MULTIWAVELENGTHS OPTICAL DIAGNOSTIC DURING Cs_2Te PHOTOCATHODES DEPOSITION

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Abstract

The production of Cs_2Te photoemissive films used as laser driven electron sources in the high brightness photoinjectors at FLASH and PITZ, is a well established activity at INFN Milano since the '90s. Our total production is of more than 100 photocathodes, with an average QE of 8.6 % (λ = 254 nm) for fresh films and an operative lifetime that nowadays is of some months at FLASH. In the last two years, we have improved the standard diagnostic used during the cathode growth to better understand the photoemissive film properties. This activity is motivated by the need to improve the photocathode performance, mainly the energy distribution of the photoemitted electrons that influences the thermal emittance. The multiwavelengths diagnostic, i.e. the on-line measurements of the photocurrent and reflectivity from the film during its growth in the 239 nm – 436 nm range, has been applied on several cathodes and the potentiality of this technique are discussed in this paper.

INTRODUCTION

Cs_2Te films are routinely used as laser driven electron sources in the high brightness photoinjectors of FLASH in Hamburg and PITZ in Zeuthen [1, 2]. The photocathodes have shown in the last two decades the required characteristic for operation in RF guns. Nevertheless, the evolution to a user facility, in particular of FLASH, and the upcoming XFEL that will use the same type of photocathodes is pushing for more reliable photoemissive films with better controlled properties. This requisite motivated the upgrade of our production system in Milano with a multi wavelength diagnostic system operated during the film growth.

In this paper, we review the experimental setup and present the main achievements. Among them, we have obtained a better control on the film growths process increasing the film reproducibility, we can better follow the Cs_2Te formation with the possibility to study the reflectivity and photoemissive threshold evolution, we can easily control the "Cs excess" that is responsible for the generation of states at low photon energy. These states may broaden the electron energy distribution and hence influence the final thermal emittance.

STANDARD AND NEW DIAGNOSTIC DURING PHOTOCATHODE GROWTH

Cs_2Te cathodes are grown on optically polished Mo plugs following the well established recipe [3]. The standard diagnostic typically used to follow the correct growth of the films is based on the photocurrent measurement during the deposition at a fixed wavelength (typically 254 nm). The new diagnostic [4], consists in the illumination of the cathode during its deposition with several radiation wavelengths, ranging from 239 nm to 436 nm. Interference filters are mounted on a motorized wheel, computer controlled. During the deposition, we record both the photocurrent at different wavelengths as well as the reflected power from the growing photoemissive film.

After the production, besides the standard characterizations, cathodes are now qualified by measuring the photoemissive threshold, from the spectral responses, and the reflectivity at the different wavelengths.

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QUANTUM EFFICIENCY ANALYSIS

The results presented here are from three cathodes grown in the same conditions (radiation power density, temperature and source rates), but with different Te thicknesses, respectively of 5 nm, 10 nm and 15 nm. This allows to grow cathodes with different final thickness and also to study the influence of the Te thickness on photocurrent and reflectivity.

In Table 1 the main photoemissive characteristics of the three cathodes are summarized.

Table 1: Main cathode parameters

Cathode	Te thickness	Evap. Cs thickness	Last QE peak pos.	QE Θ
113.2	5.1 nm	34.3 nm	31.5 nm	15.3 %
149.1	10.1 nm	60.9 nm	58.2 nm	13.4 %
146.1	15.4 nm	91.7 nm	86.9 nm	13.0 %

Θ measured at 254 nm

Film reproducibility

To study the influence of the Te thickness on the growth of the photoemissive film, in Fig. 1 we report a comparison of the QE measured at 254 nm during the Cs depositions vs. the evaporated Cs thickness. The Cs thickness has been normalized but real values are reported in the corresponding colored abscissa scales.

The typical QE plateaus, corresponding to the formation of several compounds with different Cs/Te ratio [5], are clearly visible for the three cathodes. The plateaus appear at the same normalized Cs thickness meaning that the formation of the different Cs and Te compounds depends only on the ratio Te/Cs.

Once the QE reaches the maximum, the evaporation of Cs is stopped, to avoid Cs excess, and the cathode is cooled down to room temperature.

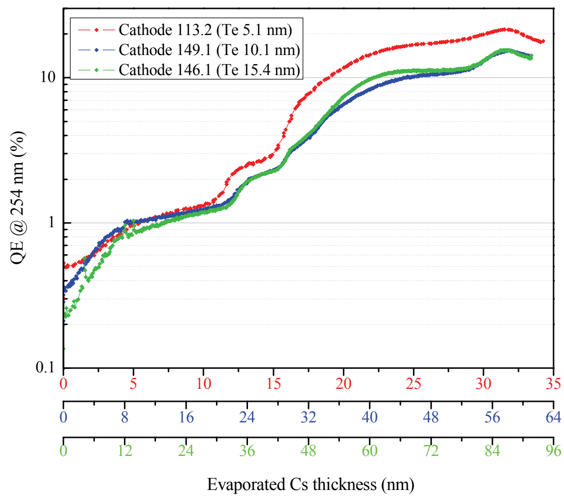

Figure 1. QE vs. evaporated Cs thickness. The behavior of the three cathodes, once the Cs thickness is normalized, is similar.

