# $Cs_2Te$ PHOTOCATHODES ROBUSTNESS STUDIES*

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*Abstract*

$Cs_2Te$ photocathodes are used as laser driven electron sources at FLASH and PITZ. Besides many aspects of their performances, their robustness to gas exposition and the effect of pollutants on photocathode properties, and indirectly on the photoemitted electrons, are a field still unexplored. In this article we present the results of controlled exposition of $Cs_2Te$ photocathodes to gases typical present in the UHV environment of an RF gun with respect to spectral responses (QE vs. wavelength), and QE uniformity. Moreover, a comparison between polluted cathodes and fresh ones during operation in an RF Gun is presented.

## INTRODUCTION

Since the '90s INFN Milano-LASA photocathode laboratory is involved in the study of the photoemissive cathodes based on alkali antimonide and telluride. Since 1998, LASA produces photocathodes for the photoinjectors at FLASH and PITZ at DESY and for the photoinjector test facility A0 at FNAL. In these years, we have studied the photoemissive properties of photocathodes with the main interest for $Cs_2Te$ films. A variety of techniques have been used such as spectroscopy techniques (Time-Of-Flight angle resolved spectrometer) and optical measurements. Moreover, we have collected a large amount of information related to cathode behaviors under operational conditions in an RF gun environment, with diagnostic on cathodes during and after their usage. Up to now, we have produced 107 cathodes, 75 with a $Cs_2Te$ film [1]. The lifetime of cathodes used at FLASH, under standard operation, varies between one and six months, depending on the vacuum conditions. However, we have observed at PITZ that for cathodes operated at higher gradients approaching 60 MV/m, their lifetime reduces to a few days only [2].

In this paper we present measurements performed at LASA on pollution of cathodes. We have investigated the robustness of $Cs_2Te$ cathodes in vacuum condition similar to the one present in the RF gun and in the case of an accidental vacuum leak. Moreover we have polluted a cathode with Oxygen to change its photoemissive properties, in order to lower its thermal emittance.

## CATHODE ROBUSTNESS

One significant characteristic of a photocathode is its robustness that contributes to its operative lifetime. The main causes of degradation of the photoemissive film are:

- Vacuum condition (in the gun, in the transport box and in the transfer devices)
- Degradation of the thin film (long operative time, sparks, high gradient, dark current, etc.).

The degradation of the surface during operation is typically related to sparks caused by high applied field in the RF guns (PITZ) and also to long time operation (damages on the coating, holes, etc.).

Vacuum is another key parameter that influences the cathode operating lifetime. We typically observe that the QE of cathodes stored in the transport boxes is stable for very long time, since the base pressure is kept at $10^{-11}$ mbar. However, bad vacuum conditions age cathodes. As an example, cathodes in operation at FLASH from April '06 to March '07, where the vacuum in the RF gun has been poor, showed an operative lifetime of 30 days only [3]. Improvements of the vacuum condition done during the shutdown resulted in an increase of the operative lifetimes to standard values [4].

### *Cathode Pollution*

In an attempt to simulate similar conditions as in an RF gun, we have experimentally measured the change of QE of a cathode polluted by switching off the ion pump.

We grew a standard cathode, following the usual recipe [5]. After the deposition, we measured the spectral response of the film, repeating the measurement also in the following days. The analysis of the spectral responses gives the low and high energy threshold (Eg+Ea) of the film [6]. Furthermore, we measured the QE map at 254 nm. Table 1 reports the main parameters of this cathode.

During the pollution process, we have monitored the photocurrent emitted from the cathode, illuminated by UV light ($\lambda$ = 254 nm, P = 180 nW, $\Phi$ = 2 mm). To minimize rejuvenation effects, the light has been modulated by a shutter with an open/close ratio of 5:60 s. The total pressure in the chamber has been recorded with a Bayard-Alpert (BA) gauge, while a Residual Gas Analyzer (RGA) recorded the evolution of the gases in the system.

