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K_2CsSb CATHODE DEVELOPMENT*

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DISCLAIMER

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Abstract. K_2CsSb is an attractive photocathode for high current applications. With a quantum efficiency of >4% at 532nm and >10% at 355nm, it is the only cathode to have demonstrated an average current of 35mA in an accelerator environment. We describe ongoing cathode development work for the energy recovery linac being constructed at BNL. Several cathodes have been created on both copper and stainless steel substrates, and their spatial uniformity and spectral response have been characterized. Preliminary lifetime measurements have been performed at high average current densities (>1mA/mm^2).

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INTRODUCTION

Alkali antimonide cathodes have been used in photoinjectors for many years [1-2]. They have high quantum efficiency for visible light, but are challenging to implement in an accelerator; the lifetime of a K_2CsSb cathode in a normal-conducting (NC) RF cavity is measured in hours [1] due to the relatively poor vacuum in the injector. With the advent of superconducting (SRF) injectors, it may be possible to lengthen this lifetime considerably, as the cavity vacuum can be orders of magnitude better (~0.01nTorr in an SRF cavity, compared to ~1nTorr in an NCRF cavity).

One project based on such an SRF injector is the energy recovery linac (ERL) project at Brookhaven National Laboratory [3]. This machine has two modes of operation, with average currents of 50mA and 0.5A. The cathode being developed for 50mA operation is cesium potassium antimonide (K_2CsSb). The cathode will be mounted on the stalk of a ¼ wave choke filter, and will be kept at 77K to reduce the radiative heat load on the cavity. The laser spot on the cathode will be ~7mm in diameter, resulting in a design current density of 1.3A/mm^2. For 0.5A operation, a diamond amplifier [4] will be used; in this case the average current required from the K_2CsSb photocathode is lower, but the cathode will be operated in transmission mode, with the laser incident from the back of the cathode through a transparent conductor.

This paper describes the current status of the cathode development for the ERL. Four cathodes have been created, and all have reached the design quantum efficiency (QE) of 10% at 355nm in reflection mode. The spectral response of each cathode has been measured, and preliminary measurements of lifetime at the design current density have been performed.

METHODS

The cathodes are created in a vacuum system with a base pressure of ~0.02nTorr. This vacuum is achieved using a 400l/s ion pump in conjunction with a titanium sublimation pump. The deposition geometry is vertical – the sources evaporate up onto the substrate, which is moved via a linear manipulator into position above each source sequentially. The antimony source is a tantalum boat packed with antimony pellets. The potassium and cesium sources are "V" sources from alvatech. The source to substrate distance is 4cm. A crystal monitor can be used to monitor the deposition rate of antimony and potassium. The cesium deposition rate is not measured; instead the QE is monitored during deposition by illuminating the cathode with a green laser (532nm), and the deposition ended when the QE stops increasing. In addition to the laser port used for deposition, the system has two horizontally aligned optical ports. After deposition, the cathode can be rotated to face one of these ports, with the back of the cathode facing the other. This arrangement allows the optical transmission of a transparent portion of the cathode substrate to be measured to check the deposition thickness, and it allows the QE to be measured in both transmission and reflection mode. Spectral response measurements are made through the reflection port by using a lamp source (DH2000 from ocean optics) with a fiber-coupled monochromator (Edmond Optics) to illuminate the cathode. This source has a 2nm bandwidth, and a 5x5mm^2 spot on the cathode. Note that measurements with the lamp source require all external light sources to be off, as even the light from the filament of an ion gauge produces more current than the lamp. A 532nm CW laser can be used for lifetime and high current measurements.

For high current tests, the cathode can be moved to a position containing a wire mesh anode, with an electrode separation of 2.5cm. The anode can be biased to 5kV, allowing higher currents to be extracted from the cathode without space charge limitation. The parallel geometry of the cathode and anode in this case allows the electric field on the cathode to be estimated. The wire mesh is coarse enough to allow 100% transmission of the 532nm laser.

The copper cathode substrate is 2.5cm in diameter, polished with 1μm diamond polishing compound to a mirror finish. Portions of the copper substrate can be covered with shims made of other materials, allowing comparison of the QE for cathodes deposited on different substrates (to date, only copper and stainless steel have been measured). A 6mm diameter hole in the substrate exposes a glass slide covered with a transparent conductor. For the current cathodes, 20-40nm of sputtered copper was used; indium-tin oxide (ITO) coated slides will be tested in the future. This 6mm region can be illuminated from either side, allowing the QE to be compared in reflection and transmission modes, and allowing the optical absorption of the cathode layer to be measured. The cathode is electrically isolated from the vacuum translation arm, enabling the cathode to be biased and the charge leaving the cathode to be measured. The arm includes a vacuum heater capable of raising the substrate to 150C, and liquid nitrogen (LN_2) cooling lines capable of cooling the cathode to -80C.

