# ON-LINE DIAGNOSTIC DURING $CS_2TE$ PHOTOCATHODES FORMATION

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## Abstract

Since the '90s our laboratory is in charge of producing $Cs_2Te$ photocathodes used as laser driven electron sources in the high brightness photoinjectors of the FLASH and PITZ facilities. The cathodes production recipe has been developed and standardized during years, fulfilling the requests for photocathode operation in the photoinjectors. Nevertheless, the growing process of the film is still not totally understood, mainly respect to the final material properties. In this paper, reflectivity and spectral response measurements, at different wavelengths, measured during the photocathode growth are presented and compared with the corresponding photocurrent behavior. This new information, together with results obtained with our standard diagnostic tools, will help to improve the understanding of the growing process, of the compounds formation with different Cs/Te ratio and of the reproducibility of the $Cs_2Te$ film structure.

## INTRODUCTION

Starting from 1987, we have produced a large number of photocathodes for the FLASH facility in DESY Hamburg and for the PITZ photo-injector test stand in DESY Zeuthen. It is important to remind that films produced during these years have fulfilled the cathode requests for operation, namely a lifetime of some months for FLASH and some weeks for PITZ (due to the more aggressive operation), an average Quantum Efficiency (QE) at the production of about 8.5 %, a good QE film uniformity, and an acceptable value of the dark current [1, 2, 3].

Nevertheless, in view of a more reliable production of $Cs_2Te$ photocathodes even for the future linear accelerator for light sources as XFEL, we are looking for deposition process improvements to obtain a more reproducible procedure. For these reasons, we have introduced two new diagnostic tools: the monitoring of the reflectivity and the measurement of the photoemitted current at different wavelengths during the film growth. The reflectivity has given valuable information during the Te and Cs deposition. The measurement of the spectral response at different wavelengths during the film deposition is instead useful to better understand the film formation and to determine when the final $Cs_2Te$ is produced.

In this paper, we present the new experimental set-up and the results so far obtained with these new diagnostics on two cathodes grown with Te different thicknesses. Moreover, results of the reflectivity measurements done during the deposition of Te on Mo plugs are presented.

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## CATHODE INVESTIGATION

### *Cathode recipe*

The deposition of $Cs_2Te$ cathodes is an established recipe [4]. The Mo plug is optically polished, cleaned and inserted in the vacuum system. After a thermal cycle up to 450 °C, the plug is cooled to 120 °C and inserted in the masking system (aperture $\phi = 5$ mm). The deposition starts growing the Te film, followed by the Cs evaporation, with a rate of 1 nm/min and 0.5-1 nm/min respectively. The evaporation rate is controlled with a microbalance and the growth of the film is monitored collecting the emitted photocurrent. An Hg lamp with interference filters illuminates the film during the deposition process. At the end of the evaporation, the Cs source is switched off and the cathode is cooled down to room temperature. Finally the photocathode is moved in the transport box where we measure the spectral response and the QE uniformity of the film at 254 nm.

### *Cathode 104.2 and 116.1 main characteristics*

For the two cathodes under analysis, the main parameters of their growth are reported in Table 1.

Table 1: Cathode growing processes main parameters.

| Cathode | Te thick | Evap. Cs thick. | Final R @ 254nm | Final QE @ 254nm |
|---|---|---|---|---|
| 104.2 | 10 nm | 70 nm | 12 % | 10.9 % |
| 116.1 | 5 nm | 30 nm | 3.7 % | 8.1 % |

The two Mo plugs have been machined starting from the same arc-cast rod, optically polished with a final reflectivity at 543 nm of 55% and 54% respectively. All the information relative to these, and to all produced cathodes, is available on a database accessible online via a web-page [3]. The two cathodes have been produced with different thickness, determined by the deposited Te, for testing the sensitivity of the new diagnostic and for having samples for investigation with XPS techniques.

In Fig. 1, the final spectral responses for the two cathodes are shown (spot diameter = 2 mm). Cathode 104.2, which was grown with a thicker Te film, shows a higher final QE. Cathode 116.1 shows a lower QE at high photon energies while at low photon energies its QEs are higher. Both cathode spectral responses do not present a significant tail at low photon energies, more evident for cathode 104.2 where the photocurrent at 436 nm was even not measurable. The low photon energy tail, usually attributed to a Cs excess during the cathode preparation [5], is absent as expected since we ended the cathode deposition just after the total completion of the films.

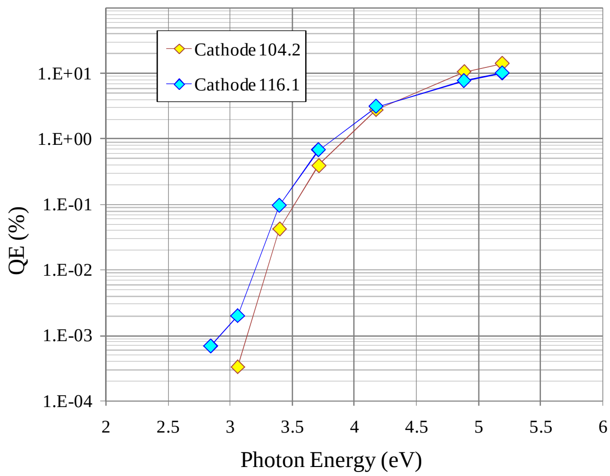


Figure 1: The final spectral responses of cathode 104.2 (10 nm Te) and 116.1 (5 nm Te).

