ISBN: 978-3-95450-227-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2022-THPOPT027

R&D ON HIGH QE PHOTOCATHODES AT INFN LASA

D. Sertore*, M. Bertucci, L. Monaco, INFN Milano - LASA, Segrate, Italy
G. Guerini Rocco[1], Università degli Studi di Milano, Segrate, Italy
[1]also at INFN Milano - LASA, Segrate, Italy
S. K. Mohanty, H. Qian, F. Stephan, DESY Zeuthen, Zeuthen, Germany

Abstract

We present the recent activities on antimonide and telluride alkali based photocathodes at INFN LASA. The R&D on Cs_2Te materials is focused on investigating effects of material thickness and growth procedures on the photocathodes performances during operation in RF guns. We aim to improve thermal emittance and long term stability of these films. The more recent work on alkali antimonide showed the need for substantial improvements in stability and QE during operation. We present here our recent achievements and plans for future activities.

INTRODUCTION

INFN LASA has a 30 years experience in producing telluride photocathodes for high brightness electron sources based on RF guns. The performances of Cs_2Te films (sensitive in the UV region of the e.m. spectrum) improved over the years, satisfying the major requests for their operation as laser triggered electron source, i.e. QE, QE uniformity, low dark current, and operative lifetimes as long as nearly 4 years in user facility operated 24h/7d [1].

These remarkable results have been achieved thanks to the long experience on photocathodes R&D, in their production and analysis after operation in RF guns. Moreover, the continuous improvement on diagnostic tools to be used during the deposition process (for example multiwavelenght diagnostic) has allowed a better understanding of photoemissive and optical properties of these films [2, 3] and, as a consequence, their improvement in term of operative performances.

Recently, the increasing interest in Continuos Wave (CW) machine moved us to start an activity on alkali antimonide films that are sensible to visible light. This properties allows reducing the requirements on the laser since there is no more need to generate the fourth harmonic, with a significant reduction in complexity of the system and with an increase of available power. R&D studies, still on-going, devoted to the development of a reproducible recipe of KCsSb films, bring us to built, in collaboration with DESY PITZ and European XFEL, a dedicated new production system at INFN LASA. With this system, we deposited three photocathodes in Summer 2021 that were later tested in the RF gun at PITZ (DESY-Zeuthen).

This paper presents and summarizes the main activities devoted to a deeper comprehension of photoemissive and optical properties of UV and green sensitive photocathodes. These studies are a key process towards developing reliable recipes that will guarantee reaching the always more challenging requirements needed for the operation of the photocathodes in the RF guns.

* daniele.sertore@mi.infn.it

Cs_2Te PHOTOCATHODES

A deeper comprehension of the properties of Cs_2Te films is a key point to guarantee the requests coming from their users. The real-time multiwavelenght technique developed at LASA has been optimized during the years and applied both during the deposition of standard films (10 nm Te) and of films grown at different thicknesses. This technique allows studying the spectral responses at different wavelengths and provides a reliable tool to better control the photocathode growth process (limiting the Cs excess), to study the photoemissive energy threshold (E_g+E_a where E_g is the energy gap and E_a the electron affinity) formation, and also to study the optical properties during the deposition process.

The optical properties have been the subject of a recent study [4]. Indeed, we grew films at different thicknesses, by changing the initial Te film, respectively with 5, 10 and 15 nm of Te. A model has been developed to calculate the reflectivity at different wavelengths (from 239 to 436 nm) of a system composed by an optical polished Mo substrate and Cs_2Te with different thicknesses. The values for the refractive index of Mo have been measured in air at wavelengths ranging from 239 to 436 nm and varying angle between 10 to 85° as we reported in the following section, while Cs_2Te values are fitted from our experimental data.

Figure 1 shows preliminary simulation results for the reflectivity at different wavelengths versus the Cs_2Te thickness. The important feature is the flattening of the reflectivity for short wavelengths when the thickness of the photocathode is increased.

