PHOTOCATHODE PERFORMANCE AT FLASH

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Abstract

Caesium telluride photocathodes are used as laser driven electron sources at the Free-Electron Laser FLASH at DESY, Germany. They will also be used at the European XFEL. One concern of the operation of photocathodes in these user facilities is the degradation of the quantum efficiency (QE) during operation. After improving vacuum conditions and removing contaminants, the cathode life time increased from a couple of weeks to several months. In this contribution we report on long time operation of Cs_2Te cathodes in terms of QE measurements and investigations on the homogeneity of the electron emission. Another concern of electron guns operated with long RF-pulses (800 μs at FLASH) is the generation of dark current either from the cathode or from the gun body. During the last five years of operation, a constant high amount of dark current emitted from the gun body itself was observed at FLASH. For this reason, the RF-gun has been replaced during the shut-down 2009/2010. The new dry-ice cleaned RF gun shows considerable less dark current. Dark current measurements under different operational conditions are presented.

INTRODUCTION

FLASH is operated with long pulse trains of up to 800 μs and a repetition rate of up to 10 Hz. Each macro pulse consists of up to 2400 electron bunches with each up to 3 nC charge. To keep the drive laser power in an reasonable range, FLASH requires photocathodes with a high quantum efficiency emitting at an acceptable wavelength. In addition, for a user facility like FLASH, downtimes caused by cathode exchanges must be minimized, requiring a long cathode life time in the normal conducting RF-gun. One criterion for the end of the cathode lifetime is based on the available laser power per pulse on the cathode. For FLASH, we consider the end of the lifetime if the QE of the cathode falls below 0.5 %. All Cs_2Te photocathodes used at FLASH are produced at INFN-Milano, LASA. Details on the production procedure itself can be found in [2]. While the principals of the production recipe did not change over the last years, efforts have been concentrated on better and more detailed diagnostics during preparation [3], yielding for instance adjustable Cs excess on the cathode. All relevant data for each cathode are stored in an on-line accessible database [4].

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QE MEASUREMENT TECHNIQUES

Quantum efficiency is the ratio of emitted electrons to the number of photons impinging on the target.

To obtain the QE of the photocathodes two different ways are used, continuous wave (cw) and pulsed measurements. The cw QE is obtained by illuminating a cathode with a Hg-lamp. Different wavelengths are obtained with appropriate interference filters. The number of photons is measured with a calibrated a power meter. The emitted electrons are collected by a biased anode and the number of electrons is calculated from the current through the anode measured with a picoammeter. These types of measurements are performed at INFN-Milano, LASA, during and after the cathode preparation as well as after operation at FLASH. The cathode transfer chambers are equipped with an UV-transparent view port and an anode, allowing cw QE measurements with the Hg-lamp while the transport chamber is connected to the FLASH RF-gun.

This contribution will concentrate on the pulsed QE measurements in the RF-gun. In this case, as for standard operation, the drive laser of the photoinjector is used to excite the valence electrons of the cathode. The emitted electrons are accelerated by the RF-field inside the gun cavity and the bunch charge is measured with a toroid. The number of photons is calculated from the laser pulse energy measured with a calibrated joulemeter (Molectron J-5) and taking the transmission of the view port as well as the reflectivity of the in-vacuum laser mirror into account. From the linear rise of the charge as a function of laser energy the QE is calculated. Here, space charge does not yet effect the QE. This measurement technique gives the QE under operational conditions and additionally allows to study the influence of the electric field at the cathode on the electron emission. Counteracting the influence of the space charge force at different gradients, the solenoid is adjusted for maximum charge at the toroid. For all pulsed measurements the phase between laser and RF is set to +38 deg w.r.t. zero crossing, corresponding to the nominal operation phase of FLASH.

CATHODE LIFETIME

The lifetime of Cs_2Te photocathodes is mainly influenced by the vacuum conditions in the RF-gun during operation. Besides the pressure itself, also the composition of the residual gas is important. Investigations on the chemical composition of fresh and used cathodes by means of X-ray Photoelectron Spectroscopy (XPS) in 2007 identified a contamination with fluorine [5]. As source of this contamination inside the FLASH injector, Teflon washers could be identified and have been removed. In the same step the overall vacuum conditions near the RF-gun have been improved. Since these changes no cathode reached its end of lifetime, based on our definition. Repeated XPS studies on photocathodes operated under the conditions confirmed the strong reduction of contaminations [6].

