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Multi-alkalai photocathodes production for LEReC DC gun

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DISCLAIMER

MULTI-ALKALI PHOTOCATHODES PRODUCTION FOR LEREC DC GUN*

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Abstract

Low Energy RHIC electron Cooling (LEReC) is a bunched electron cooler at RHIC. The LEReC's electron source needs provide up to 85 mA average current electron beam. The Bi-alkali photocathodes are chosen as electron source due to its long lifetime and high QE at the visible wavelength. Because the DC gun needs to produce 24/7 beams over several months, two cathode production systems and three transfer systems carrying multiple cathodes are designed and one set commissioned. In this report, we will describe our photocathode production and transfer systems and discuss the cathode's performance from cathode growth system to the DC gun.

INTRODUCTION

The LEReC electron source uses a duplicated Cornell university high voltage DC (HVDC) gun aiming to provide an average current of 35 mA with bunch charge up to 160 pC electron beam.[1] It also will be tested up to 85 mA with CW operation. The cathode material we chose is Bi-alkali photocathode, which has demonstrated 10s mA current with couple days lifetime. BNL has developed multiple-cathodes storage and cathode transferring systems to make sure the LEReC electron source could operate 24/7 without significant interrupt. When RHIC in operation, there are only eight hours maintenance periods every two weeks. Once the cathode storage chamber is filled with 11 cathodes, the gun could operate two weeks with RHIC in operation even assuming cathode lifetime is about 1 day at high current operation. The high current operation cathode lifetime in DC gun is one parameter to be measured in this year of commissioning.

One cathode storage and transferring chamber is in operation. It has transferred cathodes from cathode deposition chamber in a separate building to the exchange system on the DC gun in the RHIC tunnel. It has delivered three active CsK_2Sb photocathodes into DC gun with only minor quantum efficiency (QE) degradation. The photocathode deposition system was originally designed to use the co-deposition method and the effusion cell alkali sources. However, we found in practice that the cathode uniformity has not met the specification. The system was modified according to the BNL 2nd generation sequential deposition chamber design with enlarged size for adopting the large cathode puck from the DC gun. With our developed high QE CsK_2Sb recipe, we recently can grow one cathode per-day and demonstrated the good repeatability.

CATHODE DEPOSITION

Cathode Deposition System

The cathode deposition system consists of a preheating chamber, an alkali deposition chamber, an antimony chamber, a cathode exchange/measurement chamber, a load-lock chamber, and three manipulators to transfer the sample between them. An extra manipulator holds a quartz crystal monitor to record the film's thickness during evaporation. Figure 1 shows cathode deposition system. The cathode puck, on which the photocathode is deposited, is initially cleaned up by 350 °C bake for 6 hours in the preheating chamber. Then the puck is transferred by a manipulator to the cathode exchange section to install the mask that exposes the substrate with required size and position. Utilizing another manipulator, the puck can be moved to the alkali deposition chamber and the antimony deposition chamber. This manipulator has features that can heat up the puck up to 400 °C with electrical isolation. The alkali sources, Cs (or Na), K are installed on 2 separate manipulators in the alkali deposition chamber, and can each be brought back to their own sections separated from the main chamber by ultra-high-vacuum (UHV) gate valves. At present the design is capable of storing in total 3 pairs of each alkali sources and running 1 pair of each during alkali deposition. Our experiences show each pair could grow at least three cathodes. Therefore, the system is able to grow at least 9 cathodes continuously without opening the source chamber and exchange alkali. Figure 2 shows the alkali source holder in installation and one deposited photocathode. The vacuum in the deposition chamber, pumped by ion pump, TSP, and NEG can attain the high 10^{-11} Torr.

