

# CATHODE ISSUES AT THE FLASH PHOTOINJECTOR

S. Schreiber\*, S. Lederer, (DESY, Hamburg, Germany)

P. Michelato, L. Monaco, and D. Sertore (INFN Milano - LASA, Segrate (MI), Italy)

J.H. Han (Diamond Light Source Ltd, Oxfordshire, United Kingdom)

## Abstract

At the free-electron laser user facility FLASH at DESY cesium telluride photocathodes are in use in the laser driven RF-gun based injector. We report on issues concerning quantum efficiency, lifetime, and darkcurrent emission observed recently.

## INTRODUCTION

Cesium telluride ( $\text{Cs}_2\text{Te}$ ) photocathodes are in use at the Free-Electron Laser FLASH (former TESLA Test Facility Linac TTF) since the operation of its first photoinjector in 1998.

To take advantage of the superconducting TESLA type linac, long pulse trains are generated: up to 0.8 ms with up to 10 Hz. To keep the laser power in a reasonable range, FLASH requires high efficient photocathodes emitting at an acceptable wavelength. The operation as a user facility with frequent accelerator study periods results in a frequent but moderate usage of cathodes. With our long operational experience two major issues turn out to be important for FLASH as a user facility: the lifetime and the emitted dark-current.

## CATHODE PRODUCTION

Details on the production of  $\text{Cs}_2\text{Te}$  cathodes and measurements of their parameters are presented elsewhere [1, 2, 3]. The work function of  $\text{Cs}_2\text{Te}$  requires UV lasers. The FLASH injector drive laser has a wavelength of 262 nm. The preparation procedure yields in an average QE of 8.5 % (as of August 2008).[4]

All cathodes are produced at INFN Milano - LASA and shipped with transport boxes under UHV condition to DESY, either FLASH or PITZ. Since 1998, 76 shipments with a total of 249 plugs took place. Amongst them, 78 different  $\text{Cs}_2\text{Te}$  cathodes have been shipped to FLASH or PITZ. Table 1 shows details.

## LIFETIME

For us, the lifetime is defined as the time, the cathode is usable to operate FLASH. One criterion is the available laser pulse energy: when the quantum efficiency (QE) falls below 0.5 %, we consider the cathode as at the end

Table 1: Cathode transportation statistics.

Shipment	to LASA	to FLASH	to PITZ	total
from LASA	–	23	11	34
from FLASH	15	–	9	24
from PITZ	15	3	–	18
Photocathode	to FLASH	to PITZ	total	
$\text{Cs}_2\text{Te}$	57	21	78	
KCsTe	2	–	2	
Uncoated Mo	14	18	32	

of its lifetime. However, we observe a correlation between low quantum efficiency and low performance of FLASH in terms of energy of the SASE FEL radiation. In some instances, cathodes have been changed to improve SASE operation even though the QE was still moderate.

The reduction of quantum efficiency is mainly due to bad vacuum conditions. No limit on extracted total charge has been observed yet. The vacuum pressure measured with ion getter pumps in the section downstream the RF-gun is usually in the low  $10^{-11}$  mbar. This pressure is not measured directly in the RF-gun body, hence we do not know the exact pressure close to the cathode during RF operation. In some occasions, operation with RF or insertion of screens leads to an increase of vacuum pressure eventually reducing the cathode lifetime.

The lifetime of cathodes is usually in the ballpark of 2 month or longer. In 2006 we observed a considerable reduction in QE within a few weeks. At the same time, QE maps of used cathodes showed a typical 'ring' structure suggesting a reduction of QE where the laser hits the cathode. Note, that the thin cesium telluride coating has a diameter of 5 mm, where the laser beam diameter is about 3 mm or less. Recent XPS measurements [5] showed the presence of fluorine in the vacuum system to be responsible for the rapid reduction in QE and the corresponding ring structure in the QE map. The most likely explanation is that at the place, where the UV laser beam hits the cathode, conversion of  $\text{Cs}_2\text{Te}$  to metallic Te caused by the fluorine is enhanced.