Figure 2 shows, as an example, the QE at different wavelengths during the growth of the 15 nm Te cathode. The behavior for the other cathodes is quite similar. The QEs at 405 nm and 436 nm were not measurable.

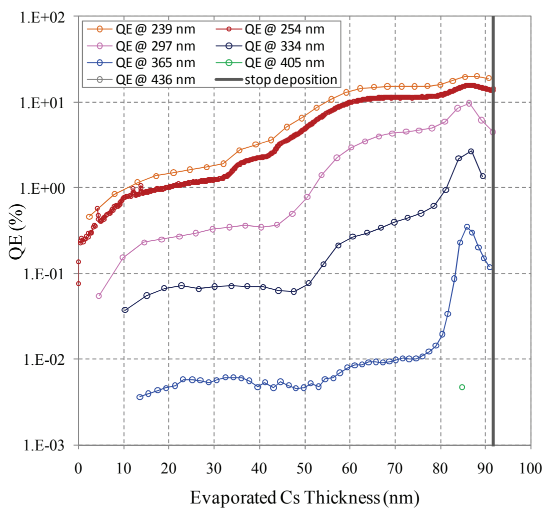

Figure 2. QE at different λ for the "15 nm" cathode. The sharp increases of the QE appear in correspondence to the cathode formation (last QE peak position in Table 1).

We observe, in correspondence with the QE maximum at 254 nm, sharp increases of the QE more pronounced at longer wavelengths. Table 2 reports the mean QE increases at different λ. The increase has been evaluated considering the QE enhancement from the plateau before the last peak. The raise of the last QE peak is very sharp and for the 10 nm Te cathode it happens within only 7 nm of evaporated Cs, about a tenth of the overall Cs amount.

The QE results shown in this paper are representative also for all the cathodes produced since 2009 [6] when the new technique was introduced. This tool has allowed having a better control of the "Cs excess" and a higher QE values and reproducibility (the average QE of these cathodes is 10.6 % at 254 nm). These results together with the improvement of the RF gun vacuum conditions have pushed the operative lifetime of the cathode to some months [1].

Table 2: Typical Increase of the QE of the last peak vs. λ

239 nm	254 nm	297 nm	334 nm	365 nm
32%	37%	120%	365%	2000%

E_g+E_a analysis

The QEs measured at different wavelengths have been used to determine the photoemissive threshold, given by E_g+E_a (energy gap and electron affinity respectively). For this purpose, we have developed a model based on the theory developed by Kane [7] to analyze measured data. As already reported in [8], Cs_2Te spectral response is modeled considering two different thresholds to take into account the "Cs excess" contribution.

The analysis of the final spectral responses shows a photoemission threshold of 3.2 eV for the main contribution and of 2.8 eV for the "shoulder" part.

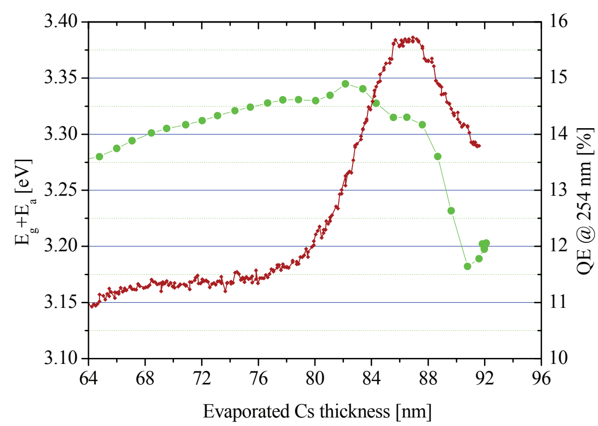

Figure 3. QE @ 254 nm (red curve) and photoemissive threshold (green curve) during "15 nm" cathode formation.

A similar analysis has been performed also on the QE data during the cathode growth. During the production, only photocurrents for wavelengths shorter than 365 nm are measureable. Assuming a not dominated "Cs excess" process, we analyzed the QE considering a single photoemission process. Figure 3 shows E_g+E_a changes from the last plateau to the final peak determined for the "15 nm" Te cathode as well as the QE at 254 nm. As for the QE data, the E_g+E_a behavior is similar once a normalized thickness is considered for the three cathodes. A short E_g+E_a plateau is observed in correspondence with the QE peak followed by a sudden decrease till a minimum at 3.18 eV. The small "Cs excess" at the end of the production process, observed also in the final spectral response, increases the photoemission threshold.

