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R&D ACTIVITY ON ALKALY-ANTIMONIED PHOTOCATHODES

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Abstract

Based on the long-term experience on R&D and production of cesium telluride photocathodes for the high brightness photo injectors and the know-how on green photocathodes developed in '90s, we have started a new R&D activity aiming to reach a reproducible and robust recipe for green photocathodes usable in RF gun. In this paper we present and discuss the first results so far obtained on K_2CsSb photo emissive films deposited on polished Mo samples and the plan for future studies.

INTRODUCTION

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

The Cs_2Te photocathodes have shown good performances during their usage in the accelerators, providing beams for 24/24h and 7/7days operation of these user facilities. They have shown very stable QE (number of emitted electron per incident photon), 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.

Besides these properties, the operation of these materials requires UV laser light with the proper temporal structure that poses stringent requirements on the laser specification. Moreover, there has been always a concern about their thermal emittance lowest achievable value that has been measured in many laboratories either directly in the RF gun [2-3] or in the production labs [4].

Recently, to investigate the possibility to overcome the limitations so far discussed of our Cs_2Te photocathodes while maintaining their performance, we have started an activity on visible sensitive photocathodes mainly based on alkali antimonide photocathodes. We had already developed such kind of cathodes in the past, when we applied also surface science techniques to investigate the material growth [5].

In this paper we present our activity on visible light sensitive materials having in mind to have photocathodes usable in an RF gun (like in PITZ at Zeuthen in Germany).

EXPERIMENTAL SETUP

The R&D activity on green cathodes has been developed in our dedicated laboratory [6] where we developed the production process for Cs_2Te and made all the optical and thermal emittance measurements on these cathodes. Here we have an 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 based pressure in the 10^{-11} mbar range provided by eight NEG St707® 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. Finally, an outdated AES detector allows basic investigation on contaminants present on the sample surface.

The light sources available to illuminate the photocathodes in the range 456 nm to 593 nm are an Ar^+ and two He-Ne lasers. We have available also broadband Hg, Xe-Hg and D_2 lamps and a Laser Driven Light Source (LDLS) with dedicated monochromators.

K_2CsSb Cathode Growth

These test cathodes are grown on samples. Up to now, we have used only high purity molybdenum (Advent 99.95 %). The sample is usually polished to mirror like finishing (reflectivity > 54 % @ 543 nm w.r.t. 57 % theoretical) before loading it into the vacuum system. Each sample is heat up to 450 °C for at least one hour before depositing the photo emissive film. The sample is then kept hot at 120°C until the film deposition is completed. The temperature is measured on the sample heater with two thermocouples in direct contact with the heating plate.

We use custom made sources for Sb and SAES Getters dispenser for Cs and K. Each source is carefully degassed before each deposition and calibrated to have the proper evaporation rate during the cathode growth.

Our present receipt foresees a deposition of 10 nm of Sb with the sample at 120°C with a constant rate of 1 nm/min. The sample temperature is then increased up to 135 °C and we proceed with K deposition until we reach the maximum of QE, monitored shining a 543 nm He-Ne laser on the cathode and collecting the emitted current with a polarized anode to overcome the space charge. Afterwards, we lower again 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 monitored until the sample cools down to room temperature.

We measure then the spectral response (QE at different wavelengths) of the newly grown cathodes to get information on the photo emissive threshold and sensitivity at different photon energies.

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EXPERIMENTAL RESULTS

First Cathode

The first cathode has been grown following the receipt described above while keeping the sample at direct contact with the sample heater. The sample was polished to mirror-like finishing as usually done with Cs_2Te photocathodes.

Figure 1 shows the spectral response of this first cathode. We report the spectral response measured in two different spots on the sample/heater region. The data referred as "Max spot" are measured on the Mo screw that holds in position the spring that keep the sample in contact with the heater. The "Sample center" data are instead measured in the middle of the Mo sample. Clearly, there is a quite large difference in QE between the two regions. We believe that the main difference is in the temperature of the two spots during deposition. A second explanation might be related to the Mo finishing or intrinsic properties. Since we monitored the QE growth illuminating the very low QE sample center, it might well be that the growing process was not properly terminated contributing to this low cathode efficiency.

