ISBN: 978-3-95450-208-0 doi:10.18429/JACoW-IPAC2019-TUPTS101

BI-ALKALI ANTIMONIDE PHOTOCATHODES FOR LEREC DC GUN*

M. Gaowei†, E. Wang, A. Fedotov, D. Kayran, R. Lehn, C. J. Liaw, T. Rao, J. Tuozzolo, J. Walsh
Brookhaven National Laboratory, Upton, NY 11973, U.S.A

Abstract

The Low Energy RHIC electron cooler (LEReC) is a bunched electron cooler at RHIC, BNL. It is the first electron cooler based on the RF acceleration of electron bunches. Alkali antimonide photocathode is chosen as the electron source material for the LEReC project based on its merit in high quantum efficiency (QE) at visible wavelength. One dedicated cathode deposition system and three transfer systems with multiple cathode storage are designed and commissioned to support the continuous operation of LEReC. In this report, we present results of the LEReC photocathode deposition and characterization, as well as the cathode lifetime during cathode transfer and storage in the run of 2018 and 2019.

INTRODUCTION

The Low Energy RHIC electron cooler (LEReC) is a bunched electron cooler at RHIC, BNL. It uses a duplicated Cornell university high voltage DC gun to produce electron bunches suitable for cooling by illuminating multi-alkali photocathodes with high power laser and is aiming to provide an average current of 35 mA with bunch charge up to 160 pC electron beam. [1] It will also be tested up to 85 mA with continuous wave (CW) operation. Alkali antimonide photocathode is chosen as the electron source material for LEReC project based on its merit in high quantum efficiency (QE) at visible wavelength and days of lifetime under high current (10s mA) operation. BNL has developed and commissioned multiple cathodes storage and transfer systems in early 2018 to supply the LEReC DC gun with electron sources that operate 24/7 with minimum interrupt. [2] In this report, we present the performance of both the cathode deposition and the transfer system in the LEReC run of 2018 and 2019.

CATHODE DEPOSITION

Cathode Deposition System

The 3 main components of the cathode deposition chamber, labelled in Fig.1, are the sample preheating/characterization chamber, the deposition chamber, and the docking chamber for the cathode transporter. There are 3 manipulators installed to move the cathode through different source locations and between chambers. The base pressure of the system can reach 6×10^{-11} Torr, with partial pressure of water and oxygen below 1/10 of the base pressure. The vacuum of the system is maintained by several ion pumps, TSPs and NEG pumps.

*This work was carried out at Brookhaven Science Associates, LLC under contract DE-SC0012704 with the U.S. DOE.
† mgaowei@bnl.gov

The Sb source used in the deposition system is pure metal beads loaded in an alumina crucible and heated for evaporation. Currently we are using SEAS getter source for our alkali deposition. 3 pairs of each alkali species are loaded onto the evaporators, as shown in Fig. 2a. The alkali sources are designed to be consumed one pair at a time and the total yield of these evaporators is over 12 cathodes. The K and Cs evaporators are installed in their dedicated chambers (Fig. 2b) and can be vented without compromising the vacuum in the main chamber for the convenience of source change.

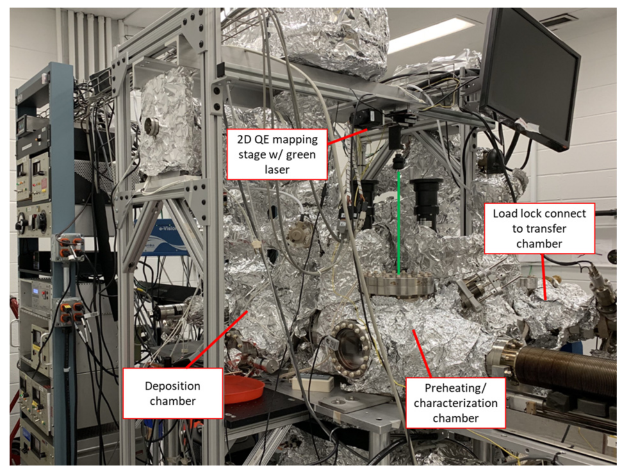

Figure 1: The LEReC bi-alkali photocathode deposition chamber.

