CHARGE LIFETIME, EMITTANCE, AND SURFACE ANALYSIS STUDIES OF K_2CsSb PHOTOCATHODE IN A JLAB DC HIGH VOLTAGE GUN*

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Abstract

For the past year, BNL and JLab groups have been collaborating to study the characteristics of K_2CsSb photocathodes inside a DC high voltage photogun. Although the first set of runs at 1 mA and at 100 kV bias voltage indicated disappointing charge lifetime, comparable to values obtained with GaAs photocathodes, subsequent measurements indicate that both the QE and charge life time increased significantly. This improvement could be attributed to the change in the chemical composition of the cathode due to UV irradiation. The charge life time measurements do not indicate any QE decay for currents of 10 mA with 350 micron FWHM spot, slight decay at 16 mA and significant decay at 20 mA for this spot size. When the spot size was increased to 850 micron, the lifetime at 20 mA increased significantly, implying local heating due to high laser intensity. Additional measurements with laser alone, without the HV, support this argument. These results as well as emittance and surface science measurements will be presented.

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 can produce a beam with small thermal emittance [1]; however, it requires strict adherence to procedures that limit the effects of its fragility. Once inside the photogun, GaAs is prone to rapid QE loss that can result from many situations such as poor vacuum and field emission. The K_2CsSb photocathode can exhibit high QE has complications of its own in practice. GaAs can be purchased from numerous reliable vendors while the K_2CsSb photocathode is an amorphous compound that must be grown while in vacuum via successive application of the elemental species on a suitable substrate and then transported and installed into the photogun also entirely under vacuum. Consistent results depend on consistent adherence to proper growth procedures. While the K_2CsSb photocathode has larger thermal emittance [1,2] as compared to GaAs:Cs, it is considered to be a prompt emitter because of its positive electron affinity nature, producing shorter bunches than GaAs:Cs. The biggest advantage of K_2CsSb however is the photocathode's ability to survive under markedly harsher vacuum conditions as compared to GaAs:Cs.

The purpose of this work was to expand on prior measurements done on the performance of a K_2CsSb photocathode. The performance directly compares to that of GaAs:Cs, which was characterized in the same 100kV DC photogun [3]. Early results indicated that the charge lifetime while illuminated at 532nm was no better than GaAs [4]; however after a major vacuum event, the lifetime at 440nm greatly improved, along with the QE of almost the entire photocathode [5]. This work revisits the initial lifetime results at 532nm and measures the beam emittance, as well as provides some insight into what factors affect the performance of a K_2CsSb cathode by using SEM techniques.

EQUIPMENT

K_2CsSb was grown at BNL on a JLab style photocathode puck [6] and was then transported via car to JLab, roughly 450 miles away, in an ultrahigh vacuum transfer vessel (10^{-11} Torr). After growth at BNL, the K_2CsSb photocathode was installed in the DC high voltage photogun within approximately 2.5 days. No appreciable QE decay was observed, which indicates a very long dark lifetime.

Cathode Fabrication

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 but made of aluminium with a thin layer of stainless steel (SS) explosion bonded to the top surface to accept the coating. Stainless steel was chosen as previous measurements at BNL indicate it provides high QE at 532 nm. Two sequential depositions were executed on the same substrate, as the first evaporation did not produce satisfactory QE. Specifics to the BNL K_2CsSb deposition system and process can be found in these proceedings [7]. During the second evaporation process the potassium dispenser was prematurely exhausted, which decreased the expected QE at wavelengths above 300nm [4, 5].

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

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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 DC JLab photogun was outfitted with a large grain niobium cathode electrode that was both mechanically and chemically polished and HV conditioned in order to allow 200 kV operations with no field emission. Photoelectrons were 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 before 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 measured in the faraday cup. Beam emittance was measured using wire scanners along the beam line.

