A STUDY FOR THE CHARACTERIZATION OF HIGH QE PHOTOCATHODES*

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Abstract

Based on our experience on photocathode production, we present in this paper the results of the application of different optical diagnostic techniques on fresh and used photocathodes. These techniques allow studying effects like non uniformity, cathode aging, etc. In particular, photocathode optical parameters and QE characterization, both done at different wavelengths, give fundamentals information for the construction of a model of the photoemission process to be applied to Cs_2Te photocathodes. These studies are useful for further improving key cathode features, such as its robustness and lifetime as well as to study and control the photocathodes thermal emittance.

INTRODUCTION

The new generations of laser driven RF gun based electron sources are pushing the requirements on the cathode performances during operation in the accelerating cavities. The Quantum Efficiency (QE) and extracted peak current are not anymore the only parameters important in the photocathode qualification. The lifetime, the dark current and the thermal emittance are some of the parameters that the R&D on photocathodes has to investigate.

For these reasons, in the last years we have developed new techniques that help in characterizing the photoemitter and that respond to the new requests. We have extended the application of the standard QE map from a simple qualification of the film photoemissive uniformity to the capability of giving information about the semiconductor properties. This technique is a valuable tool for the analysis of the film degradation during its operation in the accelerating cavities and it opens the possibility to correlate damages on the film to semiconductor basic properties.

In this paper, we present the experimental apparatus we use for spectral response measurements and QE mapping, the analysis of the photocathode spectral responses to estimate the dependence of the QE from basic photoemitter parameters (energy gap and electron affinity) and then the application to the QE maps and the results we have so far obtained.

EXPERIMENTAL APPARATUS

Our laboratory is devoted to the production of Cs_2Te photocathodes used at FLASH and PITZ since 1998 [1,2]. As part of the qualification process of the produced photocathodes, we routinely measure the spectral response and we map the QE at different wavelengths. The photocathodes are grown in a UHV chamber with a based pressure in the low 10^{-10} mbar range. The Mo is heated to 120 °C during the cathode deposition. We deposit 10 nm of Te and then Cs monitoring the QE. Once the QE reaches the maximum, we stop the Cs deposition and start the cool down of the photocathodes [3]. During the production process we monitor not only the QE but also other parameters like the reflectivity of the growing film. The light source is a high pressure Hg lamp with interference filters to select wavelengths. The filters have a bandwidth of 10 nm. A picoAmmeter collects the emitted current.

To qualify the cathode, its spectral response and QE distribution over the cathode front surface is measured. A beam steerer scans the light on the photocathode front surface for the QE maps. Fig. 1 shows a view of the photocathode production system with the diagnostic needed for the characterization of the photoemissive film.

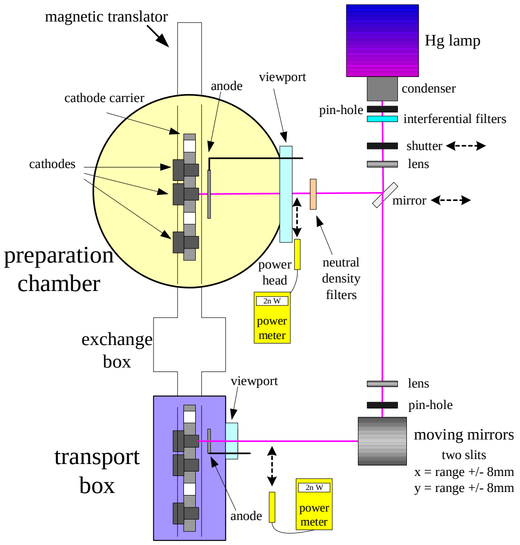

Fig. 1. Experimental set-up of the photocathode preparation with its diagnostic devices.

SPECTRAL RESPONSE

The response of the photocathode to photon of different energies is usually used to interpolate the data to determine the QE at the FLASH/PITZ laser wavelength (λ = 262 nm).

The spectral response is also important because it allows determining basic parameters of the photoemissive film. The dependence of the QE near threshold from the photon energy is described by the following relation:

$$QE = A \cdot \left(h\nu - \left(E_G + E_A\right)\right)^m \qquad (1)$$

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where hν is the photon energy, E_G+E_A is the sum of the energy gap and electron affinity of the photocathode and m depends on the type of electron transition in the material [4].

Fig. 2 shows a typical spectral response of our photocathodes. Clearly two different trends are visible on the graph, at high and low photon energy. At present, there is not an unique interpretation of this behavior. Our approach is to fit the data as if they are two distinct processes. The function we use is then:

$$QE = A\cdot\left(h\nu-\left(E_G+E_A\right)\right)^m + A_1\cdot\left(h\nu-\left(E_{G1}+E_{A1}\right)\right)^{m1} \quad (2)$$

where A and A_1 account for the ratio between the two process. The other parameters are the corresponding of Eq. 1 for the two processes.

