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EVALUATION OF THE IN-SITU PHOTOCATHODE HANDLING FOR SRF PHOTOINJECTOR OF SEALab

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Abstract

The handling of very sensitive bi-alkali antimonide photocathodes as the electron source for the SRF photoinjector of SEAlab is a critical procedure for its operation. After the growth of the photocathode, they have to be transferred in-situ under extreme UHV conditions using a vacuum suitcase and under particulate-free conditions to avoid the contamination of the SRF cavity. We investigated the storage and in-situ photocathode transfer over 40 days to study the impact of the varying vacuum conditions on the surface chemistry of the photocathode.

INTRODUCTION

At IPAC 2022 we presented our first results on the growth of Na-K-Sb photocathodes as an electron source in an SRF-photoinjector of the SEAlab facility [1, 2]. Quantum efficiency (QE) values up to 2% at 515 nm were achieved grown by alkali co-evaporation and or sequential method for reference. We focused our effort on higher reproducibility and higher QE of the photocathode recipe. This year we present a study on the robustness of photocathode WH14, under typical handling conditions anticipated for applications as an electron source for the SEAlab photoinjector. The behaviour of the photocurrent post-growth over a period of 19 days in the preparation system is evaluated. This is then followed by a discussion of the effects of sample transfer to transfer system #1 (TS#1,) attached to the preparation system [3].

PHOTOCATHODE WH14

A < 2 % QE at 515 nm Na-K-Sb photocathode, WH14, was grown in the preparation and analysis system (PAS) and monitored under dark conditions for 19 days before being transported to TS#1 where it was stored for a further 20 days. In the sections below we report on the growth procedure for WH14, followed by post-growth characterization of the film, and finally post-transfer analysis.

Growth

The growth procedure used for WH14 is based on the alkali co-deposition method developed at HZB for the fabrication of Cs-K-Sb. A full description of the growth procedure and the PAS chamber has been previously reported [4]. WH14 was one of a series of Na-K-Sb samples grown on a reusable all-Mo substrate (see Fig. 1) produced for developing a growth procedure for Na-K-Sb photocathodes [1].

The substrate was prepared by heating to 500°C inside the PAS for 1 hour, followed by Ar^+ sputter cleaning at 2.5 keV to ensure a clean Mo surface that was verified by XPS. The substrate was then heated to 100°C for the deposition of 40 nm of Sb at 0.2 Å/s. This was followed by co-deposition of Na and K at substrate temperatures of 148 – 196 – 76°C. XPS studies of previously grown Na-K-Sb photocathodes indicate a tendency for an excess of Na and a deficiency in K leading to poor performance with respect to QE [1, 5]. Therefore, the heating current applied to Na dispensers was reduced relative to K dispensers for this growth.

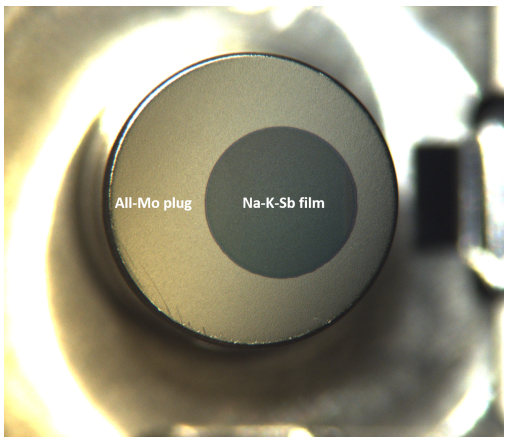

Figure 1: Image of WH14 taken shortly after growth in the preparation chamber.

Post-growth Analysis

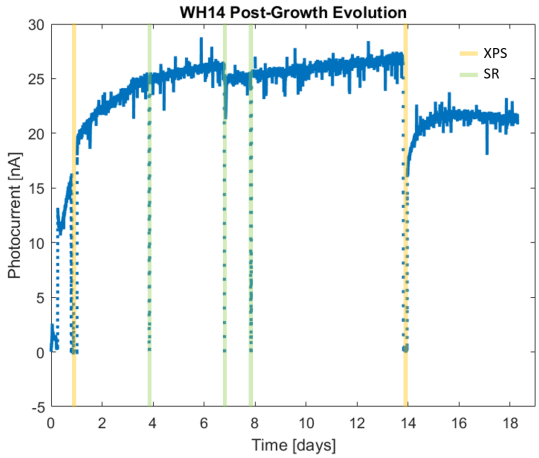

Figure 2: Post-growth evolution of WH14 photocurrent. Breaks in the measurement highlighted in orange and green indicate XPS and spectral response measurements (SR).