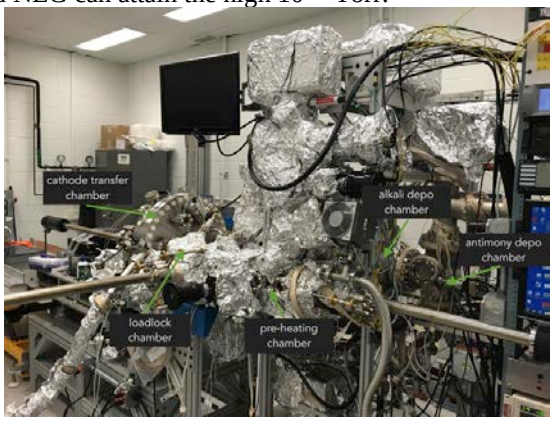

Figure 1. The bi-alkali photocathode deposition chamber.

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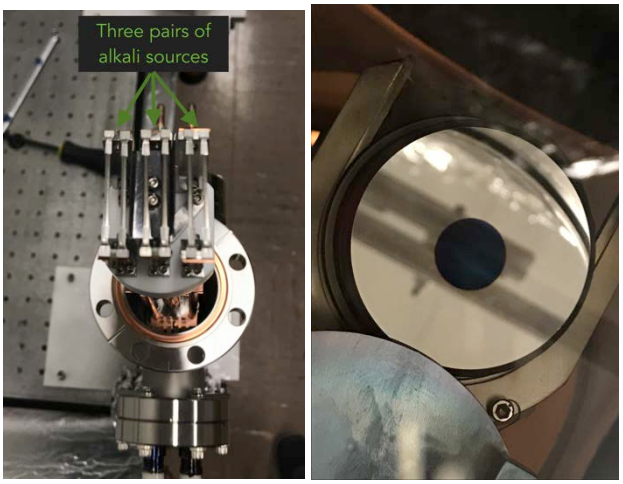

Figure 2. left) Three pairs of alkali sources installed on one manipulator; right) the deposited CsK_2Sb on the LEReC DC gun puck, cathode film exhibits dark blue due to optic absorption.

Cathodes Deposition

In 2017, we used J-band effusion cells as alkali sources. We first heat-cleaned the molybdenum substrate to 350 °C for 6 hours and then cooled down to 80 °C for Sb evaporation. After depositing 10 nm of Sb, we increased the substrate temperature to 135 °C for K evaporation. Once photocurrent began to rise, we quickly heated the substrate up to 165 °C, then turned on the Na source and started co-deposition. Pure Na and K sources are directed to the same area of cathode substrate. One advantage of effusion cells is its large alkali volume. However, in about 6 months, totally, we deposited 18 layers and K source was exhausted. In a later inspection, we discovered that the condensation of the alkali source material on the evaporation tube caused our low utilization of the sources. The control of the evaporation rate is also difficult due to slow temperature response. Thus, we got about 6-7% QE Na_2KSb cathodes, but no reproducibility. The imperfect source alignment also caused the poor uniformity of cathodes. Figure 3 shows the QE map of one Na_2KSb cathode and effusing cell alkali sources installed on our deposition chamber. This cathode has a maximum QE of 10% at one edge and 5% at another. The size of the cathode is 12 mm in diameter. Considering the project R&D timeline, at 2018, we switched back to the matured sequential deposition using SAES alkaline sources. There are four cathodes finally deliver to the HVDC gun. Table 1 listed the cathode performance after growth.

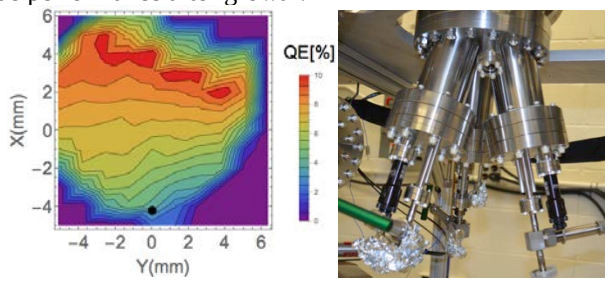

Figure 3. Left) One Na_2KSb cathode QE map; Right) Effusion cell sources of Na, K and Cs installed on the deposition chamber.

