XPS INVESTIGATIONS ON Cs_2Te PHOTOCATHODES OF FLASH AND PITZ

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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. A rapid unexpected decrease of the initial QE, from 10 % to values below 0.5 % in only a few weeks of operation, was observed end 2006/beginning 2007. In 2007 a peak of Fluorine possibly originating from Teflon was identified in XPS measurements. After identification and removal of this specific contaminant, the lifetime of the cathodes increased to several months. In addition in 2008 we have investigated the response of fully functional photocathodes to extensive usage, bad vacuum conditions, and oxidation by means of XPS measurements. The experiments - carried out at the ISISS and the PM3 beam lines at the synchrotron facility BESSY II of the Helmholtz Zentrum Berlin HZB- compare the chemical composition and electronic structure of freshly prepared, contaminated, used, and oxidised Cs_2Te cathodes.

INTRODUCTION

FLASH, at DESY Hamburg site, is operated as a user facility under nominal operational condition for SASE FEL generation and for accelerator related studies and thus has a moderate and constant usage of cathodes. PITZ, at DESY Zeuthen site, as photo-injector test facility operates with RF-gradients up to 60 MV/m and has a stronger usage of cathodes. One concern to use Cs_2Te cathodes in user facilities like FLASH and the European XFEL is their lifetime. To further understand this crucial issue, we study their chemical composition by means of x-ray photoelectron spectroscopy (XPS).

CATHODES

The photocathodes used at FLASH and PITZ are prepared at INFN-Milano, LASA. The electron emitting film is deposited on optically finished molybdenum plugs under UHV conditions in two steps [1]. In advance the quality of the Mo surface is checked by reflectivity measurements at 543 nm photon wavelength. In the first production step, the plug is coated with 10 nm tellurium. During the following cesium deposition, the quantum efficiency is monitored. After reaching maximum electron yield the Cs evaporation is stopped. During the preparation process the temperature of the plug is kept at 120 deg C [1]. All relevant information on the cathode production as well as measurements are collected in an online accessible database [2].

After production the photocathodes are stored in a transport box under UHV environment (base pressure low 10^{-10} mbar). This allows the shipment of cathodes under UHV conditions to FLASH or PITZ, where they are connected to the RF-gun load-lock cathode system. In addition an experimental set-up compatible to the cathode load-lock system was developed at BESSY to allow investigations on operated cathodes.

One known reason for increased QE degradation of Cs_2Te cathodes is bad vacuum environment. To further understand this effect, two cathodes have been prepared in the standard way and contaminated afterwards. The first cathode (#500.4) has been exposed to poor vacuum by switching off the vacuum pump several hours, yielding a base pressure of $3 \cdot 10^{-8}$ mbar [3]. The second cathode (#44.3) was polluted in a more aggressive manner by the controlled exposure to 26.5 L (Langmuir) O_2 [3].

RESULTS AND DISCUSSION

All measurements presented in this contribution have been performed at BESSY using the MUSTANG experimental station on the ISISS and PM3 beam lines. Spectra were taken with a hemispherical electron energy analyzer PHOIBOS 150.

In figure 1 survey scans with photon energies of 900 eV are presented for three photocathodes, one freshly prepared, one operated in 2007, and one used in 2008. In all spectra the dominant peaks are associated with Cs 3d and Te 3d doublets. For the cathode used in 2007 a strong contamination with F can be identified. Given the approximately one order of magnitude smaller photo-ionization cross section of F 1s in comparison to Cs 3d [4] the amount of F is much higher than given by the peak height in the scan. Lifetimes of contaminated cathodes at FLASH were few weeks and couple of days at PITZ. After removal of Teflon washers in the low energy sections of both accelerators the lifetime at FLASH increased to several month and to several weeks at PITZ. In addition, a high peak of O 1s is visible for the freshly prepared cathode. Representative for photocathodes operated in the contamination free photo-

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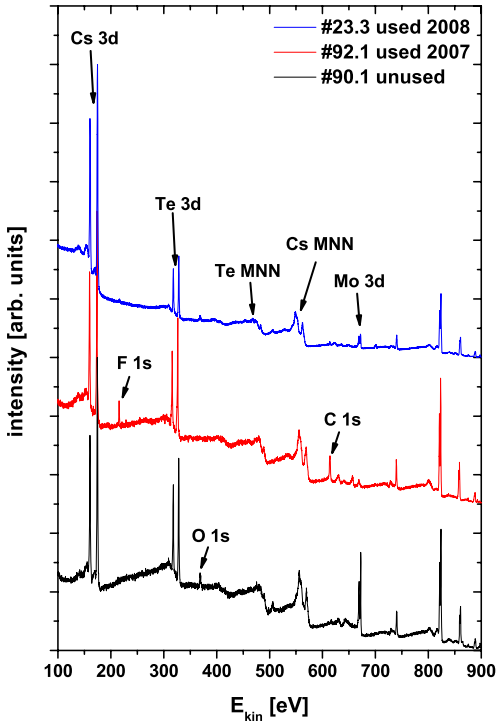

Figure 1: Survey scans with 900 eV photon energy of cathode #23.3 (operated 2008), #92.1 (operated 2007), and #90.1 (unused).

