# XPS STUDIES OF $Cs_2Te$ PHOTOCATHODES*

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*Abstract*

Cesium telluride ($Cs_2Te$) photocathodes are used as sources for electron beams because of their high quantum efficiency (QE) and their ability to release high peak current electron bunches in a high gradient RF-gun. Starting from a high QE level of about 10 % the quantum efficiency of these cathodes decreases during operation in a photo-injector to below 0.5 %. To understand this behaviour, XPS investigations on the chemical composition were performed at BESSY. In this contribution we compare two fresh cathodes from INFN with one used under normal operation at FLASH and one used at PITZ at a higher than usual RF-gradient of 60 MV/m.

## INTRODUCTION

The photocathodes used at FLASH and PITZ are prepared at INFN-LASA (Milano, Italy). The electron emitting film is deposited on polished molybdenum plugs in two steps [1]. First, the plug is coated with 10 nm tellurium. During the following cesium deposition, the quantum efficiency (QE) is monitored, and when maximum QE is reached the Cs evaporation is stopped. During the preparation process the temperature of the plug is kept at 120 °C. The diameter of the $Cs_2Te$ coating is 5 mm. Right after the production of the $Cs_2Te$ cathodes, the QE is about 10 % [2].

During operation in electron guns of accelerators, the QE reduces to below 0.5 %. For a better understanding of the QE degradation, the chemical composition of two new (#90.1 and #42.3) and two used cathodes (#34.6 and #92.1) are investigated by x-ray photoelectron spectroscopy (XPS) at BESSY (Berlin, Germany). In addition, the work function of the cathodes was measured. Cathode #92.1 was used at FLASH under the nominal operation condition for SASE FEL generation for 39 days with a final QE of 0.1 %. Cathode #34.6 was operated at PITZ with accelerating gradients at the cathode of up to 60 MV/m for several days. The QE of this cathode decreased to 2 %.

In this paper first results of the XPS measurements are presented. In the first part an overview in the sense of survey scans is given, followed by a more detailed presentation of precise XPS-studies of the Te 3d levels. In the last part, results of work function determinations are given.

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## RESULTS AND DISCUSSION

In figure 1, survey scans with photon energies of 900 eV are presented for the two fresh and the two used cathodes. For all spectra, the main peaks correspond to Cs 3d and Te 3d. While for fresh cathodes peaks corresponding to

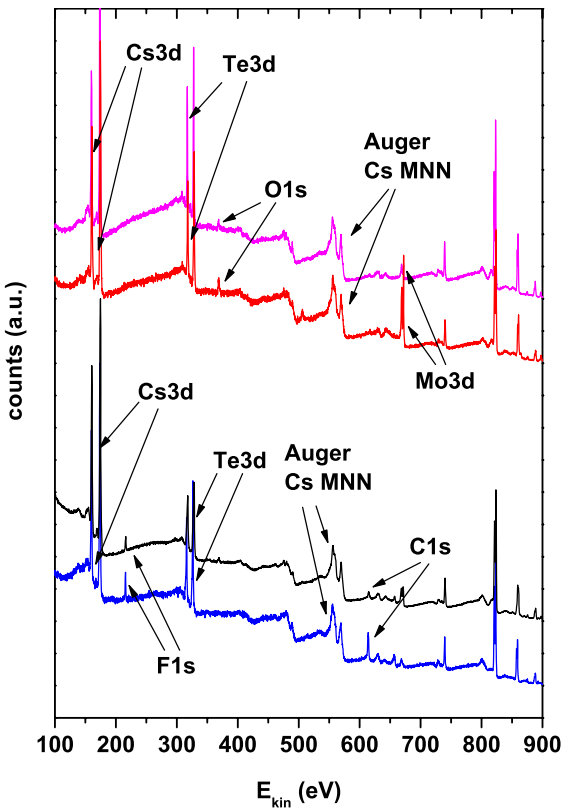


Figure 1: Survey spectra measured at photon energy of 900 eV for fresh cathodes (red: #42.3, magenta: #90.1) and used cathodes (black: #34.6, blue: #92.1)

