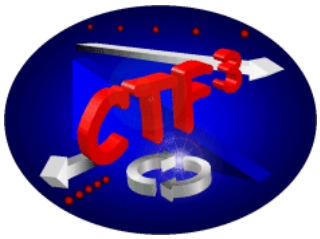
EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH
CERN — A&B DEPARTMENT



CARE-Report-07-018-PHIN

AB-Note-2007-023 ATB

CTF3-Note-089

EDMS No. 831554

Cesium-Telluride Photocathode No. 166

A. Barbiero*, E. Chevallay, K. Elsener, R. Losito

Abstract

In the CERN photoemission laboratory, a Cs_2Te photocathode has been produced in December 2006. The co-evaporation of Cs and Te onto a copper substrate is observed with two quartz oscillator thickness monitors. The calibration of these monitors and the resulting Cs and Te layer thicknesses are described, and the calculated stoichiometric ratio of the sample is given. The quantum efficiency of cathode No. 166, measured using the cathode in a DC gun, has been found to be 6.2%.

We acknowledge the support of the European Community-Research Infrastructure Activity under the FP6 “Structuring the European Research Area” programme (CARE, contract number RII3-CT-2003-506395).

* University of Naples "Federico II", Italy

Geneva, Switzerland
April, 2007

1. Introduction

The photoemission laboratory at CERN was initiated in 1989 as a test bench for photocathodes, in connection with the CLIC test facilities [1, 2]. A key feature of the photoemission laboratory is the DC gun, directly linked to the photocathode preparation chamber. This allows transferring a photocathode under UHV conditions, and reliably measuring the quantum efficiency of the cathode.

A large number of different cathodes have been produced and tested over the years. Cesium telluride photocathodes appear to be well suited for the photoinjector applications at CERN and elsewhere, and many of these have been successfully used in the RF guns of the CTF2 facility [2, 3].

Traditionally, Cs_2Te photocathodes are produced by first evaporating a Te film onto a substrate (Cu or Mo). In a second step, Cs is evaporated onto the Te film. Charge production by UV photons is observed during the evaporation process, and the process is stopped once the charge observed reaches a plateau value. A rather recent new feature introduced at CERN is the simultaneous evaporation ("co-evaporation") of Cs and Te onto the copper substrate [4].

During 2005-2006, and in preparation of photocathode production for CTF3, an in-depth maintenance programme took place in the photoemission laboratory, and a number of improvements were made. In particular, the independent measurement of the Te and Cs layer thicknesses with two quartz oscillator monitors was improved.

In December 2006, E. Chevallay produced a Cs_2Te photocathode, No. 166, following the CERN procedures including Te and Cs co-evaporation.

2. Production of cathode No. 166

The pre-requisites for cathode production involve the installation, in the preparation chamber, of the Cu piece ("plug") with a polished substrate surface, the Cs dispenser[1] and the Mo "boat heater"[2] filled with Te[3]. Standard procedures involve the baking-out of the preparation chamber, reaching a vacuum of better than 10^{-10} mbar. Due to lack of time, and since cathode No. 166 was not going to be used for electron beam production at CTF3, this cathode was produced with the preparation chamber at a pressure of about $2x10^{-8}$ mbar.

The Cu plug is placed in the "RF oven", i.e. a location in which the plug can be out-gassed using RF heating. (In the past, this oven was also used to allow evaporation onto a heated Cu substrate - cathode 166 was produced on a Cu substrate at room temperature). The Cu plug has a diameter of 19 mm, the photocathode evaporated onto it a diameter of 16 mm. The Te and Cs sources are activated by ohmic heating, the two evaporators are heated independently with separate power supplies. This allows to adjust the Te/Cs ratio during co-evaporation (or to evaporate one element after the other).

During the out-gassing of the two dispensers, i.e. during the initial evaporation of Cs and Te (presumably mixed with some impurities), the polished Cu surface on the "plug" is protected by a metallic shutter (pneumatically activated IN-OUT movement). The evaporation of Te and Cs is observed by two quartz oscillator monitors[4]. The main components in the preparation chamber are shown in Figure 1.