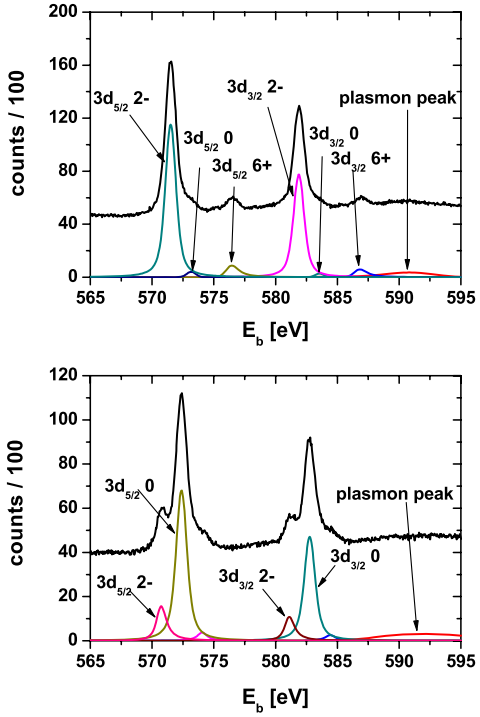

Figure 2: XPS spectra of Te 3d doublet of cathode #90.1 (top) and #92.1 (bottom).

injectors is the survey scan of cathode #23.3 in figure 1. The amount of oxygen on cathode #23.3 is smaller than on cathode #90.1 which turned out to be related to improved vacuum conditions during the preparation.

More information on the chemical composition we derive from detailed XPS measurements of the Te 3d doublet by investigating the chemical shift of the photoemission line, i.e. the change in electron binding energy due to different chemical environment or bonds. In figure 2 measurements of the Te 3d doublet for cathode #90.1 (top) and #92.1 (bottom) are presented. For the analysis the measured kinetic electron energy E_{kin} was converted into the binding energy E_b with the help of:

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

with E_{ph} being the energy of the excitation photon and ϕ the work function of the analyzer. For the unused cathode main peaks are related to Te^{2-} $3d_{5/2}$ and Te^{2-} $3d_{3/2}$. In addition peaks corresponding to oxidation states of Te^0 and Te^{6+} are present. The spectrum for the cathode used in F contaminated environment dramatically changes. The main peaks now are related to metallic tellurium and only a small portion of Te^{2-} is found. These results in combination with the F identified in the survey scans is interpreted as a reaction of Cs_2Te to CsF and metallic tellurium [5].

As already pointed out, the removal of Teflon washers as source of F and C yielded in an increased lifetime of cathodes and the survey scan shows no strong contaminations from the residual gas in the RF-guns. These observations are confirmed by the detailed measurement of the Te 3d doublet of cathode #23.3 shown in figure 3. The spectrum consists mainly of Te^{2-} $3d_{5/2}$ and Te^{2-} $3d_{3/2}$. The amount of Te^0 found on the cathode is negligible.

In figure 4 survey scans of the two polluted cathodes are presented (blue line #500.4, black #44.3). For both cathodes the amount of oxygen is higher than for cathode #23.3 and comparable with #90.1 (unused) in figure 1. In addition chlorine and small amounts of fluorine are present on this

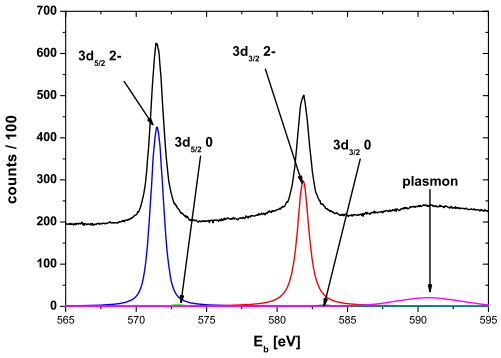

Figure 3: XPS spectrum of Te 3d doublet of #23.3. Black curve: measurement, colored curves: fitted peaks by removing background in advance.