REFLECTIVITY DATA

As for the photocurrent measurements, the reflectivity of the three cathodes during their formation has been recorded at all the available wavelengths.

Table 3: Reflectivity of Mo plugs, their decreases after Te deposition and reflectivity of the Cs_2Te films (at 254 nm)

Cathode	R (Mo)	ΔR decrease§	R % (Cs_2Te)
113.2	52.8%	5.4%	21.5 %
149.1	52.8%	16.7%	17.1%
146.1	51.4%	25.6%	13.8%

§ Reflectivity decrease during the Te deposition on Mo (λ = 254 nm)

Table 3 reports the main characteristics of the produced cathodes, including the reflectivity of the Mo substrates.

Before starting with the film deposition process, the reflectivity of the Mo plugs is measured to qualify their surface roughness (σ ~ 10 nm).

Reflectivity during Te and Cs deposition

Figure 4 reports the reflectivity at 254 nm measured during the Cs evaporation for the three cathodes. The reflectivity during Te deposition is also plotted.

The three cathodes show a similar reflectivity trend. The initial decrease of the Mo reflectivity during Te evaporation agrees with the attenuation given by the Te film thickness. During Cs evaporation, a minimum appears at about 20 nm of evaporated Cs thickness, followed by a maximum whose position depends on the Te thickness. For the "10 nm" cathode the maximum is at about 40 nm of evaporated Cs while for the "15 nm" cathode its position moves to 50 nm. After reaching the maximum, both cathodes show a decreasing reflectivity. Unlike the photoemission data, reflectivity does not depend only on the Cs/Te ratio but mainly on the Cs evaporated thickness.

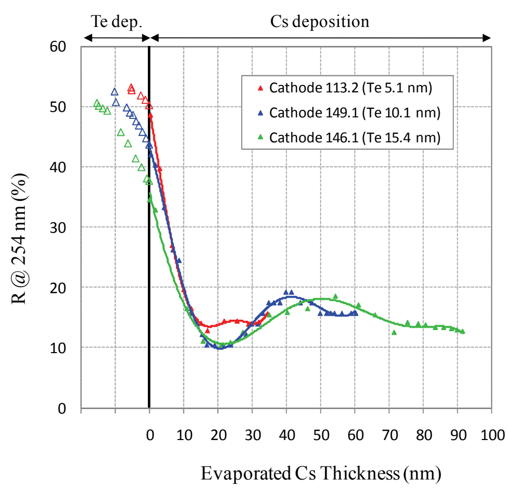

Figure 4: Reflectivity @ 254 nm for the different cathodes during Cs evaporation. Also reflectivity during the Te evaporation is shown.

At the other wavelengths, the reflectivity behavior is similar to the one just described for λ = 254 nm. Nevertheless, the minimum position moves to larger evaporated Cs thickness as the wavelength increases.

Finally, we have measured the reflectivity after the production process. Figure 5 shows the data for the three cathodes at all the available wavelengths. We first observe that, independently from the Te thickness, the final reflectivity for the three cathodes for wavelengths shorter than 297 nm is comparable within few percents. In particular, the reflectivity at 254 nm is about 17 %. A quite different trend is instead visible at longer wavelengths where we measure higher reflectivity for thicker cathode.

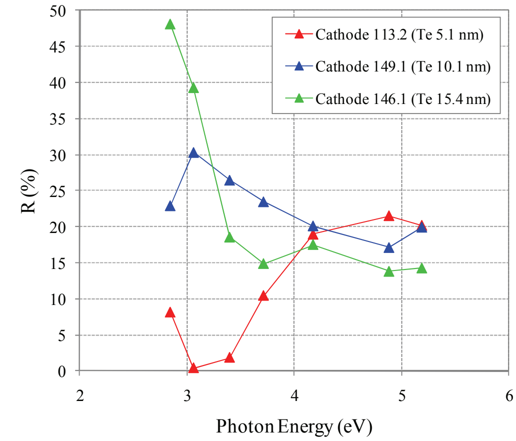

Figure 5: Reflectivity vs. photon energies for the three produced cathodes.

CONCLUSION

The application of the new diagnostic technique has improved the control on the film characteristics (i.e. deposited Te thickness, the final QE, the "Cs excess", etc.) and also increased the film reproducibility. Moreover, this technique is a useful tool for a better comprehension of the photoemissive properties of Cs_2Te. The understanding of the reflectivity behavior during the film growth, together with the improvement of the model used to analyze the threshold formation, will give further information widening the knowledge of the Cs_2Te photoemissive film properties in view of a thermal emittance control.

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