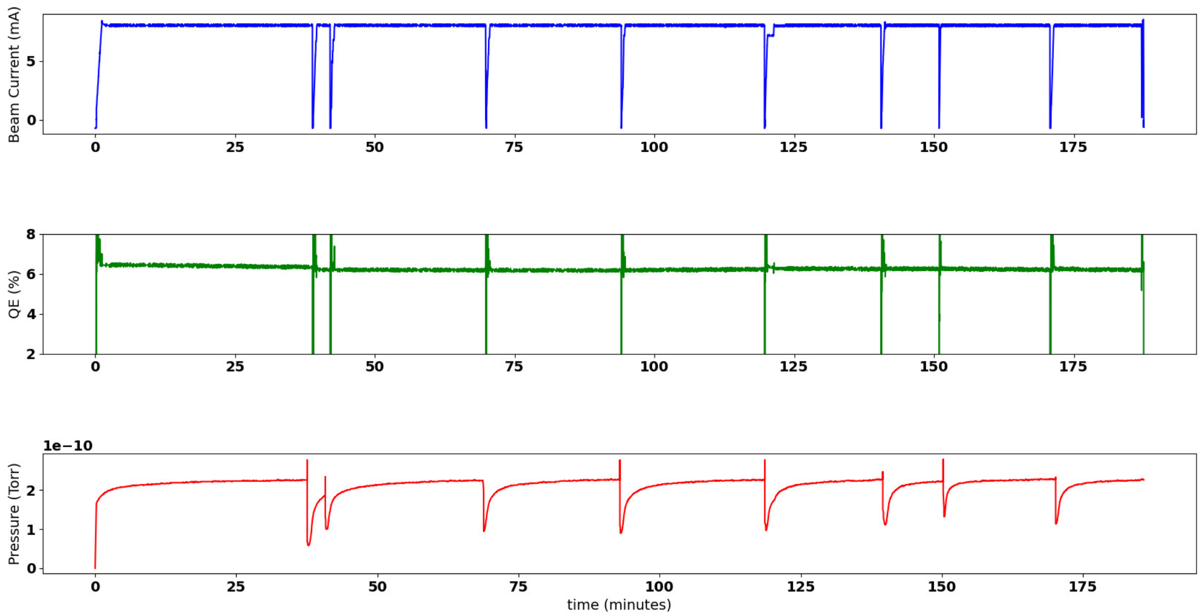

Figure 3: High current demonstration run in HERACLES with a Cs_3Sb photocathode. The measured beam current shown in blue with drops in the beam current corresponding to radiation trips. The QE and pressure at the gun are shown in green and red, respectively.

at 200 keV. We have presented a high-current run at 8 mA to demonstrate the present capabilities of our facility. Higher current is achievable with an upgrade to the lead shielding around HERACLES.

The environment of a DC gun can be harsh for photocathodes during high current operation. In addition to raised vacuum levels, ion back-bombardment from residual ionized gas inside the gun and thermal desorption from a high intensity laser can reduce the lifetime of the cathode. Understandably, the majority of cathode development happens in relatively clean growth chambers at low voltages ($\approx$ 10 V) and currents ($<$ 10 nA) where the degradation mechanisms at high currents are not as prevalent. The goal of HERACLES, in conjunction with the Cornell photocathode laboratory, is to form a tight loop between cathode development in a growth chamber and improvements in robustness at high current operation.

ACKNOWLEDGMENTS

This work was supported by the Department of Energy under Grant No.DE-SC0021425 and the National Science Foundation under Grant No.PHY-1549132, the Center for Bright Beams.

REFERENCES

[1] D. Pellegrini, A. Latina, D. Schulte, and S. A. Bogacz, "Beam-dynamics driven design of the LHeC energy-recovery linac," *Phys. Rev. ST Accel. Beams*, vol. 18, no. 12, p. 121 004, Dec. 23, 2015, ISSN: 1098-4402, doi:10.1103/PhysRevSTAB.18.121004

[2] N. Nakamura *et al.*, "Challenges towards industrialization of the ERL-FEL light source for EUV lithography," *Proceedings of the 10th Int. Particle Accelerator Conf.*, vol. IPAC2019, in collab. with B. Mark (Ed.), T. Hitoshi (Ed.), B. David (Ed.), D. Rohan (Ed.), S. RW (Ed.) Volker, and T. Eugene (Ed.), 2019, ISBN: 9783954502080.

