INVESTIGATIONS ON THE INCREASED LIFETIME OF PHOTOCATHODES AT FLASH AND PITZ

S. Lederer*, S. Schreiber (DESY, Hamburg, Germany)
M. Haenel, F. Stephan (DESY, Zeuthen, Germany)
P. Michelato, L. Monaco, C. Pagani, and D. Sertore (INFN Milano - LASA, Segrate (MI), Italy)
J.H. Han (Diamond Light Source Ltd, Oxfordshire, United Kingdom)

Abstract

Cesium telluride photocathodes are used as laser driven electron sources at FLASH and PITZ. FLASH is operated as a user facility as well as for accelerator related studies and therefore has a constant and moderate usage of the cathodes. In contrary, PITZ is an injector R&D facility with a stronger usage of cathodes due also to gradients in the RF-gun of up to 60 MV/m. In the past, one concern of operating RF-guns with Cs_2Te cathodes was the degradation of the quantum efficiency in a few weeks at FLASH and a couple of days at PITZ. Improved vacuum conditions and removing contaminants in both accelerators yielded an increased lifetime of several months. In this contribution we report on routinely performed QE measurements, investigations on the homogeneity of the electron emission, and dark current issues for both facilities.

INTRODUCTION

The operation of Cs_2Te photocathodes requires a drive laser with a wavelength in the UV. The quantum efficiency has to be high in order to keep the average laser power in a reasonable regime for high duty cycle operation. Usually starting from about 10 % the QE degenerates during operation in RF-guns. If the QE is below 0.5 % the end of the cathodes lifetime is reached. In 2006 and 2007 an unexpected decrease of the lifetime was observed. Investigations by means of x-ray photoelectron spectroscopy (XPS) on cathodes operated at FLASH and PITZ showed that the photoemissive film was destroyed by contamination with fluorine [1]. After removal of teflon washers and improved vacuum conditions the cathode lifetime increased in both photo-injectors.

CATHODE PRODUCTION

The photocathodes used at FLASH and PITZ are prepared at INFN-Milano, LASA. Details on the production procedure can be found in [2]. After fabrication the QE dependency on the photon wavelength (spectral response) is measured by means of applying interference band pass filters to the cw output of an Hg-lamp. From the spectral response the QE at the drive laser wavelength ($\lambda = 262$ nm for FLASH and $\lambda = 257$ nm for PITZ) are extrapolated. Until now an average of 8.5 % [3] is obtained for $\lambda = 262$ nm.

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

After production the cathodes are stored in a transport box under UHV environment with a base pressure in the low 10^{-10} mbar. This allows the shipment of cathodes to FLASH or PITZ, conserving the QE over months. At the photoinjectors the transport boxes are connected to the RF-gun load-lock cathode system [4].

CATHODE LIFETIME

After the already mentioned removal of Teflon washers in both injectors and improved vacuum conditions the cathode lifetime increased considerably. Since then, no cathode has been changed because of a low QE. Cathode exchanges at FLASH have been motivated by the still not understood observation that fresh cathodes ease the high energy SASE generation [5]. At PITZ reasons for cathode changes are for example a changed homogeneity of photoelectron emission, influencing emittance measurements.

The quantum efficiency is the electron yield per incident photon on the cathode. Determination of this quantity relies on measurements of the number of photons impinging the cathode and the measurement of the number of photo emitted electrons.

At FLASH the laser energy is measured with a calibrated joulemeter (Molectron J-5 [6]). The extracted charge is measured with a calibrated toroid just downstream the RF-gun. At PITZ the number of photo emitted electrons is measured with a Faraday cup and the laser pulse energy by means of a photo diode (OPHIR PD10-PJ [7]). The systematic error of both measurement techniques is in the order of 20 %. The QE is determined from the not space charge dominated linear slope of a charge vs. laser energy scan [8].

In figure 1 the QE evolution over days of operation for two photocathodes at FLASH (#13.4 and #77.2) and one at PITZ (#128.1) are shown. The experimental conditions for all measurements in figure 1 have been the same: $P_{for} = 3.8$ MW, phase between laser and RF +38 deg w.r.t

* sven.lederer@desy.de

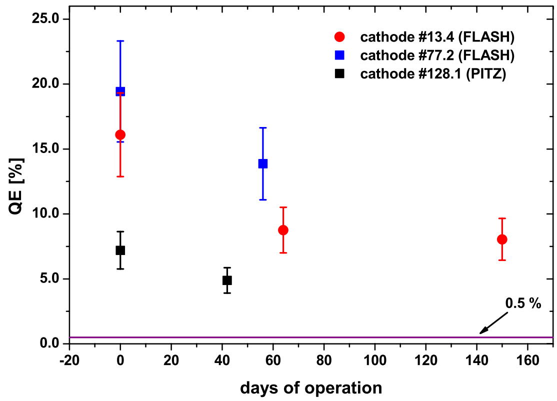

Figure 1: QE vs. operation time for cathodes #13.4 and #77.2 (both used at FLASH), and cathode #128.1 operated at PITZ.

zero crossing. For the cathodes operated at FLASH the QE decreases after first usage, but even after 150 days of operation it is in the order of several percents, far away from the operational minimum of 0.5 %. The relatively low QE of the cathode measured at PITZ is related to the already low cw QE of 5.98 % after the production.

