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DEVELOPMENT OF A MULTIALKALI ANTIMONIDE PHOTOCATHODE AT INFN LASA

S. K. Mohanty †[1], DESY Zeuthen, Zeuthen, Germany
P. Michelato, L. Monaco, D. Sertore, INFN - LASA, Segrate, Italy
C. Pagani, G. Guerini Rocco, Università degli Studi di Milano & INFN, Segrate, Italy
[1]also at INFN-LASA, Segrate, Italy

Abstract

Owing to their excellent properties including high quantum efficiency (QE), low emittance, good lifetime and fast response, alkali antimonides Photocathodes has been considered as one of the eminent candidates for the electron source such as in energy recovery linacs (ERL) and free electron laser (FEL). Along with this fact, our recent projects are aiming for CW operation, where these kinds of material are more suitable for the laser specification. So, by considering this fact and stimulating from former successful development of Cesium Telluride photocathodes, our R&D activity has been started to develop specifically the K-Cs-Sb based multi-alkali photocathodes which are sensitive to the green light at INFN LASA. The primary goal is to develop a stable reproducible alkali antimonide film on INFN plug and test them in the photo injector test facility at DESY in Zeuthen (PITZ). In this report, we present and discuss the different growth procedure and results so far obtained for KCsSb material.

INTRODUCTION

Semiconductor materials belonging to the alkali antimonides family have been widely used for many decades in photon detection application because of their high efficiency in the visible range of the spectrum [1]. But, the reliable growth process for these materials is largely based on recipes obtained by trial and error [2]. So, in order to get highly efficient cathode, a series of different growth procedure and characterization techniques is currently being followed in our R&D activity. Currently our major interest on to develop a reliable and reproducible recipe of K-CS-Sb material, in which we have implemented our past gathered data related on these types of photocathode material [3]. Also, we have included some surface science techniques to investigate the material growth [4].

Information about the film thickness, substrate temperature, thermal treatment and their possible effects on properties of photocathode are discussed in this paper together with a comparison of the performances of the photocathode produced so far.

EXPERIMENTAL LAYOUT

In order to get a stable and reproducible recipe, the current R&D activity has been developed in a dedicated UHV (Ultra High Vacuum) system [5] that consists of two interconnected chambers which are used for cathode growing and storage of samples. The cathode growing chamber is maintained with based pressure in the 10^{-11} mbar range provided by eight SAES Getters NEG St707® modules and a 400 ls^{-1} ion pump. It is also connected with a μ-metal chamber which hosts a Time Of Flight spectrometer used for thermal emittance measurements [6].

A LDLS (Laser Drive Light Sources) system accompanied by a certain dedicated optical filter (in a range of 239 nm to 436 nm) is used to measure the spectral response of the photocathode. An Ar^+ and three He-Ne lasers are also used to cover the range from 457 nm to 633 nm.

Photocathode Preparation

To get a better handling, the photo emissive materials are currently being developed on a simplified Mo sample instead of INFN real plug, used in RF guns. These samples are prepared from a thin slab of high purity molybdenum (99.95 %) through machining. Afterwards, these samples are polished to a mirror like finishing (reflectivity > 54 % @ 543 nm w.r.t. 57 % theoretical) to allow reflectivity measurements during and after the photocathode growth. All samples are ultrasonically cleaned before loading then into the UHV system. Afterwards, each sample is heat up to 450 °C for at least one hour to remove the eventual residual on the surface before starting the deposition process.

A custom-made source for Sb and SAES Getters dispensers for Cs and K is used in the operation. Each source is carefully degassed before each deposition and calibrated to have the proper evaporation rate during the cathode growth. The calibration is repeated before each growth process. The usual rate during deposition is 1 nm/min.