Figure 2 shows the on-line data recorded during the production of cathode No. 166. The Te evaporation rate is increased and adjusted first, with the shutter closed. Once a stable evaporation rate is established for Te, the Cs evaporation is started. Soon after this, the shutter is opened and the co-evaporation onto the Cu substrate starts. For cathode 166, the Te evaporation rate was approximately 0.1 nm/min., while the Cs evaporation rate varied from initially 0.2 to 0.4 nm/min later on in the process.

[1] SAES Getters CS/NF/8/25 FT10x10, http://www.saesgetters.com/default.aspx?idPage=470
[2] UMICORE Molybdenum boat 0482047, http://www.thinfilmproducts.umicore.com/pdf/PVD_Materials.pdf
[3] Alfa Aesar, Tellurium shot 1-2mm diameter, 99.9999% (metal basis), product No. 42213, http://www.alfa.com/alf/laboratory_chemical_suppliers.htm
[4] INFICON deposition monitor XTM/2 and deposition controller XTC/2, http://www.inficonthinfilmdeposition.com/en/xtm2thinfilmmonitor.html

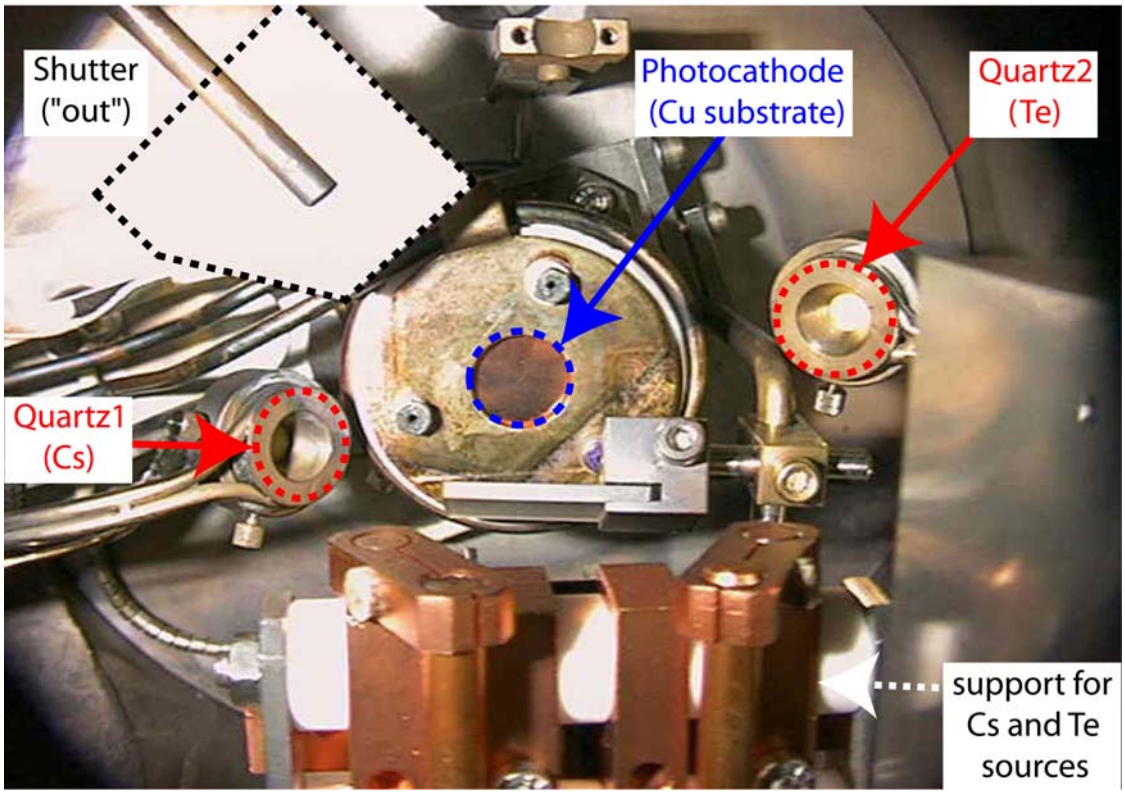


Figure 1: Photograph taken inside the preparation chamber. The Cu substrate (polished surface on the "plug"), the two quartz oscillator monitors and the shutter (in its "out" position) are indicated. Note that the Cs and Te sources are hidden by their support / current feed structure.

