

## PHOTOCATHODE ACTIVITIES AT INFN LASA

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### Abstract

We present the activity on alkali antimonide photocathodes at INFN LASA. The long-term goal is to transfer to these photocathodes the know-how acquired in the successful development of cesium telluride photocathodes, nowadays successfully used in many leading FEL facilities and accelerator complex. In this paper, we present and discuss the results so far obtained on alkali antimonide films grown in our R&D system and the status of the new preparation system specifically designed for these sensitive materials.

### INTRODUCTION

INFN LASA has a long experience [1] in the production and handling of cesium telluride photocathodes used as laser trigger electron sources in RF guns in many accelerators for FEL in Europe (FLASH, PITZ, XFEL) and in the USA (FNAL, LBNL, LCLS-II).

Nowadays, Cs<sub>2</sub>Te photocathodes provide beams and guarantee 24/24h and 7/7days operation to these user facilities. This is possible due to their performances and the development of dedicated systems that allow maintaining these characteristics. The key performances are very stable QE (number of emitted electrons per incident photons), good robustness with respect to the RF gun environment, low dark current during operation in high electric fields and good emittance satisfying the requests for the accelerators where they are in operation. We preserve these qualities by proper handling in UHV environments from the production to the insertion into the RF guns avoiding any contamination from detrimental gases.

The operation of our photocathodes relies on the laser specifications that, shining on the photocathode film, trigger the electron emission generating bunches with the proper temporal structure. Moreover, there has been always a concern about the lowest thermal emittance achievable value. This parameter has now been measured in many laboratories either directly in the RF gun [2-3] or in the production labs [4] and it has been shown to be a no showstopper for the present requirements for Cs<sub>2</sub>Te operation in accelerator-based FEL.

Recent projects are aiming to CW (Continuous Wave) operation of the accelerator to be able to achieve MHz extraction of bunches from photocathodes. This poses challenging requirements to laser specifications that can hardly be achieved with present photocathodes. To investigate the possibility to overcome the limitations so far discussed of

our Cs<sub>2</sub>Te photocathodes while maintaining their performance, we have recently started an activity on visible sensitive photocathodes mainly based on alkali antimonide compounds [5], on the basis of the experience we gathered in the past on these types of photocathode when we applied also surface science techniques to investigate the material growth [6].

This activity on visible sensitive photocathodes is developed in collaboration with PITZ in DESY Zeuthen where we plan to test our photocathodes for fall 2019 to have feedback on a “real” environment operation and use it to improve the growth process.

### EXPERIMENTAL LAYOUT

The R&D activity on green cathodes has been developed in our dedicated laboratory [6] where we have a UHV (Ultra High Vacuum) system of interconnected chambers where the samples can be moved keeping the vacuum conditions. In this system, we have available: a cathode growing chamber with a base pressure in the 10<sup>-11</sup> mbar range provided by eight NEG St707<sup>®</sup> modules from SAES Getters; a μ-metal chamber hosts a Time Of Flight detector, based on a Nd:Glass fs-laser, to measure the thermal emittance of the cathodes within an electron energy range from 0.3 eV up to 5 eV, angle-resolved; an outdated AES (Auger Electron Spectrometer) for basic investigation on contaminants present on the sample surface.

The laser light sources available to illuminate the photocathodes are in the range 457 nm to 633 nm and comprehend an Ar<sup>+</sup> and three He-Ne lasers. We have also available broadband sources as Hg, Xe-Hg and D<sub>2</sub> lamps and a Laser Driven Light Source (LDLS) with dedicated monochromators.

### Preparation for Deposition

For the R&D activity, we are not depositing our photocathodes on the plugs operated in RF guns but instead we use smaller samples that can be easily handle. They are machined from a thin slab of high purity molybdenum (99.95 %) and then they might be polished to mirror like finishing (reflectivity > 54 % @ 543 nm w.r.t. 57 % theoretical) to allow reflectivity measurements during and after the photocathode growth. After the polishing, they are then ultrasonically cleaned before loading into the vacuum system. Each sample is heat up to 450 °C for at least one hour to remove eventual residual on the surface before starting the deposition process.

We use custom made sources for Sb and SAES Getters dispensers for Cs and K. Each source is carefully degassed

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before each deposition and calibrated to have the proper evaporation rate during the cathode growth. The calibration is repeated before each growth process. Our usual rate during deposition is 1 nm/min.

## CATHODE GROWTH

One of the most important parameters to control the photocathode growth is the substrate temperature. In our present setup, the sample is held on a heating plated by two Mo springs. The non-ideal thermal contact introduces some uncertainty in the sample measured temperature.

Our present recipe foresees the deposition of 10 nm of Sb with the sample at 120 °C at a constant rate of 1 nm/min. The temperature is then increased up to 150 °C during the K deposition until we reach the maximum of QE, monitored at 543 nm and collecting the emitted current with a polarized anode. Afterwards, we lower the temperature to 120 °C and we deposit Cs until a new maximum of QE is achieved. After that, the Cs evaporation is stopped, and the QE is monitored until the sample cools down to room temperature.

