

CHARGE LIFETIME STUDY OF K_2CsSb PHOTOCATHODE INSIDE A JLAB DC HIGH VOLTAGE GUN

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Abstract

Two photocathodes are frequently considered for generating high average current electron beams and/or beams with high brightness for current and future accelerator applications: GaAs:Cs and K_2CsSb . Each photocathode has advantages and disadvantages, and need to demonstrate performance at “production” accelerator facilities. To this end a K_2CsSb photocathode was manufactured at Brookhaven National Lab and delivered to Jefferson Lab within a compact vacuum apparatus at pressure $\sim 5 \times 10^{-11}$ Torr. This photocathode was installed inside a dc high voltage photogun biased at voltages up to 200 kV, and illuminated with laser light at 440 or 532 nm, to generate beams up to 20 mA. Photocathode charge lifetime measurements indicate that under some conditions this cathode has exceptionally high charge lifetime, without measurable QE decay, even from the center of the photocathode where operation using GaAs photocathodes is precluded due to ion bombardment. These studies also suggest a complex QE decay mechanism likely related to chemistry and localized heating via the laser beam.

INTRODUCTION

Photoelectron guns are well suited to provide the high brightness, and often high average current, electron beams required for light sources and energy recovery LINAC accelerator applications. Two popular photocathode choices are: GaAs:Cs and K_2CsSb . The GaAs:Cs photocathode can exhibit very high QE and produce a beam with small thermal emittance [1], but it is widely recognized to be a very fragile photocathode material requiring strict adherence to procedures that maintain cleanliness of the photocathode surface on an atomic scale. And once inside the photogun, it is prone to rapid QE loss that can result from many situations including poor vacuum, high voltage discharges within the gun, and low level field emission. The K_2CsSb photocathode can exhibit high QE. While GaAs can be purchased from numerous reliable vendors, the K_2CsSb photocathode is an amorphous compound “grown” by the user near the gun, by successive application of the elemental species on a suitable substrate. Consistent results depend on consistent adherence to proper growth procedures. The K_2CsSb photocathode has larger thermal emittance [1,2]

compared to GaAs:Cs but it is considered to be a prompt emitter because of its positive electron affinity nature, producing shorter bunches than GaAs:Cs. The biggest advantage however is the photocathode’s ability to survive under markedly harsher vacuum conditions compared to GaAs:Cs. The purpose of this work is to compare the performance of the K_2CsSb photocathode inside a dc high voltage photogun that had been used extensively to characterize GaAs:Cs performance [3].

EQUIPMENT

Cathode Preparation

The K_2CsSb cathode was prepared at BNL in a UHV chamber by depositing sequentially high purity Sb, K and Cs onto a puck, similar to the standard JLab puck [4] but made of aluminium with a thin layer of stainless steel explosion bonded to the top surface to accept the coating. Stainless steel was chosen because previous measurements at BNL indicated it provides high QE at 532 nm. Two sequential evaporations were executed on the same substrate. Specifics to the BNL K_2CsSb deposition system and process can be found in these proceedings [5]. During the second evaporation process the potassium dispenser was exhausted before the process was complete leading to a lower than expected K concentration in the second sequence. This can be seen in the lower than expected QE spectrum at longer wavelengths, shown in Figure 1.

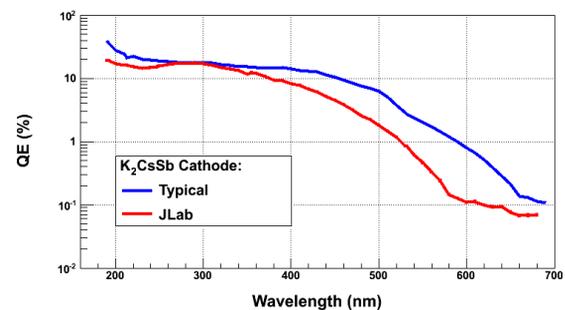


Figure 1: Spectral response of the K_2CsSb photocathodes created at BNL. The red curve represents the photocathode created for these measurements and the blue curve is considered “ideal”.

Transfer of the Cathode

After deposition, the puck was pulled into an ultra high vacuum puck transfer “suitcase”, shown in Figure 2, that consists of a rotating/translating manipulator attached to a

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4.5 in. 6-way CF Cross with a 20 L/s (N₂) ion pump and a 600 L/s (H₂) NEG pump. A battery supply provides power to the ion pump during transit. It was driven 450 miles, over ~10hr, to the Injector Test Stand at Jefferson Lab, where it was inserted into the JLab/CEBAF load-locked DC photogun for charge lifetime evaluation.