The measurement lasts for about two days with the ion pump switched off for about 24 h. We observed an unexpected increase of the photocurrent. The starting pressure was $2.2 \cdot 10^{-10}$ mbar. After about 3 hours, the total pressure reached its maximum at $2.9\ 10^{-8}$ mbar. The main residual gas was found to be $CH_4$ (in the $10^{-8}$ mbar range). Other relevant contributions are from $H_2$ and CO (a few $10^{-9}$ mbar). The water vapour pressure was below $10^{-11}$ mbar. This is expected since we regularly bake out the vacuum chambers. These gases have a low influence on the cathode properties: more reactive gases for $Cs_2Te$ are $O_2$ and $CO_2$ [7] that in our case have partial pressures

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below $10^{-11}$ mbar. When we switched on back the ion pump the pressure reached rapidly its starting value. Fig. 1 shows the measured photocurrent and the total vacuum pressure during the exposition time.

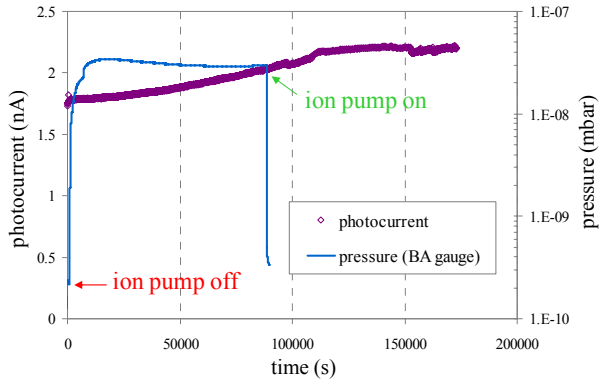


Figure 1: Photocurrent and vacuum pressure vs. time. The time, when the ion pump has been on or off is indicated.

## *Diagnostic: spectral responses and QE maps*

After the pollution process, we measured QE map at λ=254 (Fig. 2) and spectral response of the film (Fig. 3).

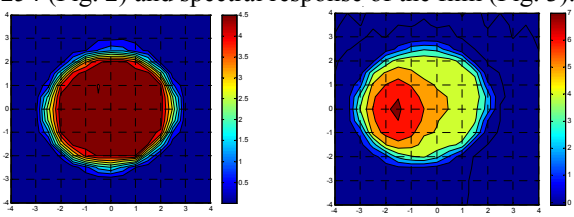

Figure 2: QE maps before (left) and after pollution (right).

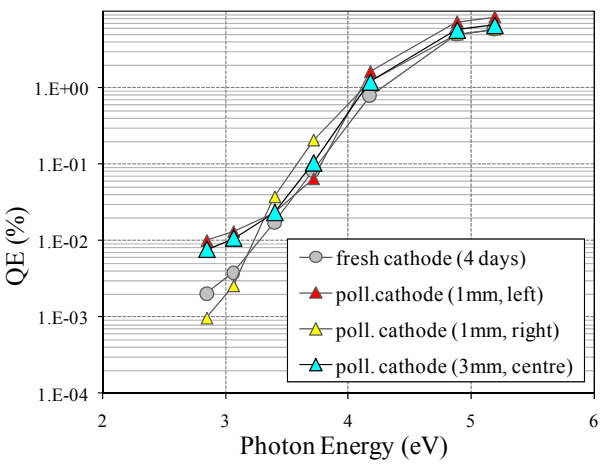


Figure 3: Spectral responses before and after the pollution process, measured at different position on the cathode.

