FORMATION OF THE Cs_2Te PHOTOCATHODE: AUGER AND PHOTOEMISSION SPECTROSCOPY STUDY

A. di Bona, F. Sabary, CEA-BIII, France
S. Valeri, Istituto Nazionale di Fisica della Materia, Modena, Italia
P. Michelato, C. Pagani, D. Sertore, INFN-LASA, Milano, Italia

Abstract

The formation of the Cs_2Te photocathode on a molybdenum substrate passes through different phases, each of them has been characterised by X-ray photoemission spectroscopy and Auger spectroscopy as well. During the fabrication process different cesium tellurides have been identified in the photoemissive material. The ruggedness to pollution with molecular oxygen at different fabrication stages has been tested. Approximately $5 \cdot 10^{-5}$ sec·torr of exposition reduces the quantum efficiency to one tenth of its original value. The oxidation damage can be partially recovered by simultaneously heating the substrate to ≈ 230 °C and illuminating it with the 4.9 eV ultraviolet radiation. No recovering has been observed under the effect of the temperature or the radiation alone.

1. INTRODUCTION

For many years, the practical applications of Cs_2Te photocathodes was limited to solar blind light detectors [1] and reference standards for ultraviolet (UV) light intensity [2]. Very recently, the interest on this material has been renewed due to the application they could have in high quality electron sources for particle accelerators [3,4]. Their operational lifetime in the radiofrequency cavities is 20 - 30 times longer than that of (multi)alkali antimonide photocathodes [5,6] making Cs_2Te the "ideal" photoemitter for laser-driven photoinjectors. The price we must pay for this, is the relatively high threshold energy (3.6 eV), which forces us to use UV radiation to produce the electron emission.

Even though the physical parameters that control the quantum efficiency have been known for over fifty years, the improvement of a particular material is usually attained by changing the fabrication parameters (by a combination of "intelligent guessing" and luck) in feedback with the photocurrent yield alone. Not much information can actually be gained about the processes that lead to the photoemissive material. An understanding of these processes may be useful for improving the reproducibility and the quantum efficiency of the photocatodes. To this purpose, a Cs_2Te preparation system has been connected, by a Ultra-High Vacuum (UHV) transfer system to an analysis chamber, equipped with standard surface science facilities (scanning Auger, Ar^+ depth profiling, X-ray photoemission spectroscopy). With this experimental set-up, the changes in the quantum yield can be directly correlated to the electronic structure of the material, which in turn give us much more information than the photocurrent alone.

2. EXPERIMENTAL

Cs_2Te thin films (tens of nm thick) were fabricated under UHV conditions (base pressure less than $5 \cdot 10^{-11}$ mbar) on Mo substrates. Before the introduction in the fabrication system, the substrates were mechanically polished with 1 μm diamond powder, then rinsed with acetone and ethanol. Once UHV conditions were obtained, the substrates were heated at 500 °C for about 30 min to improve the surface cleaning. During this phase, the total pressure never exceeded $2 \cdot 10^{-9}$ mbar.

During the fabrication process, the substrate was held at 120 °C by resistive indirect heating. First, we deposited 10 nm of Te at a rate of 1 nm/min. Then, the film was illuminated by the 253.7 nm radiation and Cs was deposited at a rate of 1 nm/min. The photocurrent gave us a real time control of the growth process, as shown in Fig. 1. At the end of the fabrication, the Cs source and the substrate heater were simultaneously switched off. The cooling rate was 6 °C/min.

The Auger emission was excited by an electron beam operating at 3 keV, 1 μA, over a 30 μm × 30 μm area. Auger spectra have been measured using a single pass Cylindrical Mirror Analyser (CMA) operating at 0.6 % relative resolution and in the first derivative mode (modulation voltage of 15 V peak-to-peak). Auger depth-profiles were achieved by an Ar^+ ion gun, operating at 1 keV, 30 $\mu A/cm^2$, rastered over a 2 mm × 2 mm area.

XPS spectra have been collected by a Leybold LHS-12 subsystem, equipped with a Concentric Hemispherical Analyser (CHA) and a non-monochromatised, Mg X-ray source, tilted by 45° with respect to the CHA axis.

3. RESULTS AND DISCUSSION

Fig. 1 shows the Quantum Efficiency (QE) at 254 nm as a function of the Cs nominal thickness. The photocathode formation starts at (a), where the Cs vapour reacts onto the pure Te film, then proceeds through (b)-(c)-(d) showing several characteristic and reproducible changes in the slope of the photocurrent curve, and finally in (e) a