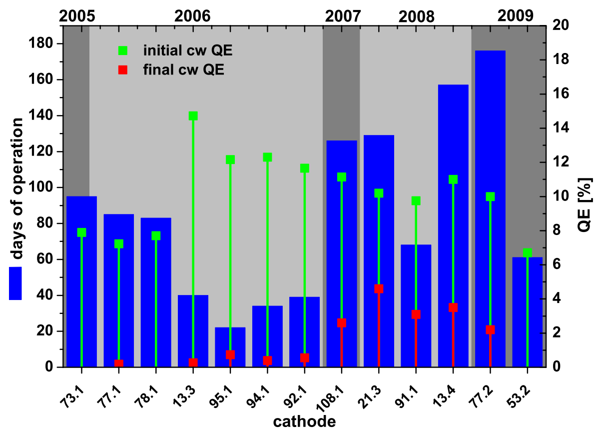

Figure 1: Cathode statistics: days of usage, cw QE after preparation (initial) and after usage (final) [4].

For illustration figure 1 shows the operational days of photocathodes used since 2006 until the RF-gun exchange in 2009. Note that only cathodes which have been used for operation are shown. In addition, the cw QE right after production (initial) and after operation (final) are presented. Even before the improvements of the vacuum system, the life time of several cathodes exceeded several month with a QE above 0.5 %. However, after the improvemnts of the vacuum conditions, no cathode has been changed up to now because of low QE.

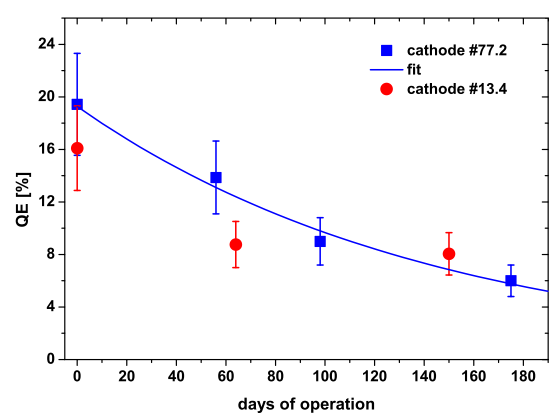

Figure 2: Quantum efficiency vs. days of operation.

A more detailed view on the QE degradation behavior is given in figure 2. Here the pulsed QE measurements for the cathodes #13.4 and #77.2 as function of the operational days are presented. The measurements have been performed in between adjacent user periods at FLASH in 2008 for cathode #13.4 and in 2009 for cathode #77.2. For both cathodes holds that even after more than 150 days of operation the QE is about one order of magnitude higher than our criteria for the end of life time. Applying a simple exponential decay for QE(t) (blue line in Fig. 2) the decay time obtained for cathode #77.2 is 144 days.

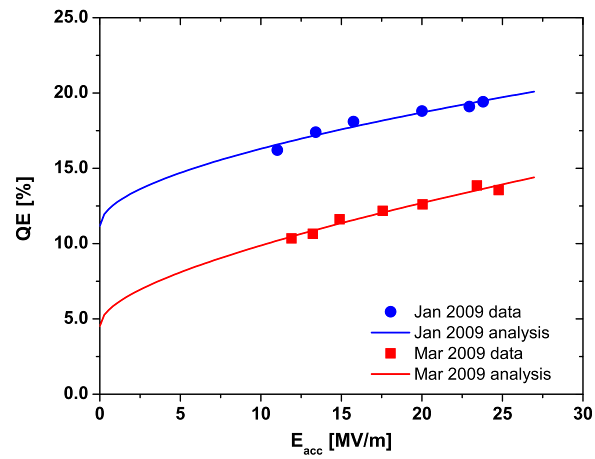

Figure 3: QE vs. accelerating gradient at the moment of electron emission for cathode #77.2.

The influence of the electric field on the electron emission is studied in addition at FLASH. In figure 3 quantum efficiencies as function of the accelerating field at the cathode (E_{acc}) are presented for cathode #77.2. The measurements have been performed in January (blue) and March (red) 2009. Neglecting the space charge, $QE(E_{acc})$ is analyzed in terms of equation 1.

$$QE\left(E_{acc}\right) = A\left(E_{ph} - (E_g + E_a) + q_e\sqrt{\frac{q_e\beta E_{acc}}{4\pi\epsilon_0}}\right)^m \tag{1}$$

with the proportional constant A, the elementary charge q_e, and the dielectric constant of vacuum ϵ_0. The parameter m, containing information on the emission process itself [7], for simplicity is fixed to $m = 2$ in this analysis. β covers all possible, still to be investigated, effects of the high electric field to emission process of Cs_2Te. From the fit of equation 1 to the data an important information on the electronic structure of the semiconductor cathode is derived, the sum of electron affinity (E_a) and band gap (E_g).