Photocurrent is extracted from photocathodes grown in PAS by illuminating the sample with green light at 2.4 eV and applying a bias voltage of 150 V between a pick-up an-

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ode and the sample. In the case of WH14, no photocurrent was measured during the growth due to interference cause by another device. Consequently, only post-growth photocurrent data is available.

In Fig. 2, we observe the evolution of the photocurrent from day zero up to almost three weeks after growth. Drop outs in the photocurrent are highlighted in orange or green indicating breaks in the photocurrent measurement for spectral response and XPS measurements respectively. The photocurrent is observed to increase after the growth for several days before plateauing. One possible explanation for this is that excess alkali material on the cathode surface disassociates over time in vacuum, resulting in an overall improvement of the photoemissive surface. However, further in-situ measurements post-growth would be necessary to test this theory.

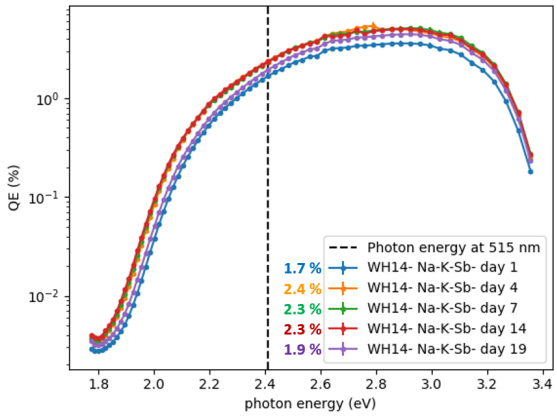

Figure 3: Spectral response measurements for WH14. The QE at 2.4 eV (black dotted line) is displayed for measurements taken up to 19 days after growth.

Spectral response measurements were taken at various intervals post-growth to characterize the QE(λ) of WH14 over time (see Fig. 3). The QE at 2.4 eV is labelled in the plot for each data set. A maximum QE of 2.4 % is measured 4 days after the growth, after which it plateaus before degrading to 1.9 % by day 19.

It is important to note that the degradation in photocurrent comes directly after the XPS measurement on day 14 (see Fig. 2), however there is no definitive explanation for this occurrence. No significant change in film composition is observed after the day 14 XPS measurement, and the base pressure in the analysis chamber is almost one order of magnitude lower than in PAS. Therefore degradation due to vacuum degradation is improbable. It is possible however, that the degradation is directly linked to the XPS measurement itself; a couple of degrees increase in sample temperature is observed during XPS which may suggest that the localized heating of the sample from x-ray irradiation is responsible for the degradation observed.

Post-transfer Analysis

After almost three weeks monitoring the photocurrent of WH14, the sample was transferred and stored in TS#1 for 20 days. The base pressure of TS# 1 is 7×10^{-11} mbar, but during transfer the pressure increased up to 4×10^{-8} mbar. Upon transferring back to PAS after storage in TS#1, a massive drop in QE was observed: 0.03% at 2.4 eV. XPS measurements taken after the transfer offer a possible explanation.

XPS analysis before and after transfer suggest that the degradation in QE maybe due to changes in chemical composition of the sample surface.

In Fig. 4, Na 1s, K 2p and Sb 3d spectra before and after transfer are compared. A Shirley background subtraction is carried out for each spectra to enable direct comparison of peak intensity and position.

In the case of Na 1s and Sb 3d (see Fig. 4 a) and b)), there is a reduction in peak intensity, particularly for Sb 3d, indicating a decrease in the Na and Sb content post-transfer. There is very little change to the intensity of the K 2p peaks, however there is a peak broadening indicating an overall increase in potassium content. Potassium enrichment in the surface due to diffusion or segregation of potassium from the bulk has been previously reported in the literature [6].

A closer look at the post-transfer K 2p spectrum (see Fig. 5) reveals that the peak broadening observed is as a result of a mixed chemical state. The dominant K 2p 3/2 peak at 293.5 eV, and the secondary peak (that emerged post-transfer) at 294.7 eV is associated with values reported for K-Sb and metallic potassium respectively [7]. This further supports the idea of potassium segregation.