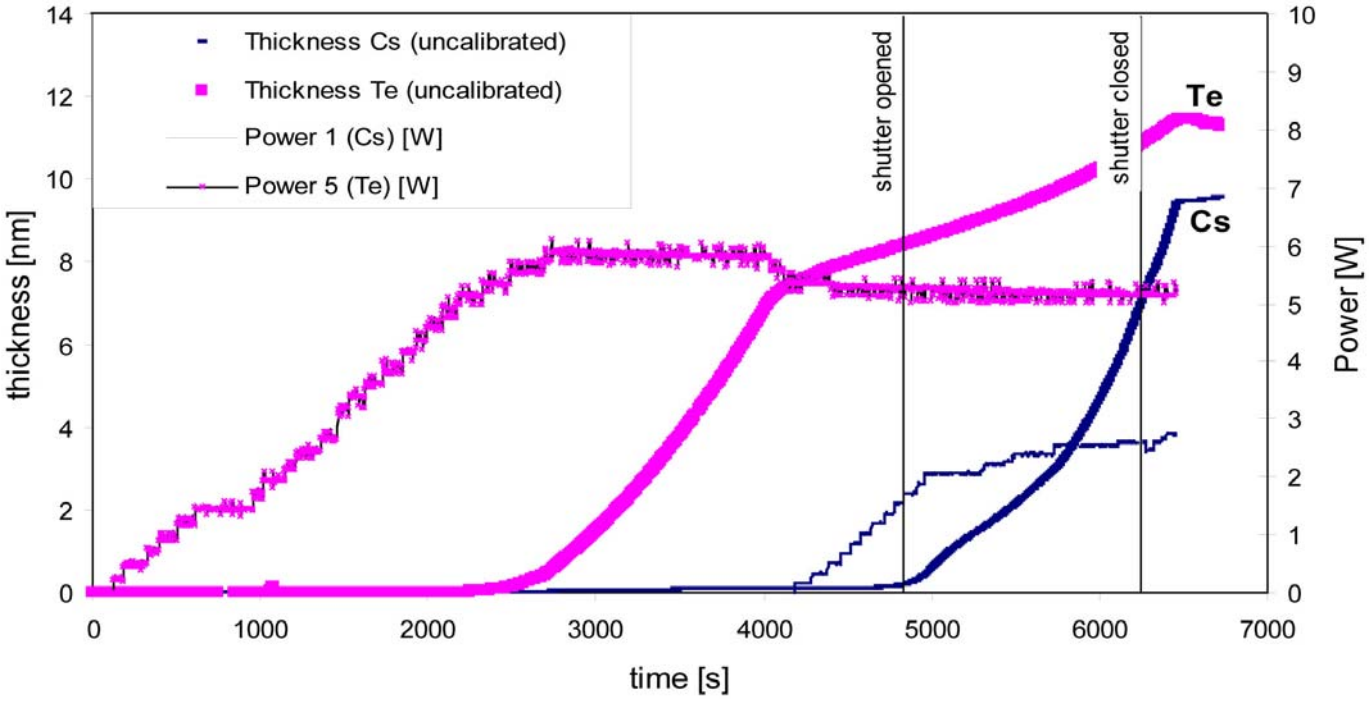


Figure 2: Evaporation of Te and Cs vapours as observed "on-line" by the two quartz oscillator monitors. The power delivered to the two dispensers (heated separately by two power supplies) is also shown. (Note that a second short period with open shutter, from t=6248 to t=6424 s, is not shown in the figure).

During the evaporation process, the 266 nm laser light from a frequency quadrupled Nd-YAG laser is illuminating the cathode which is being created. A voltage of 1.3 kV is used to extract the produced photo-electrons, and the extracted charge is measured in a pre-amplifier / integrator system linked to an ADC. The data recorded are shown in figure 3. Since the charge measurement system saturates at 2 Volts, the laser power is reduced whenever needed to avoid saturation, in steps of 1/4. (Reduction of power is achieved by attenuators, which are installed on the laser table).