The fit to the data in Fig. 3 by Eq. 1 (blue line) results in an $E_g + E_a$ value of 3.5 eV, which is in excellent agreement with the theoretical value [8], and $\beta = 4.7$. Measurements performed after 56 days of operation (red line in figure 3) result in an increased $E_g + E_a$ value of 3.8 eV, reflecting the decreased QE, and an β of 12.7.

The homogeneity of the electron emission over the cathode is investigated at FLASH routinely. For this type of investigations the laser spot size at the cathode is minimized ($\sigma \approx 0.26$ mm) and scanned over the cathode. The

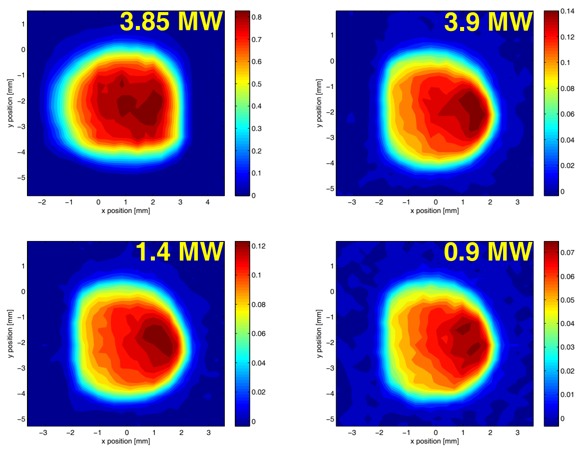

Figure 4: QE maps of cathode #77.2 for different RF forward powers (indicated inside the plots) and dates, upper left: 2009-01-17, upper right: 2009-03-13, lower plots: 2009-03-15.

laser pulse energy is adjusted in order not to be affected by saturation affects. In figure 4 QE-maps for cathode #77.2 obtained at different dates and different accelerating fields are presented. A pronounced change of the homogeneity is neither visible over time nor for different fields at the emission.

NEW RF-GUN AND DARK CURRENT

The dark current emitted from the RF-gun body and the cathode is a crucial issue for operating linacs at long RF-pulses in combination with high electric fields. For FLASH, losses of dark current along the machine can increase the heat load to the superconducting cavities, and significantly decrease the lifetime of diagnostic components or even the undulators. A dark current of more than 1 mA would make the operation of FLASH impossible.

Since 2007 a pronounced increase of the dark current emitted from the gun body itself (DESY-Gun 2) could be observed [1, 9]. In figure 5 the dark current as function of the forward RF-power (P_{for}) is shown for different cathodes operated in Gun 2. The amount of dark current is nearly independent of the cathode. Therefore, we conclude that the major part of the dark current is emitted from the gun body itself.

During the shut-down 2009/2010 the old RF-gun, which has been operated for more than 5 years at FLASH, was exchanged by the new DESY-Gun 4.2 [10]. The new dry-ice cleaned gun has been conditioned and characterized at PITZ [11].

First measurements of the dark current emitted from the new gun are shown in figure 5. Compared to Gun 2, the dark current is dramatically reduced. The values measured with Gun 4.2 are about one order of magnitude smaller than for the previous gun. This improvement is of outermost importance for FLASH, since the standard repetition rate of FLASH has been increased from 5 Hz to 10 Hz. It is also planned to significantly increase the gun RF power. Continued investigations are necessary to understand the dark current evolution over time.

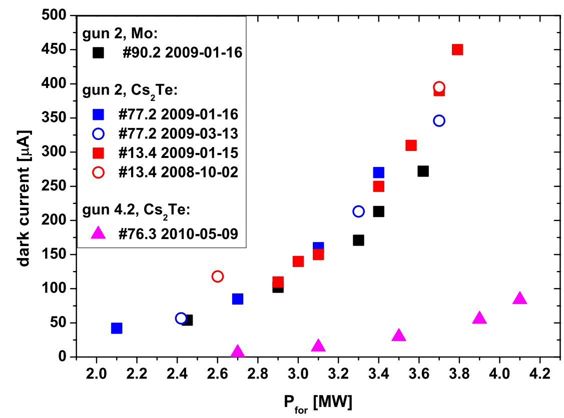

Figure 5: Dark current as function of P_{for} for DESY-gun2 and gun4.2 operated at FLASH.

SUMMARY AND OUTLOOK

After improvements of the vacuum conditions around the RF-gun, a typical photocathode life time of several month is achieved. In the last two years no cathode had to be exchanged because of a too low quantum efficiency. This improvement is important for the operation of FLASH as user facility and as well as for the European XFEL.

The RF-gun has been exchanged during the FLASH upgrade 2009/2010. First measurements show a decrease of dark current by one order of magnitude – as expected from data measured at PITZ. For the new gun cavity the investigations on the evolution of field emission and the photocathode life time will be continued for a better understanding of these crucial points.

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