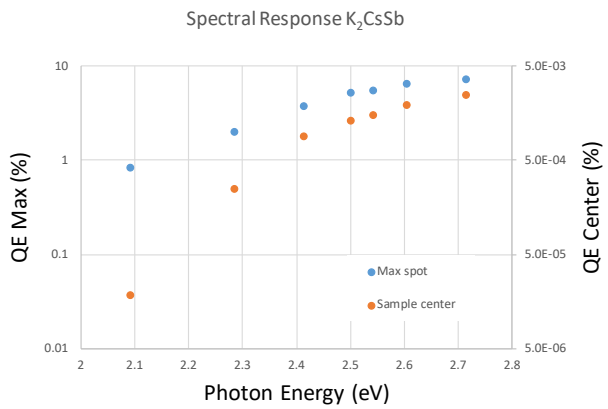

Figure 1: Spectral response of the first K_2CsSb photocathode. The "Max spot" data refers to the response of the highest QE spot located on the sample heater while "Sample center" is the measurement on the sample. Notice the large difference on QE values between the two areas.

Second Cathode

For this cathode, we selected a sample of the same material of the first sample but with a mat finishing. To investigate the effect of the temperature, only half of the sample was in contact with the heater while the other part was not in direct contact with the heater but heated by conduction through the sample.

We followed our standard growth procedure with the sequential deposition of antimony, potassium and cesium. This time the photocathode was more uniform in QE as shown in Fig. 2, where the spectral response of the most sensitive area and the center of the sample are reported. This time the QE of the two areas is comparable, differently from the first deposition. We haven't observed a significant difference in the QE of the two areas on the sample. The Mo screw of the cathode holder has still the highest QE.

Given the better performance of this cathode, we have done a long exposition to evaluate the QE degradation and the extractable charge. This is one of the debating point for this kind of photocathodes due to their sensitivity to gas pollution. The measurement we did in the past showed at least one order of magnitude more sensitivity of antimonide photocathode w.r.t. telluride ones [7].

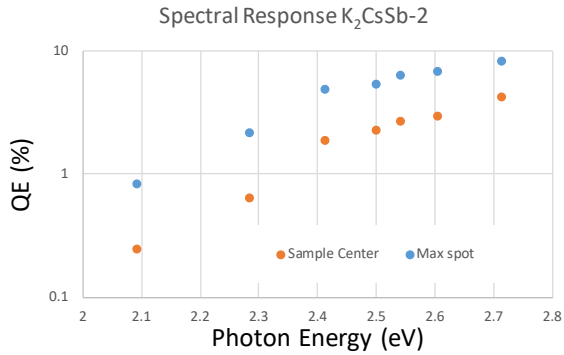

Figure 2: Spectral response of the second K_2CsSb photocathode. The "Max spot" data refers to the response of the highest QE spot located on the sample heater while "Sample center" is the measurement on the sample.

Figure 3 reports the QE trend during four months of exposition to white light. Initially we have used a 5 W broad band white LED light lamp (blue dots). We then switched to a Laser Driven Light Source capable to emit a collimated spot that we focused on the sample (orange dots). The main difference between the two sources is the power density deposited on the sample.

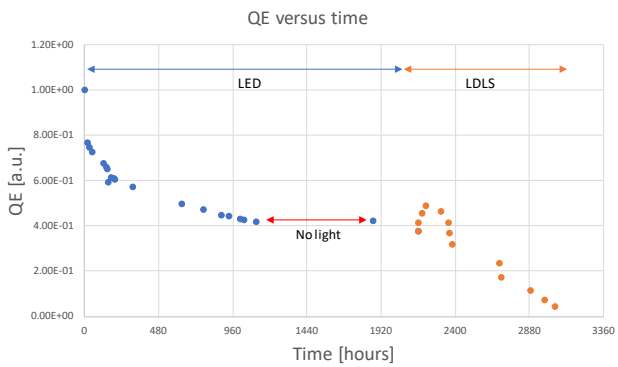

Figure 3: QE trend during four months of illumination. The blue dots represent illumination with an unfocused LED lamp. Orange dots correspond to a collimated beam produced with an LDLS lamp.

During illumination with LED lamp, a nearly logarithmic decay of the QE was observed. Afterward, while using the LSLD source, after an initial bump, we have observed a linear decrease of the QE. During this test, we have also calculated the total extracted charge. Figure 4 shows the total extracted charge versus time. Up to now, we have extracted more than 1800 C collected from the cathode. The clear change in the slope of the plot is due to the change of the light source from LED to LDLS. The

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long plateau between 1200 and 1900 hours corresponds to a period when the cathode was not illuminated.