As deeply discussed in the before referred paper, the reflectivity presents minima and maxima that are related only to the amount of deposited Cs, i.e. the Cs_2Te thickness. To complete this analysis, our plan is to deposit a even more thick film (20 nm Te) that will allow us completing the analysis in view of better understanding the optical properties of these films.

PITZ colleagues performed emittance measurements on these three cathodes at different thicknesses finding an unexpected anticorrelation between thermal emittance and photocathode QE [5]. A model was developed based on the assumption that the negative correlation between the TMS (Transverse Momentum Spread) and the QE is potentially related to the excess of Cesium that could cause promotion

ISBN: 978-3-95450-227-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2022-THPOPT027

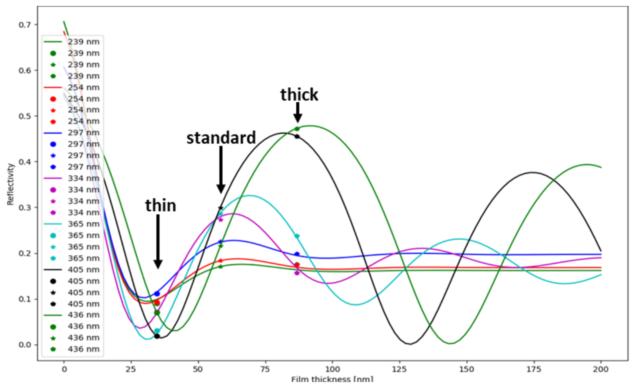

Figure 1: Simulated reflectivity for Cs_2Te versus its thickness. At shorter wavelengths, the reflectivity oscillation are damped when the photocathode thickness is sufficiently increased. "thin", "standard" and "thick" correspond to film with, respectively, 5, 10 and 15 nm of Te.

of the band bending effect and increase the ion scattering on the cathode surface. In collaboration with PITZ, to further investigate this effect we are planning to grow a Cs_2Te photocathode by stopping the Cs evaporation just before reaching the last peak in QE. This cathode is plan to be tested in the PITZ RF gun to validate this hypothesis.

Last item that we are planning is to study the growing of a Cs_2Te with the co-evaporation technique. This technique has shown to allow growing film with reduced roughness [6] w.r.t. our "standard" sequential deposition process. An improved smoothness of the film itself will reduced the dark current, increase the QE (the authors of the cited paper referred 19 % at 266 nm) and possibly also reduce the contribution of the roughness to the thermal emittance of the photocathode, further improving the performance of these photocathodes during their operation in the RF guns.

Complementary to the optical and photoemissive characterization of Cs_2Te films, we are also developing a new instruments to measure the transverse momentum of the photoemitted electrons. The principle is similar to the "momentron" developed at LBNL [7] but adapted to our production systems. TRAMM will allow including the photoelectron transverse momentum as parameters during the growing process. Recent updates and status of this project are presented at this conference [8].

MOLYBDENUM PROPERTIES

The Mo substrate plays a significant role in determining the optical properties of the deposited Cs_2Te film and, by its roughness, the dark current of the photocathode during the operation in the RF guns.

For these reasons, we have made dedicated measurements of the Mo reflectivity, polarization resolved, to determine the real and complex part of the refractive index at different wavelengths as well as the roughness of the substrate by changing the final polishing of the plug. The measurements were done in air in the spectral range 239 to 436 nm and varying the incident angle between 10 to 85°. Figure 2 shows a measurement done at 436 nm where n and k are, respectively, 3.04 and 3.7 with a surface roughness of about 9 nm.