The evaporation process continues until the extracted charge reaches a plateau value, at which point it is considered (by experience) that the "best possible" photocathode has been produced. (NB. For cathode 166, the co-evaporation process with shutter open lasted approximately 1300 seconds, of which the last 200 seconds show the stable "plateau" value of extracted charge).

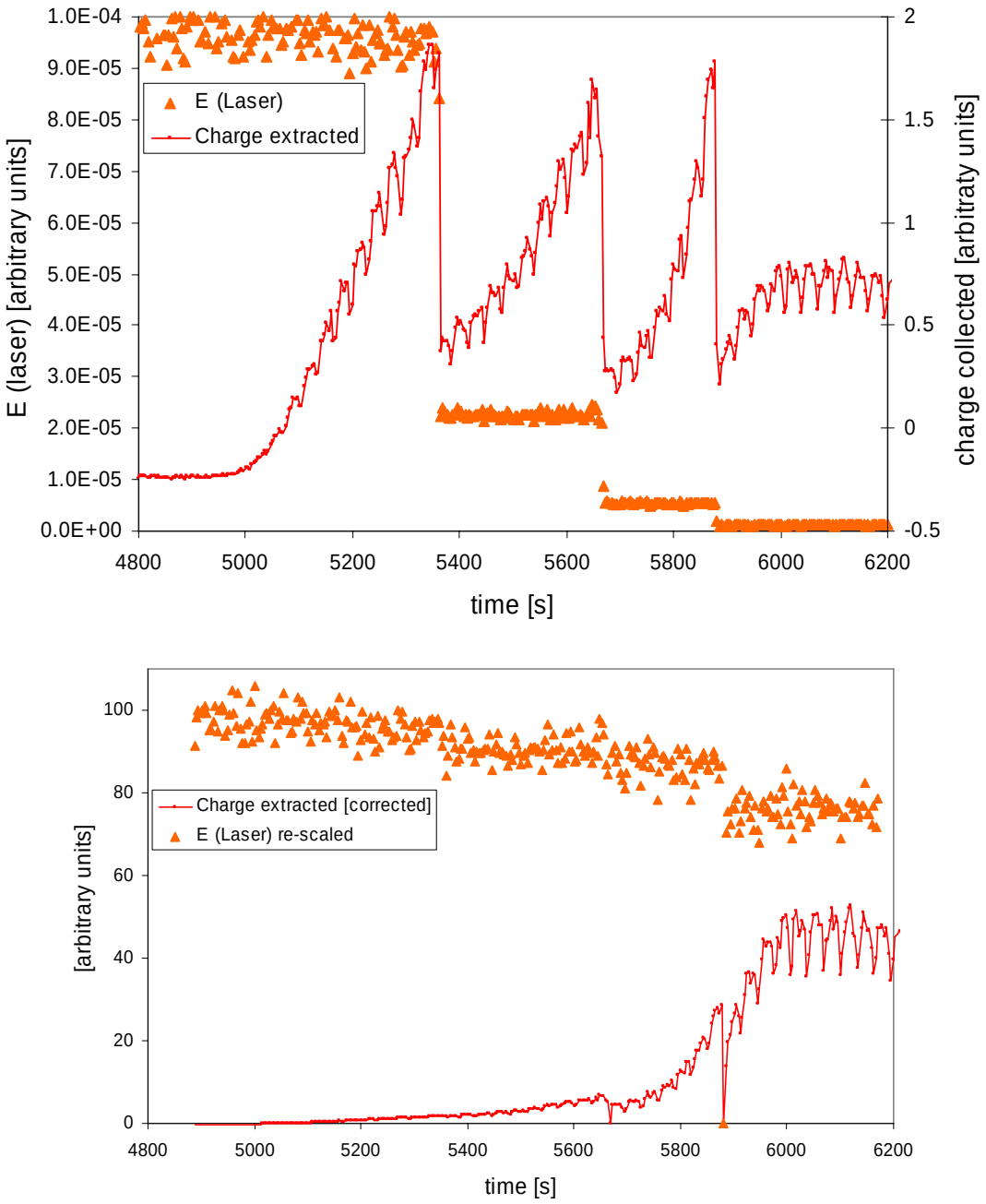


Figure 3: Energy in the laser pulse and charge extracted, as observed during the co-evaporation process. Raw data recorded are shown (top), indicating the step-wise reduction of laser power to avoid saturation in the charge collection electronics. In the bottom figure, the data have been corrected to take the effect of this power reduction into account. Note that absolute laser energy and charge measurements are not crucial here - these are however needed in the QE measurement using the DC gun.