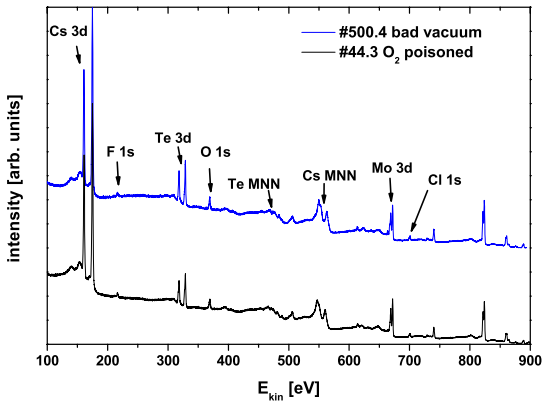

Figure 4: Survey scans with 900 eV photon energy for cathode #500.4 (bad vacuum) and cathode #44.3 (26.5 L O_2).

cathodes. The origin of these contaminants is still under investigation. Teflon as source can be excluded because of the absence of carbone, found on cathodes operated in 2007.

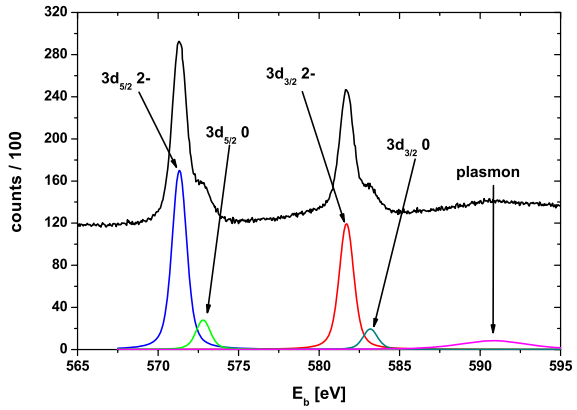

Figure 5: XPS spectrum of Te 3d doublet of cathode #500.4 polluted by bad vacuum. Black curve: measurement, colored curves: fitted peaks by removing background in advance.

In figure 5 detailed measurements of the Te 3d doublet for cathode #500.4 are presented. As for cathode #23.3 most of the Tellurium is assigned to Te^{2-} but in addition a pronounced fraction of Te^0 is present. No higher oxidation states can be identified. Caused by the lower electronegativity of cesium the contaminants found in the survey scan brake the Cs_2Te bonding by coupling to the Cs, which is supported by figure 5.

In figure 6 detailed measurements of the Te 3d doublet for cathode #44.3 are shown. Compared to cathode exposure to bad vacuum the oxygen contamination yields in higher amount of Te^0 but still the majority is Te^{2-}. Again no hints of tellurium dioxide (TeO_2) or tellurium trioxide (TeO_3) are visible.

The results for the cathodes used in 2008 clearly show,

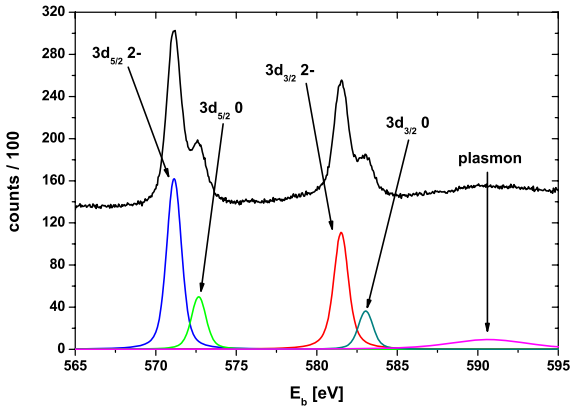

Figure 6: XPS spectrum of Te 3d doublet of cathode #44.3 polluted with oxygen. Black curve: measurement, colored curves: fitted peaks by removing background in advance.

that oxidation of an already finished cathode either by bad vacuum or pure oxygen does not produce tellurium oxides. This is in contrary to the measurements on cathode #90.1 where TeO_3 (Te^{6+}) could be identified. During the production of the latter one the vacuum conditions have been worse than usual. Based on this we conclude that already during the tellurium deposition fractional oxidation took place.

CONCLUSION

The chemical composition of different Cs_2Te photocathodes have been investigated by means of XPS. After strong fluorine and carbon contaminations on cathodes used in 2007 in the FLASH and PITZ photo-injectors, Teflon washers have been removed. This resulted in a strong reduction of contaminations on the cathodes and more important in an increased lifetime of several month [6, 7].

The pollution of cathodes by bad vacuum and oxygen, as expected, yields mainly an increased amounts of O on the cathodes. The oxygen breaks the Cs_2Te bonding in that way that it couples to Cs, while oxidized tellurium could not be identified.

REFERENCES

[1] D. Sertore et al., Proc. PAC 05, pp 671.

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

[3] P. Michelato et al., Proc. EPAC 08, pp 241.

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

[5] S. Lederer et al., Proc. FEL 07, pp 457.

[6] S. Schreiber et al., "Cathode Issues At The FLASH Photoinjector," *Proc. FEL 08, Gyeongju, Korea, 24-29 August 2008.*

[7] S. Lederer et al., "Investigations on the increased life time of photocathodes at FLASH and PITZ," *to be published in Proc. PAC 09.*