PERFORMANCE STUDY OF K_2CsSb PHOTOCATHODE INSIDE A DC HIGH VOLTAGE GUN*

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Abstract

In the past decade, there has been considerable interest in the generation of tens of mA average current in a photoinjector. Until recently, GaAs:Cs cathodes and K_2CsSb cathodes have been tested successfully in DC and RF injectors respectively for this application. Our goal is to test the K_2CsSb photocathode inside a DC gun. Since the multialkali cathode is a compound with constant characteristics over its entire thickness, we anticipate that the lifetime issues seen in GaAs:Cs due to surface damage by ion bombardment would be minimized. Hence successful operation of the K_2CsSb cathode in a DC gun could lead to a relatively robust electron source capable of delivering ampere level currents. In order to test the performance of a K_2CsSb cathode in a DC gun, we have designed and built a load lock system that allows the fabrication of the cathode at Brookhaven National Lab (BNL) and its testing at Jefferson Lab (JLab). In this paper, we will present the performance of the K_2CsSb photocathode in the preparation chamber and in the DC gun.

INTRODUCTION

Light sources and energy recovery linacs require bright electron beams, often at high average current. The photoguns that provide these bright beams must exhibit long operational lifetime to accommodate a demanding User community. The accelerator community can choose between two photogun choices: DC high voltage guns and RF guns. Today's DC high voltage guns use GaAs photocathodes to produce CW beam but at modest energy (< 500kV) whereas RF guns use metal, CsTe or alkali-antimonide photocathodes to produce MeV beam but at low duty factor. Many gun groups are working diligently to address the limitations of these two approaches: e.g., to increase the bias voltage of DC guns, and to build an RF gun that can provide CW beam. In this submission, we address the ultra-high vacuum requirement associated with using GaAs:Cs photocathode inside a DC high voltage gun.

GaAs:Cs

The first GaAs-based DC high voltage photogun was used at SLAC to conduct a seminal parity-violation experiment [1]. The benefit of using GaAs was that it provided spin polarized beam. Since then, GaA-based DC high voltage guns have been constructed for FELs and ERLs [2,3] although the polarization feature is not utilized. GaAs is considered a delicate photocathode, requiring an atomically clean surface and a mono-layer coating of cesium and oxidant to create a negative electron affinity (NEA) condition. In addition, the photocathode can survive only in an ultrahigh vacuum environment (10^{-11}Torr or better), which avoids chemical poisoning and minimizes ion bombardment. Despite these drawbacks, GaAs has distinct advantages including high quantum efficiency (QE) over a broad wavelength range, particularly at 532nm (QE ~ 20%) where high power RF-pulsed lasers are readily available. When illuminated with IR light near the bandgap, GaAs can provide beam with very low thermal emittance, although this will produce bunches with "tails" because the light travels deeper into the photocathode material. Finally, GaAs is readily available commercially and relatively inexpensive. To date, GaAs has been used to generate ~ 10mA average current CW beam with RF-structure [2], although charge lifetime is not acceptable for a production User facility operating 24 hours/day and seven days/week.

K_2CsSb

Alkali-antimonide photocathodes have been used for decades inside RF guns, with the noteworthy demonstration of 32mA average beam current from a K_2CsSb photocathode inside a room temperature RF gun at 25% duty factor [4]. Like GaAs, the K_2CsSb photocathode exhibits high QE at 532 nm (> 10%) and is considered a "prompt" emitter, producing short bunches without tails, because it has a positive electron affinity (PEA) surface condition. The biggest perceived selling point of K_2CsSb however, is that it does not require exceptional vacuum. The vacuum level inside the Boeing room temperature RF gun cited above was likely 10^{-8}Torr and photocathode lifetime was reported to be quite robust. This property of robust QE under relatively modest vacuum conditions seems an ideal feature for high current accelerator projects that do not require spin polarized beam. In this experiment, a K_2CsSb photocathode was installed inside a 100kV DC high voltage photogun and illuminated with DC light at 532 nm to measure charge lifetime at 1mA average current. Results are compared to similar measurements performed using the same apparatus but with a GaAs photocathode.

EQUIPMENT

K_2CsSb was grown on a photocathode "puck" using a deposition chamber at BNL and transported to JLab, roughly 450 miles away, inside an ultrahigh vacuum

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transfer vessel (10^{-11} Torr). The process of growing the K_2CsSb photocathode at BNL, transporting it to JLab by car, and installing it within the DC high voltage photogun took approximately 2.5 days. No appreciable QE decay was observed, which indicates a very long dark lifetime.

