

SURFACE CHARACTERIZATION AT CERN OF PHOTOCATHODES FOR PHOTINJECTOR APPLICATIONS

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Abstract

R&D on photocathodes takes place at CERN within the CLIC (Compact Linear Collider) project. Photocathodes are produced as thin films on Oxygen Free copper substrate using a co-deposition technique, and characterized in a dedicated laboratory with a DC photo-electron gun. A new UHV carrier vessel compatible with CERN's XPS (X-ray Photoelectron Spectroscopy) analysis equipment has been commissioned and is used to transport photocathodes from the production laboratory to perform a systematic study of different compounds used as photoemissive materials. In this paper photocathodes used in a RF photoinjector will be characterized and the correlation of their surface properties with their performance will be investigated.

INTRODUCTION

Within the CLIC (Compact Linear Collider) project, feasibility studies of a photoinjector option for the drive beam as an alternative to its baseline design using a thermionic electron gun [1] are on-going. This R&D program covers both the laser and the photocathode side. The main challenge for a drive-beam photoinjector is to achieve high bunch charges, long trains and high bunch repetition rates together with sufficiently long cathode lifetimes. Cs₂Te cathodes, sensitive to ultra-violet (UV) laser beam, produced at CERN showed good quantum efficiency and reasonable lifetime in the high-charge PHIN RF photoinjector [2]. However the CLIC design parameters are more demanding (Table 1). The available laser pulse energy in UV for 140 μ s long pulse trains is currently limited due to a degradation of the beam quality during the 4th harmonics conversion process. Using green laser beam in combination with Cs₃Sb cathodes would overcome this limitation.

Both Cs₃Sb and Cs₂Te photocathodes were produced at CERN by co-deposition process and tested in the PHIN RF photoinjector (more detail in ref. [3]). In this paper the cathode surface composition is analysed through XPS technique and correlated to the cathode performance.

CATHODES PRODUCTION AND CHARACTERIZATION

In the CERN photoemission laboratory the cathodes are produced by co-deposition technique resulting in high Quantum Efficiency (max QE~20% for Cs₂Te, max QE~7% for Cs₃Sb) [4,5]. The different chemical elements (Cs, Te or Sb) are evaporated at the same time to mix together in the vapour phase before the deposition onto the OFE copper substrate.

2: Photon Sources and Electron Accelerators

T02 - Electron Sources

Table 1: CLIC and PHIN Beam Parameters

| Parameter | CLIC | PHIN |
|--|-------|---------------------------------|
| Charge/bunch (nC) | 8.4 | 2.3 (nominal) 9.2 (achieved) |
| Bunch length (ps) | 10 | 10 |
| Bunch rep. rate (GHz) | 0.5 | 1.5 |
| Number of bunches | 70000 | 1800 |
| Train length (μ s) | 140 | 1.2 |
| Charge/train (μ C) | 590 | 4.1 |
| Macro pulse rep. rate (Hz) | 50 | 5 |
| Charge stability (%) | <0.1 | <0.25 |
| Beam current/train (A) | 4.2 | 3.4 |
| Cathode lifetime (h) at QE>3% (Cs ₂ Te), QE>0.5% (Cs ₃ Sb) | >150 | >50 |

The cathodes are illuminated with a UV (or green for Cs₃Sb) laser beam during the deposition in order to measure the QE evolution and optimize the process accordingly. The deposited layer thicknesses vary between tens to hundreds of nm [5].

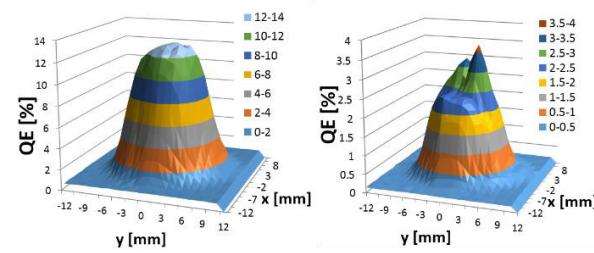


Figure 1: QE maps of Cathode #198 (Cs₂Te) as newly produced (left) and used in the RF photoinjector (right).