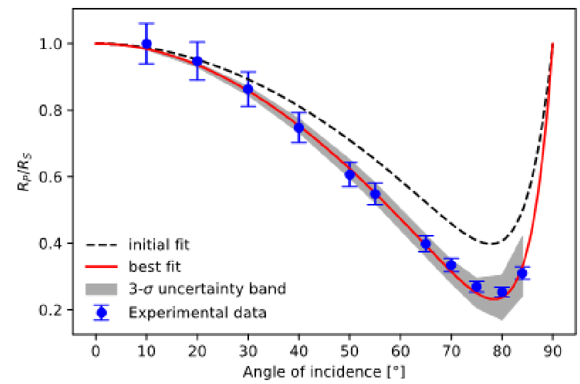

Figure 2: Mo substrate reflectivity measured at 436 nm at different angles. The data are fitted to get the complex refractive index of Mo and the film roughness.

Dark current measurements done at PITZ on the three cathodes with different thicknesses showed that cathode 672.2 (10 nm Te) had a higher value compared to the other ones (see [9]). To validate this hypothesis, we have performed further measurement of Mo plug's reflectivity in the range 239 to 436 nm at a fixed angle of 5° degree to estimate their roughness. From this data we have measured for 672.2 the highest roughness value (σ_r = 11 nm) compared with the other two photocathodes (σ_r = 6 nm for 676.1 and σ_r = 7 nm for 678.1, respectively the thin and thick one). Figure 3 shows the results for 672.2 Mo plug.

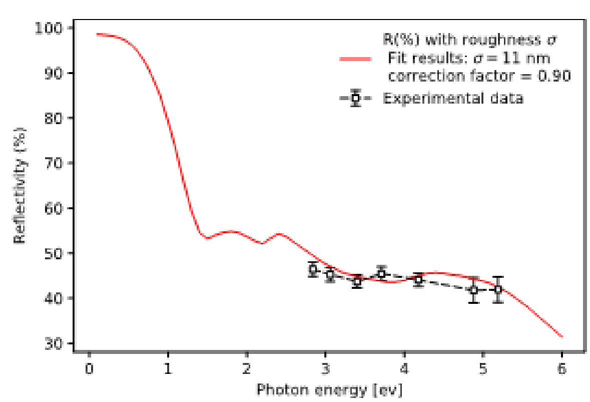

Figure 3: Photocathode 672.2 roughness estimation. The result of the fit is σ_r = 11 nm.

MULTI ALKALI ANTIMONIDE PHOTOCATHODES

As it was reported in previous papers [10–13], we have established a reproducible recipe for KCsSb photocathode in our R&D development. Stimulated by these positive results, we started to produce the first batch of green cathode films

ISBN: 978-3-95450-227-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2022-THPOPT027

Table 1: Summary of Cathode Growing Parameters

Cathode	Sb evaporation	K evaporation	Cs evaporation	QE @ 515 nm
147.1	120 °C, 10 nm	150 °C, 62.4 nm	135 °C, 178.2 nm	5.3 %
112.1	120 °C, 5 nm	constant power, 44.6 nm	constant power, 153.6 nm	7.87 %
123.1	120 °C, 5 nm	constant power, 153.6 nm	constant power, 156.6 nm	7.58 %

on INFN-designed Mo plugs in a newly developed production chamber [13]. These photocathodes were then tested inside the high gradient RF gun at PITZ. A total number of 3 photocathodes have been produced through a sequential deposition method by varying the thickness (i.e., two films with 5 nm of Sb and one with 10 nm of Sb). The detailed recipe parameters of produced photocathodes are summarized in Table 1.

During the growth of the two thin photocathodes (i.e., 112.1 and 123.1), we could not measure the real substrate temperature due to the misalignment of the temperature reading system. So, we set the plug heating power as for the first produced cathode, 147.1. The spectral response and reflectivity have been measured after the production and are reported in Fig. 4 and Fig. 5 respectively.

Figure 6 shows the photos of the three photocathodes after production. As already observed on R&D samples, the film color differs between thick (blue) and thin (violet) ones.