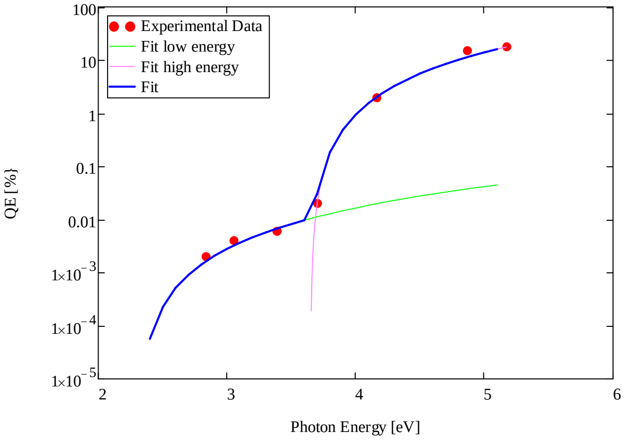

Fig 2. Spectral response of a photocathode (red dots). The blue curve is the interpolation of the experimental data with the Eq. 2 and the parameters reported in Table 1. Green and magenta lines show the high and low energy threshold contribution.

The blue curve in Fig. 2 is the fit of Eq. 2 to our data with the parameters reported in Table 1. There is a good agreement between the experimental and the theoretical data. This allows us to be confident of the applicability of this model for further studies reported in the following section.

Table 1: Parameters of the fit of the spectral response shown in Fig. 2.

	High Energy	**Low Energy**
$A\backslash A_1$	7.614	0.0018
$E_G+E_A\backslash\ E_{G1}+E_{A1}$	3.65 eV	1.6 eV
m\m1	2	2

To simplify the analysis, we assume m = 2 since we measured it independently during our activities on the optical properties of the Cs_2Te photocathodes [5].

QE MAPS

The uniformity of the photoemissive film is needed to guarantee the good quality of the laser generated electron beam in the RF gun. Our scanning system is able to raster a small spot, generated by a focusing lens, on the front cathode surface. The spot diameter is about 1 mm and each step of the scanning is 0.5 mm. The qualification of the cathode is done at λ = 254 nm and a typical map is shown in Fig. 3.

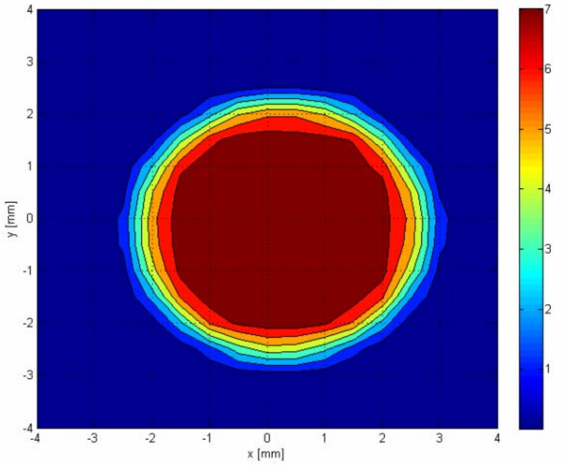

Fig 3. QE map of the photocathode at λ = 254 nm. The QE values in [%] are reported in the colorbar.

The method of the QE mapping has been extended in order to be able to use Eq. 2 on the whole map and hence gather information on E_G+E_A over the photoemissive surface. Therefore, we have acquired QE maps at different wavelengths in the range λ = 239 nm to λ = 436 nm. A set of these maps is reported in Fig. 4. It is clearly visible that we have the optimal uniformity at λ = 254 nm. Larger variations of the QE are visible at longer wavelengths.

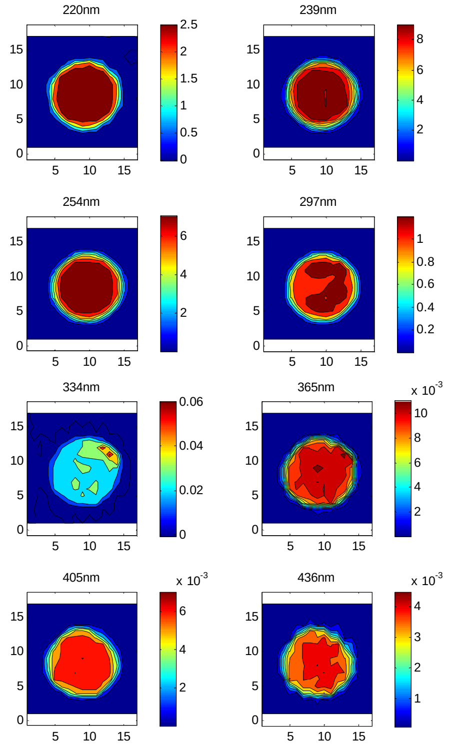

Fig. 4. A set of QE maps using different photon energies.