On the occasion of the last FLASH shutdown in 2007 we rebuilt the vacuum section between the RF-gun and the first accelerating module. The new vacuum chamber has better pumping abilities. Moreover, we discovered that Teflon

\* siegfried.schreiber@desy.de

washers have been used at the screen holders of the old chamber. Under the high radiation level – mainly from the darkcurrent emitted by the RF-gun –, fluorine has been released into the vacuum explaining the observed rapid QE reduction.

Since the removal of the Teflon washers in May 2007, the lifetime of cathodes has considerably improved. Cathode #108.1 has been used 126 days from July to November 2007, cathode #21.3 for 129 days from December 2007 to May 2008, and cathode #91.1 for 68 days from May to end July 2008.

A change of cathodes is sometimes motivated by the observation, that fresh cathodes ease the generation of high SASE energy levels at FLASH. Figure 1 shows an example of an increase of the production of SASE-FEL radiation after a change to a fresh cathode. There is no conclusive

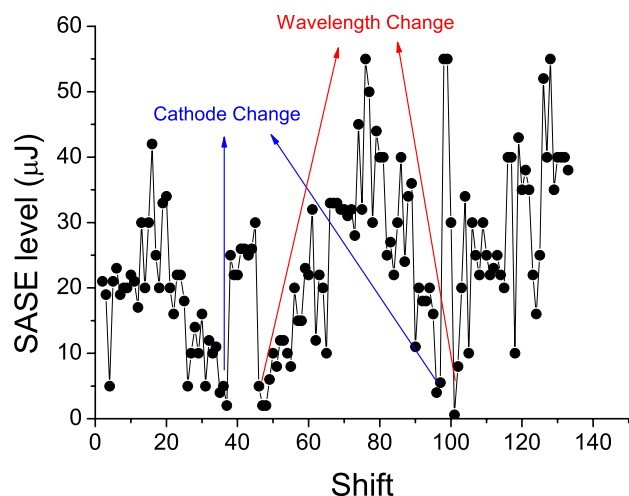


Figure 1: Energy of the SASE FEL radiation during the last part of the 1<sup>st</sup> user run in 2007. With a fresh cathode, the energy of the SASE radiation increased considerably.

explanation yet on this observation. Arguments point to a different emission process of fresh cathodes, since the SASE process is dominated by the longitudinal structure of the compressed bunch.

As an example for the stable quantum efficiency observed since the improvements made during the 2007 May shutdown figure 2 shows the quantum efficiency of cathode #108.1 during its operation from July to November 2007. Even after 126 days of operation, the QE has not decreased: it stayed roughly constant in the order of 9%. Due to the specific measurement set-up during FLASH user operation, the systematic error of the data points is quite large. We estimate about 20%.

Note, that the QE is measured with nominal parameters of the RF-gun: accelerating field 28 MV/m (forward power 3.8 MW at a launch phase of 38 °) and a small laser beam diameter of 2 mm. Figure 3 shows a typical measurement for cathode #123.1: the extracted charge is plotted against the initial laser pulse energy. The charge increases proportional to the laser pulse energy until it saturates due to space

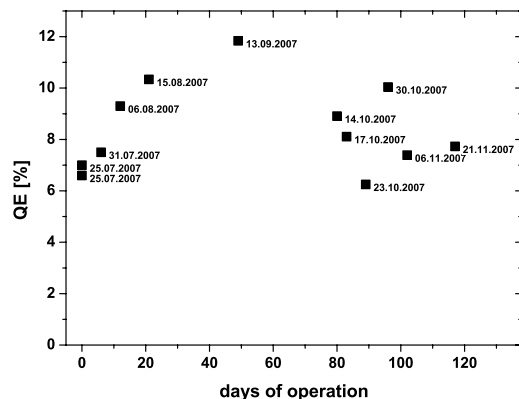


Figure 2: QE cathode #108.1 during operation.