High electric fields at the cathode favor the photoelectron emission by affecting the work function of the emitting material. To further understand this effect for Cs_2Te, the QE is measured for different accelerating fields at the cathode (E_{acc}). Neglecting the space charge, the QE dependency on E_{acc} is analyzed by equation 1

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

with the proportional constant A, the elementary charge

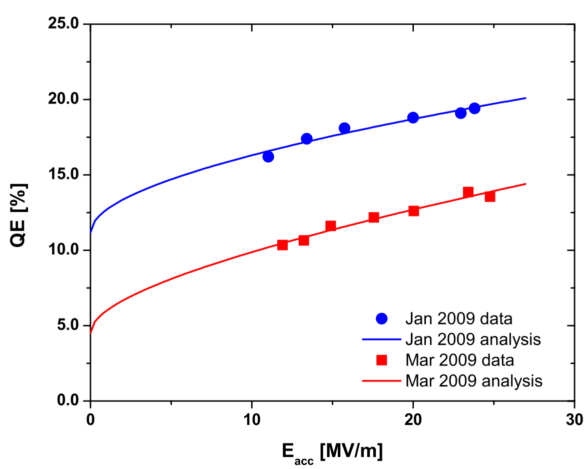

Figure 2: QE vs. accelerating gradient at the cathode for cathode #77.2 obtained at FLASH January 2009 (blue) and March 2009 (red); symbols: data, lines: fit by Eq. 1.

q_e, the macroscopic accelerating field at the cathode E, and the dielectric constant of vacuum ϵ_0. The parameter m, containing information on the emission process itself [9], for simplicity is fixed to $m = 2$ in this analysis. From the fit of equation 1 to the data an important information on the electronic structure of the cathode is derived, the sum of electron affinity (E_a) and band gap (E_g). Setting the dielectric constant of Cs_2Te to $\epsilon_r = 1$, an upper limit of the microscopic field enhancement is reflected by the parameter β.

Figure 2 shows the QE as function of the accelerating field on the cathode. The blue data points are obtained directly after insertion of cathode #77.2. The fit to the data 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 [10], and a field enhancement factor of $\beta = 4.7$. Analogue measurements performed after 56 days of operation at FLASH (red symbols in figure 2) result in an increased $E_g + E_a$ value of 3.8 eV, reflecting the decreased QE, and an β of 12.7.

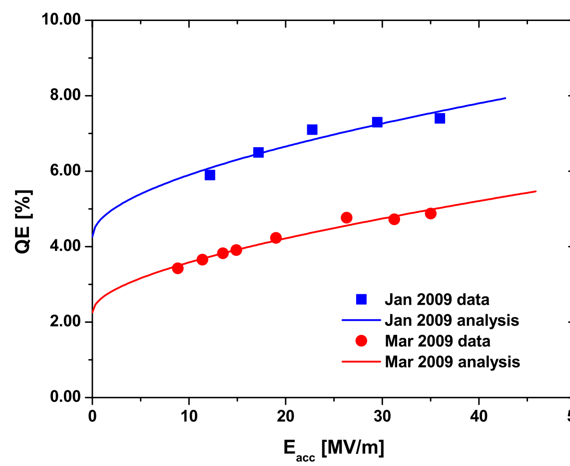

Figure 3: QE vs. accelerating gradient at the cathode for cathode #128.1 obtained at PITZ January 2009 (blue) and March 2009 (red); symbols: data, lines: fit by Eq. 1.

In figure 3 the QE dependence on the accelerating field for cathode #128.1 operated at PITZ is presented for different dates (symbols: data, lines: fit of Eq. 1). In this case the $E_g + E_a$ value increased from 3.9 eV after the first usage of the cathode to 4.1 eV and the field enhancement factor from $\beta = 1.9$ to $\beta = 2.6$.

As already pointed out one reason for cathode exchanges at PITZ is a change in the homogeneity of photoelectron emission. In figure 4 (left) a QE-map of cathode #128.1 after 42 days of operation is shown. The image was obtained at $P_{for} = 7$ MW. The map shows a stronger degradation of the QE in the region where the drive laser impinges on the cathode. The physical and chemical reasons for this behavior are still under discussion. At FLASH, we do not observe this fast changes in homogeneity. Figure 4 (right) shows the QE-map of cathode #13.4 ($P_{for} = 3.8$ MW)

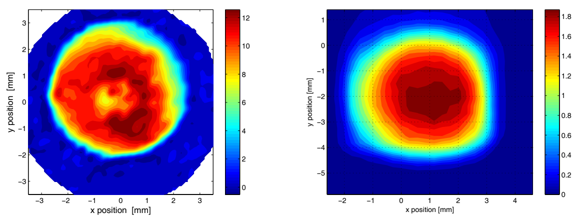

Figure 4: QE-maps of cathode #128.1 used at PITZ (left), and cathode #13.4 operated at FLASH (right).

taken after more than 150 days of operation. Even after this long period no significant inhomogeneities are visible.