a) b)

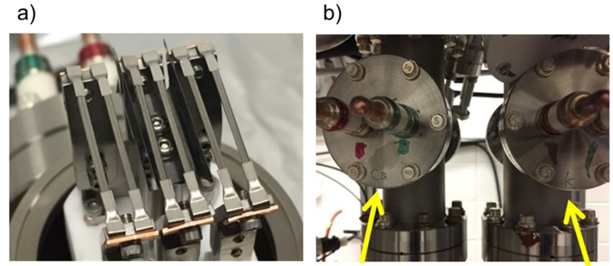

Figure 2: a) Three pairs of alkali sources installed on one manipulator; b) the alkali evaporators installed on the LEReC deposition chamber.

K_2CsSb Cathode Deposition

Since 2018, we have switched from the effusion cell deposition back to the sequential 3 step deposition using SEAS getter sources. The deposition procedure we used for the bi-alkali antimonide photocathode was well developed for the ERL and CeC projects. [3] Compared to the CeC system, the LEReC deposition chamber differs slightly in geometry and does not have an active cooling capacity for the substrate. Therefore, the growth procedure in the LEReC deposition chamber has been optimized for this specific application.

ISBN: 978-3-95450-208-0 doi:10.18429/JACoW-IPAC2019-TUPTS101

The substrate we used for LEReC DC gun is a Mo puck with 1.75 in diameter circular surface. Prior deposition, the puck surface is mechanically polished and covered with a shadow mask to define the deposition area. Currently, the cathodes are deposited 4 mm off the puck center and 6 mm in diameter (see Fig.4a). Substrate is then heated in the pre-heating chamber to 350 ˚C for 7 hrs, then cooled down to 80 ˚C and translate to Sb location for deposition. After depositing 10 nm of Sb, substrate is heated up to 135 ˚C to 140 ˚C and translated to another location for K deposition. The thickness of the Sb step is controlled by a quartz crystal monitor (QCM) at the Sb location. The deposition rate is 0.5 Å/s. The deposition of the K step is controlled by monitoring the photocurrent generated by a green laser aligned with the K location. After depositing sufficient amount of K, substrate is translated to Cs location and the sample heater turned off as we deposit Cs. The temperature profile of the substrate with respect to the QE evolution in the Cs step is indicated in Fig. 3. The photocurrent here is generated by a green LED due to the alignment difficulty of the off-centered cathode, and the QE scaled by post QE calibration with a green laser with known power from the characterization chamber. The Cs growth is stopped after substrate temperature drops below 70 ˚C, which is the known temperature for maintaining the stable stoichiometry of K_2CsSb [4].

We typically let the substrate cool down below 50 ˚C before removing the mask to minimize disturbance. The QE of each cathode is then mapped with a green laser mounted on the x-y raster motors. The photocurrent is recorded with Keithley 6487.

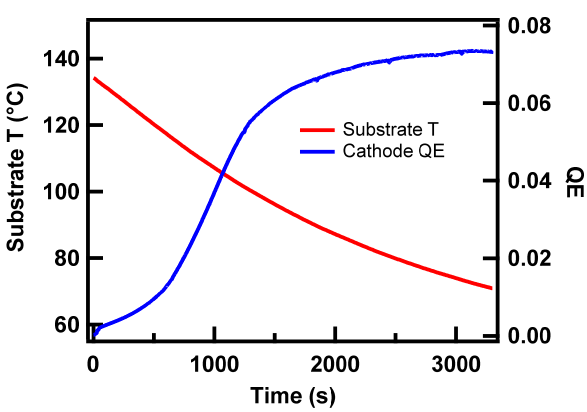

Figure 3: The temperature profile of the substrate with respect to the QE evolution in the Cs step.

K_2CsSb Cathode Characterization

Figures 4a and 4b present the photo of a freshly deposited K_2CsSb and the corresponding QE map. The average QE measured from the QE map is 7.05%, with a standard deviation of 0.33. The max QE measured is 7.5% from the center area of the map and a QE minimum of 6.5% measured at the edge area, indicating a slight edge effect possibly caused by the shadow mask. One explanation could be that the radiative heat from the shadow mask is changing the temperature distribution on the puck surface and slightly tempering with the sticking coefficient of the alkali material from the source.