## THE NEW DIAGNOSTICS: SET-UP

The new diagnostic set-up allows the on-line measurement of the film reflectivity and photocurrent at different wavelengths.

A calibrated photodiode measures the light power reflected from the film at the wavelength of 254 nm. The reflectivity of the film has been recorded during both Te and Cs deposition. During Cs deposition, due to the higher temperature of the source, we had a large undesired contribution from the infrared radiation emitted from the source itself that we need to subtract.

A motorized and remotely controlled filter wheel, able to hold up to 8 filters, allows shining light at different wavelengths on the cathode. The filters used are: 239 nm, 254 nm, 334 nm, 365 nm, 405 nm, 436 nm and a yellow filter to check the correct alignment of the optical path. The dimension of the light spot on the cathode has been sized to fit the film surface. This is mainly done to avoid the contribution, to the collected photocurrent, from other sources than the photocathode (like the masking) that interfere with the monitoring of the photoemissive film growth. To maintain nearly the usual experimental condition, we made a measurement at a different wavelength every three measurements done at 254 nm.

## SPECTRAL RESPONSES

### *Cathode 104.2 (Te = 10 nm)*

In Fig. 2 the QE at different wavelengths measured during the growing of cathode 104.2 (Te = 10 nm), after the Te deposition, are plotted vs. evaporated Cs thickness. Our reference QE is at 254 nm that we usually used during cathode growth and that shows different plateaus as different Cs/Te compounds are created [6]. These steps are also clearly visible at 239 nm. At longer wavelengths, these steps are no more clearly present except at 40 nm and the last one at 64 nm of evaporated Cs thickness.

This last peak corresponds to the complete formation of the $Cs_2Te$ and it is more evident at longer wavelengths. Moreover its position, in term of the evaporated Cs amount, is related to the Te thickness deposited. A stop of Cs evaporation before it produces a not totally finished cathode that is less stable, while a stop after it leads to a cathode with a Cs excess (and hence an increase of the low energy threshold of the final spectral response [5]). Since our final goal is the production of a stable cathode for gun operation and possibly without the Cs excess [7], cathode 104.2 was produced stopping the deposition just after reaching the last peak. Since the measurements at 365 nm are the most sensitive, we increase the number of samples measured at this wavelength to have a prompter control on the peak maximum.

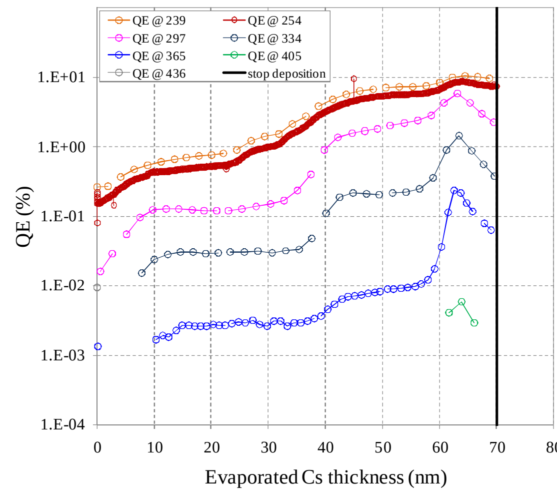


Figure 2: QE at different wavelengths vs. Cs thickness for cathode 104.2.

### *Cathode 116.1 (Te = 5 nm)*

This cathode was grown starting from a 5 nm layer of Te. Fig. 3 shows the QE at different wavelengths versus evaporated Cs thickness. These trends show, also for this cathode, the presence of the plateaus corresponding to different completion of the Cs/Te compounds.

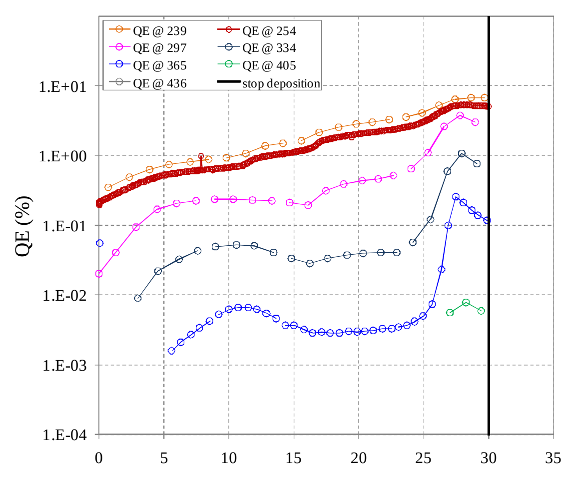


Figure 3: QE at different wavelengths vs. Cs thickness for cathode 116.1.