CATHODE PERFORMANCE AND DISCUSSION

Previous Lifetime Measurements

Initial measurements made with a 532 nm, 350 μm FWHM (Gaussian) DC laser running 1 mA at 100 kV showed charge lifetimes around 100 C, which were comparable to an unmasked GaAs:Cs photocathode [4]. Measurements made with a 440 nm, 850 μm FWHM (Gaussian) DC laser were presented at IPAC 11 [5]. The initial QE scan of the photocathode, shown in Figure 1, with 440 nm light roughly agrees with the QE at 440 nm originally measured at BNL. The QE scan was accomplished by extracting ~1 μA 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.

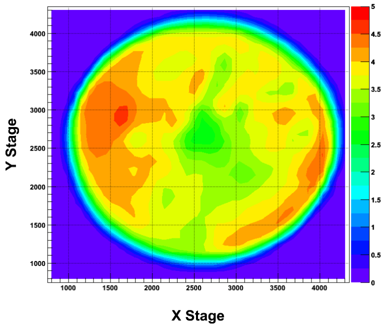

Figure 1: QE scan along the photocathode with 440 nm.

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, and no QE degradation was observed, even from beam extracted from the electrostatic center of the cathode. While further stressing the photocathode by running higher current, a power failure cause the electron beam to impact a section of 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 $5x10^{-10}$ Torr environment. Again a vacuum event of this magnitude would have quickly degraded the QE of GaAs:Cs, but this is not the case for K_2CsSb.

A subsequent QE scan over the photocathode, shown in Figure 2, showed that only the EC was severely damaged and there were still useable extraction sites around the EC. 5 mA was extracted for 24 hr and no permanent QE decay was observed, despite several vacuum events that temporarily lowered the QE in a manner similar to earlier runs [5].

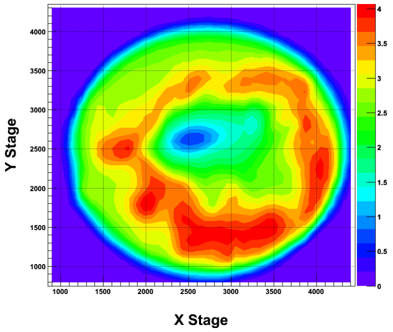

Figure 2: QE scan after a major vacuum event caused beam to be extracted in a $5x10^{-10}$ environment for ~ 2 hr. Visual inspection of the puck after the event seems to indicate that the K_2CsSb material at the EC was sputtered away leaving the stainless steel substrate.

Laser Heating

All charge lifetime measurements with 440 nm light indicated that QE did not decay with extracted change; for the higher current runs, the QE actually increased. The QE continued to increase merely while illuminating several spots along the photocathode without a bias voltage for various periods of time and laser powers. Up to a maximum power density of 0.37 W/mm^2 at 440 nm the QE at any illuminated spot increases, which indicated that the stoichiometry of the photocathode is improving locally at the illuminated spot with 440 nm. Of note is that this behaviour was not observed during previous charge lifetime measurements made with 532 nm. This suggests an absorption depth and/or surface chemistry dependence for K_2CsSb [5].

Redone Charge Lifetimes at 532 nm

The QE of the photocathode at 532 nm was increased relative to its value before the 440 nm runs after the occurrence of the major vacuum event previously mentioned. Figure 3 shows the typical QE evolution as function of charge for 5 mA at 532 nm and 200 kV, with a 350 μm laser spot. The initial QE was higher than before the vacuum event, and then continued to rise over time, similarly to the 440 nm lifetime runs.

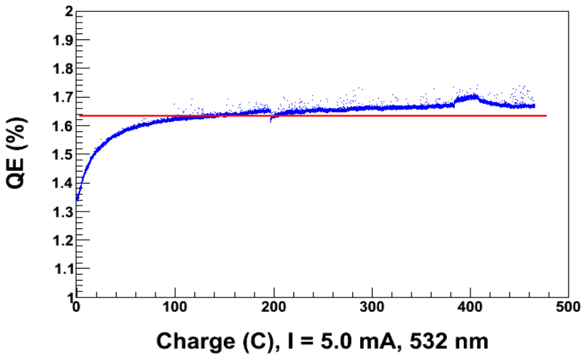

Figure 3: QE evolution vs. accumulated charge when using a 532 nm/350 μm (FWHM) Gaussian laser spot.