3. Calibration of quartz oscillator thickness monitors

The two quartz oscillator monitors used to observe the thickness of the evaporated layer during cathode production are installed at a few centimetres distance from the cathode. Quartz1 is used to measure the Cs layer, Quartz2 measures the Te layer. Metallic masks prevent Te vapour to reach Quartz1 and Cs vapour to reach Quartz2. This separation has been measured to be better than 98% for both Cs and Te evaporation. A metal plate ("shutter") is used to protect the cathode from deposition of vapour, while deposition on the quartz monitors is being monitored.

While the quartz oscillator monitors are factory-calibrated for various elements, an in-situ calibration is nevertheless necessary in order to take into account the geometrical arrangement of vapour source vs. cathode and vs. quartz oscillators. This calibration can be done for Te only, and is done in a series of "off-line" evaporation tests. A test disc (polished quartz) is inserted at the place of the Cu surface in a modified "plug". For the calibration of Quartz1, the mask against Te deposition is removed to allow Te vapour to reach this quartz oscillator. Evaporation of a typical Te layer (around 20 nm, according to the reading on the quartz monitors) is performed.

Later, the test disc is removed and the Te layer thickness is measured with a stylus profiler[5]. Using this method, a calibration factor of 1.7±0.2 has been found for Quartz1, as an average from 5 different evaporated layers measured at 6 different points each [5]. Considering the geometrical arrangement of Te source, photocathode and quartz oscillator in the preparation chamber, a calibration factor > 1, as measured, is perfectly plausible (i.e. less deposition on the quartz oscillator than on the photocathode).

For Quartz2, the calibration procedure is straightforward, since the masks are in the standard configuration. A calibration factor of 2.4 has been found for Quartz2. The uncertainty in this calibration, estimated from the scattering of 6 different data points on one evaporated layer [5], is 20% (this might be interpreted as a measure of the non-uniformity of the evaporated layer). It should be noted that the calibration factors above are valid for a new (almost full) Te dispenser, as in the present case - additional geometric effects for a half-full or close-to-empty dispenser have been observed and will need further investigation. Note that the difference between the two calibration factors is plausible, since Quartz2 is at a larger distance from the cathode layer than Quartz1.

Due to lack of an appropriate method to measure Cs layer thicknesses (Cs immediately reacts in air, thus transforming the original layer), the calibration factor obtained with Te is assumed to be correct also for Cs evaporation. An additional, uncorrelated uncertainty of 20% is introduced, due to this assumption, in the present evaluation of the Cs layer thickness.