We measure then the cathode spectral response (QE at different wavelengths) to get information on the photoemissive threshold and on the sensitivity at different photon energies.

As already discussed in [5], the first two photocathodes (deposited at “standard” temperature as previously described, on polished and mat Mo sample) showed a low QE if compared with the one measured on the heating system. Moreover, in both cases the photoemissive films were not visible on the samples, indicating that the film was not properly deposited on the Mo plug. Since both samples, polished and mat Mo, behaved similarly, the surface finishing was excluded as a possible cause of low QE and we started investigating instead the temperature of the sample. Our hypothesis was that, during the deposition the temperature reading of the heater holder did not correspond to the Mo sample one. Indeed, a temperature higher than requested could prevent the growth of the cathode and hence justify the results so far obtained.

Based on this assumption, we set up dedicated measurements at different substrate temperatures. We used a polished Mo sample to measure not only the photocurrent but also the reflectivity during growth.

### CsKSb-3 Production

The first test was done by starting with a relatively low temperature of the heater. After the usual cleaning cycle (from room temperature to 450 °C held for 1 hour) the polished Mo sample temperature was stabilized at 60 °C, well below the temperature (120 °C) used for the CsKSb-1 & 2 cathodes. For this cathode, we monitored also the sample reflectivity at 543 nm during the deposition of the three materials (Sb, K and Cs), for deriving more information on the growing process. Also, for this cathode, the growing was done sequentially evaporating 10 nm of Sb followed by K and Cs, at an evaporation rate of 1 nm/min.

Figure 2 shows the photocurrent and reflectivity vs deposition time. During the Sb deposition, we measure a

reflectivity decrease of 27%, as expected by considering the optical properties of Sb on Mo. Then, we started the K evaporation and we observed an increase of the photocurrent and a further decrease of the reflectivity.

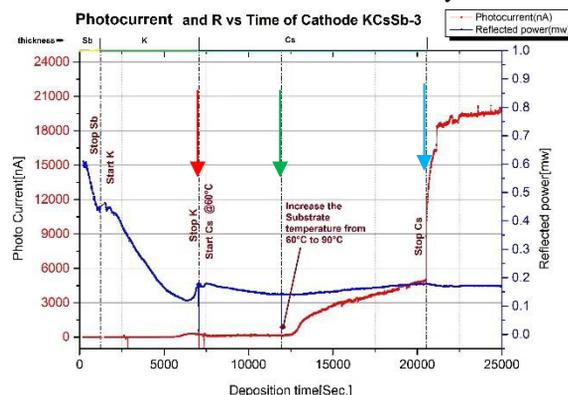


Figure 1: photocurrent (red, left axis) and reflected power (blue, right axis) during deposition of cathode KCsSb-3. The incident power was about 1.9 mW @ 543 nm.

K deposition is stopped once reached the maximum in the photocurrent (red arrow, ~ 7500 s in Fig. 1). Afterwards, we started Cs evaporation for about 1h. The observed unchanged photocurrent (and the low decreasing of the reflected power) was unexpected. We hypothesized that this behavior was due to a non-effective reaction between the KSb film and the Cs vapor, caused by a too low temperature of the sample. We then started increasing the temperature to facilitate the necessary chemical reaction. The temperature increase was immediately reflected on the photocurrent that increased significantly (green arrow at 13000 s in Fig. 2), indicating the starting of the usual chemical reaction for the photocathode formation.

The Cs evaporation was stopped once the last photocurrent maximum was reached. All sources were switched off and the cooling down started (cyan arrow on Fig. 1). Corresponding to the switching off of the sources, we observed a sharp and massive increase of the photocurrent due to the increased collection efficiency of the anode, no longer shielded by the presence of the source frame. The photocathode appears to be blue colored.

Spectral response and reflectivity measurements at different wavelengths are shown in Fig. 2 as measured one day after the deposition.

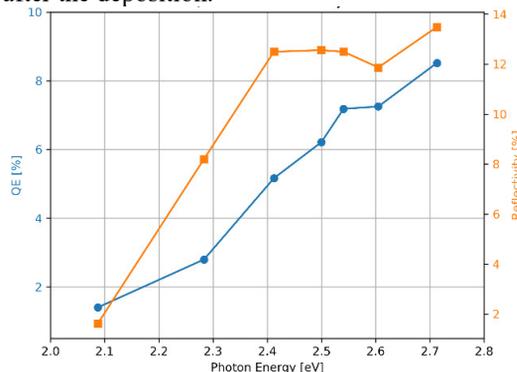


Figure 2: QE (blue) and reflectivity (orange) after one day from the deposition of cathode KCsSb-3.

We studied the behavior of the photocurrent and reflectivity of our photocathode also during the heating process that is used to remove it from the substrate.

Firstly, we heated the plug from room temperature to 120 °C and we observed a significant increase of the photocurrent at 543 nm, indicating the formation of a different compound. We kept this temperature for 30 minutes and then we cooled down to verify that the new compound was stable. The spectral response at room temperature showed a QE increase at all wavelengths (see Fig. 3, 12 d after dep). After this, the photocathode was completely removed by heating the substrate to 450 °C.