The cathode is deposited sequentially, following the general method of D. Dowell [1]. The substrate is at 150C for the antimony deposition, and the rate is set to ~0.5nm/s. 20nm of antimony is deposited, after which the substrate is cooled to ~140C for the potassium deposition. 40nm of potassium is deposited, again with a rate of ~0.5nm/s. The substrate is cooled to 135C, and the substrate is biased to -20V. The cathode is illuminated with ~0.5mW of 532nm light, and the emitted current is monitored. Cesium is deposited until the emitted current stops rising, at which point the cathode is cooled to room temperature by flowing LN_2 through the arm.

RESULTS

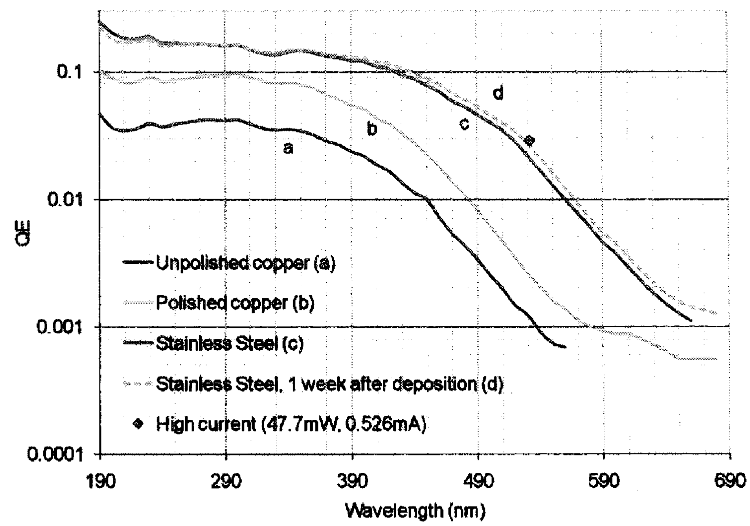

FIGURE 1. Spectral Response of a K_2CsSb cathode on copper and stainless steel substrates. The high current point was taken 8 days after deposition, immediately after response curve (d).

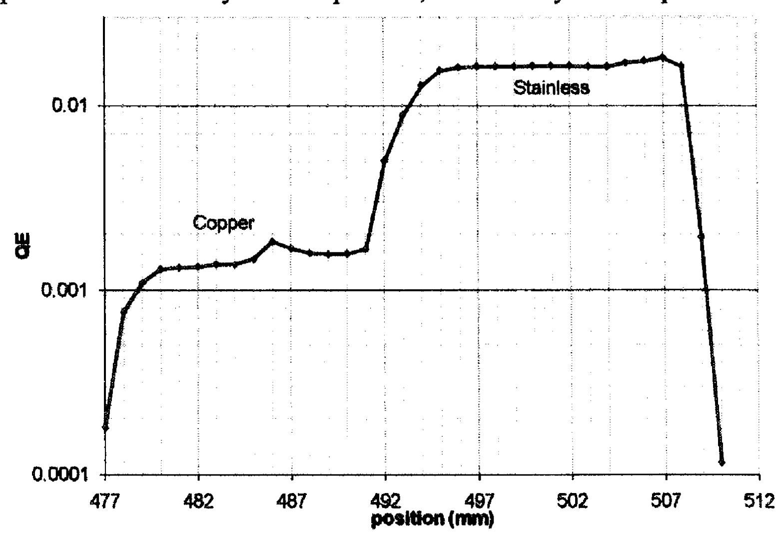

FIGURE 2. Spatial uniformity of cathode 2 measured with a laser (532nm).

Figure 1 shows the spectral response of cathode 2 deposited on both copper and stainless steel substrates. The spatial uniformity of this cathode is shown in figure 2. The QE was also measured on the unpolished copper fork which holds the substrate puck. To test the linearity of the response with flux, a 532nm CW laser was used to deliver 47.7mW to the cathode, resulting in 0.526mA of emitted current. The QE was the same as that measured with the lamp source, which provides 20nW and 226pA at 532nm. Cathode 2 was also cooled to -80C, with no change in the spectral response.

Figure 3 shows the spectral response of 4 cathode depositions. Cathode 4 had a second cathode deposited on top of the first after the lifetime measurements, restoring its QE. Cathode 3 was deposited with the substrate at 120C (rather than 150C-135C); this exhibited somewhat inferior QE.

