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ALKALI ANTIMONIDE PHOTOCATHODES IN A CAN

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Abstract

The next generation of x-ray light sources will need reliable, high quantum efficiency photocathodes. These cathodes will likely be from the alkali antimonide family, which currently holds the record for highest average current achieved from a photoinjector. In this work, we explore a new option for delivering these cathodes to a machine which requires them: use of sealed commercial vacuum tubes. Several sealed tubes have been introduced into a vacuum system and separated from their housing, exposing the active photocathode on a transport arm suitable for insertion into an injector. The separation was achieved without large loss of QE. These cathodes have been compared to those grown via traditional methods, both in terms of QE and in terms of crystalline structure, and found to be similar.

INTRODUCTION

Alkali antimonide photocathodes have a long history in low-light photodetection, including image intensifiers. These needs have been met by commercial production, principally by RCA and its successors. The accelerator community also has great interest in alkali antimonide photocathodes – they are a prime candidate for use in high-brightness photoinjectors for free electron lasers and 4th generation light sources [1-3]. However, within the accelerator community, cathodes have traditionally been grown in dedicated vacuum systems tied to specific injectors. In some cases, cathodes have been transferred from one system to multiple injectors, typically on a limited basis [2,4].

We have developed tools to understand the formation of alkali antimonides, both structurally and chemically, with the goal of altering growth processes to produce cathodes with less roughness, better stoichometry, and larger crystal grains. The *in situ* techniques being used are x-ray diffraction (XRD), grazing incidence small angle x-ray scattering (GISAXS) and x-ray reflection (XRR). These tools enable determination of the crystal form of the cathode at each phase of growth, the film thickness and roughness, the texture and grain size of the film, and the presence of "imperfectly reacted" material. This work has been carried out at the National Synchrotron Light Source (NSLS) using beamline X21 and at the Cornell High Energy Synchrotron Source (CHESS) using beamline G3.

The goal of this work is to enable the large scale production of identical photocathodes, using recipes developed in the *in situ* analysis chamber, which will provide high QE while minimizing the surface roughness which can dominate the intrinsic emittance [5,6]. One aspect of this effort is collaboration with an industrial partner to produce photocathodes in sealed tubes which can be separated in vacuum.

Figure 1 shows a prototype photocathode in a sealed vacuum capsule. The capsule is sealed with a low temperature solder visible around the copper. A window on the isolated top electrode enables the QE of the device to be measured while the capsule is still sealed. The photocathode is visible as the blue area in the picture on the right, through this window. For the cathodes reported here, single crystal Molybdenum substrates were used, brazed to a copper plug as shown in the picture to the left. The substrates have an RMS roughness of better than 100 nm; although this was an improvement over cathodes grown on polycrystalline Mo [7], it is still too rough to allow evaluation of the roughness from the cathode itself.

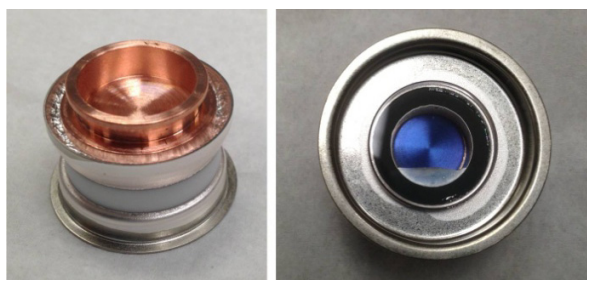

Figure 1: Sealed photocathode.

EXPERIMENT

In the interest of space, the growth chamber with *in situ* x-ray analysis capability is described elsewhere [8]. This chamber has been used to both measure the capsule photocathodes and to grow cathodes for comparison. The growth method for the comparison cathodes is described in a companion paper [9]. Four Photonis K_2CsSb photocathodes were grown via sequential depositions on the Molybdenum substrates. For this process, the alkali deposition is non-directional, as is common in PMT manufacture – the structure is exposed to an alkali vapor, which interacts with the antimony film to form the cathode. The four cathodes (designated 011R, 015T, SA001R and SN013RO2) were distinct – the primary differences being how the QE was monitored during deposition (the photocurrent feedback is used to control the process) and the surface oxidation method (or lack thereof). The recipes used were similar to that used by the company for its transmission-mode cathodes (traditionally grown on glass substrates), and has yet to be optimized

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for this application. The spectral response of the cathodes as delivered and after opening of the capsule in vacuum is shown in figure 2, along with a response curve from a comparison cathode.