Cathode Fabrication

The cathode was fabricated in an UHV vacuum system by evaporating high purity Sb, K and Cs sequentially onto a photocathode puck similar to those used at JLab, but made of aluminium with a thin layer of stainless steel affixed via explosion-bonding. Stainless steel was chosen because previous measurements at BNL indicated it provides high QE. A description of the BNL deposition system can be found in reference 5. First, an Sb layer 141Å thick was applied to the stainless steel substrate maintained at 100ºC. Then the substrate was heated to 140C and ~ 300Å of K was applied. Then the substrate was cooled to 135 ºC and Cs was applied. Photocathode QE was less than expected so an additional ~ 40Å of Sb was applied as well as more Cs. Unfortunately, the K source was depleted making the stoichiometry of the final photocathode uncertain. A spectral QE scan of the photocathode is shown in Figure 1, compared to an "ideal" K_2CsSb grown in the same chamber. Clearly, the reduced QE above 300nm suggests imperfect stoichiometry. In particular, it may indicate the surface of the photocathode was closer to Cs_3Sb than to the desired K_2CsSb. This discrepancy should be considered in all of the following discussion.

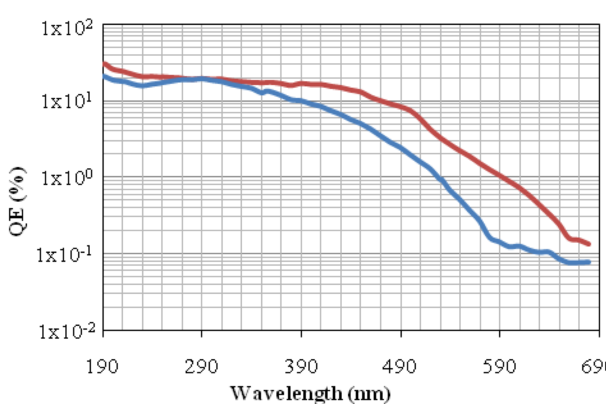

Figure 1: Spectral response of the K_2CsSb photocathodes created at BNL. Blue curve represents the photocathode created for these measurements, and red curve is considered "ideal".

Load- Lock DC High Voltage Photogun

The CEBAF load-locked DC photogun [6] is composed of four vacuum chambers separated by all-metal gate valves: the high voltage chamber, where the electron beam is generated, the preparation chamber, which is normally used to heat and activate GaAs:Cs photocathodes and was instead used here as a transfer and storage area, and a small-volume loading chamber. The fourth chamber, the Suitcase, is attached to the photogun only when photocathodes are replaced. The Suitcase was used to deliver the K_2CsSb from BNL.

The 100kV DC high voltage photogun was attached to a diagnostic beamline used to measure photocathode charge lifetime, which is defined as the amount of charge that can be extracted before QE falls to 1/e of its initial value. Light from a DC drive laser at 532nm (350µm dia. spot size, Gaussian FWHM) was used to extract 1mA from the K_2CsSb photocathode. Beamline focusing and steering magnets were used to deliver the beam to a Faraday cup ~ 5m away. The same photogun, beamline and drive laser were used to evaluate a GaAs:Cs photocathode in a previous set of measurements [7].

CATHODE PERFORMANCE AND DISCUSSION

Charge Lifetime

Upon successful installation of the K_2CsSb photocathode into the gun high voltage chamber, a QE scan was performed. This was accomplished by extracting ~ 1uA from the grounded photocathode, with the anode biased at ~ 200V, while scanning the laser across the photocathode using a focusing lens mounted to x/y stepper motor stages. The initial QE across the 12.8mm dia. photocathode ranged from 0.6 to 1.6% (Figure 2, top). The photocathode was then biased and charge lifetime runs were performed from five different radial locations.

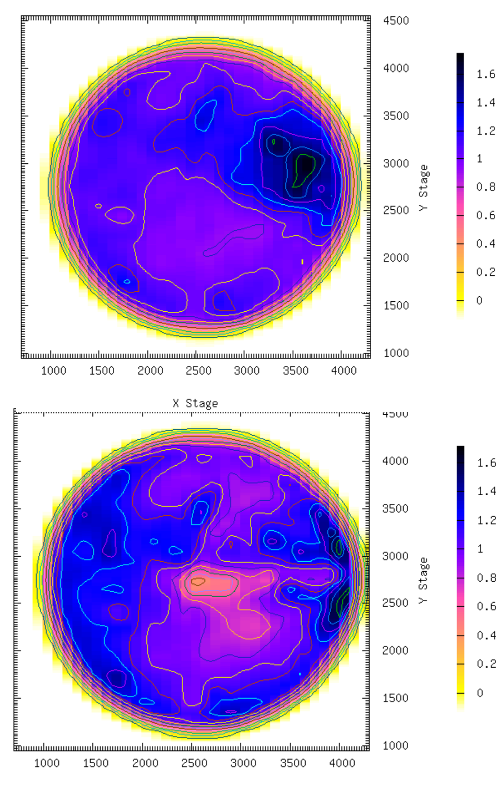

Figure 2: QE scans of the K2CsSb photocathode before (top) and after (bottom) extracting beam from five locations.