Table 1: Cathodes growth using alkali co-deposition method from effusion cells.

	Material	**QE_center [%] @ 532 nm**
Cathode 1	Na_2KSb	1.7
Cathode 2	Na_2KSb	7
Cathode 3	Na_2KSb	4
Cathode 4	CsK_2Sb	5

The sequential cathode growth recipe was well developed for both ERL and CeC projects. Routinely we can get 8-12% QE illuminating by 532 nm laser from the CeC deposition chamber. The detailed procedure was presented in reference. [2] Different from the CeC system, the LEReC deposition chamber does not have an active cooling capability for the substrate. We have to tune the Cs evaporation rate to match the gradual puck cool down speed. Up to now, we have successfully deposited 4 CsK_2Sb cathodes from the LEReC deposition chamber. Without fine tuning the recipe in the new arrangement, all the cathodes were already showing acceptable QE in a range of 3-6%. The uniformity has significant improvement compare to the previously deposited cathode from this chamber. Figure 4 shows the QE map of one cathode before moving into the gun.

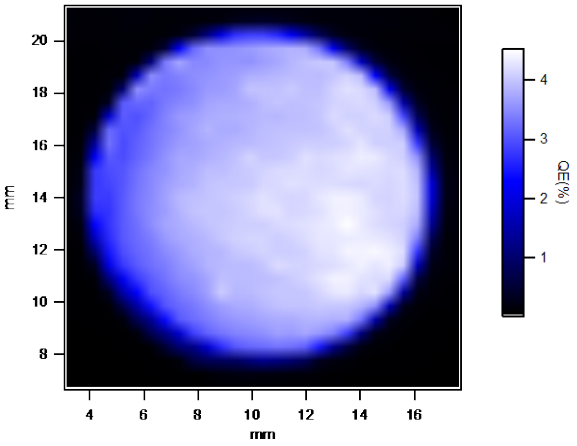

Figure 4 Cathode QE uniformity with sequential deposition from the LEReC disposition system.

CATHODE TRANSFER AND STORAGE

The RHIC tunnel is a high radiation area when RHIC is in operation. The photocathode preparation system is in another building away from RHIC tunnel about 1.5 miles. Multiple cathode transfer system called “the Ferris wheel” has been designed to deliver up to 12 cathodes to RHIC tunnel. The Ferris wheel is a rotatable storage wheel with 12 cathode holders opening inside a UHV chamber. The cathodes are locked in the opening by four spring detents. By rotating the wheel, a long manipulator can select a cathode on the wheel and secure it with a head spring

controlled by two manipulator magnets. To avoid the loosing cathodes from vibration during transport, another non-rotatable locking wheel locks the pucks in position when chamber is in transportation. The Ferris wheel 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 $3x10^{-11}$ Torr baseline vacuum has been measured by a cold cathode gauge. A QE measurement device, which includes a mesh-plate anode and viewport, is installed in the chamber for checking each cathode performance during transposition and storage. Figure 5 shows the Ferris wheel attached to the LEReC cathode deposition system.