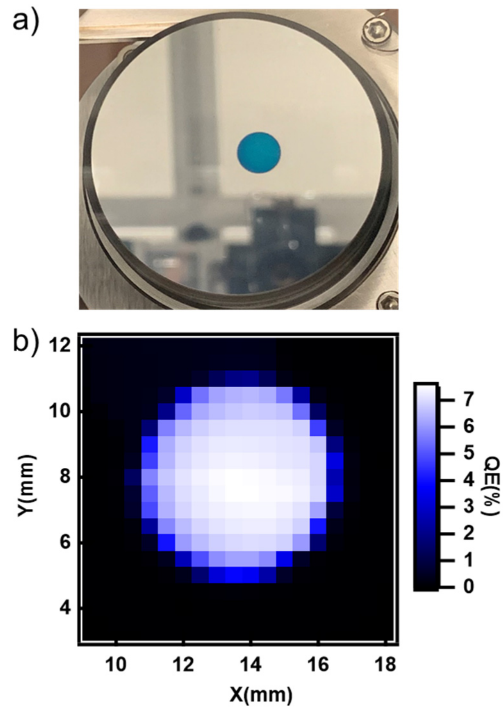

Figure 4: a) The sequentially deposited K2CsSb cathode with off-centered design on the on the LEReC puck; b) 2D QE map indication the cathode uniformity.

The 28 cathodes were deposited in 2018 for the LEReC DC gun and until May 2019, there have been over 30 cathodes delivered to support the increasing needs for the cathode consumption. Fig. 5 plotted all the QE measured from the characterization chamber after deposition. From Fig. 5 and Table 1 we can see that from run 2018 to run 2019, the optimized deposition procedure for the LEReC deposition system has yielded ~ 1% higher average QE and an overall stable output. The QE vitiation within a run is commonly observed due to the variation in the outgassing rates and deposition rates of individual alkali source. Cathode QE measured in the LEReC DC gun is typically 10 % ~ 20% higher than the deposition QE, due to the difference in the QE measuring scheme.

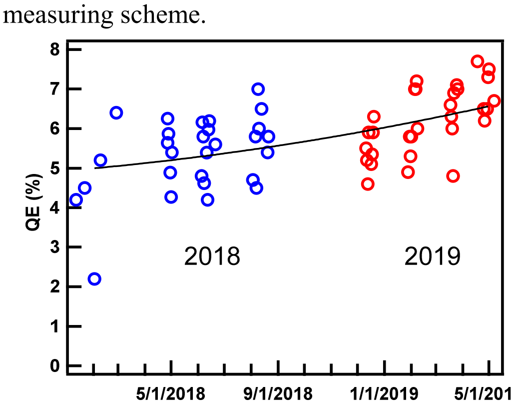

Figure 5: The cathode QE summary of LEReC run 2018 (blue cirlces) and run 2019 (red circles).

ISBN: 978-3-95450-208-0 doi:10.18429/JACoW-IPAC2019-TUPTS101

Table 1: The Cathode QE Summary of LEReC Run 2018 and 2019

	Run 2018	Run 2019 (to May)
# of cathodes	28	34
RMS Deposition QE (%)	5.41	6.25
SDEV of QE (%)	0.97	0.85

CATHODE TRANSFER AND STORAGE

The LEReC deposition system is about 1.5 miles away from the RHIC tunnel. In order to sufficiently transfer the cathodes, a multiple cathode transfer system has been designed and commissioned to deliver up to 12 cathodes to RHIC tunnel. The transfer system is a UHV chamber consists of a rotatable storage wheel with 12 cathode holders and a long manipulator for cathode selection. The chamber vacuum is maintained by a TSP intergraded ion pump (150 L/s) and 400 L/s NEG pump. A VAT Kalrez seal gate valve serves as the connection to the load lock of both cathode deposition side and gun side. The baseline vacuum measured by a cold cathode gauge can reach as low is 3×10^{-11} Torr and keep the vacuum under 5×10^{-10} Torr when manipulator is moving. A mesh-plate anode is installed in the chamber and a green laser (or LED for the off-centered cathodes) outside the viewport to directly monitor QE during the transposition and storage. The commissioning of the first transfer system was done in early 2018 and the details can be found in reference [2].