It has been interesting to measure the spectral response of this cathode after this long period of illumination to estimate the fatigue effect on this sample. Figure 5 shows the spectral response of three different areas on the sample. "Area A" and "Area B" are two spots taken on the sample itself, the former on the heated zone the latter on the indirect heated one. "Area C" corresponds instead to the "Max spot" region of Fig. 2. The ratio in QE between the sample and the high QE region is now a factor five. Moreover, the measurement done on the sample ("Area A" and "Area B") are nearly identical, within the measurement error.

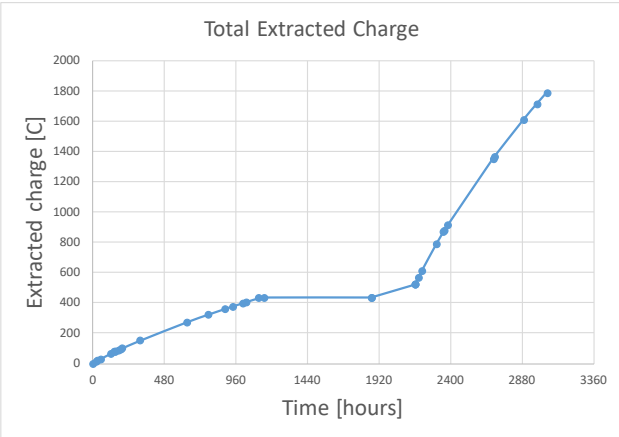

Figure 4: Total extracted charge versus time. Between 1200 and 1900 hours, the cathode was not illuminated.

We have also made a fit to the measured data in order to estimate the photo emissive threshold for the three cases. Using the Kane's model [8] for interpolating the photoemission data near threshold, we have estimated a photoemission threshold value of 1.9 eV for "Area A" and "Area B" while a lower value of 1.7 eV has been extrapolated for "Area C". Moreover, the power dependence of the data for all three cases as 5/2 indicated a "non-direct" process.

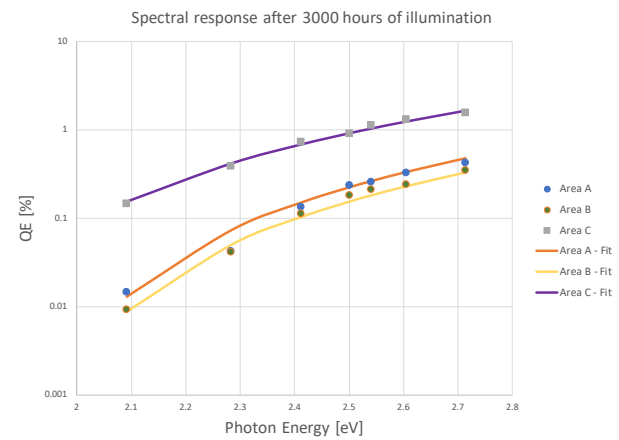

Figure 5: Spectral responses of three areas: A and B on the sample while C correspond at region "Max spot" of Fig. 2. The data has been also fitted applying the Kane's model to extrapolate the photoemission threshold and the type of transition involved in the emission process.

CONCLUSION

Two cesium potassium antimonide photocathodes have been grown in the R&D apparatus at INFN – LASA. While the first cathode showed a low QE on the sample but good QE on a component of the sample heater, the second one reached good QE on the sample as well on the heater. This second photocathode was tested for more than four months exposing it to a continuous illumination firstly by a white light LED lamp and afterward with on LDLS source. Over this long period, the extracted charge has been up to 1800 C and the QE dropped by a factor five for the high QE region and by a factor 10 in the low QE areas. By comparing the photoemission thresholds extrapolated by the data measured in the different areas, the high QE region has a value of 1.7 eV while the low QE region a value of 1.9 eV. These measurements show high stability of this material for the extend period of usage and high extracted charge.

In the near future, we plan to increase the reliability of the production process by studying in deeper detail the effect of sample preparation and heating distribution during the cathode growth. Our final goal is to develop a robust recipe and to transfer it to our plugs so to prepare cathodes able to withstand the harsh environment typical of an RF Gun.

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