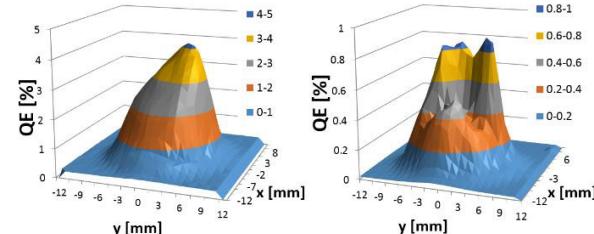


Figure 2: QE maps of Cathode #199 (Cs₃Sb) as newly produced (left) and used in the RF photoinjector (right).

The QE maps (see Fig. 1 and Fig. 2) are obtained in the photoemission laboratory scanning the cathode surface with a small spot size laser beam while the produced charge

is measured with a WCM (Wall Current Monitor) downstream of a DC gun (70 kV bias).

XPS ANALYSIS

XPS (X-ray Photoelectron Spectroscopy) was used to identify and quantify the relative elemental composition of the surface as well as to distinguish the chemical bonding states of such elements. Both XPS literature data [6,7,8] and reference samples are used for detailed analysis.

Measurement Setup

XPS spectra were collected by a SPECS system, equipped with a hemispherical energy analyser (Phoibos 150) and a monochromatized Al x-ray source. The studied cathodes are extremely sensitive to contamination therefore a dedicated UHV transport carrier was used to transfer them from the coating system to the XPS analysis setup. The vacuum level in the XPS setup is good with average pressure: $P \sim 5 \times 10^{-10}$ mbar.

Reference Samples

Both pure tellurium and pure antimony samples were measured in the same XPS setup in order to have reference data for analysis of XPS spectra obtained from the cathode.

The high resolution XPS spectrum taken on the antimony reference sample (Purity 99.999%, GoodFellow) in the as-received state is displayed in Fig. 3, which exhibits the typical doublet pairs of the 3d electronic levels (in this case Sb 3d) due to the spin-orbit splitting. The analysis is in this case complicated by the overlap of the O 1s peak with the Sb 3d energy region. The fit of the experimental data shown in Fig. 3 is obtained by using Gaussian-Lorentzian peaks with fixed area ratio between the two components of the doublet pairs ($Sb\ 3d\ ^{3/2}$ and $Sb\ 3d\ ^{5/2}$). This allowed the identification of the oxygen contribution as the residual intensity. Sb^0 is the covalent antimony (pure metal) while Sb^{3+} is the chemical state of the antimony as in the compound Sb_2O_3 , native oxide generated during exposure to air.

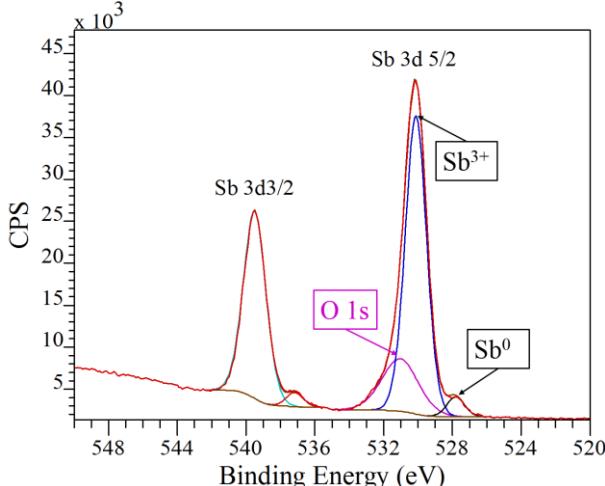


Figure 3: XPS high resolution spectrum of Sb3d + O1s region of oxidized antimony reference sample. Red line—measured spectrum, brown lines—Shirley background, other colours line-fitting profiles.