Charge extracted for each run ranged from 6 to 30C. Following each run, a QE scan was performed (Figure 2, bottom) and an exponential fit was applied to the QE decay. Charge lifetime measurements are plotted in Figure 3, as a function of radial position of the laser beam relative to the electrostatic center (EC) of the photocathode. Figure 3 also includes charge lifetime measurements from bulk GaAs photocathode [7], using the same photogun and drive laser but at 2mA average current.

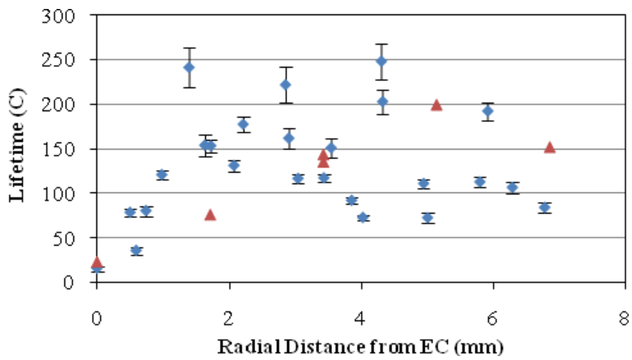

Figure 3: Charge lifetime of both K_2CsSb (red triangle) and GaAs:Cs (blue diamond) photocathodes versus the radial distance from the laser spot to the EC of the cathode.

The charge lifetime of the K_2CsSb photocathode is comparable to that of GaAs and improves as the laser beam is moved away from the center of the photocathode, consistent with behavior attributed to the QE decay mechanism of ion bombardment. Ions produced by the beam are preferentially focused toward the center of the photocathode, so by operating with the laser beam displaced from the photocathode center, lifetime is enhanced.

This result (i.e., charge lifetime comparable to that of GaAs) is surprising. The pressure inside the gun HV chamber is considered to be very good: ~ $5x10^{-12}$ Torr as measured using a Leybold extractor gauge (raw value) and with the valve to the beamline open. During beam delivery, the vacuum gauge was OFF but vacuum monitoring using a sensitive current meter within the ion pump power supply of the gun ion pump indicated no detectable change in pressure beam ON versus OFF. Ion pumps downstream of the gun indicated a pressure rise and it must be noted that 10 to 100pA of beam loss was detected on the electrically isolated anode plate. Similar observations were made with the GaAs photocathode and suggest stray light must illuminate the entire photocathode creating "halo" beam that was not efficiently transported away from the gun.

Surface Charge Limit Effects

The laser was moved to a fresh photocathode location and an extended run performed. During this run, the laser power was varied to measure the surface charge limit of the photocathode as a function of total extracted charge. A photocathode with surface charge limit has QE that decreases as a function of beam current. The plots in Figure 4 indicate the K_2CsSb photocathode did not suffer this problem, which is not surprising as surface charge limit likely adversely affects NEA photocathodes. In fact, the QE of the K_2CsSb photocathode appears to rise with laser power, which was a maximum 0.72W for each trial.

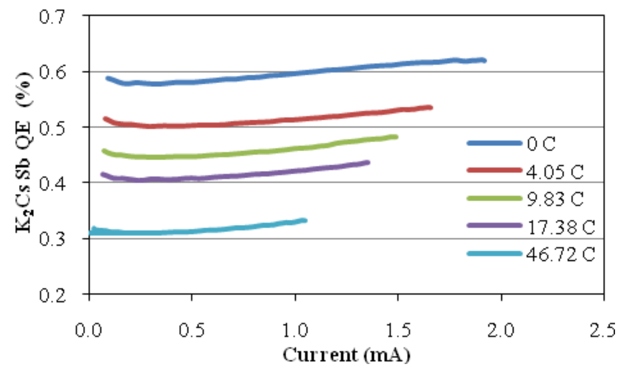

Figure 4: QE response as a function of extracted beam current for K_2CsSb. Different curves relate to total charge extracted from the cathode at time of measurement.

CONCLUSION

For the first time at JLab, a K_2CsSb photocathode was tested inside a DC high voltage photogun and its performance compared to GaAs:Cs. The charge lifetime of K_2CsSb was roughly the same as GaAs:Cs. Similar measurements will be made in the future to better understand the QE decay mechanism of alkali-antimonide photocathodes.

The dark-lifetime of the K_2CsSb is exceptionally long, as illustrated by the formation of the photocathode at BNL and delivered to JLab inside a modest vacuum transport vessel.

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