PHOTOCATHODE STUDIES AT FLASH

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Abstract

Since several years, the DESY photoinjectors at FLASH and PITZ use cesium telluride photocathodes. One concern of operating an electron source with these cathodes is the degradation of the quantum efficiency (QE), starting from about 10 % to below 0.5 % during operation. To further understand this behavior the QE is monitored routinely. In this paper recent results from photocathode studies at FLASH are presented.

INTRODUCTION

FLASH is operated as a user facility under nominal operational condition for SASE FEL generation and for accelerator related studies and thus has a moderate and constant usage of cathodes. Cesium telluride (Cs_2Te) photocathodes are used at FLASH because of their high quantum efficiency (QE) and their ability to release high peak current electron bunches in the high gradient RF-gun. One concern to use Cs_2Te cathodes at FLASH and most probable at the European XFEL is the lifetime. To further understand this crucial issue, the QE is monitored routinely during operation. In addition more detailed studies on the spectral response and the QE dependence on the operational conditions are performed. In this contribution we report on recent QE and spectral response measurements as well as on lifetime issues since summer 2007.

CATHODE PREPARATION

The photocathodes used at FLASH are produced at INFN Milano - LASA. The photoemissive Cs_2Te film is grown on an optically finished molybdenum plug in an UHV chamber with a base pressure of low 10^{-10} mbar. The Mo surface quality is checked by measuring the reflectivity R at λ = 543 nm, average of about R = 55 %.[1] During the photocathode preparation the Mo surface is kept at 120°C. At first, 10 nm Te are grown. Then the evaporation of Cs is started. During the Cs deposition the QE of the photocathode is monitored. During the deposition different Cs_xTe_y compounds are formed. The correct stoichiometric ratio of $x = 2$ and $y = 1$ is reached when the QE reaches its maximum.[2] At this point, the Cs evaporation is stopped. This preparation procedure yields in high quality Cs_2Te photocathodes with an average QE of 9.9 %.[3]

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After production the photocathodes are stored in a transport box under UHV environment. The box is shipped to FLASH and connected to the RF-gun load-lock cathode system.

For each prepared cathode the relevant data like reflectivity of the Mo surface, QE after production, and measurements during operation at FLASH are summarized in an online accessible database [3].

QE MEASUREMENTS AT FLASH

The quantum efficiency is defined as the ratio between the number of emitted photoelectrons to the number of photons impinging the photocathode.

At FLASH the QE is obtained by two different measurement techniques: in cw-mode and pulsed-mode. The first one uses a setup comparable to the one used at LASA [4] and operates in cw mode. It mainly consists of a Hg-lamp, interference filters, a power meter, and a picoamperemeter with included voltage source. The cw measurements at

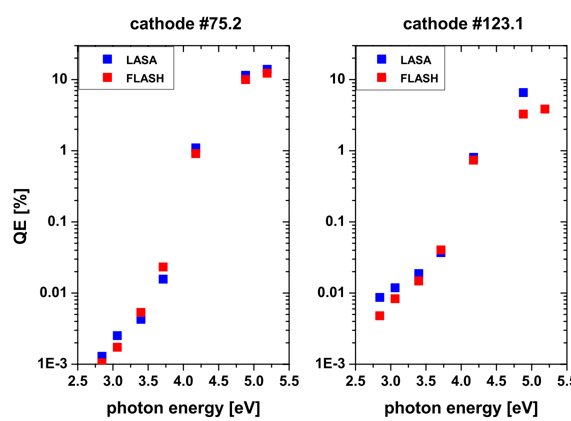

Figure 1: Spectral responses of cathode #75.2 measured at LASA Aug 3, 2007 and at FLASH Jan 8, 2008 and cathode #123.1 measured at LASA May 9, 2008 and at FLASH May 20, 2008.

FLASH are performed with the cathodes being in the transport chamber mounted to the RF-gun cathode system. The transport chamber is equipped with a UV transparent viewport to illuminate the cathode. An anode is positioned close to the cathode surface. The anode is biased by the voltage source and is used to measure the photoelectron current.