DARK CURRENT

Besides the QE another crucial point of operating RF-guns with long RF-pulses (up to 800 μs at FLASH) and high peak powers (up to 7 MW at PITZ) is the dark current. Therefore the dark current is measured routinely with a Faraday cup located 0.82 m downstream of the cathode at PITZ and 1.09 m at FLASH. Due to the specific geometry of the beam line, the dark current measured at the Faraday cup depends on the focusing strengths of the solenoid. Therefore we refer here to the maximum dark current when scanning the solenoid magnetic field.

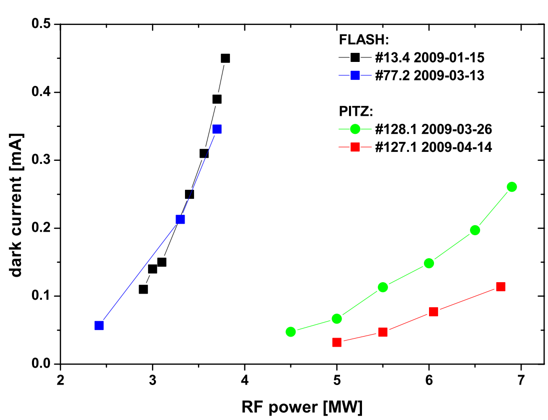

Figure 5: Dark current as function of RF-power for different cathodes measured at FLASH and PITZ.

In figure 5 recent dark current measurements from FLASH (for cathodes #13.4 and #77.2) as well as for PITZ (cathodes #127.1 and #128.1) are presented. The dark current measured at FLASH is an order of magnitude higher than at PITZ. Furthermore, at FLASH we measure the same level of dark current for all cathodes. At PITZ, the dark current emitted changes from cathode to cathode. The measured dark current consists of two fractions. One part originates from the gun body, independently of the cathode. The other part is emitted from the cathode itself. The findings at FLASH suggest, that the dark current is dominated by field emission from the gun body itself. This is supported by optical inspection of the gun backplane and RF contact spring area in May 2008. Damages and signs of sparks have been found on the cathode body close to and on the RF contact spring [5]. At FLASH, the tolerable dark current for normal operation of the FEL is limited to a few 100 μA per RF-pulse. The dark current is transported through the linac and is lost in several places leading to activation of beam line components and damage of electronic devices close to the beam line.

At PITZ, the dark current emission is dominated by the cathodes. We already started an R&D effort to further improve the cleaning and handling procedure of cathodes. To reduce the dark current load at FLASH, we plan to exchange the RF-gun in the winter 2009 upgrade with gun #4.2 actually in operation at PITZ.

SUMMARY AND OUTLOOK

One crucial issue of operating Cs_2Te photocathodes as electron sources in high gradient RF-guns is the lifetime. An improved vacuum environment yields improved lifetimes at FLASH of several months and at several weeks at PITZ, operating with higher accelerating gradients of up to 60 MV/m. This result is important especially for the future European XFEL, operating as a user facility like FLASH but with gradients at the cathode comparable to PITZ.

We plan to exchange the RF-gun at FLASH during the winter 2009 upgrade with the PITZ gun #4.2. This will reduce the dark current transported through the FLASH linac by an order of magnitude.

REFERENCES

[1] S. Lederer et al., "XPS studies of Cs_2Te photocathodes," *Proc. FEL 07, Novosibirsk, Russia, 26-31 Aug 2007, pp 457.*

[2] D. Sertore et al., "Review of the production process of TTF and PITZ photocathodes," *Proc. PAC 05, Knoxville, Tennessee, 16-20 May 2005, pp 671.*

[3] http://wwwlasa.infn.it/ttfcathodes/

[4] P. Michelato et al., "High Quantum Efficiency Photocathode Preparation System For TTF Injector II," *TESLA FEL-Report 1999-07, pp 39.*

[5] S. Schreiber et al., "Cathode Issues At The FLASH Photoinjector," *Proc. FEL 08, Gyeongju, Korea, 24-29 August 2008.*

[6] http://lasers.coherent.com

[7] http://www.ophiropt.com

[8] D. Sertore et al., "First Operation Of Cesium Telluride Photocathodes In The TTF Injector RF Gun," NIM A **455** (2000), 422.

[9] E. Kane, "Theory of Photoelectric Emission from Semiconductors," Phys. Rev. **127** (1962), 131.

[10] R. Powel et al., "Photoemission Studies Of Cesium Telluride," Phys. Rev. B **8** (1973), 3987.