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UPDATE ON THE PHOTOCATHODE LIFETIME AT FLASH AND EUROPEAN XFEL

S. Lederer*, F. Brinker, S. Schreiber,
Deutsches Elektronen-Synchrotron, Hamburg, Germany
L. Monaco, D. Sertore,
INFN Milano - LASA, Segrate, Italy

Abstract

The photoinjectors of FLASH and the European XFEL at DESY (Hamburg, Germany) are operated by laser driven RF-guns. In both facilities Cs_2Te photocathodes are successfully used. In this paper we give an update on the lifetime, quantum efficiency (QE), and dark current of the photocathodes used over the last years. At FLASH cathode #73.3 was operated for a record lifetime of 1413 days and was replaced December 2018 by cathode #105.2. At the European XFEL cathode #680.1 is in operation since December 2015, for 1356 days up to now.

INTRODUCTION

At DESY (Hamburg, Germany) two free-electron laser user facilities are operated. Since 2005 FLASH [1–4] delivers successfully high brilliance femtosecond short XUV and soft X-ray SASE to photon experiments. Based on TESLA type superconducting linac technology, FLASH is able to accelerate in burst mode several thousand electron bunches per second. The macro-pulse repetition rate is 10 Hz with a useable length of the RF pulses of maximal 800 µs. With a micro-bunch frequency of 1 MHz up to 8000 bunches per second can be accelerated at FLASH, limited by the present laser systems. The bunch charge depends on the requirements on the FEL-light and is usually within a span of 20 pC to 1 nC. After acceleration to 1.25 GeV, the electron bunches are distributed into two different undulator beamlines. While the FLASH1 beamline utilizes fixed gap undulators, the FLASH2 beamline is equipped with variable gap undulators.

The second FEL user facility operated at DESY is the European XFEL [5]. It aims for the delivery of high brilliance femtosecond short X-ray pulses in the energy range of 0.25 to 25 keV. As FLASH, the European XFEL uses TESLA type superconducting linac technology with 10 Hz macro-pulse repetition rate. With a micro-bunch frequency of up to 4.5 MHz and an RF-pulse length of 600 µs, the European XFEL can deliver 27000 bunches per second. Downstream the accelerator the beam can be distributed to three variable gap undulator sections generating the desired SASE light. After the successful commissioning of the accelerator in 2016 [6] and first lasing in May 2017 [7], the first user periods have been successfully accomplished [8].

* sven.lederer@desy.de

THE ELECTRON SOURCES

The photoinjectors of FLASH and the European XFEL are very similar. They are both driven by a normal conducting 1.5 cell 1.3 GHz L-band RF-gun, based on the design by [9]. Currently the accelerating field at the photocathode during standard operation at FLASH is 52 MV/m and 54 MV/m for the European XFEL respectively. The complete gun set-ups are dedicated to be interchangeable between both facilities.

Since August 2013 Gun3.1 is operated at FLASH [10]. The first RF-gun operated at the European XFEL was Gun4.3. It was installed in 2013 and operated during the commissioning phase and the first user runs. In December 2017 it was exchanged with Gun4.6 and serves now as hot spare.

In both facilities the electron bunches are generated inside the RF-gun by means of photoemission. The drive lasers at FLASH operate at a wavelength of 262 nm and 257 nm [11], the two lasers at the European XFEL at 257 nm and 266 nm. The vacuum pressure in the RF-guns during operation is in the lower 10^{-9} mbar regime or better. The good vacuum condition allows for the operation of Cs_2Te as photocathode emitting material. The high quantum efficiency (QE) of this material in the UV keeps the required average laser power in a reasonable regime.

The photocathodes are either prepared at INFN-LASA in Milano, Italy, [12] or at DESY. Transfer to the accelerators is done with UHV transport boxes, maintaining a pressure in the low 10^{-10} mbar range. The transport boxes can be equipped with up to four cathodes.

In both facilities a very similar load-lock transfer system is used to insert the Cs_2Te photocathodes under the required UHV conditions into the RF guns [12].

QE AND LIFETIME

QE measurement procedure

To monitor the photocathode performance we perform QE measurements on a regularly bases, if the operational schedules allow. For monitoring purposes the QE is measured always under comparable conditions. The on-crest accelerating field during the measurements is in the order of 52 MV/m. The launch phase is set to 38° w.r.t. zero crossing. This phase was chosen years ago and kept as reference for the QE measurements. It is neither the on-crest phase nor the launch phase during standard operation of the accelerators. On-crest, about 30% more charge is extracted than at 38°.