The application of Eq. 2 for the values corresponding at the same spatial position on the maps, allows getting the band energy information spatially resolved. The result of this analysis on the cathode, whose QE maps are reported in Fig. 4, is shown in Fig. 5. The Cs_2Te E_G+E_A values around 3.4 eV are in good agreement with the values quoted in literature [6].

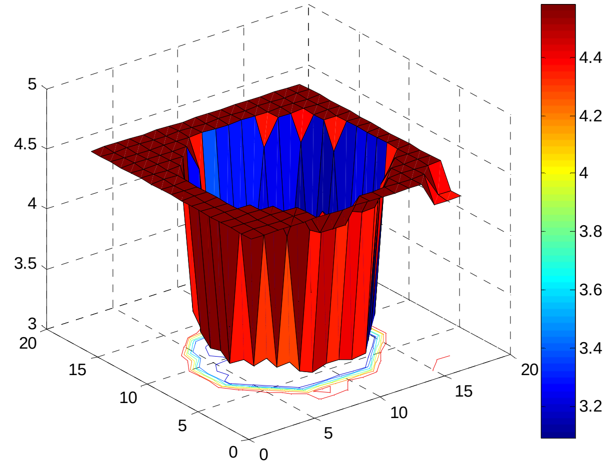

Fig. 5. E_G+E_A spatial mapping on a fresh cathode in eV. The position resolution is about 0.5 mm. The probe diameter is about 1 mm. The 4.5 eV level corresponds to the Mo plug work function.

This kind of analysis is even more important on cathode that come back from the laboratories after a long period of storage in UHV condition or of operation in the gun. In fact, the analysis helps in evaluating aging effects and the condition of the surface from the photoemission point of view. A typical result is shown in Fig. 6 where the E_G+E_A mapping of a long stored cathode is calculated. The QE of this cathode at $\lambda = 254$ nm is about 8 %, comparable with the one of new photocathodes. The value of the E_G+E_A in the central region of the photoemissive film is instead about 3.8 eV, 0.4 eV higher than the fresh cathode. This result is important because, even if the QE value is still high, a significant variation of the energy levels has been observed. This result, already noteworthy for the photoemission characteristics of the cathode, is even more important if one considers the thermal emittace of this kind of photocathodes.

The thermal emittance strongly depends on the energetic levels of the photoemissive film. If we assume that the energy gap is constant, since it is related to bulk properties of the cathode, then the observed E_G+E_A increase is due to a variation of the electron affinity i.e. of the quality of the film/vacuum interface. Since the emission process into vacuum of the photo generated electron depends strongly on the surface energy level through the critical emission angle, a variation of the electron affinity influences the distribution in energy and angle of the emitted photoelectrons and hence the thermal emittance [7].

Moreover, this measurements highlights that the QE has not to be the only parameter for the characterization of the cathodes and, in some case, might lead to misleading interpretation.

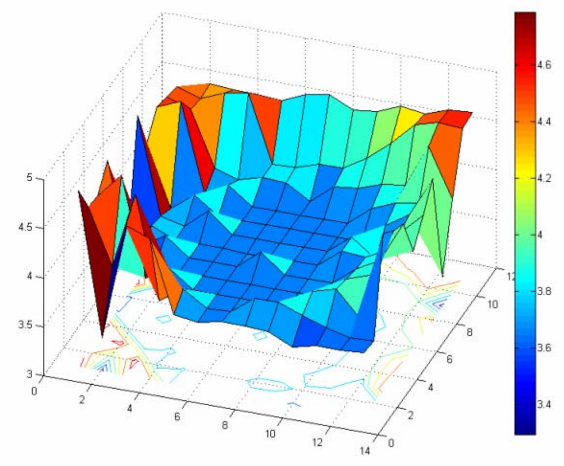

Fig. 6. E_G+E_A spatial mapping on a used cathode in eV. A central region of higher E_G+E_A with respect to the fresh cathode is observable even if the QE at $\lambda = 254$ nm is about 8 %.

CONCLUSION

The characterization of photocathodes requires new tools and should not be limited to standard parameters like QE. We have shown that the spectral response has much more information especially concerning the energetic properties of the photocathodes. The knowledge gather from this analysis has been applied to extend the capability of the QE maps. We have reported the application of this technique to fresh and used cathodes. In particular, on used cathodes this tool allows to show that, even if the QE value are at acceptable value, the energy level of the material are significantly changed.

These results will be applied and included in a photoemission model mainly devoted to the study of the thermal emittance of the cathodes produced in our lab, aiming at its reduction keeping the QE at about the actual working point.

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