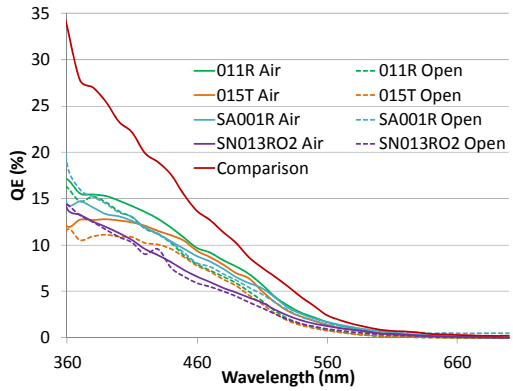

Figure 2: Spectral response of Photonis K_2CsSb photocathodes before (air) and after (open) cap removal.

In addition to the K_2CsSb cathodes, Photonis also provided a Na_2KSb cathode grown on an identical substrate. The spectral response of this cathode is shown in figure 3, along with a comparison Na_2KSb cathode. Surprisingly, this cathode had the largest degredation upon removal of the cap. The XRD results (figure 7) provide some insight as to the cause.

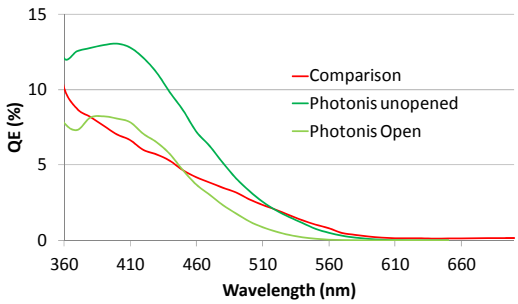

Figure 3: Spectral response of Photonis Na2KSb cathode.

RESULTS

Transfer and Separation

The initial and final stages of the capsule loading and separation are shown in figure 4. On the left is a capsule loaded onto the platen. On the right is the cathode ready to be transferred off the platen and into an injector. This design is compatible with the transfer system for the BNL 112 MHz Gun [10], and future iterations of this design will be tested in this gun (some design modifications are required to mask the solder joint from the gun).

The sequence of cap removal is shown in figure 5. First the platen with capsule is loaded onto the heater. Second, the platen temperature is increased slowly to ~100 C (the solder eutectic temperature is 72 C; thermal conduction from the platen to the solder joint as well as alloying of the solder with the base materials likely explains this difference). A manipulator is used to gently pry at the cap (bottom left), eventually resulting in the cap tipping away from the cathode (bottom right). The QE of the cathode is measured using white light and a monochromator immediately after the removal process (figure 2). In most cases there was a small decrease in the cathode QE after removal.

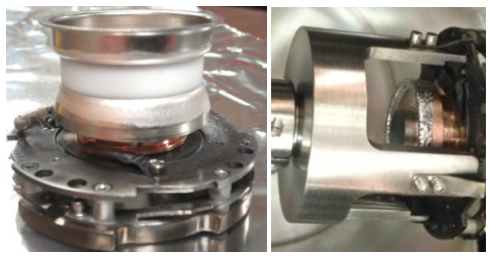

Figure 4: Left, sealed cathode mounted on platen. Right, cathode after cap is removed, still attached to platen.

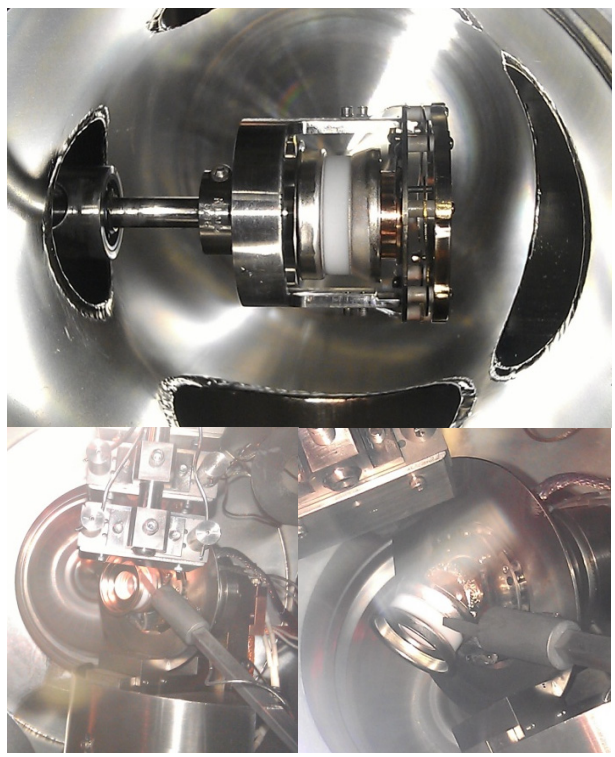

Figure 5: Top, Capsule loaded onto platen and mounted for insertion. Bottom Left, Finger positioned to remove cap. Bottom Right, Cap partially off.