Measurements on Used Cs_2Te Cathode

XPS measurements were performed on Cathode #198 (Fig. 4) after having been used in the PHIN RF photoinjector for beam production (more details in ref. [3]). The measured Cs to Te atomic ratio is lower than what it should be for an optimal stoichiometric ratio of the photoemissive compound Cs_2Te .

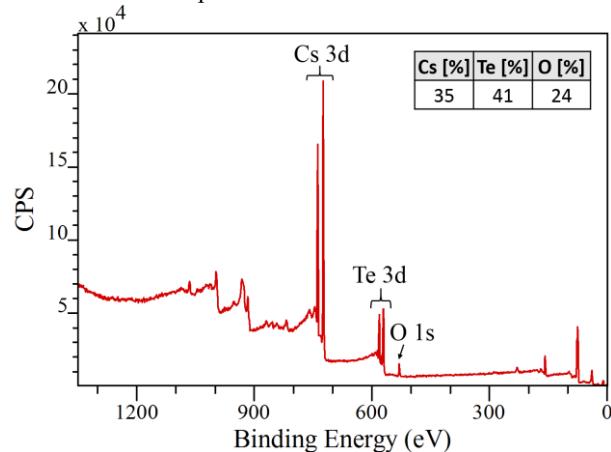


Figure 4: XPS wide range spectrum of used Cathode #198 (Cs_2Te).

Figure 5 shows the XPS spectrum measured with high resolution in the region of tellurium 3d peaks on the same cathode surface. The experimental data are fitted by assuming the coexistence of two different compounds in the broad peak of highest intensity at around 570.5 eV: Cs_2Te (Te^{2-}) together with a Te-rich phase, simulated by the higher binding energy (BE=571.5 eV) peak. The cathode surface is also slightly oxidized (TeO_2) as visible from the presence of the component at 575.3 eV attributed to Te^{4+} .

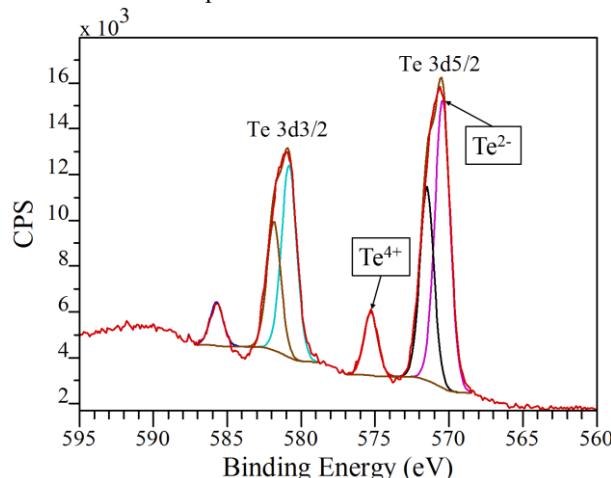


Figure 5: XPS measurements on used Cathode #198 (Cs_2Te), Te 3d region.

The QE map (Fig. 1, right) exhibits an overall QE reduction compared to the newly produced cathode (Fig. 1, left) which can be explained by the possible change of the composition of the photoemissive layer. This will be verified by XPS studies on a newly produced Cs_2Te cathode.

Measurements on Used Cs_3Sb Cathode

Similar studies were done on the used Cathode #199. The quantitative analysis shows a strong lack of Cs compared to the desired compound Cs_3Sb (Fig. 6).

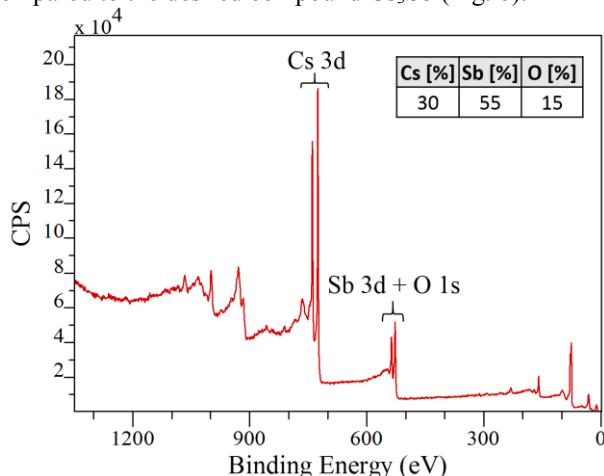


Figure 6: XPS wide range spectrum of used Cathode #199 (Cs_3Sb).