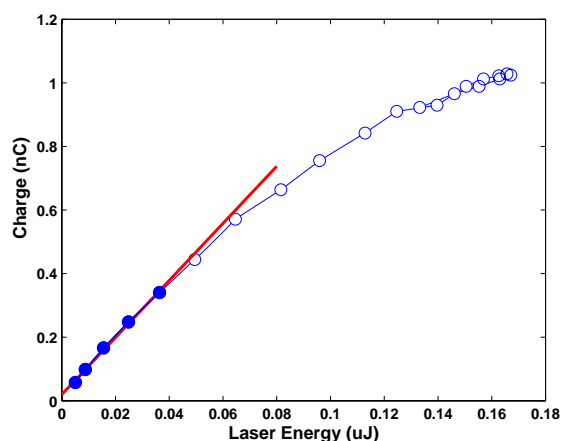


Figure 3: Charge vs. laser energy for cathode #123.1.

charge effects. We calculate the QE from the slope of the linear part, resulting in 4.3% for this example. Cathode #123.1 has been exposed on purpose to a poor vacuum of  $10^{-8}$  mbar resulting in a QE degradation.

The accelerating field at the cathode enhances the quantum efficiencies considerably. Figure 4 shows quantum efficiencies obtained at different accelerating gradients for cathode #123.1, including a measurement at zero field with a cw Hg-lamp.

The field enhancement is described by

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

with a proportional constant  $A$ , the elementary charge  $q_e$ ,  $E$  the macroscopic accelerating field at the cathode, and  $\epsilon_0$  the dielectric constant of vacuum. Space charge effects are neglected. From the fit, we obtain the work function  $(E_G + E_A)$  and the enhancement factor  $\beta$ . The work function  $W$ , in the case of the semiconductor  $\text{Cs}_2\text{Te}$ , is the sum of energy band gap  $E_G$  and electron affinity  $E_A$ . The parameter  $m$  contains information on the emission process

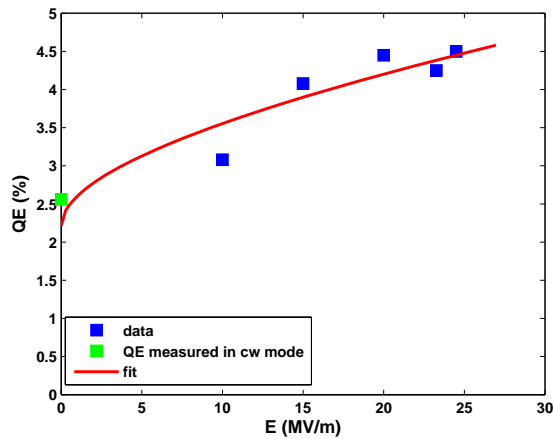


Figure 4: QE vs. accelerating field at the cathode for cathode #123.1; squares: data, red curve: fit by Eq. 1.

itself.[6] 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  $\beta = 7$  (represented by the red curve).[7]

## DARKCURRENT

Darkcurrent emitted from the RF-gun is a major issue for the operation of FLASH. The darkcurrent originating from the cathode or the RF-gun backplane close to the cathode is lost at various places along the linac. Part of the darkcurrent even reaches the undulator and may not be completely eliminated by the collimation system. When darkcurrent is lost, electro-magnetic showers and neutrons are created which may damage beamline components and electronic devices close to the beamline.

In a recent review on darkcurrent at FLASH and PITZ [8] it has been pointed out, that darkcurrent originating from field emission at the RF-gun backplane/cathode interface is slowly reduced with operating time. Typical values are in the ballpark of  $200 \mu\text{A}$  measured with a Faraday cup at the gun exit. Darkcurrent values above about 1 mA would make the operation of the facility impossible. Note, that the superconducting accelerator is operated at an RF pulse length of  $800 \mu\text{s}$ .