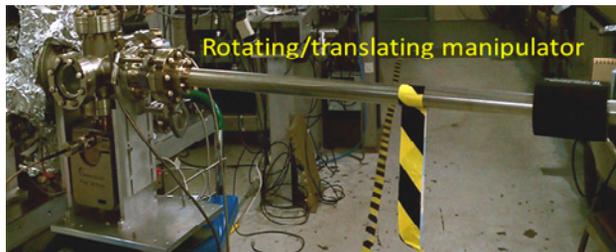


Figure 2: Photograph of Puck Transfer Suitcase. The coated puck is held inside a “garage” and transferred using a rotating/translating manipulator. The normal operating pressure is $\sim 10^{-11}$ Torr.

Load Lock DC High Voltage Photogun

The typical 100 kV DC JLab photogun [4] was outfitted with a large grain niobium cathode electrode that was both mechanically and chemically polished and HV conditioned in order to reach a bias voltage of 200 kV with no field emission. Photoelectrons are accelerated in the gun chamber and then steered through a diagnostic beam line ending in a Faraday cup ~ 5 m downstream. Charge lifetime, defined as the amount of charge that can be extracted when the QE falls to $1/e$ of its initial value, was measured by monitoring the QE evolution as a function of accumulated charge. Measurements are made at a particular electron beam current by continually adjusting the laser power striking the photocathode to ensure a constant current is measured in the faraday cup.

CATHODE PERFORMANCE AND DISCUSSION

Charge Lifetime at 440 nm

Initial measurements made with a 532 nm, 350 μ m FWHM (Gaussian) DC laser showed charge lifetimes around 100 C for a 100 kV bias voltage and were presented at PAC 11 [6]. Here we present our measurements made with 440 nm, 850 μ m FWHM (Gaussian) DC laser. The initial QE scan of the photocathode, shown in Figure 3, with 440 nm light roughly agrees with the QE measured at BNL, shown in Figure 1. Here a QE scan is accomplished by extracting ~ 1 μ A from the grounded photocathode, with the anode biased at ~ 375 V, while scanning the laser across the photocathode by translating a focusing lens mounted to x/y stepper motor stages.

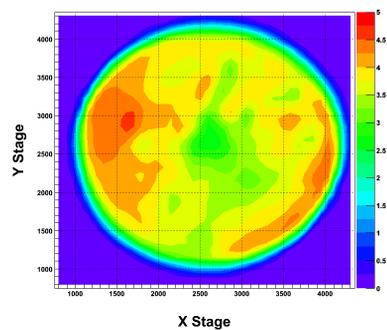


Figure 3: QE scan along the photocathode with 440 nm.

Charge lifetime measurements were performed at a 1 mA beam current with 100 and 200 kV gun voltages and at different positions on the photocathode. Each measurement was allowed to run for 24 hr. Figure 4 shows the typical QE evolution observed, with 440 nm light, plotted as a function of accumulated charge. The QE showed no sign of decay for any of these runs, even those performed at the EC of the photocathode. Recall the emittance is expected to be smallest at the EC, an important consideration for high brightness applications, however, extracting charge from the EC of a GaAs:Cs photocathode is usually avoided to preserve the charge lifetime, due to the detrimental effects of ion bombardment. At 1 mA currents ion bombardment seems to have no effect on the charge lifetime of K₂CsSb at 440 nm.

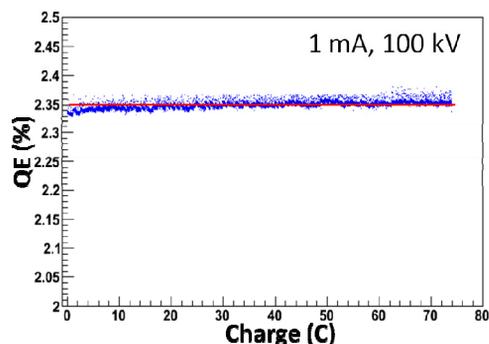


Figure 4: QE evolution vs. accumulated charge when using a 440 nm/850 μ m (FWHM) Gaussian laser spot positioned at the EC of the photocathode.

In order to investigate longer term QE evolution, 3mA of beam current was extracted for ~ 3 days. Figure 5 shows the QE evolution for this measurement where the laser position is 3.2 mm from the EC. The abrupt drops in QE are due to pressure bursts in the gun and beamline. Stray light striking the photocathode accumulates on components along the beam line, like a retracted viewer screen or the laser window, which eventually releases causing a large (~ 100 x) but brief pressure spike which reduces the QE of the photocathode for a short time. We note that unlike GaAs:Cs, where these pressure spikes would quickly degrade the QE, K₂CsSb recovers and sometimes improves.