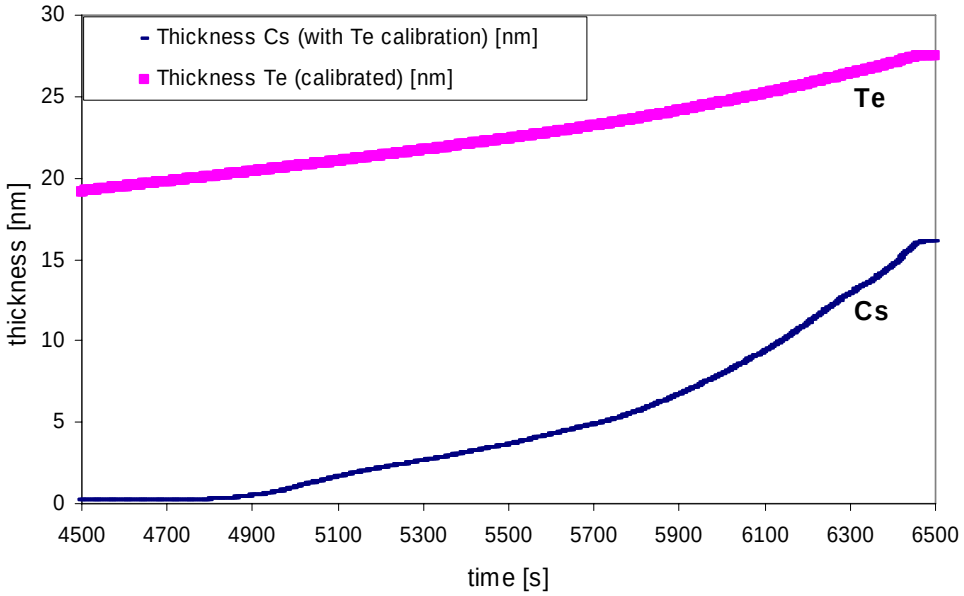


Figure 4: Calibrated layer thicknesses on the quartz balances, for Cs and Te during co-evaporation.

[5] Profilometer VEECO, Model DEKTAK 6M, http://www.veeco.com/

4. Co-evaporation of the cathode and stoichiometric ratio

The Cs and Te vapours reach the Cu substrate of the photocathode only during periods with open shutter. The corresponding layer thicknesses on the cathode are, therefore, obtained from the quartz balance values by subtracting the values measured at the time the shutter is opened. The resulting layer thicknesses (after correction) are shown in Figure 5.

From the layer thicknesses, density and atomic weight, a theoretical value for the stoichiometric ratio can be calculated. The resulting ratio is shown in figure 5 as a function of co-evaporation time. The average stoichiometric ratio is found to be 0.50. (Weighted with the sum of Cs + Te layer thickness the average is 0.52). For the ideal semiconductor Cs_2Te, referred to in the literature, this ratio should obviously be 2. Note, however, that in earlier work [6] it is argued that the theoretical ratio of 2 might not necessarily give the best photocathode.

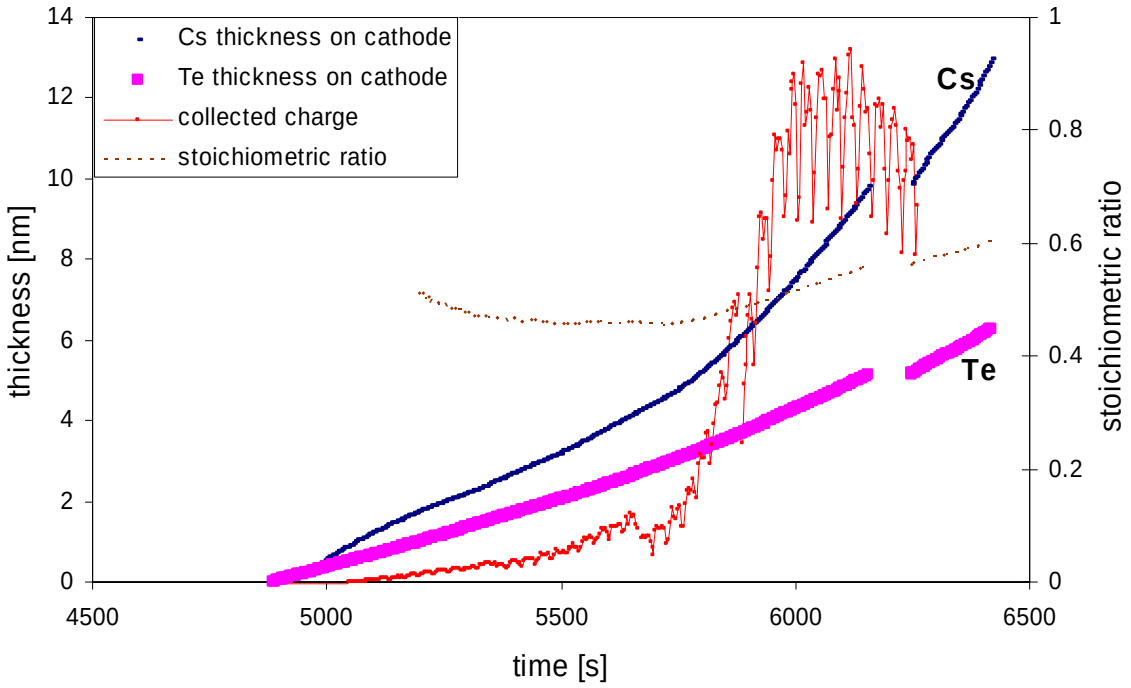


Figure 5: Calibrated layer thicknesses on the cathode (i.e. during periods with open shutter), for Cs and Te during co-evaporation. The calculated stoichiometric ratio is indicated. Also shown, in arbitrary units, is the observed charge produced by the laser during the co-evaporation - it reaches a "plateau" value after approximately t=6000 s.