Occasionally a very high darkcurrent level of 1.3 mA is emitted by specific cathodes. One example is cathode #37.2 (August 2004), where the emitter could be identified as a macroscopic particle on the cathode surface.[8]

Recently, in winter 2007 and spring 2008 several cathodes exhibited an enormous darkcurrent after insertion into the gun. Already with low gradients in the gun, the limit of 1 mA has been exceeded. All cathodes with this exceptional high dark current show similar image structures. Darkcurrent images are taken with a Ce:YAG screen just after the RF-gun exit. As example, figure 5 shows a darkcurrent image of cathode #36.2 obtained in April 2008. A darkcurrent of  $500 \mu\text{A}$  is measured at an RF power of

just  $P_{for} = 2.4$  MW (operational RF power 3.8 MW). The solenoid current was 300 A. Most of the dark current is emitted at an off center location (lower right on the image), presumably from the RF contact spring. Indeed, typical signs of sparking at one location has been seen on the RF contact spring during inspection in April 2008 and on the corresponding part of the cathode plug. The RF contact spring has been replaced by a new spring in May-2008.

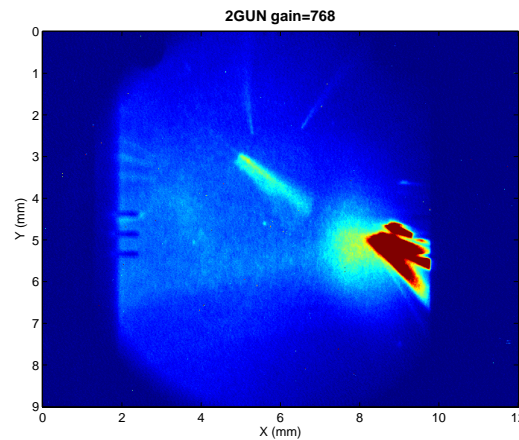


Figure 5: Darkcurrent image of cathode #36.2. Strong emission close to the RF contact spring is visible.

We observe also strong single emitters. For example figure 6 shows a strong emitter seen with cathode #13.4. In this case, the darkcurrent was  $450 \mu\text{A}$  for a forward power of  $P_{for} = 3.2$  MW and a solenoid current of 298 A.

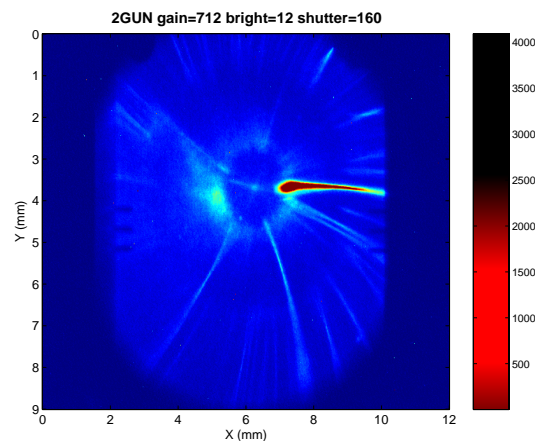


Figure 6: Darkcurrent image of cathode #13.4. A strong single emitter is visible.

Some of these emitters could be identified as particles of Mo, Ag, and Fe. After years of operation, we accumulated particles in the load-lock system, in the preparation chamber, and in the transfer boxes. The silver particles most likely originate from the Ag-coated RF contact spring, the Mo and Fe particles from the unavoidable handling of the cathode plugs during transfers.

After careful cleaning of the system in May 2008, the number of emitters has been reduced. Newly produced

cathodes tested in August still show one or two emitters, but with a 'normal' level of darkcurrent. Improved cleaning and handling procedures such as dry-ice cleaning are being tested.

## SUMMARY AND OUTLOOK

Lifetime and darkcurrent emission from Cs<sub>2</sub>Te cathodes are important issues for the operation of FLASH. The lifetime could be improved by a better pumping scheme in the diagnostics section after the RF-gun. Since the removal of Teflon from the vacuum system, the quantum efficiency of cathodes is stable at a high level of 9%. Cathode #108.1 has been used 126 days, #21.3 for 129 days, and cathode #91.1 for 68 days.

Massive darkcurrent emission has been observed for several cathodes late 2007 and spring 2008. The origin of the emission was a spark close to the RF-contact spring and at the same time the presence of strong emitting particles. Since the exchange of the RF-contact spring and the cleaning of the system, darkcurrent emission is back to an acceptable level.

More rigorous cleaning and handling procedures to avoid contamination with particles are being tested.

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