With suitable interference wavelength filters we can select several photon energies in the range from 2.8 to 5.5 eV. Obtaining the QE for different photon energies yields the spectral response of the cathode. From the spectral response we can extrapolate to the photoinjector drive laser wavelength of 262 nm. Figure 1 shows the spectral responses measured at LASA and FLASH. The spectral response of cathode #75.2 did not change between the production at LASA and the measurements at FLASH four month later (Fig. 1 left). This shows, that the base pressure of 10^{-11} mbar in the transport boxes preserves the high QE of the photocathodes for several months. In contrary to this, the data for cathode #123.1 measured at LASA on May 9, 2008 and at FLASH on May 20, 2008 differ especially in the low and high photon energy regions. The performance and lifetime of Cs_2Te photocathodes strongly depends on the vacuum conditions. On purpose cathode #123.1 has been exposed to a poor vacuum of 10^{-8} mbar resulting in a decrease of the QE.

The QE dependence on the photon energy E_{ph} at the photoemission threshold is described by the following equation:

$$QE = A\,(E_{ph} - W)^m \tag{1}$$

where W is the work function of the material, in case of the semiconductor Cs_2Te the sum of energy band gap E_G and electron affinity E_A. From the parameter m information on the emission process itself can be derived. [5] A typical feature of the spectral responses of Cs_2Te cathodes is the appearance of two QE trends on the photon energy, one at low and a second at high energies. Up to now, there is no unique interpretation of this behavior. Therefore the measured data are fitted in terms of two independent emissions with the following function:

$$QE = A_1\,(E_{ph} - W_1)^{m1} + A_2\,(E_{ph} - W_2)^{m2} \tag{2}$$

Figure 2 shows the analysis of data of cathode #123.1 obtained at FLASH. The blue curve is the result of the fit and

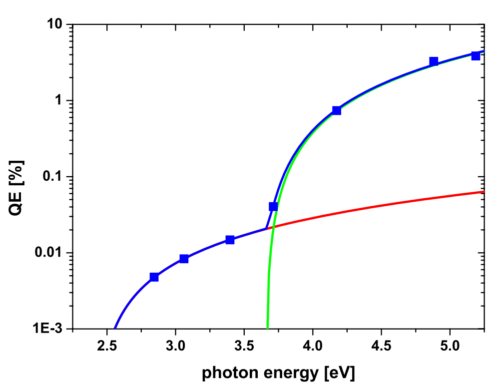

Figure 2: Spectral response of cathode #123.1 measured at FLASH, squares: data, lines: analysis with Eq. 2.

the red and green ones represent extrapolations of the two distinct emission trends. The results from the fitting procedure are summarized in table 1. The experimental data are well reproduced by the analysis method.

Table 1: Response analysis for cathode #123.1.

trend	A	E_G+E_A	m
low energy	0.015	2.4 eV	1.4
high energy	2.1	3.65 eV	1.6

The resulting $E_G + E_A$ value in the high photon energy region is higher than expected from the band gap of Cs_2Te which is 3.3 eV and the electron affinity of 0.2 eV.[6] However, the increased work function is in well agreement with the observed QE degradation, caused by the poor vacuum conditions.

The second technique of measuring the QE is in pulsed-mode. Here the cathode is inserted into the the RF-gun and applied to a high accelerating field. An automated procedure is used to monitor the QE during operation. [7] In this measurements the number of photons is calculated from the laser pulse energy obtained with a calibrated joulemeter (Molectron J-5). The transmission of the vacuum window and the reflectivity of the vacuum laser mirror is taken into account. The extracted charge is measured with a calibrated toroid to ± 1 %. The error of this measurement technique is in the order of 20 %.

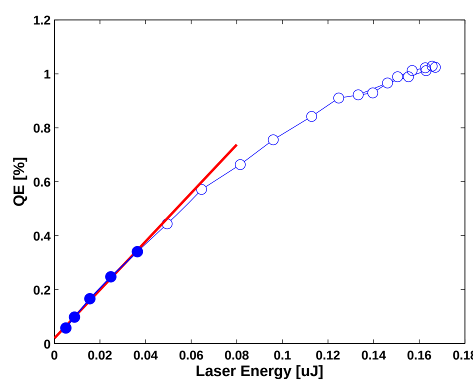

Figure 3: Charge vs. laser energy for cathode #123.1.

In figure 3 a typical charge versus laser energy measurement is shown for cathode #123.1. For this measurement the RF power into the gun was $P = 3.3$ MW and the RF phase in respect to the laser pulse 38° off zero crossing. Under these conditions, the accelerating field on the cathode surface is 26.5 MV/m. The extracted charge increases proportional to the laser pulse energy until it saturates due to space charge effects. The QE is calculated from the slope of the linear part, resulting in 4.3 % for this example.