Taking advantage of a seemingly indestructible photocathode, maximum current was extracted from the cathode, using maximum laser power. Figure 4 shows the QE vs time of this run. Up to 10 mA, the QE seemed to either rise over time, or at least was constant; however, at 16 mA the QE started to slowly decline. At 20 mA, the QE sharply dropped.

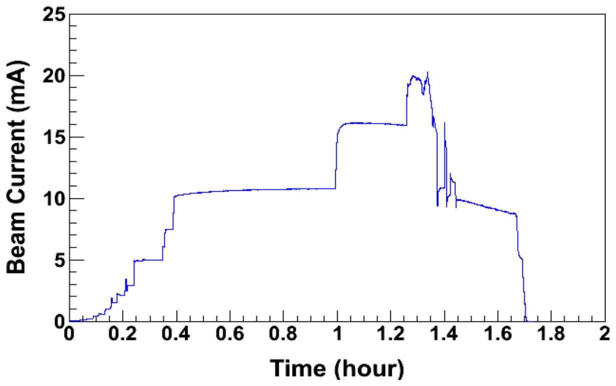

Figure 4: QE evolution vs. time while trying to extract maximum current using a 532 nm/350 μm (FWHM) Gaussian laser spot.

Because laser heating seemed to help improve QE at 440 nm, it was suspected that too much heating was occurring due to high laser power densities. QE scans indicated that the QE surrounding the area that beam was extracted from actually increased, which was likely a result of the extreme heating being primarily localized to the location of the laser. In addition, lowered laser powers were noted to locally increase the QE of the cathode in a similar way to the 440 nm light. To check suspicions of a heating threshold being reached that hurt the cathode, 20 mA was again run, but with a laser spot of 800 μm, and the resulting QE evolution is shown in Figure 5(b), along with the 200 mA 350 μm run, which is Figure 5(a).

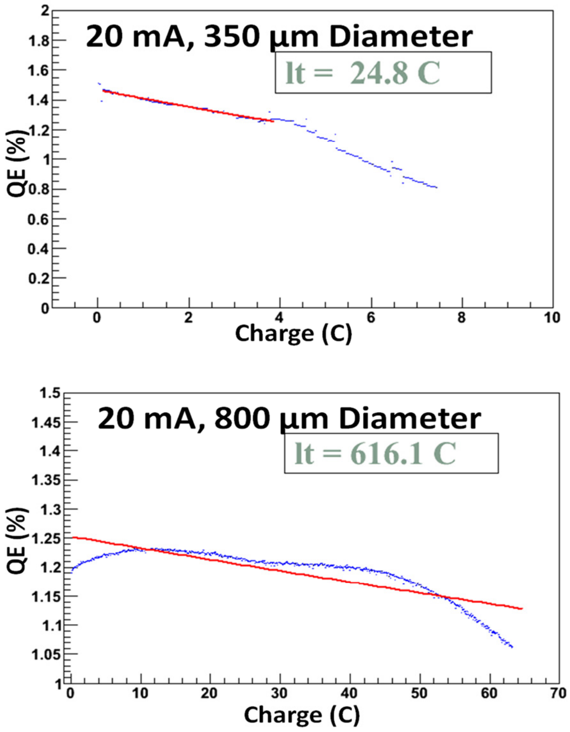

Figure 5: QE evolution vs. charge at 20 mA for (a) 350 μm spot and (b) 800 μm spot. Lifetimes per a 1/e fit are indicated in boxes.

Emittance

The emittance of the K_2CsSb photocathode was measured using a solenoid scan technique. 3 μA of beam was run at both 100 kV and 200 kV and also at both 440 nm and 532 nm in order to measure the emittance. Table 1 shows the results of these measurements. The emittance is roughly twice that measured in previous measurements at Cornell, although the following SEM analysis provides a possible explanation for this discrepancy.