The high resolution XPS spectrum in the region of antimony peaks with the result of an accurate fitting procedure is shown in Fig. 7. The highlighted different chemical states of Sb are interpreted as the occurrence in the cathode surface of Cs_3Sb (peak at 525.9 eV, Sb^{3-}) together with a Sb-rich phase (at 527 eV). There is moreover a component at 527.9 eV which has a chemical state close to that of metallic antimony (Sb^0). Part of the antimony (peak at 529.8 eV labelled as Sb^{3+}) is bound as the oxide Sb_2O_3 like in the reference sample (see Fig. 3).

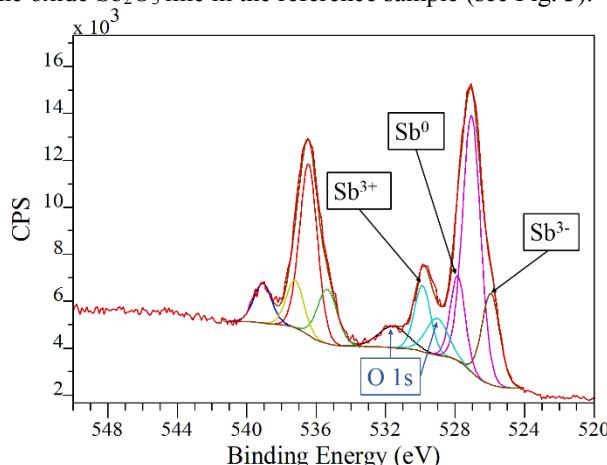


Figure 7: XPS measurements on used Cathode #199 (Cs_3Sb), Sb 3d and O 1s region.

The residual oxygen O 1s contribution (split in two peaks) might be related to the Sb_2O_3 and to another oxide produced with cesium, which is a highly reactive element.

The very low QE (Fig. 2) could therefore be explained by the mixture of the different Sb-based compounds. The analysis of a newly produced Cs_3Sb cathode will allow a confirmation of such hypothesis.

CONCLUSION

Both cathodes were oxidized, most likely during the photoinjector operation as the static vacuum level in the RF gun was very good ($P \sim 10^{-11}$ mbar, no oxygen detected in the mass spectrum of residual gas). However the oxidation seems to not fully explain the deteriorated photoemissive properties. Moreover the overall lack of cesium is a hint of the presence of different Te-based (for Cathode #198) and Sb-based (for Cathode #199) compounds.

According to the analysis done, the Cs_2Te is still the main constituent (more than 50%) of the used Cathode #198 (Fig. 5), which in fact shows still reasonable average quantum efficiency (QE~3%, see Fig. 1).

The analysis made for the Cs_3Sb cathode with the peaks model of Fig. 7 instead attributes to a Sb-rich phase the major component of the used cathode #199, which could explain its poor photoemissive properties (Fig. 2).

During the photoinjector operation many QE degrading processes are acting in parallel (chemical contamination by Electron Stimulated Desorption ESD, ions back-scattering) and can be only partially controlled when related to the cathode material and to the operational condition (e.g. ESD by field emitted electrons) [3].

More investigations are needed to understand whether the Cs-Te and Cs-Sb compounds with the wrong stoichiometry were produced during the test in the RF photoinjector (e.g. by backscattered high energy ions) or result from an inaccuracy in the deposition process.

Measurements on newly produced photocathodes are planned to complete these studies.

ACKNOWLEDGMENT

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement no 289191. We acknowledge collaborators from the Laboratoire de l'Accélérateur Linéaire (LAL) for design and construction of the UHV transport carrier which enabled the XPS studies of the photocathodes.

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