To determine the QE we measure the charge as function of the laser energy. The charge is measured by means of a toroid

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right after the RF-gun (uncertainty 1%). At FLASH the laser energy is measured by means of a calibrated joulemeter in front of the vacuum window (uncertainty 2%). At the European XFEL the measurement is done by a photo diode which is cross-calibrated with a pyroelectric detector. To obtain the laser energy at the cathode the transmission of the vacuum window and the reflectivity of the in-vacuum mirror are taken into account in the data analysis.

From the linear slope of the charge vs. laser energy data in the not space charge limited regime we calculate the QE [13]. Typical laser spot diameters at the photocathodes during the measurements are 1 to 1.2 mm.

Lifetime at European XFEL

Figure 1 shows the quantum efficiency of cathode #680.1 over time. The cathode is operated at the European XFEL since 2015.

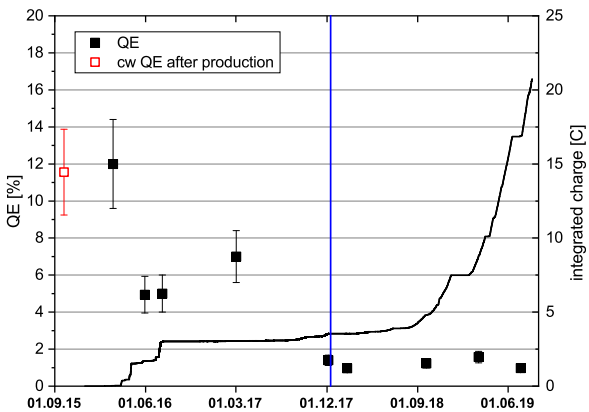

Figure 1: Quantum efficiency (black squares) and integrated charge vs. time for cathode #680.1, operated at European XFEL. The red data point shows the QE right after production in September 2015 measured with Hg-lamp at 254 nm. The vertical blue line marks the change of RF-guns.

Over the first months of operation the quantum efficiency dropped quiet a lot but since than is stable. During operation in the first RF-gun of the European XFEL (Gun4.3) around 3.5 C have been extracted from the cathode. Since Gun4.6 is operated up to now 17.2 C have been extracted from cathode #680.1. Overall the cathode is in usage for 1356 days up to now.

Lifetime at FLASH

In the past 4 years at FLASH only two cathodes have been operated. From February 2015 to December 2018 cathode #73.3 was used for a record of 1413 days.

In Fig. 2 the QE of cathode #73.3 as well as the integrated extracted charge are shown over the whole operation time. Even after the 1413 days of usage the QE was still in the order of 4%.

In addition to the regular QE measurements at FLASH, the homogeneity of electron emission from the photocathodes

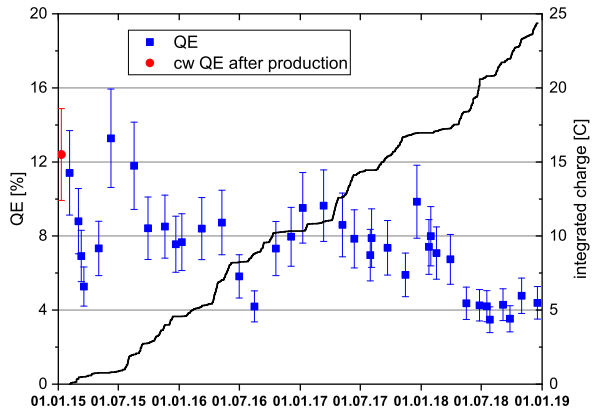

Figure 2: Quantum efficiency (blue squares) and integrated charge vs. time for cathode #73.3, operated at FLASH from February 2015 to December 2018. The red data point shows the QE right after production 23-May-2013, measured with Hg-lamp at 254 nm.

is studied by QE-maps. For this investigations a small spot laser beam (100 µm) is scanned over the cathode and the emitted charge is measured with a high resolution toroid (detection threshold <1 pC). The laser energy is adjusted to generate a maximum charge of 10 to 30 pC.