For investigations on the influence of the accelerating field at the cathode on the photoemissive properties of Cs_2Te, the QE is investigated under different operational conditions. Figure 4 shows quantum efficiencies obtained at different accelerating gradients for cathode #123.1 (blue scares) as well as the QE measured in cw mode (green square). The measured QE's in the RF gun depend on the

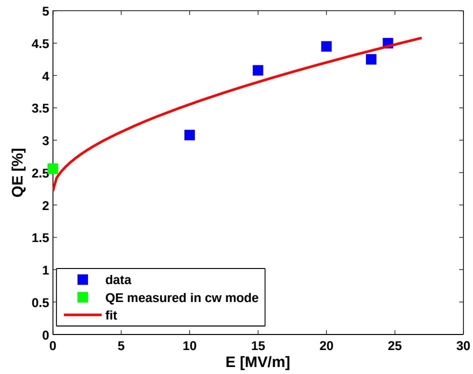

Figure 4: QE vs. accelerating field at the cathode for cathode #123.1; squares: data, red curve: fit by Eq. 3.

accelerating field and differ from the one obtained in cw mode. This behavior is interpreted in terms of field enhancement. Neglecting the space charge, we analyze the QE dependence on the accelerating field with the following function:

$$QE = A\left(E_{ph} - (E_G + E_A) + \sqrt{\frac{q_e \beta E}{4\pi\epsilon_0}}\right)^m \quad (3)$$

with A as proportional constant, q_e as elementary charge, E the macroscopic accelerating field at the cathode and ϵ_0 the dielectric constant of vacuum. From the fit, we obtain the work function $(E_G + E_A)$ and the geometric enhancing factor β. For simplification m = 2 is assumed in this analysis. The fit to the data in figure 4 gives $E_G + E_A$ = 3.6 eV and β = 7 (represented by the red curve).

CATHODE LIFETIME

Besides a high QE, the lifetime of the photocathodes is an essential demand, especially when used in a user facility. After the shutdown in 2007 we observed an increased lifetime of the Cs_2Te cathodes. From July 2007 to May 2008 only two cathodes have been used, #108.1 and #123.1. In addition, both cathodes have not been removed because of low QE. The change was rather motivated by a not yet conclusive observation, that fresh cathodes ease the generation of high SASE energy levels at FLASH. If this would turn out to be indeed the case, the lifetime would be determined by the SASE performance of the machine rather than the achievable charge. In figure 5 the QE versus days of usage for cathode #108.1 is shown. It turns out, that even after 120 days of operation the QE is still comparable to the fresh QE.

Up to now there is no straightforward explanation for the present improved lifetime. Our suggestions are on one hand an improved vacuum, also during operation the base pressure was in the low 10^{-11} mbar domain. On the other hand Teflon washers responsible for a fluorine contamination of the cathodes were removed from the injector section during the shutdown. Our assumption is, that the presence of fluorine in the residual gas lead to a destruction of the Cs_2Te compound resulting in CsF and metallic Te clusters. See also [8] for more details on this subject. Further investigations on the chemical composition of used cathodes are necessary to fully understand the described behavior.

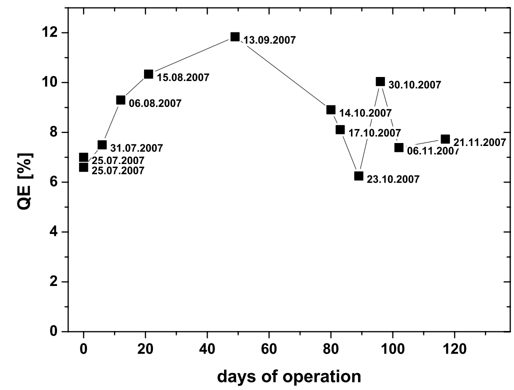

Figure 5: QE over time for cathode #108.1.

SUMMARY AND OUTLOOK

In this contribution recent investigations on Cs_2Te cathodes at FLASH are presented. The QE of photocathodes were measured in cw mode as well as inside the RF-gun and compared. Moreover, from the spectral response and the dependency of the QE on the accelerating field more material properties were revealed.

Due to an improved vacuum base pressure during operation and the removal of Teflon from the vacuum system an increased lifetime of Cs_2Te cathodes is observed. From July 2007 to May 2008 only two cathodes have been used. In both cases the QE did not drop during normal operation in the FLASH RF-gun.

To further understand the effects of operation in an RF-gun on the photoemissive properties of Cs_2Te, more experimental techniques as the QE and spectral response measurements are required, especially to study changes in the chemical composition.

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