Table 1: Emittance for K_2CsSb for Varying Wavelengths and Bias Voltages

Laser Wavelength (nm)	Laser FWHM (um)	HV (kV)	Normalized Emittance (mm mrad/mm(rms)
440	850	100	1.11 +/- 0.10
440	850	200	0.97 +/- 0.18
532	330	100	1.25 +/- 0.08
532	330	200	1.12 +/- 0.35
532	700	100	1.01 +/- 0.08
532	700	200	1.19 +/- 0.27

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SEM Analysis

After all lifetime and emittance measurements were conducted, an attempt was made at measuring the lifetime in a poor vacuum setting. In order to simulate a high H_2 environment, the NEG pumps in the gun were heated in order to release gases. During this heating, 1 mA was run from the cathode and the QE rapidly decayed. The QE of the entire cathode fell by a factor of 3, which indicated that the high heat caused by the hot NEGs negatively impacted the cathode.

Visual inspection of the photocathode surface revealed several features that were not present initially. Figure 6 shows the cathode upon removal from the gun. Location 1 refers to the spot of complete QE loss due to the major vacuum event, and visually appears to be the stainless steel substrate. Location 4 was masked by the cathode from being exposed directly to the gun vacuum. Locations 2 and 3 refer to spots of the photocathode that were exposed to beam related events. This area is partially frosted to the eye, as seen in location 2.

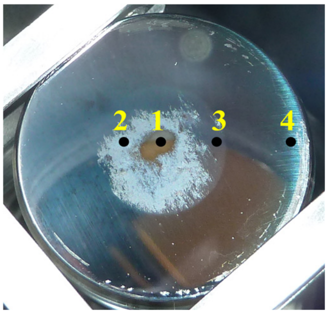

Figure 6: The K_2CsSb puck after removal from the JLab DC gun.

An attempt was made to restore the QE of the cathode by withdrawing it from the DC gun to place it in the JLab preparation chamber, which is usually used to heat and activate GaAs. The puck was brought to 130°C while Cs was evaporated onto it; however, the QE of the cathode dropped to zero in this time.

The cathode was moved into the transport suitcase at this time for transfer to a SEM. A glove bag filled with argon was used for the hand off between the suitcase and the vacuum vessel of the SEM. The SEM confirmed that Location 1 was indeed stainless steel, which indicates that the vacuum event was severe enough to sputter away the entire photocathode layer. Importantly, the rest of the cathode survived this major event, which would have been completely destroyed a GaAs cathode.

Figure 7 shows two of the SEM images, with (a) referring to location 2 and (b) referring to location 3. The frosted region, location 2, is comprised of islands of Cs, K, and Sb, with SS and some Sb in between. While smooth to the eye, location 3 shows some cracking of the photocathode film, with SS located in the cracks. The rough surface of the photocathode possibly contributed to the higher than expected measured emittance.

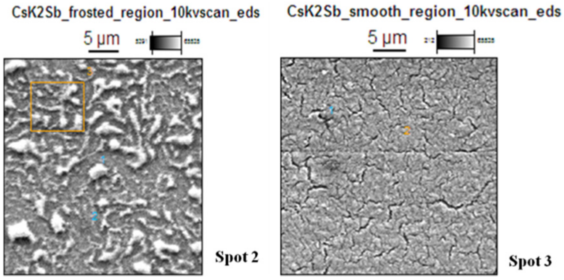

Figure 7: SEM images of the K_2SbCs puck taken at 20 keV electron energy of (a) location 2 on the puck and (b) location 3.

SUMMARY 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. While extracting beam, a vacuum event modified the surface of the photocathode, which restored QE at 532 nm. Charge lifetime at 532 nm was subsequently greatly improved due to either the vacuum event or from laser irradiation at 440nm. At both 532 nm and 440 nm, it was possible to locally improve QE via laser heating the cathode. Maximum current run was 20 mA at 532 nm, and was limited by too much laser heating of the cathode. Decreasing the power density of the drive laser improved lifetime at 20 mA. Emittance was measured and was slightly higher than expected, which was potentially due to the rough surface of the cathode that was seen via SEM analysis.

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