Comparing the QE maps measured before and after the pollution process, we immediately observe a degradation of the uniformity. In Fig. 2 (right), a high QE region, higher also with respect to the fresh cathode one, is visible on the left of the coating. Fig 3 shows the spectral responses measured before (4 days after the film deposition) and after the poisoning procedure. Comparing the fresh cathode spectral response with the polluted one (cyan coloured triangle) we observe an increase of the QE at all the photon energies, more pronounced at low energy values. Moreover, we measured the spectral responses of the low and high QE regions with a smaller spot size (Φ≤ 1 mm) as shown in Fig. 3 ("1 mm") right and left respectively. The region that was illuminated during the poisoning, even with low duty cycle, shows higher QE values than the not illuminated area. This is possibly due to a rejuvenation process on the illuminated part of the film. From the analysis of the spectral responses, the high QE region shows a low value of $Eg+Ea_{low}$, even compared to the fresh cathode, while $Eg+Ea_{high}$ is essentially the same. Referring back to the RF gun environment, the vacuum quality is usually worse than in our case. The RF guns are not baked at high temperature and hence the $H_2O$ partial pressure is higher. In Table 1 the main parameters of the polluted cathode, measured in the two QE regions are summarized together with the ones obtained for the fresh cathode.

Table 1: Main parameters of the fresh and the polluted cathode (switching off the ion pump)

| Cath. | Meas. area | Spot (mm) | QE at 254nm | $Eg+Ea_{low}$ (eV) | $Eg+Ea_{high}$ (eV) |
|---|---|---|---|---|---|
| fresh[£] | centre | 3 | 4.75 % | 1.5 | 3.7 |
| fresh[§] | centre | 3 | 5.01 % | 1.4 | 3.7 |
| poll. | centre | 3 | 5.72 % | 1.1 | 3.6 |
| poll. | left | 1 | 7.22 % | 0.9 | 3.7 |
| poll. | right | 1 | 4.96 % | 2.6 | 3.7 |

[£] measured 1 day after the cathode production
[§] measured 5 days after the cathode production

# $O_2$ POLLUTED CATHODE

This measurement has been done to produce an "ad hoc" cathode, trying to modify its photoemissive properties to lower the thermal emittance. The information collected up to now show that:

- Used cathodes show a lower thermal emittance than fresh cathodes [8]
- Used cathodes show an increase of the Eg+Ea thresholds [6]
- A loss of the uniformity of the QE for old/used cathodes [3].

All these information show that a possible solution for reducing the thermal emittance is to control the energy threshold, Eg+Ea. To increase the energy threshold while guaranteeing the film uniformity, we decided to age the photemissive film in a controlled way.

## *Cathode Pollution*

The cathode has been grown with the usual recipe. In Table 2 the cathode main parameters are summarized.

The cathode was polluted with $O_2$ gas. The $O_2$ partial pressure was monitored with an RGA and its flux was regulated by a leak-valve. The total pressure in the chamber was read by the BA gauge and by the ion pump current. To prevent the rejuvenation effect maintaining the uniformity of the coating, we changed the optical set-up

to have a UV spot larger than the coating dimension of 5 mm, we decreased the power of the UV light down to 47 nW, and we also reduced the open/close ratio to 2:60 s. The cathode was exposed for 57 minutes to $O_2$ at about $1{\cdot}10^{-8}$ mbar. The final Oxygen exposition was 26.5 L (1 Langmuir ~ 1 $10^{-6}$ mbar·s) with a reduction of the QE at λ = 254 nm from 5.1 % to 3.1 %. After closing the leak valve, the photocurrent was monitored for about 3 hours. During this time, the rejuvenation process was prevented by decreasing the open/close ratio to 2:1200 s. Fig.4 shows the QE and the gas exposition (L) vs. time during and after the $O_2$ poisoning.