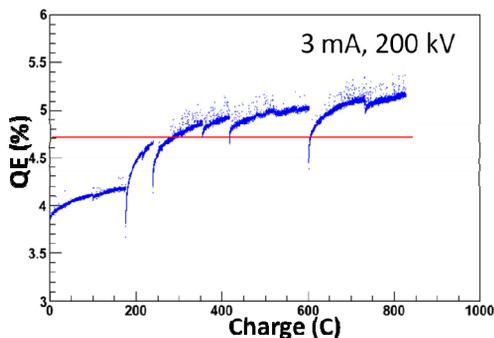


Figure 5: QE evolution for 3mA beam current extracted with 440 nm/850 μm (FWHM) Gaussian spot size positioned 3.2 mm from the EC.

As one can see, the QE does not show any sign of decaying. The run was ended when a site wide electrical power glitch caused the electron beam to be steered into a section of the beamline, causing a major vacuum event which decreased the QE by a half. During this time, neither the laser nor HV supply were affected and about 1.5 mA of beam was extracted from the photocathode for ~ 2 hr in a 5×10^{-10} Torr environment. Again a vacuum event of this magnitude would have quickly degraded the QE of entire GaAs:Cs cathode, but this is not the case for K_2CsSb .

A subsequent QE scan over the photocathode, shown in Figure 6, showed that only the EC was severely damaged and there were still useable extraction sites around the EC. A 5 mA charge lifetime measurement was performed, with maximum available laser power at this wavelength, over 24 hr and no QE decay was observed at these currents either, despite several vacuum events that temporarily lowered the QE of the photocathode in a similar fashion as seen during the 3 mA measurement.

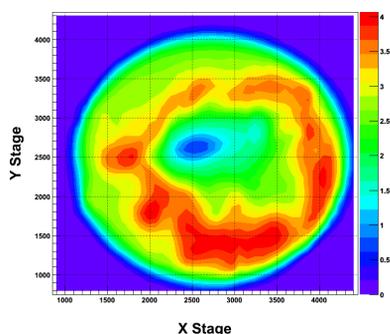


Figure 6: QE scan after a major vacuum event caused beam to be extracted in a 5×10^{-10} environment for ~ 2 hr. Visual inspection of the puck after the event seems to indicate that the K_2CsSb material at the EC was sputtered away leaving the stainless steel substrate.

Laser Heating

Throughout all our charge lifetime measurements with 440 nm light, we observed that the QE did not decay and

for the higher current runs, the QE actually increased. To investigate whether or not this is beam related, we illuminated several spots along the photocathode without a bias voltage for various periods of time and laser powers. Up to our maximum power density of 0.37 W/mm^2 at 440 nm the QE at the illuminated spot increases.

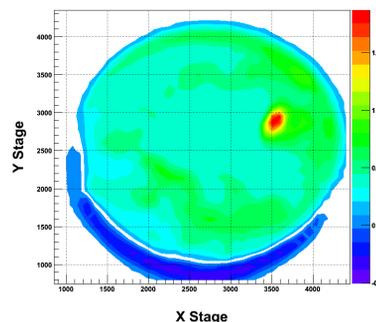


Figure 7: QE difference plot after illuminating the K_2CsSb with 0.37 W/mm^2 density of 440 nm for 12 hr without bias.

We postulate that the stoichiometry of the photocathode is improving locally at the illuminated spot with 440 nm. It is interesting that this behaviour was not observed during our previous charge lifetime measurements made with 532 nm. This suggests an absorption depth and/or surface chemistry dependence for K_2CsSb .

CONCLUSIONS

A K_2CsSb photocathode was prepared at BNL and transported to JLAB with no QE degradation. At JLab, beam was extracted in a 100 and 200 kV DC CEBAF load locked gun. Charge lifetime measurements made with a 440 nm/850 μm (FWHM-gaussian) laser showed no QE decay, even when extracting charge from the EC. When illuminated with 440 nm light, the photocathode is very robust to pressure bursts and in total $\sim 2000 \text{ C}$ was extracted. Illumination with just the laser, gun bias off, shows a local QE increase for power densities up to 0.37 W/mm^2 with 440 nm, suggesting the chemistry of the cathode at the laser spot is changing.

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