O 1s are visible, these lines reduce with operation time. We interpret this as a cleaning process during operation caused by the laser pulses (wavelength 262 nm) and the high electrical field at the cathode. Both effects results in

a local heating up of the photocathode. This is consistent with the effect, known now for several years, that $Cs_2Te$ photocathodes poisoned with oxygen can be rejuvenated by a heating process [3, 4, 5]. A further difference in the spectra is that on used cathodes F 1s and C 1s lines appear. The amounts of both elements are non negligible, be-

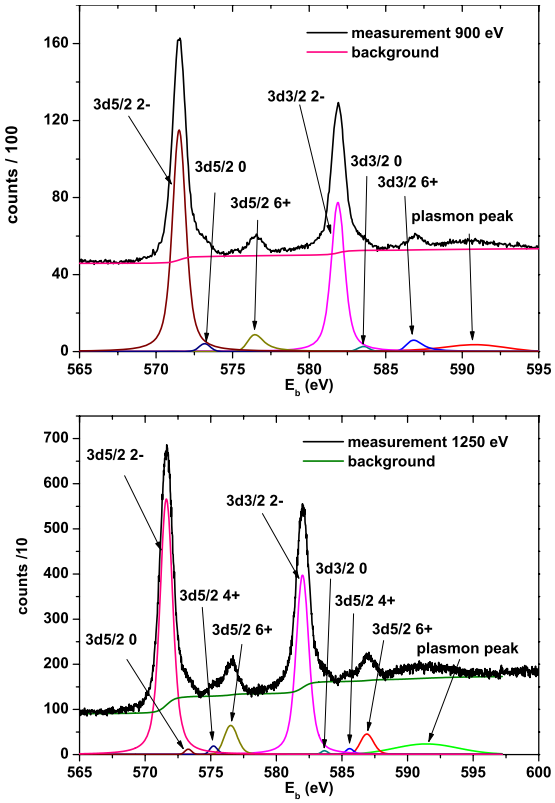


Figure 2: Te 3d lines measured with photon energies of 900 eV (top) and 1250 eV (bottom) at the center of cathode #90.1. In both graphs the measurements as well as the fits to the measurements are presented.

cause of the approximately one order of magnitude smaller photoionization cross sections in comparison to Cs 3d and Te 3d [6]. The origin of this contaminations can be related to some teflon parts inside the beamlines of both facilities right after the gun section.

In figure 2 precise measurements of the Te 3d lines of fresh cathode #90.1 are presented. In this and the following figures, the measured kinetic electron energies ($E_{kin}$) are converted to the binding energies $E_b$ by the classical formula:

$$E_{kin} = E_{ph} - E_b - \Phi \qquad (1)$$

with $E_{ph}$ being the photon energy and $\Phi$ the work function of the analyser. The spectrum on the top of the figure was obtained with an photon energy of 900 eV, the one at the bottom with 1250 eV. For the higher energy the analyzing depth is around 2.5 nm, for the lower 1.5 nm. The dominant peaks in both spectra are assigned to $Te^{-2}$ 3d5/2 with $E_b = 571.6$ eV and $Te^{-2}$ 3d3/2 with $E_b = 581.9$ eV. In coincidence with the oxygen found in the survey scan (figure 1), additional lines caused by chemical shifts are present ($Te^{+4}$ and $Te^{+6}$) for both spin orbit couplings of the 3d electrons. Also a small amount of metallic tellurium is visible.