X-ray Diffraction

Figure 6 shows the crystalline structure of the capsule cathodes, along with the comparison cathode. The comparison cathode (C002) is cubic phase K_2CsSb with a predomantly 222 surface texture. The grain size estimated from Scherrer analysis is 13.4±2.0 nm. No unreacted K_3Sb is observed in this cathode. The capsule cathodes are similar, except P011R, which has a more pronounced 220 texture. The grain sizes are 16-19 nm. The strong peak at 32.4 degrees is from the Molybdenum substrate.

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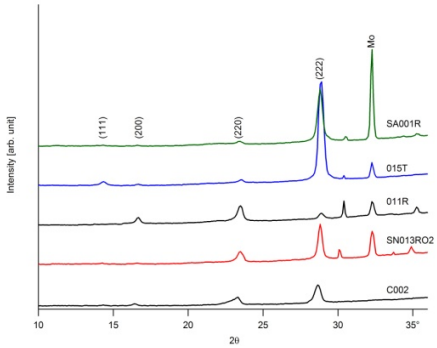

Figure 6: XRD results of Photonis cathodes after cap removal, along with "C002" for comparison.

Na_2KSb and Exposure Studies

Figure 7 shows the XRD pattern of the Photonis Na_2KSb cathode. For this cathode, the XRD was measured twice – once immediately after cap removal and again after the cathode spent 7 hrs stored in the system load lock (an unbaked UHV chamber with a base pressure of 140 nTorr). This exposure completely eliminated any photoemission from the cathode. The first XRD measurement showed the cathode was mostly Na_2KSb, but with some residual Na_3Sb, suggesting an excess of sodium in the initial growth or decomposition due to the heating required to remove the cap. The XRD after exposure shows a marked reduction in the NaK_2Sb amplitude, likely due to a loss of well-ordered material. This suggests that this level of exposure causes a structural change to the cathode, not merely surface contamination.

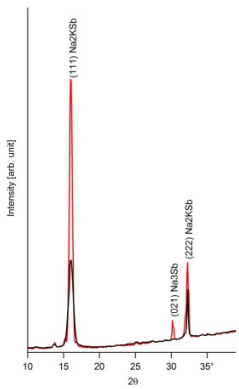

Figure 7: XRD results for Na2KSb after cap removal (red), and after exposure to poor vaccum (black). Note that the (222) peak overlaps with the Mo substrate peak.

Other exposure tests were performed as well. SA001R was placed in the load lock for one minute, exhibiting a reduction in QE of 90% (from a peak QE of 20% to under 2%) without observable structural change in the XRD. SN013RO2 was exposed to the vacuum with the load lock open (which increases the main chamber vacuum from 0.2 nTorr to 10 nTorr) for one minute, and experienced a small but measurable QE reduction (on the order of 5%), again with no XRD impact.

CONCLUSIONS

Sealed "Phototube like" photocathodes have been prepared to be separated in vacuum, allowing the photocathodes to emit electrons into a test system. The removal process can preserve the QE of the cathodes; 4.6% QE at 532 nm was observed both before and after opening. While this QE is somewhat inferior to purpose-grown cathodes, the process has not yet been optimized and is expected to improve significantly. This technique has the potential to allow injector projects to purchase photocathodes that are produced commercially in batches, providing quality control and reproducibility, and dramatically reducing costs.

Further, the ability of these cathodes to be studied and compared to existing recipes using *in situ* materials diagnostic techniques will allow the evaluation and optimization of the cathode properties relevant to accelerator applications. These are somewhat different than traditional phototube attributes – in particular, the eventual ability to use GISAXS to evaluate surface roughness will provide insight into the expected intrinsic emittance of these cathodes. This was not possible on the current samples, as the growth substrate was "rough." Samples grown on refinished single crystal molybdenum are already in production, and roughness measurements are part of the near-term future plan. In the somewhat longer term, these cathodes will be tested in the BNL 112 MHz SRF injector.

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