From 2018 to 2019, 3 transfer systems have been built and 8 batches of cathodes has been successfully delivered to the RHIC tunnel to support the LEReC operation. No QE decay has been observed during the transportation and the load lock connection process. During the load lock bakeout, the cathode QE decreased for ~ 5%. The transfer chamber vacuum was 3×10^{-10} Torr (while the loadlock is over 1×10^{-7} Torr) during bakeout. Figure 6 shows the cathodes QE inside the transfer system decrease over the bakeout process.

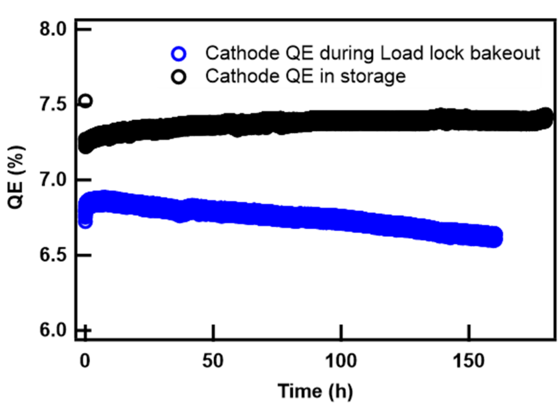

Figure 6: LEReC cathode QE monitored in the transporter for cathode in storage (dark circles) and cathode during load lock bakeout (blue circles).

There are certain stages of vacuum spike during the cathode transfer system, e.g. the valve open/close as well as the lock/unlock from the rotation wheel might generate high 10^{-9} Torr spikes. However, the sufficient pumping in the transfer chamber ensured the rapid recovery of the chamber vacuum and no QE decay has been observed over the transfer process for all the cathodes in the batch. The storage lifetime of the cathode in the transfer system is also plotted in FIG.6. A slight increase in the cathode QE has been observed for all the cathodes in the transfer system.

CONCLUSION

The LEReC cathode deposition system have been successfully and steadily providing bi-alkali antimonide photocathodes with high QE and good uniformity for the LEReC operation in 2018 and 2019. The cathodes show no QE decay during transportation and storage in the transfer system for as long as the cathode batch is in use.

ACKNOWLEDGEMENT

Special thanks are given to D. Asner, R. Begay, J. Smedley, B. Walsh, J. Warren and many staff from Instrumentation Division, Brookhaven national Lab for their essential support on the LEReC deposition system and SEM operation. Authors would also like to thank K. Decker, C. Degen, J. Ditta, D. Gassner, X. Gu, P. Inacker, J. Jamilkowski, J. Kewisch, V. Litvinenko, M. Minty, M. Mapes, L. Nguyen, M. Paniccia, J. Sanfilippo, L. Smart, S. Seletskiy, K. Sinclair, D. Vonlintig, Z. Zhao and many staff from collider-accelerator department, Brookhaven National Laboratory for their devoted work on the LEReC project.

REFERENCES

[1] A. V. Fedotov *et al.*, “Accelerator Physics Design Requirements and Challenges of RF Based Electron Cooler LEReC”, in *Proc. North American Particle Accelerator Conf. (NAPAC'16)*, Chicago, IL, USA, Oct. 2016, pp. 867-869. doi:10.18429/JACoW-NAPAC2016-WEA4CO05

[2] E. Wang *et al.*, “Multi-alkalai photocathodes production for LEReC DC gun”, BNL-205696-2018-TECH United States, 2018. doi:10.2172/1438329, 2018

[3] E. Wang *et al.*, “Enhancement of photoemission from and postprocessing of K_2CsSb photocathode using excimer laser” *Phys. Rev. ST Accel. Beams*, vol. 17, 023402, 2014.

[4] Z. Ding *et al.*, “Temperature-dependent quantum efficiency degradation of K-Cs-Sb bi-alkali antimonide photocathodes grown by a triple-element codeposition method,” *Phys. Rev. Accel. Beams,* vol. 20, no. 11, p. 113401, 2017.