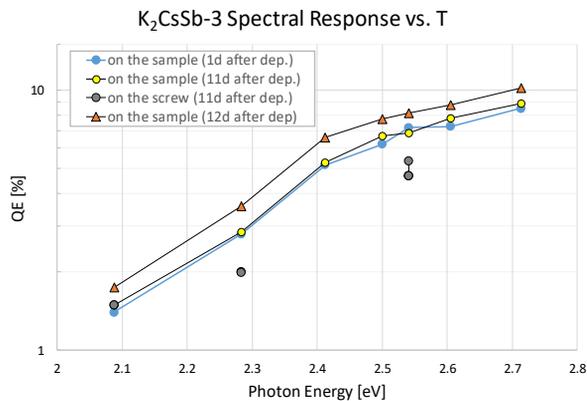


Figure 3: spectral response of KCsSb-3 1d after deposition, 11d after deposition (on sample and on the screws to compare) and after the heating cycle to 120 °C (12d case).

### CsKSb-4 Production

Based on KCsSb-3 experience, this cathode was grown keeping the temperature for all process at 90 °C and monitoring the photocurrent and the reflected power at 543 nm.

For KCsSb-4 all parameters were the same except for the Sb amount that was reduced to 5 nm. The growth process proceeded as expected from the Sb deposition to the end of Cs evaporation (see Fig. 4), with a reflectivity decrease of 10% after Sb deposition. Moreover, before starting with Cs evaporation, the KSb film was characterized by measuring the spectral response and reflectivity. The KCsSb-4 film appeared to be violet, and QE and reflectivity measured are reported in Fig. 5.

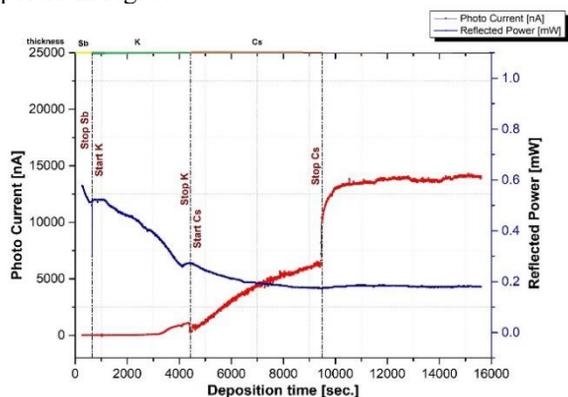


Figure 4: photocurrent (red) and reflected power (blue) during deposition of cathode KCsSb-4. The incident power was about 1.9 mW @ 543 nm.

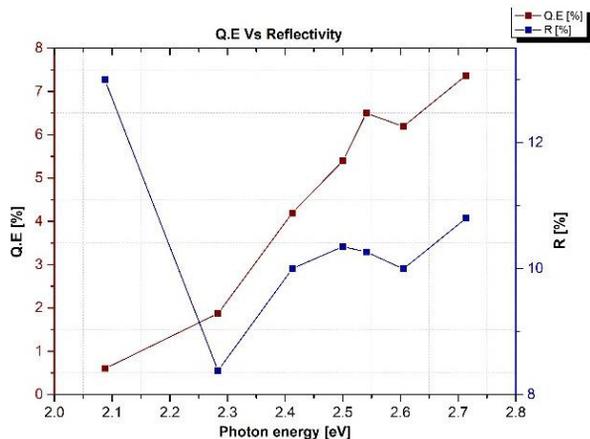


Figure 5: QE (brown) and reflectivity (blue) for cathode KCsSb-4.

The QE for the KCsSb-4 is lower at all wavelengths with respect to KCsSb-3 (see Fig. 6). Surely being the Sb film thinner, the total thickness of the cathode is lower, and this influences the QE values.

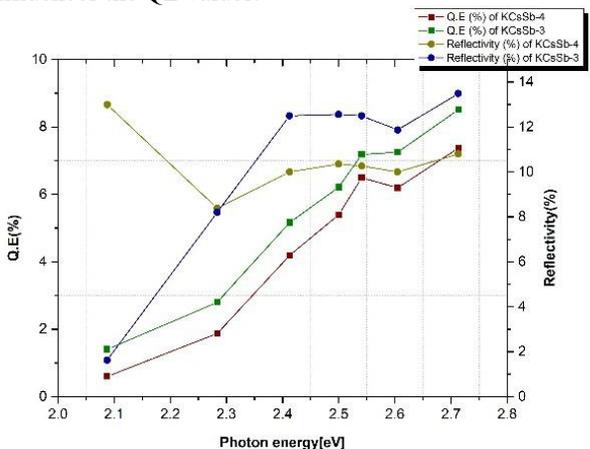


Figure 6: QE and reflectivity for cathode KCsSb-3 and KCsSb-4 at different wavelengths.

## CONCLUSIONS

Two KCsSb have been deposited on Mo samples as part of the R&D program we are developing for transferring reproducible photocathode recipe from sample to plugs useable in RF gun.

Now that the sample temperature is better under control, our program will proceed with the optimization of the present sequential deposition but also with the investigation of co-evaporation techniques.

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