[3] S. Koscielniak, N. Lockyer, and L. Merminga, "ELECTRON LINAC CONCEPTS FOR THE PRODUCTION OF MOLYBDENUM 99," *Proceedings of PAC09*, 2009. https://accelconf.web.cern.ch/pac2009/papers/tu6pfp014.pdf

[4] "Major nuclear physics facilities for the next decade: Report of the NSAC subcommittee on scientific facilities," 2013. https://science.osti.gov/-/media/np/nsac/pdf/docs/2013/NSAC_FacilitiesReport.pdf

[5] "Reaching the horizon: The 2015 long range plan for nuclear physics," 2015. https://www.osti.gov/biblio/1296778-reaching-horizon-long-range-plan-nuclear-science

[6] (for the PEPPo Collaboration), "The PEPPo method for polarized positrons and PEPPo II," presented at the INTERNATIONAL WORKSHOP ON PHYSICS WITH POSITRONS AT JEFFERSON LAB, Newport News, VA, USA, 2018, p. 050 001. doi:10.1063/1.5040220

[7] K. Aulenbacher *et al.*, "The MAMI source of polarized electrons," *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, vol. 391, no. 3, pp. 498–506, Jun. 1997, ISSN: 01689002. doi:10.1016/S0168-9002(97)00528-7

ISBN: 978-3-95450-227-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2022-THPOMS036

[8] C. K. Sinclair *et al.*, "Development of a high average current polarized electron source with long cathode operational lifetime," *Phys. Rev. ST Accel. Beams*, vol. 10, no. 2, p. 023 501, Feb. 7, 2007, ISSN: 1098-4402. doi:10.1103/PhysRevSTAB.10.023501

[9] L. Cultrera *et al.*, "Photocathode behavior during high current running in the cornell energy recovery linac photoinjector," *Phys. Rev. ST Accel. Beams*, vol. 14, no. 12, p. 120 101, Dec. 8, 2011, ISSN: 1098-4402. doi:10.1103/PhysRevSTAB.14.120101

[10] J. Grames *et al.*, "Ion back-bombardment of GaAs photocathodes inside DC high voltage electron guns," in *Proceedings of the 2005 Particle Accelerator Conference*, Knoxville, TN, USA: IEEE, 2005, pp. 2875–2877, ISBN: 978-0-7803-8859-8. doi:10.1109/PAC.2005.1591299

[11] M. Kuriki *et al.*, "Dark-lifetime degradation of GaAs photocathode at higher temperature," *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, vol. 637, no. 1, S87–S90, May 2011, ISSN: 01689002. doi:10.1016/j.nima.2010.02.029

[12] K. Smolenski *et al.*, "Design and performance of the cornell ERL DC photoemission gun," in *AIP Conference Proceedings*, Charlottesville (Virginia): AIP, 2009, pp. 1077–1083. doi:10.1063/1.3215596

[13] B. Dunham *et al.*, "Record high-average current from a high-brightness photoinjector," *Appl. Phys. Lett.*, vol. 102, no. 3, p. 034 105, Jan. 21, 2013, ISSN: 0003-6951, 1077-3118. doi:10.1063/1.4789395

[14] I. V. Bazarov *et al.*, "Benchmarking of 3d space charge codes using direct phase space measurements from photoemission high voltage dc gun," *Phys. Rev. ST Accel. Beams*, vol. 11, no. 10, p. 100 703, Oct. 30, 2008, ISSN: 1098-4402. doi:10.1103/PhysRevSTAB.11.100703

[15] E. Pozdeyev, "Ion trapping and cathode bombardment by trapped ions in dc photoguns," *Phys. Rev. ST Accel. Beams*, vol. 10, no. 8, p. 083 501, Aug. 6, 2007, ISSN: 1098-4402. doi:10.1103/PhysRevSTAB.10.083501

[16] S. Full, A. Bartnik, I. V. Bazarov, J. Dobbins, B. Dunham, and G. H. Hoffstaetter, "Detection and clearing of trapped ions in the high current cornell photoinjector," *Phys. Rev. Accel. Beams*, vol. 19, no. 3, p. 034 201, Mar. 3, 2016, ISSN: 2469-9888. doi:10.1103/PhysRevAccelBeams.19.03421

[17] J. Grames *et al.*, "Charge and fluence lifetime measurements of a dc high voltage GaAs photogun at high average current," *Phys. Rev. ST Accel. Beams*, vol. 14, no. 4, p. 043 501, Apr. 20, 2011, ISSN: 1098-4402. doi:10.1103/PhysRevSTAB.14.043501