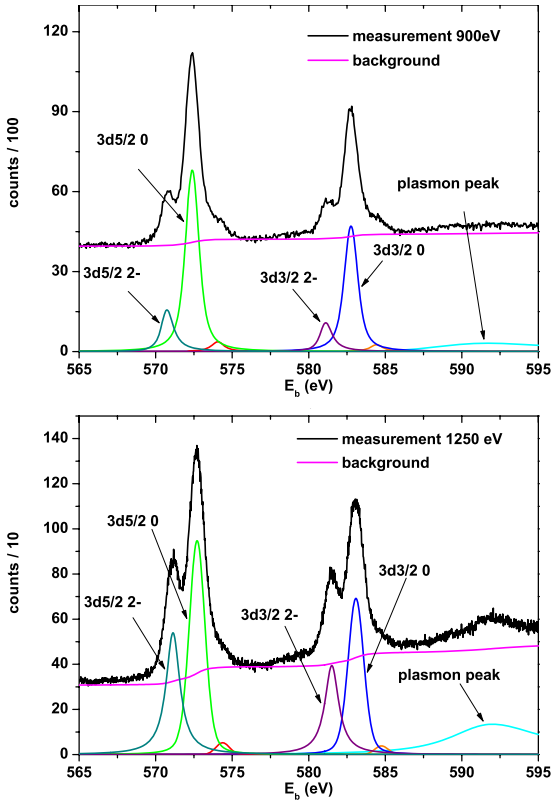


Figure 3: Te 3d lines measured with photon energies of 900 eV (top) and 1250 eV (bottom) at the center of cathode #92.1. In both graphs the measurements as well as the fits to the measurements are presented.

The picture of the Te 3d lines changes dramatically for used cathodes as shown in figure 3. Like for the fresh cathode, measurements were performed in the center of the cathode. Here the dominant peaks for both photon energies are related to the $Te^0$ 3d5/2 and $Te^0$ 3d3/2. For 1250 eV photon energy the amount of $Te^{-2}$ with $E_b = 571.1$ eV for $j = 5/2$ and $E_b = 581.5$ eV for $j = 3/2$ is higher than for the lower energy. Since the analyzing depth is lower for the latter one, the metallic Te states are located close to the surface, while in the bulk region $Cs_2Te$ is still present. The oxidation states $Te^{+4}$ and $Te^{+6}$ disappeared in comparison to the fresh cathodes. This result of being mainly $Te^0$ on the used cathode we interpret as reason for the reduced QE of this cathode, since a large amount of the cathode changed from $Cs_2Te$ to metallic tellurium. Due to the work function of tellurium of 4.95 eV [7] electron emission caused by the drive laser of the accelerators should be strongly reduced.

As seen in figure 4 (left) [2] cathode #92.1 shows a dark area in the center, which has approximately the same diameter as the laser spot size during operation. This area is sur-

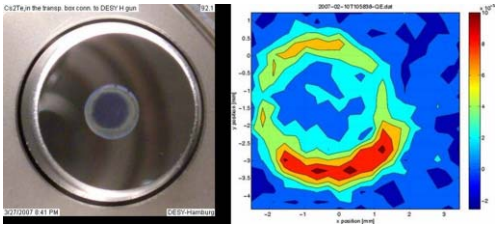

Figure 4: Photograph (left) and QE-map of cathode #92.1.

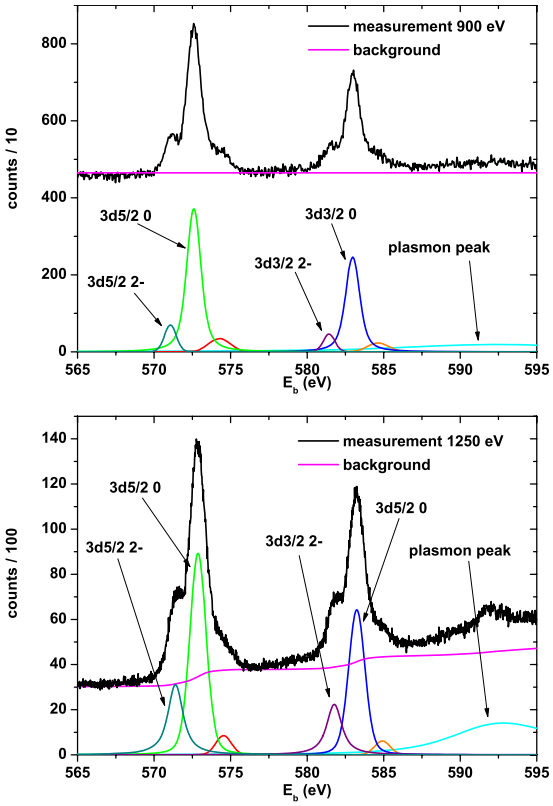


Figure 5: Te 3d lines measured with photon energies of 900 eV (top) and 1250 eV (bottom) at the outer part (for details see text) of cathode #92.1. In both graphs the measurements as well as the fits to the measurements are presented.