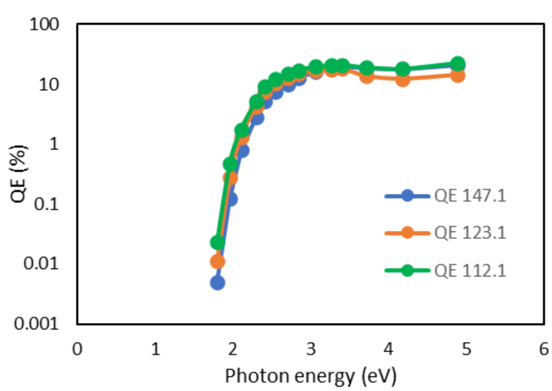

Figure 4: KCsSb photocathode spectral responses: 147.1 (thick, 10 nm of Sb), 123.1 and 112.1 (thin, 5 nm of Sb).

New R&D Development

To further improve the KCsSb photocathode recipe, we explored the effect of different deposition rates on the cathode properties. A new cathode KCsSb-8 has been grown in the R&D preparation system. We have deposited 5 nm of Sb at 90 °C, followed by K at 130 °C and Cs at 120 °C. During the K deposition, we kept the deposition rate at 0.2 to 0.4 nm/min (compared to 1 nm/min before), whereas in the Cs case, the deposition rate was maintained at 0.3 to 0.6 nm/min (compared to 1 nm/min earlier). Due to different deposition rates and slightly improved substrate temperature (i.e., 130 °C) during K deposition, we observed a significant higher QE, of about 1.2 % for KSb compound, compared to previous QEs of about 0.3 %.

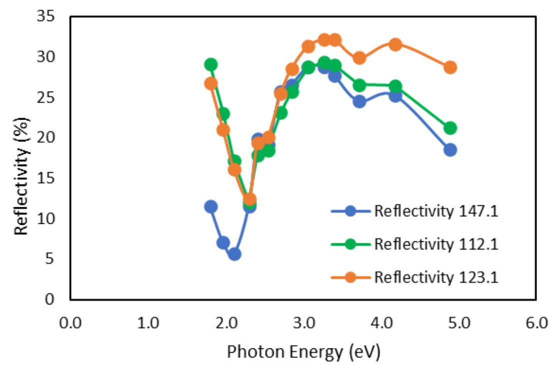

Figure 5: Reflectivity measurements of the three photocathodes. The thick film shows a deeper variation of R at lower photon energy.

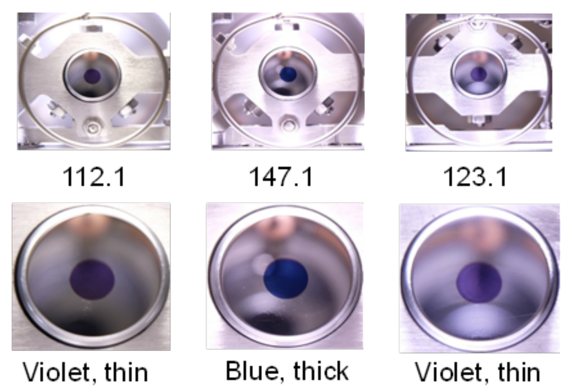

Figure 6: Pictures of the three photocathodes after the deposition in the transport box before delivery to PITZ.

The final QE of the KCsSb cathode was measured as 5.1 % at 543 nm and 8.84 % at 515 nm. The optical characterization of this cathode is currently under-way and we will report the outcome in a future paper.

CONCLUSIONS

The activity on high QE photocathodes at INFN LASA is progressing both with alakli telluride and with alkali antimonide. The investigation of the optical properties of Cs_2Te is the main subject of our R&D activity and the results obtained so far will be completed in the near future. The new co-evaporation technique will be introduced in our production system to explore its effect on the operation of our photocathodes in RF guns. The activity on alkali antimonide photocathode is progressing as well and, after the first three cathodes tested at PITZ, we have had clear indications of the parameters to be improved to increase the now limited lifetime of our photocathodes.