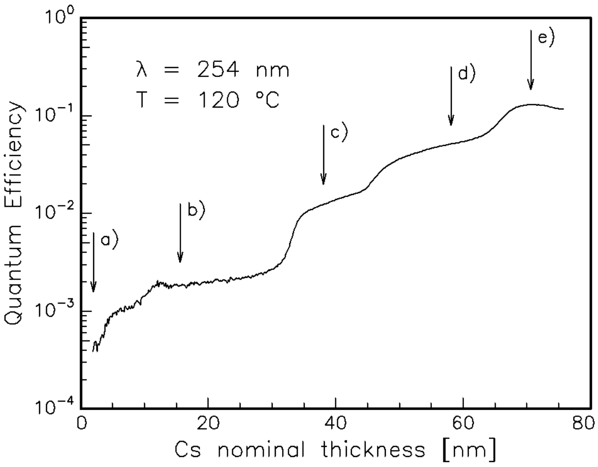

Figure 1: Quantum efficiency as a function of the Cs nominal thickness during the fabrication of the photocathode. The arrows indicate the fabrication steps at which XPS experiments have been performed.

maximum in the photocurrent is reached and the fabrication is terminated.

The Auger depth-profile of the completed photocathode shown in Fig. 2 rules out the presence of Mo up to 20 nm from the surface, and establishes the uniformity of the photoemissive film. The contamination from O is limited to the interface between the substrate and the film, and probably it is due to a residual oxidised layer which survives to the substrate cleaning procedure.

The "stepped" behaviour of the QE of Fig. 1 suggests us that the formation of the Cs_2Te film takes place through different phases [9]. The Te 3d XPS features after each fabrication step are shown in Fig. 3. The spectra b) - d) have been synthesised in terms of three spectral components obtained by shifting and/or rescaling the spectrum of pure Te, curve a), to minimise the sum of the squared residuals. This synthesis procedure is justified by the charge potential model (CPM) for the core-level line shifts in photoemission [10] and each component correspond to a different Cs-Te chemical bond.

After 20 nm of Cs evaporation (Fig. 3b), a second Te component appears at 572.2, indicating that approximately a half of the Te reacts with the Cs vapour. The -0.6 ÷ -0.7 eV BE shift, also indicates that a charge transfer from the Cs to the Te valence shells occurs. At this growth stage, the photocathode is in a two-phase state: "pure", *i.e.* covalent, Te and a Cs-Te compound with a Cs-to-Te ratio of 1.2. As the Cs evaporation is carried on, the low BE component grows at the expense of the covalent Te one (Fig. 3c). A small feature (12%) at + 0.8 eV with respect to covalent Te can be observed.

At 60 nm of Cs deposition (fig. 3d), the Te 3d lineshape is synthesised by three components having similar intensities: covalent Te at 572.9 eV, $Cs_{1.2}Te$ at 572.2 and a new component at 571.0 ± 0.1 eV, which can be assigned to a Cs_xTe compound, with x higher than 1.2.

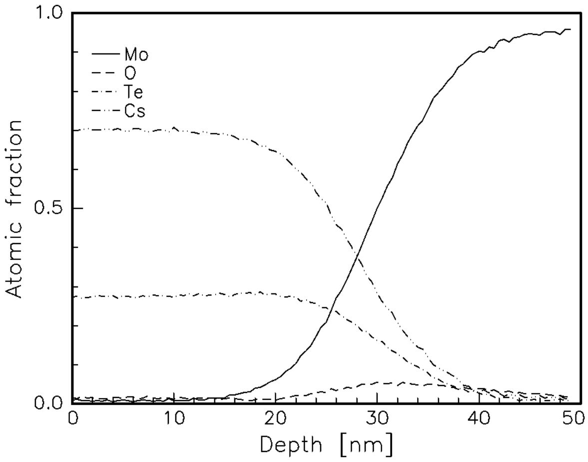

Figure 2: Ar^+ Auger depth profile of the photocathode fabricated on Mo substrate.

The photocathode completion occurs after 70 nm of Cs deposition (Fig. 3e). The quality of the peak synthesis is poorer with respect to the previous cases, indicating that the simple CPM model fails to explain the actual spectral shape. Nevertheless, the energy position of the barycentre of the full 3d feature (571.5 eV), is intermediate between $Cs_{1.2}Te$ and Cs_xTe. If we assume that phase e) corresponds to Cs_2Te, then the Cs_xTe component, falling at BE lower than that of Cs_2Te, should correspond to a Cs-Te compound with $x > 2$.

The operational lifetime of Cs_2Te photocathode under the non-UHV conditions which normally occur in the RF cavities, has been tested by exposing it to few hundred Langmuirs ($1\ L = 10^{-6}$ torr × sec) of O_2. The QE shows a quite fast drop (it reduces to $1 / e$ with respect to its initial value after 15 L) followed by a saturation, rather than an exponential decay law, indicating that a sort of surface passivation takes place. This behaviour has been observed under more realistic vacuum conditions, *i.e.* during the operation of the photocathode in the RF cavity; the QE decreased roughly as a sequence of two exponential decays, the former lasts 30 hours with a decay time of 21 hours, the latter lasts 250 hours and the decay time is 670 hours [11]. The XPS analysis after 100 L of O_2 exposure, shown elsewhere [9], points out that a thick layer of Cs oxide (thicker than the escape depth of the photoelectrons, ≈ 2 nm) forms at the photocathode surface and lowers the QE by two orders of magnitude.