FABRICATION RECIPES

Up to now, six photocathodes have been grown and four of them have already been reported in previous papers [5, 7] and summarized in Table 1. The main outcome of this experience was the need for a better temperature control and a diversification of the temperatures for K and Cs. We explored also photocathodes with different Sb thickness to evaluate its influence on the photocathode properties. The details of growth of two successive cathodes including the influence of both temperature and thickness on photo-cathode's properties has been reported in this report.

KCsSb-5

Since, we recorded a low Quantum Efficiency (QE) for KCsSb-4 (Table 1) where we used 5 nm of Sb, we assumed this was mainly related to the thickness of photocathode material. So, we decided to grow a thicker photocathode. We have grown 10 nm Sb followed by K and Cs at 90 °C

† sandeep.mohanty@desy.de.

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as for KCsSb-4. The detailed photocurrent (@ 543 nm) and reflected power history is reported in Fig. 1. A very long exposition to Cs is clearly visible without a clear maximum indicating the formation of the photocathode. With this recipe, the QE was recorded 4.6 % at 514 nm.

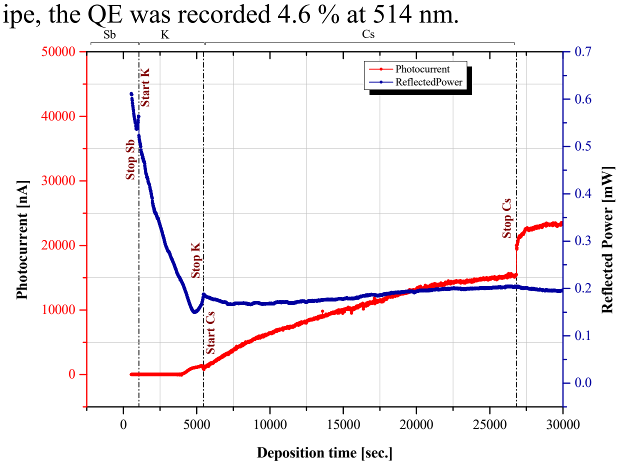

Figure 1: Photocurrent (red) and reflected power (blue) during deposition of cathode KCsSb-5. The incident power @ 543 nm during photocathode growth was 1.9 mW.

KCsSb-6

To further investigate the effect of thickness and temperature, we produced this new cathode with a thin Sb layer by changing the substrate temperature. We have grown 5 nm Sb at 90 ˚C. Thereafter we increase the substrate temperature up to 120 ˚C and deposited the K until the maximum photocurrent. During this process we observed a comparatively less amount of K was deposited than the cathode KCsSb-4 as reported in Table 1. Potentially, increase in substrate temperature helps a faster reaction between K and Sb, so that the photocurrent reached to the maximum in less time and required a less amount of K. Thereafter, we decreased the substrate temperature to 90 ˚C and deposited Cs until the photocurrent reached maximum (see Fig. 2). With this recipe, the final photocathode QE was recorded 4.6 % at 514nm.

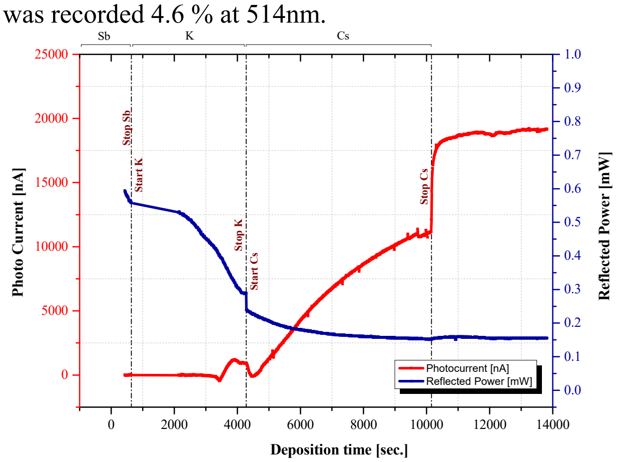

Figure 2: Photocurrent (red) and reflected power (blue) during deposition of cathode KCsSb-6. The incident power @ 543 nm during photocathode growth was 1.9 mW. Notice the much shorter production time with comparable final photocurrent.