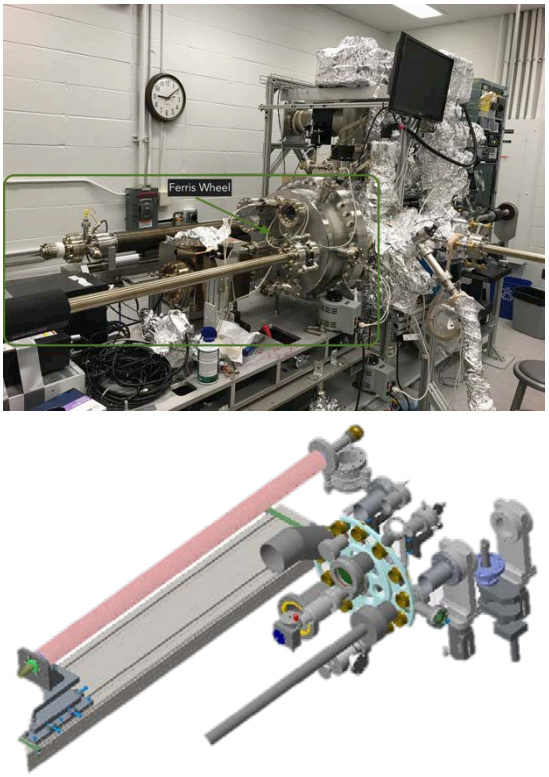

Figure 5. Up) The cathodes transferring chamber connects to the cathode deposition chamber. Bottom) The inner view of the cathodes transferring chamber.

There are three active cathodes stored in the Ferris wheel and delivered to the HVDC gun. All cathodes survived the transportation and the load lock connection process. Table 2 shows the cathodes QE evolution inside the Ferris wheel. After initial pumping down, the load lock was baked for 48 hours and reached the baseline vacuum at about $3x10^{-10}$ Torr. The cathodes QE degraded about 10% during vacuum bake of the connecting chamber because the Ferris wheel pressure increased up to $2x10^{-10}$ Torr for about 36 hours due to valve heat up. After the 48 hours bake, the Ferris wheel pressure recovered to $8x10^{-11}$ Torr and cathode QE were measured very stable in dark environment. The cathode QE measured in the gun is the same as the QE measured in Ferris wheel indicates there was no QE degradation in cathode transferring from Ferris wheel to the gun. Figure 6 shows the Ferris wheel pressure change and cathode QE evolution in the gun side load lock baking in RHIC tunnel.

The valve open/close generates a high 10^{-9} Torr spike that will not degrade the cathode performance. However, the manipulator movement can rise the Ferris wheel pressure to high 10^{-10} - low10^{-9} torr for about 5 minutes. Each cathode exchange requires manipulators to move forward/backward four times causing slight QE degradation (typically 0.3%) in about 20 minutes. If the Ferris wheel is filled up with 12 cathodes, the last cathode will experience accumulated 11x 20 minutes in 1e-9 Torr pressure, which may add up to a significant QE degradation. Because of multiple gun conditions session during commissioning, cathode #3 has experienced 10 times more exchanges than other cathodes resulting in QE deduction from 6% to 3.4% in the last three months. That means in routine operation, 10 cathodes could survive in cathodes exchange with acceptable QE decay.

Table 2: The cathodes QE before transferring and after load lock valve open

	Initial QE [%]	Open valve to the gun [%]
Cathode #1	2.7	2.2
Cathode #2	5.4	4.5
Cathode #3	6	5.2

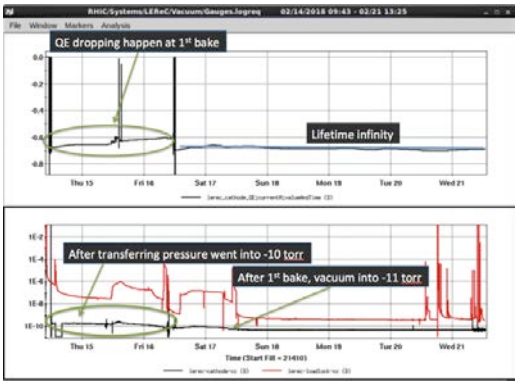

Figure 6 Up) One cathode QE evolution in loadlock bake and in storage. Bottom) The corresponding vacuum pressure changes. The red curve is load lock pressure and black curve is Ferris wheel pressure.

CONCLUSION

The cathode deposition system has been commissioned and demonstrated its capability of producing high QE and uniform bi-alkali antimonide photocathodes repeatedly. The cathode transportation and storage chamber is in commission. So far three cathodes have been delivered to the gun and survived in loadlock bake and multiple cathodes transferring.

ACKNOWLEDGEMENT

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