ISBN: 978-3-95450-227-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2022-THPOPT027

REFERENCES

[1] S. Lederer, F. Brinker, L. Monaco, S. Schreiber, and D. Sertore, "Update on the Photocathode Lifetime at FLASH and European XFEL," in *Proc. FEL'19*, Hamburg, Germany, Aug. 2019, pp. 427–429. doi:10.18429/JACoW-FEL2019-WEP047

[2] A. di Bona, F. Sabary, S. Valeri, P. Michelato, D. Sertore, and G. Suberlucq, "Auger and x-ray photoemission spectroscopy study on cs2te photocathodes," *Journal of Applied Physics*, vol. 80, no. 5, pp. 3024–3030, 1996. doi:10.1063/1.363161

[3] L. Monaco, P. M. Michelato, C. Pagani, and D. Sertore, "Multiwavelengths Optical Diagnostic During Cs2Te Photocathodes Deposition," in *Proc. IPAC'10*, Kyoto, Japan, May 2010, pp. 1719–1721.

[4] L. Monaco, G. G. Rocco, P. Michelato, C. Pagani, and D. Sertore, "Growing and Characterization of Cs2Te Photocatodes with Different Thicknesses at INFN LASA," in *Proc. FEL'19*, Hamburg, Germany, Aug. 2019, pp. 297–300. doi:10.18429/JACoW-FEL2019-WEA04

[5] P.-W. Huang *et al.*, "Anomalous correlation between quantum efficiency and transverse momentum spread in semiconductor cathode photoemission," *Phys. Rev. Accel. Beams*, vol. 25, p. 053 401, 5 2022. doi:10.1103/PhysRevAccelBeams.25.053401

[6] M. Gaowei *et al.*, "Codeposition of ultrasmooth and high quantum efficiency cesium telluride photocathodes," *Phys. Rev. Accel. Beams*, vol. 22, p. 073 401, 7 2019. doi:10.1103/PhysRevAccelBeams.22.073401

[7] J. Feng, J. Nasiatka, W. Wan, T. Vecchione, and H. A. Padmore, "A novel system for measurement of the transverse electron momentum distribution from photocathodes," *Review of Scientific Instruments*, vol. 86, no. 1, p. 015 103, 2015. doi:10.1063/1.4904930

[8] D. Sertore *et al.*, "Assembly and Characterization of Low-Energy Electron Transverse Momentum Measurement Device (TRAMM) at INFN LASA," Bangkok, Thailand, Jun. 2022, presented at IPAC'22, Bangkok, Thailand, Jun. 2022, paper THPOPT026, unpublished.

[9] P. W. Huang *et al.*, "Test of Cs2Te Thickness on Cathode Performance at PITZ," in *Proc. FEL'19*, Hamburg, Germany, Aug. 2019, pp. 473–476. doi:10.18429/JACoW-FEL2019-WEP062

[10] D. Sertore, P. Michelato, L. Monaco, and C. Pagani, "R&D Activity on Alkali-Antimonied Photocathodes at INFN-Lasa," in *Proc. IPAC'18*, Vancouver, Canada, Apr.-May 2018, pp. 4284–4286. doi:10.18429/JACoW-IPAC2018-THPMF088

[11] D. Sertore, G. G. Rocco, P. Michelato, S. K. Mohanty, L. Monaco, and C. Pagani, "Photocathode Activities at INFN LASA," in *Proc. IPAC'19*, Melbourne, Australia, May 2019, pp. 2203–2206. doi:10.18429/JACoW-IPAC2019-TUPTS117

[12] S. K. Mohanty, G. G. Rocco, P. Michelato, L. Monaco, C. Pagani, and D. Sertore, "Development of a Multialkali Antimonide Photocathode at INFN LASA," in *Proc. FEL'19*, Hamburg, Germany, Aug. 2019, pp. 448–451. doi:10.18429/JACoW-FEL2019-WEP053

[13] S. K. Mohanty *et al.*, "Development of Multi-Alkali Antimonides Photocathodes for High-Brightness RF Photoinjectors," in *Proc. IPAC'21*, Campinas, Brazil, May 2021, pp. 1416–1419, doi:10.18429/JACoW-IPAC2021-TUPAB034