CHARACTERIZATION OF THE PHOTOCATHODES

Since, the QE of cathode 1 and 2 was very low, we did not consider them for the following characterization. Figure 3 shows the comparison of QE @ 543 nm during K deposition for KCsSb-3,4,5,6 cathodes. It clearly shows that the substrate temperature plays a significant role in terms of QE for both thin (5 nm Sb) and thick (10 nm Sb) cathodes. A comparatively higher temperature (120 °C for 5 nm and 90 ˚C for 10 nm Sb) gives a higher final QE. Moreover, regarding thickness higher temperatures favor less amount of K deposition. All these indications confirm that a higher substrate temperature induces a faster chemical reaction between K and Sb, requiring then less amount of K to reach comparable QEs.

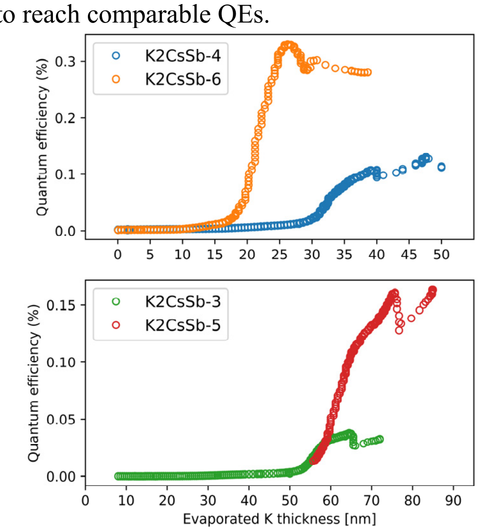

Figure 3: Comparison of QE @ 543 nm during K deposition. Upper plot "5 nm Sb", lower plot "10 nm Sb".

Similarly, the QE during the Cs deposition behaves dependently to the substrate temperature for all four cathodes as shown in Fig. 4. For thick cathodes, KCsSb-5 (grown at 90 ˚C) observed a higher QE slope compare to the KCsSb-3. Similarly, KCsSb-6 cathode observed a higher QE slope compare to KCsSb-4.

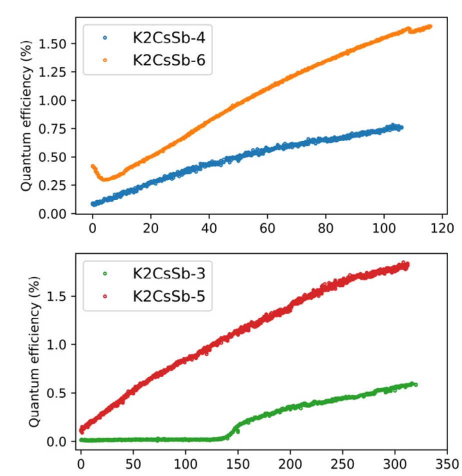

Figure 4: Comparison of QE @ 543 nm during Cs deposition. Upper plot "5 nm Sb", lower plot "10 nm Sb".

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By comparing the reflected power during the deposition between similar thickness cathodes, we found that the behavior of the reflected power curve is quite reproducible, and it's related to the thickness of the material. This behavior is reported in Fig. 5 for "5 nm Sb" (left) and "10 nm Sb" (right).

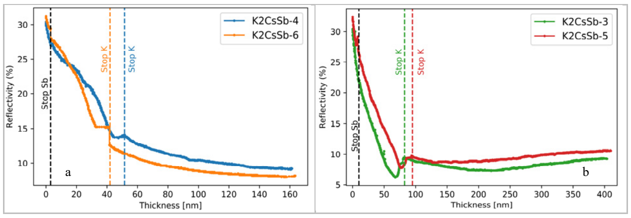

Figure 5: Comparison of reflected power during the photocathodes deposition for 5 nm (a) and 10 nm (b) at 543 nm. The trend is clearly dependent of the Sb layer thickness.