The last peak, also in this case, is well visible especially at longer wavelengths. It appears, on the evaporated Cs thickness scale, at about 30 nm. This agrees quite well with the expected Cs amount, given the reduced Te layer. Differences in the QE with respect to the cathode 104.2 can be found on the shape at longer wavelengths that show a minimum at about 15 nm of evaporated Cs thickness. Moreover, for this cathode the QE trends at longer wavelengths show a less structured behavior than for cathode 104.2. In the final spectral response, as shown in Fig. 1, we observe a quite negligible “tail” at longer wavelengths, as for cathode 104.2, due to the rapid stop of the Cs evaporation after the appearing of the last peak.

## REFLECTIVITY

### *Cathode 104.2 (Te = 10 nm)*

As mentioned before, we implemented the measurement of the photoemissive film reflectivity at 254 nm during the deposition of Te and Cs. The reflectivity is normalized to the one of the Mo plug.

Fig. 4 shows reflectivity and QE measured for cathode 104.2. During the Te deposition, we observe a reflectivity decrease of about 18% from its initial value. This reduction, obtained also in the previous studies [7], has been recorded for several cathodes starting from 2007 and can be estimated for a typical cathode (10 nm of Te) between 12% and 26%, mainly depending on the cathode temperature and Mo plug finishing.

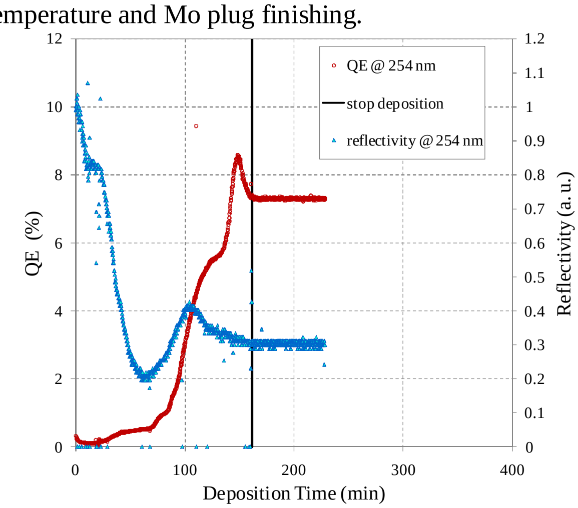


Figure 4: Reflectivity and QE at 254nm vs. deposition time for cathode 104.2.

During the Cs deposition, we observe an initial sharp decrease till a minimum that correspond to one of the plateau of the Cs/Te compound formation at 60 min (corresponding to a evaporated Cs thickness of 19 nm) and then an increase up to a maximum located between two QE plateaus at about 105 min (42 nm). The reflectivity then slowly diminishes until the end of the deposition where it stabilized. The reflectivity at the end of the cathode growth is about 30% of its initial value.

### *Cathode 116.1 (Te = 5 nm)*

This cathode was grown with half of the Te thickness than the previous cathode. As expected, the reflectivity decreases less (7%) from the initial value after Te deposition. During the Cs deposition, we observed a behaviour of the reflectivity similar with respect to the one obtained with cathode 104.2 even if less evident. Indeed, the reflectivity decreases during the whole Cs deposition process and the maximum is barely visible. It reaches a stable value only after the end of the Cs evaporation as shown in Fig. 5. The reflectivity at the end of the photoemissive film deposition is about 10% of its initial value.

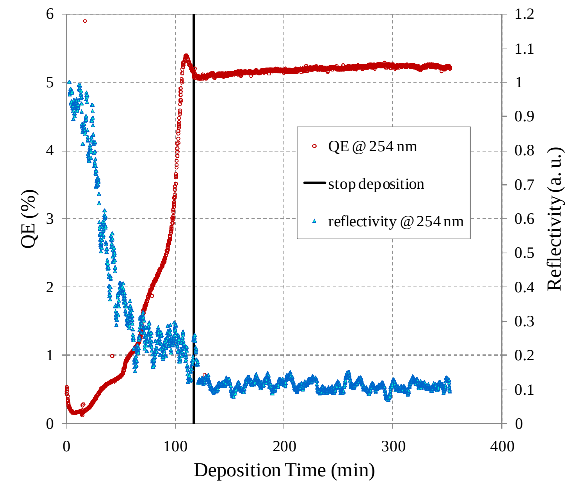


Figure 5: Reflectivity and QE at 254 nm vs. deposition time for cathode 116.1.

## CONCLUSION

We have introduced two online diagnostic tools in the cathode growing process to improve the reliability of the photocathode formation process.

The reflectivity measurements have given information about the Te film and have shown a maximum in the middle of the cathode growth that we will further investigate.

The online QE measurements instead provide a direct signal for the correct interpretation of the complete $Cs_2Te$ cathode formation.

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