Cs_2Te photocathodes degraded by exposure to poor vacuum conditions could be rejuvenated by a heating process [4]. We found [9] that O_2 pollution could be recovered if, and only if, *i)* the fabrication procedure is carried on until point e) of fig. 1 and *ii)* the heating process is assisted by the 254 nm UV light. The latter condition is fundamental for a successful recovering, as clearly indicated in Fig. 4. In this experiment an oxidized photocathode was heated to 230 °C and two small, circular portions of it, namely 2 mm in diameter, were subsequently illuminated by the 254 nm radiation,

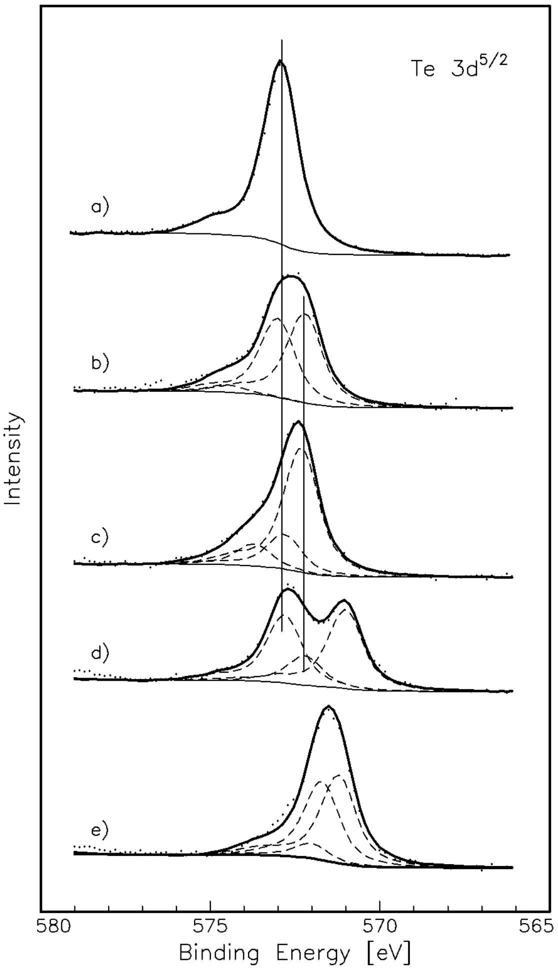

Figure 3: Te 3d 5/2 line at the different fabrication steps. The labels refer to Fig. 1. Spectra b) - e) have been synthesized in terms of the peak a).

600 µW/cm^2. In the illuminated zones the quantum efficiency is better by a factor of 50 with respect to the obscured ones. No rejuvenation was observed in a similar experiment performed at 300 nm wavelength, indicating that there is a thereshold energy for the rejuvenation.

4. CONCLUSIONS

Thin films of Cs_2Te photocathodes have been fabricated, transferred and analysed by Auger and XPS spectroscopy under UHV conditions. Mo substrates have been employed, giving high QE values (6 and 12 %, respectively). The Cs_2Te formation goes on through several steps: *i)* a two-phases system Te + $Cs_{1.2}Te$ is observed at the beginning of the reaction of the Te film with the Cs vapour; *ii)* as the Cs deposition is carried on a new $Cs_{x>2}Te$ phase has been detected ≈ 0.5 nm below the surface; *iii)* finally, a homogeneous, single phase Cs_2Te film results.

The oxygen damages could be partially recovered by heating the photocathode to 230 °C under the effect of the 254 nm UV radiation. No rejuvenation has been observed under the effect of the temperature alone. The wavelength thereshold for rejuvenation has been found between 254 and 300 nm.

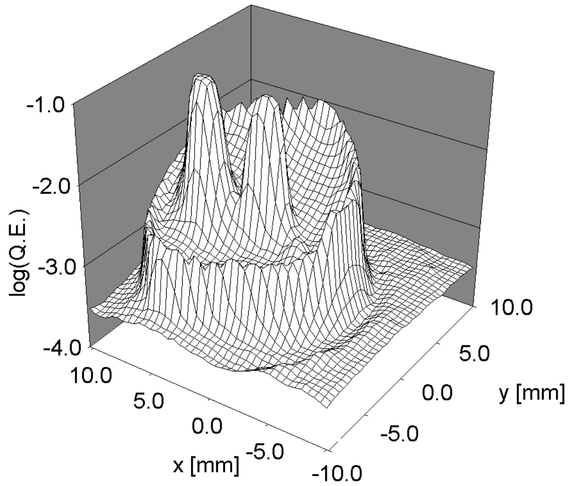

Figure 4: Quantum efficiency map of a rejuvenated photocathode. Only two small spots were illuminated by the 254 nm radiation during the heat treatment at 230 °C.

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