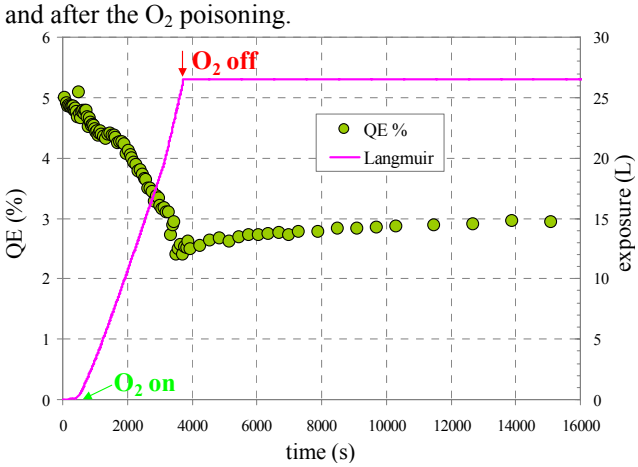


Figure 4: QE and pollution in Langmuir vs. time during $O_2$ exposition.

### *Diagnostic; Spectral Responses and QE Maps*

As for the previous cathode, after the poisoning process, we performed the usual diagnostics by measuring the QE map and the spectral response. In fig. 5 and 6, QE maps and spectral responses of the fresh and polluted cathode are compared.

The QE maps show a good uniformity before and after the pollution (Fig. 5). No visible effect of rejuvenation is observable.

The spectral responses (Fig. 6) show, as expected, a lower QE at all the photon energies and also an increase of the Eg+Ea thresholds for the polluted cathode.

In Table 2 the main parameters of the cathode before and after the pollution are reported. The fresh cathode shows an increase of the low Eg+Ea threshold after a few days. The high Eg+Ea threshold remains constant.

Table 2: Main parameters of the fresh and the $O_2$ polluted cathode.

| Cath. | Meas. area | Spot (mm) | QE at 254nm | $Eg+Ea_{low}$ (eV) | $Eg+Ea_{high}$ (eV) |
|---|---|---|---|---|---|
| fresh[£] | centre | 3 | 5.24 % | N.A. | N.A. |
| fresh[§] | centre | 3 | 5.02 % | 1.0 | 3.6 |
| fresh[#] | centre | 3 | 5.16 % | 1.9 | 3.6 |
| poll. | centre | 3 | 3.14 % | 2.1 | 3.8 |

[£] measured 4 day after the cathode production
[§] measured 7 days after the cathode production
[#] measured 11 days after the cathode production

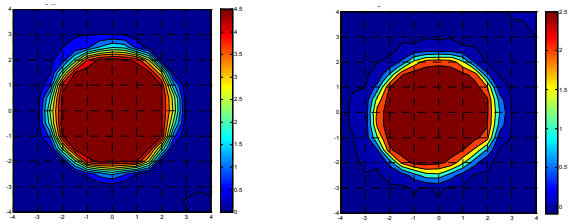

Figure 5: QE maps after the deposition (left) after the pollution process (right).

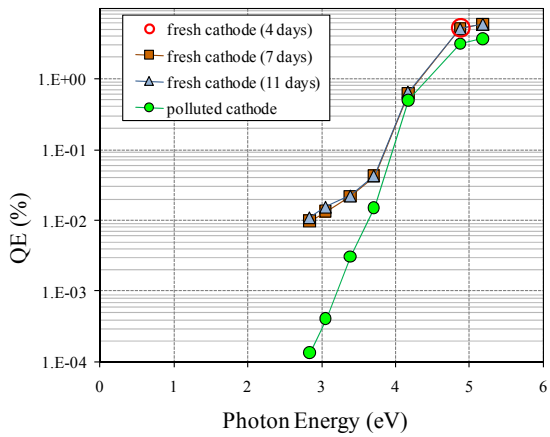


Figure 6: Spectral responses before and after $O_2$ poisoning.

## CONCLUSION

We studied the robustness of $Cs_2Te$ photocathodes used in RF guns by polluting a standard cathode and measuring its energy threshold and QE. We have observed an aging of the film but also rejuvenation in the region illuminated by UV light. The $O_2$ poisoning has instead produced a cathode with higher Eg+Ea energies and good uniformity. This cathode will be used for future tests in a RF gun for evaluating its thermal emittance value.

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