rounded by a brighter ring, which also has still some points of higher QE (figure 4 right). Figure 5 shows the measurements of the Te3d lines for 900 eV (top) and 1250 eV (bottom) photon energy together with the fits obtained in the described outer ring. Despite the fact that the laser was most of the time not hitting this area no tellurium oxides can be identified. While the QE of this ring is in some regions higher than in the center of the cathode, the Te 3d spectra measured at both points are comparable. Confirming the observations for the center spot, the main peaks in figure 5 correspond to $Te^0$ and only small amounts of $Te^{-2}$ with binding energies of $E_b = 571.4$ eV for $j = 5/2$ and $E_b = 581.5$ eV for $j = 3/2$ are found.

In figure 6 secondary electron cut offs are measured with

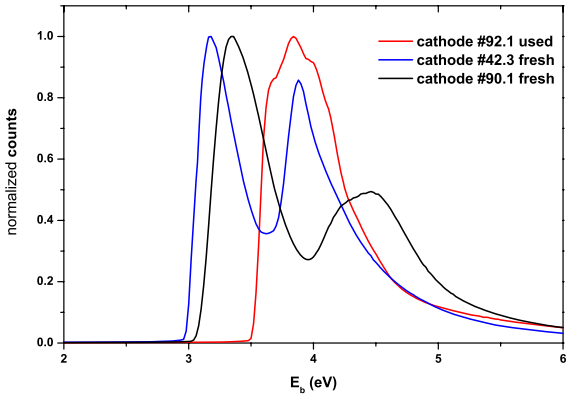


Figure 6: Secondary electron cut offs measured at the center of the two fresh and one used cathode; black curve: #90.1, blue curve: #42.3, red curve: #92.1. For comparison all spectra are normalized to their maximum.

100 eV photon energy for the two new and one used cathode (#92.1). The plot clearly shows that there is a shift of the work function between the fresh cathodes and the used one of about 0.5 eV. Since the lasers at PITZ and FLASH have fixed energies of 4.72 eV, which leads to kinetic energies of 0.55 eV of the emitted electrons, the increase in the work function of 0.5 eV decreases the emission probability of the excited electrons. This results in a strong reduction of the QE (down to 0.1 % for cathode #92.1).

## CONCLUSIONS

The chemical composition of $Cs_2Te$ photocathodes has been analyzed by XPS. Both fresh cathodes were contaminated with oxygen, while on the used ones these lines disappear with longer usage in the gun. Survey spectra of the used cathodes clearly showed F and C. The source of these contaminations was identified as teflon parts inside the beamlines at FLASH and PITZ, which will be removed in future.

Precise measurements of the Te 3d levels show, that the main contribution for fresh cathodes originates from $Te^{-2}$, which corresponds to the expected chemical composition of $Cs_2Te$. In the case of the used cathode #92.1, the main peaks are related to $Te^0$ (metallic tellurium). These results are confirmed by comparing the work functions of used and unused cathodes. An increase of about 0.5 eV for used cathodes was obtained, resulting in a reduced QE.

Based on the measurements performed in this work we relate the decreasing of the QE of $Cs_2Te$ photocathodes to a change in the chemical composition. Starting from $Cs_2Te$ after cathode production, metallic tellurium is formed during operation, which leads to the QE degradation.

## REFERENCES

[1] D. Sertore et al., "Review of the production process of the TTF and PITZ photocathodes", PAC05, Knoxville, Ten-

nessee, USA, 2005.

[2] http://wwwlasa.mi.infn.it/ttfcathodes/

[3] S.H. Kong, J. Kinross-Wright, D.C. Nguyen, and R.L. Sheffield, J. Appl. Phys. **77**, 6031 (1995).

[4] S.H. Kong, D.C. Nguyen, R.L. Sheffield, and B.A. Sherwood, Nucl. Instrum. Methodes A **358**, 276 (1995).

[5] A. di Bona, F. Sabary, S. Valeri, P. Michelato, D. Sertore, G. Suberlucq, J. Appl. Phys. **80**, 3024 (1996).

[6] J.J. Yeh, and I. Lindau, At. Data Nucl. Data Tables **32**, 1 (1985).

[7] H.B. Michaelson, J. Appl. Phys. **48**, 4729 (1977).