5. Quantum efficiency measurement with DC gun

The photocathode "plug" is transferred from the preparation chamber to the DC gun using a manipulator arm (under vacuum). Once the cathode is inserted in the gun, the valve towards the preparation chamber is closed. The vacuum in the DC gun reaches approx. 3×10^{-11} mbar.

The 266 nm laser beam (pulse width 5 ns FWHM, repetition rate 10 Hz) is re-directed into the DC gun using mirrors on the laser table. The laser has an angle of a few degrees w.r.t. the electron beam axis of the DC gun and illuminates the cathode over a diameter of 6 mm.

The DC gun is operated at 80 kV. The dark current observed is typically 38 μA. The electron beam produced is measured bunch-by-bunch in a wall current monitor (WCM) [7]. The electron beam is centred by moving the laser beam using a set of mirrors on the laser table. The electron beam is also monitored using a scintillating CsI(Tl) screen and a CCD camera. A typical beam spot and X/Y profiles are shown in figure 6.

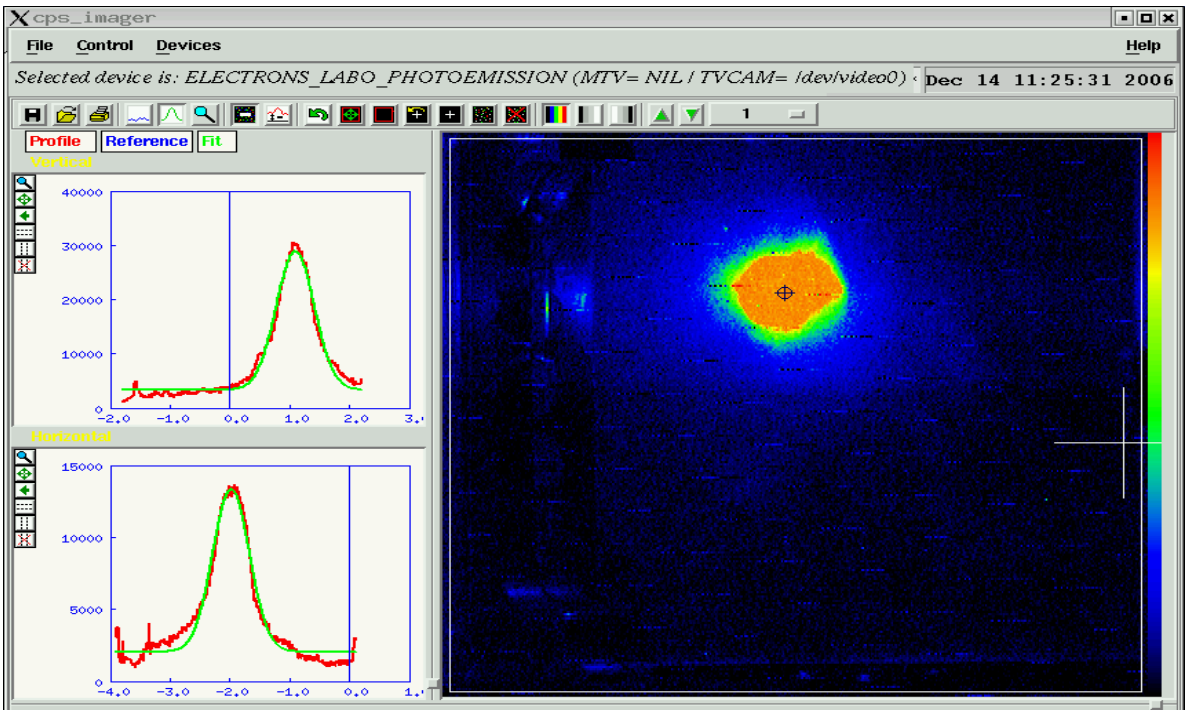


Figure 6: Electron beam spot in the DC gun, observed using a scintillating screen and a CCD camera.