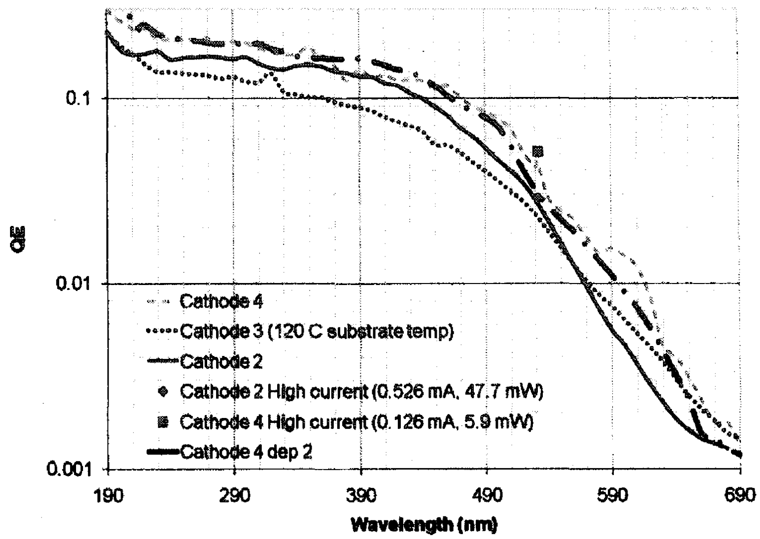

FIGURE 3. Spectral Response of a K_2CsSb cathodes on stainless steel substrates.

The performance of the cathodes in transmission mode depends strongly on the cathode thickness. Cathode 3 was the best, with a QE in transmission mode half that of reflection mode after accounting for the 20% transmission of the sputtered copper layer used to provide conduction.

Lifetime

Cathode 4 was used to test the performance of K_2CsSb under continuous operation at the ERL current density. Tests on earlier cathodes have shown that the QE is unchanged after 40 days of storage in the chamber vacuum. The measurement station with the anode was used for these tests to achieve a field necessary to overcome space charge. The 532nm laser was focused to 80μm FWHM on the cathode to achieve a current density of up to 2.2mA/mm^2 with a bias of 3kV (1.45mW optical power, 10.9μA emitted current). The optical power was modulated to keep the current density near the ERL goal of 1.3mA/mm^2; for a 1kV bias on the anode, the cathode emission was space charge limited to 1.1mA/mm^2. Figure 4 shows the result of this test. For 2kV and 3kV anode bias, the QE decay is consistent with a 1/e lifetime of 100hrs; as the emission was space charge limited at 1kV, no estimate of lifetime can be made. A similar measurement was made with a 3mm diameter laser spot on the cathode and a bias of 500V, with 60μA of emitted current. In this case the QE decayed from 2.3% to 2.0% in 40 hrs, yielding a 1/e lifetime of 360hrs. Two possible causes of this decay are ion bombardment of the cathode and local vacuum pressure rise near the cathode due to electron stimulated desorption from the anode (as the 1-3keV electrons strike the anode).

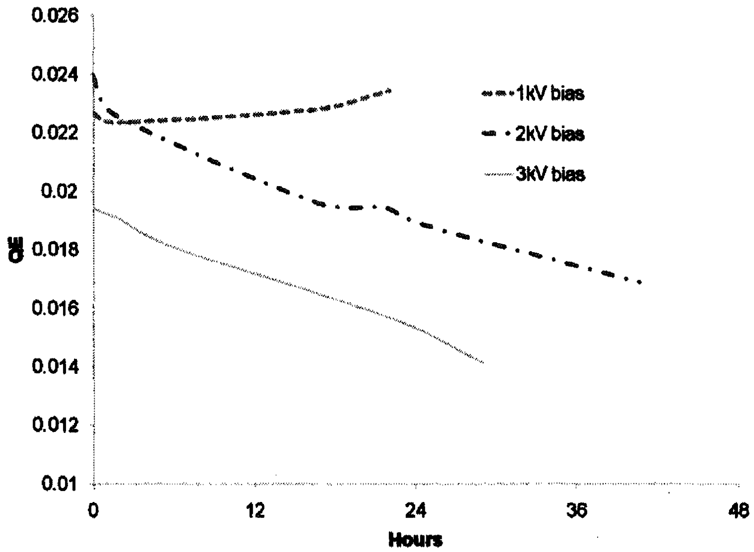

FIGURE 4. Decay of QE under continuous extraction of 1.3mA/mm^2.

CONCLUSIONS

K_2CsSb is an attractive cathode for high average current injectors. It has less stringent vacuum requirements than Cs:GaAs and has a high QE for visible light. It has been shown to have a limited lifetime in a NCRF injector, but in the better vacuum of a SRF or DC injector, lifetimes of days to weeks should be possible, even at high current density. Cathodes have been fabricated that meet the QE and current density requirements of the BNL ERL.

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