Furthermore, there is a small oxygen increase measured on the surface of WH14 after transfer that could also be a contributing factor to the QE reduction, as indicated by the O 1s peak in Fig. 4 c). The oxide formation could have been accelerated by the pressure increase observed during the transfer. To minimize the pressure increase, it is necessary to move the sample extremely slowly and with great care.

CONCLUSION

The production of a stable and robust Na-K-Sb photocathode has been demonstrated in this work. A maximum QE of 2.4 % was achieved followed by slow degradation down to 1.9 % over 19 days storage in the PAS chamber under dark conditions. To test the robustness of the cathode during transfer, the sample was transferred to TS#1 and stored for a further 20 days before transferring back to PAS for analysis. By day 39 the QE had reduced to 0.03 %; this degradation is ascribed to changes in the surface composition accelerated by the pressure increase during transfer.

OUTLOOK

Our goal based on the presented results is to further improve the QE of the photocathodes grown with our setup. For a better understanding we also built a vacuum suitcase

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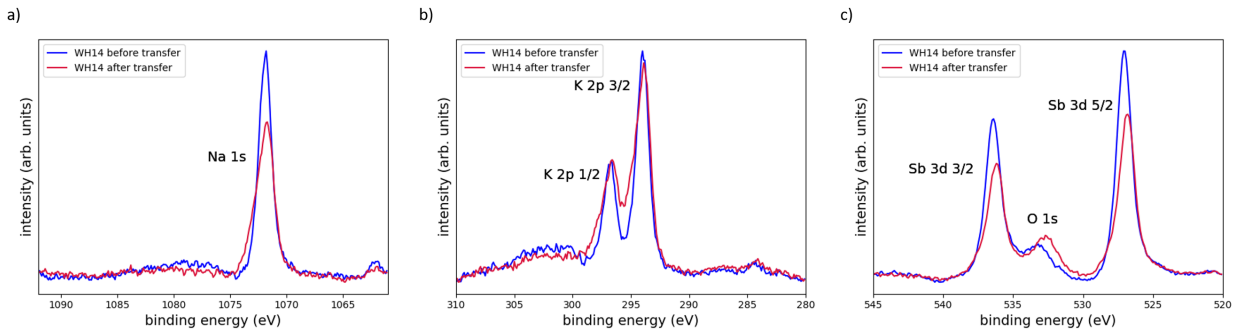

Figure 4: A comparison of XPS region spectra for WH14, before and after transfer. a) Na 1s spectra, b) K 2p spectra and c) Sb 3d and O 1s spectra.

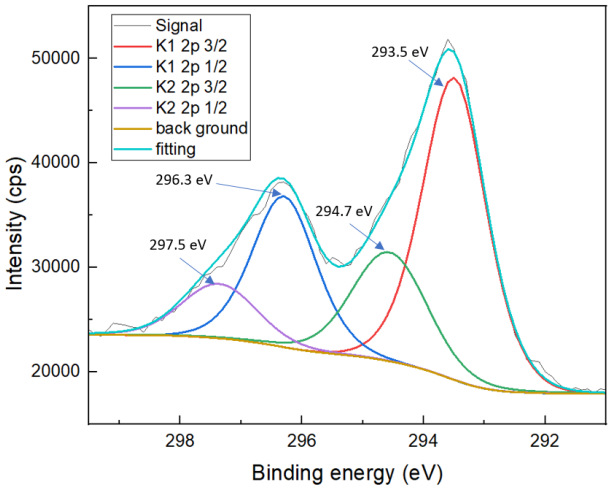

Figure 5: XPS region spectrum post-transfer for K 2p with peak fittings.

(which is ready to use) to transfer samples in-situ to a synchrotron facitily for advanced X-ray spectroscopies. With this approach we are aiming for a better understanding of the electronic structure of Na-K-Sb photocathodes in the framework of our DFG project ""Fundamental characterization and photoemission properties of multi-alkali antimonides for ultra-bright electron sources (FunPhotoSource)". Besides the basic research we are planning to deliver a photocathodes for commissioning of the SRF-photoinjector in the SEAlab facility and for future accelerator physics experiments [8, 9].

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