The quantum efficiency QE is defined as the ratio of electrons produced by photons injected,

$$QE = n_e / n_\gamma$$

which, by using the relevant constants, transforms into the expression used in the photoemission laboratory

$$QE\ [\%] = 124 \times \text{charge [nC]} / 266\ [\text{nm}] \times E(\text{laser})\ [\mu\text{J}]$$

The electron charge is readily obtained from the wall current monitor, with an uncertainty of less than 20%. The laser energy is determined in three steps:

a) an on-line Joule-meter (accuracy approximately 5%) allows monitoring a fraction of the laser beam during all the measurements

b) a calibration factor K1 of the on-line Joule meter is measured before and after each QE measurement, using a second Joule meter inserted into the main laser beam at the exit of the laser table - this calibration factor K1 is typically around 0.30, i.e. only about 30% of the laser power is sent to the photocathode.

c) a transmission of K2=0.66 has been established, between exit of the laser table and the photocathode in the DC gun - a measurement in October 2006 confirmed this transmission.

For cathode 166, produced on 14 December 2006, a QE = 6.2% (average over 100 pulses) has been measured the following day, on Friday, 15 December. Note that this value of QE is in line with earlier Cs_2Te cathodes, since (1) published values for "initial QE" in new photocathodes are usually measured immediately after the cathode production [2,3], while No. 166 was measured a day later, (2) the vacuum in the preparation chamber was worse than usual (see chapter 1).

A scheduled power cut during the following weekend implied a slight degradation of the vacuum in the DC gun, to 1.2×10^{-10} mbar. After re-starting the pumps and once a vacuum of 3×10^{-11} mbar had been reached, a QE = 5.2% has been measured on Monday, 18 December.

A conservative estimate, based on calibration errors and uncertainties in laser attenuation through the system, leads to an error $\Delta QE/QE = 30\%$.

6. Summary

Following an interruption of more than three years, a Cs_2Te photocathode has been produced in December 2006 in the photoemission laboratory, using the standard CERN methods including the co-evaporation technique. An "a posteriori" calibration of the two quartz oscillation monitors used for evaporated film thickness measurements was performed. This allows, for the first time, to obtain an approximate absolute value of the amount of Te and Cs evaporated onto the copper substrate. The stoichiometric ratio found for cathode 166 is about 0.5 (rather than 2). The quantum efficiency of cathode 166 has been found to be QE=6.2%, with a relative uncertainty of about $\Delta QE/QE = 30\%$. This experimental result is higher than what is required for the CTF3 drive beam (QE=3%). Further photocathodes will be produced in 2007 following the approach described here, but with a different, larger value of the stoichiometric ratio.

References

[1] Y. Baconnier and A. Pisent, "CLIC Test Facility: The Photocathode Test Bench", https://edms.cern.ch/document/832419/

[2] G. Suberlucq et al., "Photocathodes tested in the dc gun of the CERN photoemission laboratory", Nucl. Instr. Meth. A340 (1994) 146-156.

[3] Web-page of the CERN photoemission laboratory: http://photoinjector.web.cern.ch/photoinjector/

[4] G. Suberlucq, "Technological Challenges for High Brightness Photoinjectors", Invited talk at EPAC2004 https://edms.cern.ch/document/831688/1;

[5] A. Barbiero and E. Chevallay, AB-ATB-LPE internal note, April 2007, https://edms.cern.ch/document/831555/

[6] E. Chevallay et al., "Production and Studies of Photocathodes for High Intensity Electron Beams", paper contributed to XX International Linac Conference, Monterey, USA, 2000, and references therein, https://edms.cern.ch/file/837637/1/clic449_mob08.pdf

[7] J. Durand, "Utilisation du Wall Current Monitor au Laboratoire de Photoemission PS-LP", PS/LP/Note 91-10 https://edms.cern.ch/document/832423/; J. Durand, T. Tardy, M. Wurgel, "A 10 GHz Wall Current Monitor", PS/LP/Note 95-09 (Tech) https://edms.cern.ch/document/831673/