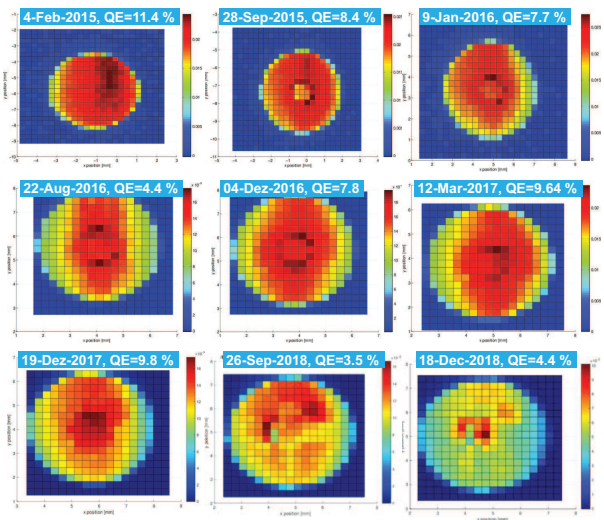

Figure 3: QE-map evolution of cathode #73.3 from February 2015 to December 2018.

In Fig. 3 the evolution of QE-maps of cathode #73.3 is shown. Starting from a homogeneous emission over the whole cathode, over the first months we observe a decrease of QE at the place where the laser hits the cathode. After further operation the picture changes in a way that the point, where the laser impinges, shows higher QE than the rest of the cathodes [10, 14, 15]. In 2018 we observed an severe increase in non-uniformity, resulting in small spots of high QE. This, and not a too low QE, yielded in the decision to exchange the cathode with #105.2 in December 2018.

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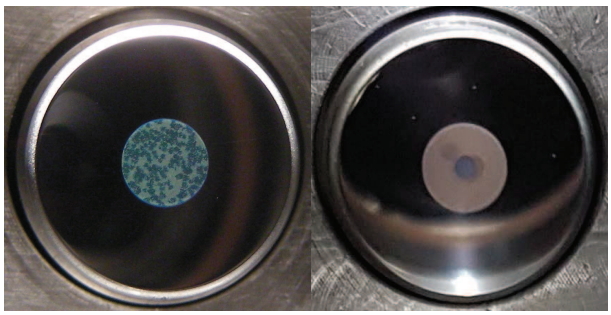

Figure 4: Pictures of cathode #73.3 in the transport box right after deposition in July 2013 (left) and after usage in December 2018 (right).

In Fig. 4 pictures of cathode #73.3 in the transport box are shown. The left one was taken after the production of the cathode in July 2013, the right one after the extraction from Gun3.1 at FLASH in December 2018. The points where the laser usually hits the cathode during operation are clearly visible. But despite of this we can not observe severe irregularities like on other cathodes (see [16]) which could explain the spots in the QE maps.

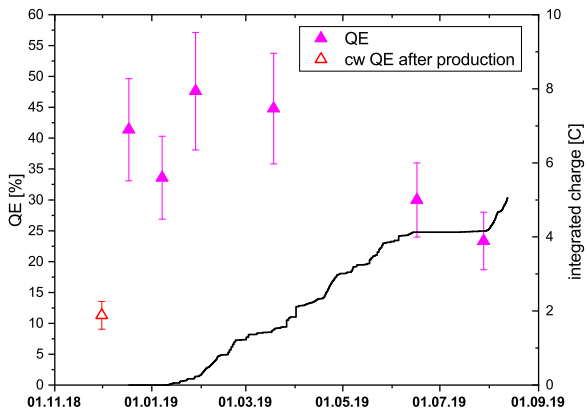

Figure 5: Quantum efficiency (magenta triangles) and integrated charge vs. time for cathode #105.2, operated at FLASH since December 2018. The red data point shows the QE right after production measured 6-Jun-2013 with a Hg-lamp at 254 nm.

Figure 5 shows the QE as well as the integrated charge over time for the new cathode, #105.2. The quantum efficiency obtained for this cathode is remarkable high. Even though it was produced in 2013 the first QE measured in the FLASH RF-gun was about 40%. The big difference between the cw QE and the pulsed QE as well as the high numbers is not understood and under investigation.

SUMMARY

The Cs_2Te photocathodes operated at FLASH and the European XFEL during the last years show a remarkable lifetime. Cathode #680.1 is in use at European XFEL for 1356 days with a total extracted charge of 20.7 C. An even longer operational time was obtained for cathode #73.3 at FLASH. This cathode was in use for 1413 days and a charge of 24.4 C has been extracted. Since December 2018 cathode #105.2 is operated at FLASH, showing a remarkable high quantum efficiency.

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