The comparison of final QEs between all four photocathodes is reported in Fig. 6. Due to some technical problem, a spectral response has been limited from 457 nm to 594 nm for KCsSb-3 & 4. Besides this, the behavior of QE at all the wavelengths for all four cathodes is comparable. The maximum QE @ 514 nm recorded 5.2 % for KCsSb-3 and 4 cathodes.

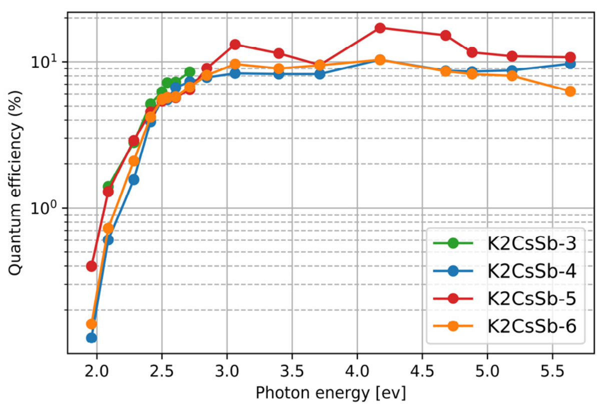

Figure 6: Comparison of QE for KCsSb-3,4,5,6 cathodes.

However, from the comparison of reflectivity behavior between the four cathodes (Fig. 7), shows that thin cathodes (5 nm Sb) at higher wavelength (543 nm, 594 nm) behave completely opposite compare to the thick ones (10 nm Sb).

Table 1: Summary Of Cathode Growing Parameters

Cathode	Sb (nm)	T_{Sb}-T_K-T_{Cs} (°C)	QE (514nm) (%)
KCsSb-1	10	120-150-120	9 10^{-3}
KCsSb-2	5	120-150-120	1.9
KCsSb-3	10	60-60-90*	5.2
KCsSb-4	5	90-90-90	3.9
KCsSb-5	10	90-90-90	4.6
KCsSb-6	5	90-120-90	4.6

*increased from 60 °C to 90 °C during Cs evaporation as reported in [5]

Table 1 summarizes the growing conditions for the KCsSb photocathodes grown so far. All the photocathodes have been grown monitoring the photocurrent @ 543 nm. The temperature column reports the substrate temperatures during the different element depositions. As already noticed in our previous works, cathode 1 and 2 suffers a too high temperature during K deposition that inhibits the proper cathode formation. Moreover, for thin cathodes 120 °C substrate temperature during K evaporation results in higher QE.

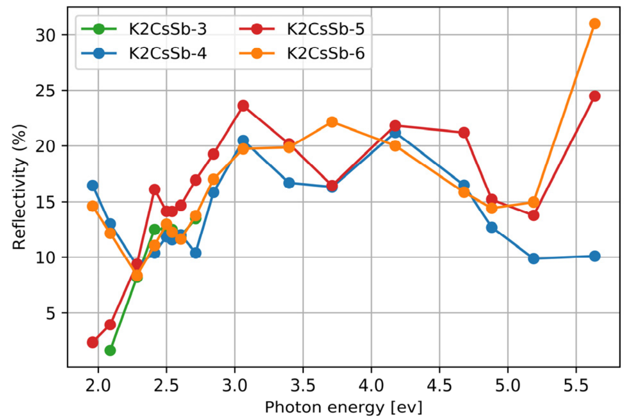

Figure 7: Reflectivity for KCsSb-3,4,5,6 cathodes.

CONCLUSION

The INFN LASA activity on photocathode sensitive to visible light is progressing. A stable recipe is now established, and the R&D activity is exploring influence of Sb thickness and substrate temperatures.

At the same time, we are progressing towards the assembly of a new photocathode production system dedicated to these types of cathodes for growing them on our INFN plugs. This will allow testing them in the environment of RF guns, in particular at the PITZ facility in DESY Zeuthen

AKNOWLEDGEMENT

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