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Cs_2Te PHOTOCATHODE LIFETIME AT FLASH AND EUROPEAN XFEL

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Abstract

The photoinjectors of FLASH and the European XFEL at DESY (Hamburg, Germany) use Cs_2Te photocathodes. In this contribution we give an update on the lifetime and quantum efficiency of the cathodes operated in both facilities. Cathode #680.1 was operated at the European XFEL from the injector commissioning to the first user run for over 700 days. At FLASH cathode #73.3 has been operated with a record of more than 1000 days.

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 its TESLA type superconducting linac technology [5] FLASH is able to accelerate several thousand electron bunches per second in burst mode. The macro-pulse repetition rate is 10 Hz with a length of maximal 800 µs. With a micro-bunch frequency of 1 MHz up to 8000 bunches per second can be accelerated at FLASH. The bunch charge depends on the requirements on the FEL-radiation 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.

In 2016 the commissioning of the European XFEL [6, 7] had started [8]. 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 a TESLA type SRF linac 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 and first lasing in May 2017 [9], the first user periods have been successfully accomplished.

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 L-band RF-gun, based on the design by [10]. It is operated at 1.3 GHz. 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 interchangeable between both facilities.

At FLASH currently Gun3.1 is in operation. This gun was built in 2005 and conditioned at PITZ (DESY, Zeuthen site) in 2006 for a 5 Hz operation at 45 MV/m (4.5 MW RF-power) [11]. In 2012 the gun was completely disassembled and the gun cavity as well as the input-coupler have been dry-ice cleaned [12]. After re-assembly it was conditioned at PITZ to 5 MW at 830 µs RF-pulse length and 10 Hz. In August 2013 Gun3.1 was installed at FLASH.

The first RF-gun operated at the European XFEL was Gun4.3. Conditioning was done at PITZ in 2013 [13]. It was installed at the European XFEL in 2013 and operated during the commissioning phase and the first user runs. In December 2017 it was exchanged with Gun4.6 [14] 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, the two lasers at the European XFEL at 257 nm. The vacuum pressure in the RF-guns during operation is in the lower 10^{-9} mbar regime or better. This allows for the operation of Cs_2Te as emitting material for the photocathodes. Utilizing the high quantum efficiency (QE) in the UV of this material allows to keep the required average laser power in a reasonable regime.

The photocathodes are either prepared at INFN-LASA in Milano, Italy, [15] or at DESY. Transfer to the accelerators is done by means of UHV transport boxes, maintaining a pressure in the low 10^{-10} mbar regime. The transport boxes can be equipped with up to four cathodes.

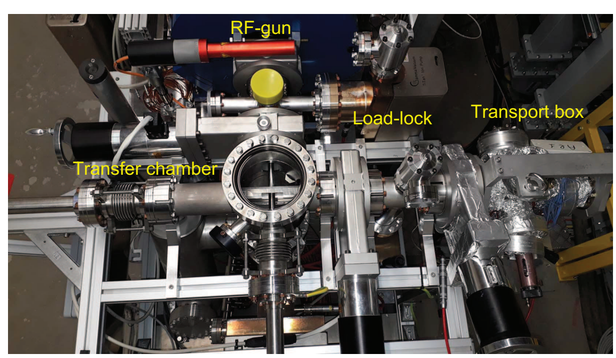

Figure 1: Cathode transfer system of the European XFEL. It is a copy of the FLASH system with a few improvements.

To insert the Cs_2Te photocathodes under the required UHV conditions into the RF guns dedicated transfer systems are used [15]. Figure 1 shows a picture of the cathode transfer system installed at the European XFEL. It is an improved version of the one used at FLASH. Changes include

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an improved visibility of the cathodes in the transfer chamber using additional view ports and exchangeable rails for the carrier.

QE AND LIFETIME

QE Measurement Procedure

To monitor the photocathode performance we perform QE measurements on a regularly bases usually every month. 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 vs. laser energy. The charge is measured by means of a toroid right after the RF-gun (uncertainty 1%). At FLASH the laser energy is measured with 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. The transmission of the vacuum window and the reflectivity of the in-vacuum mirror are taken into account in the data analysis.

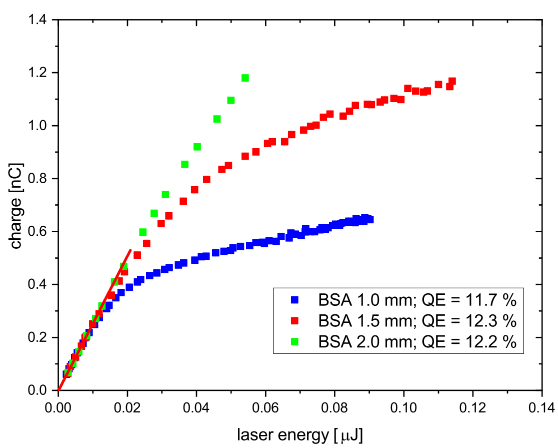

Figure 2: Charge as function of laser energy for cathode #680.1 for three different laser spot sizes (BSA) at the cathode, blue squares: 1.0 mm, red squares: 1.5 mm, green squares: 2.0 mm, red line: fit to the data as described in the text.

From a linear fit to the charge vs. laser energy trend in the not space charge dominated regime we calculate the QE. For homogeneous cathodes this technique makes the QE independent from the laser spot size at the cathode, as shown in Fig. 2. The figure shows the charge plotted as function of the laser energy for cathode #680.1 for three different laser spot sizes. The QE for all three spot sizes is the same within the measurement errors (the average QE is 12.1 ± 0.3 %).

Lifetime

Figure 3 shows how the QE of cathode #680.1 developed during operation of the European XFEL. The cathode was prepared in September 2015 at DESY and is in constant operation since December 2015. The plot also shows the integrated charge extracted over time. The initial QE was 12 % and dropped afterwards during operation. Up to now a total charge of 3.7 C has been extracted from the cathode. Even though the QE dropped quite a lot, the cathode is now (up to the start of the conference) in operation for 872 days. This number becomes even more remarkable, taking into account that the cathode is operated already in the second RF-gun (Gun4.6). After the conditioning of Gun4.6 at PITZ the RF-window configuration had to be changed in order to match the waveguide distribution of the European XFEL. Consequently a re-conditioning on-site was necessary and for operational aspects cathode #680.1 was used for this. So it was exposed to vacuum conditions not preferable for Cs_2Te photocathodes.

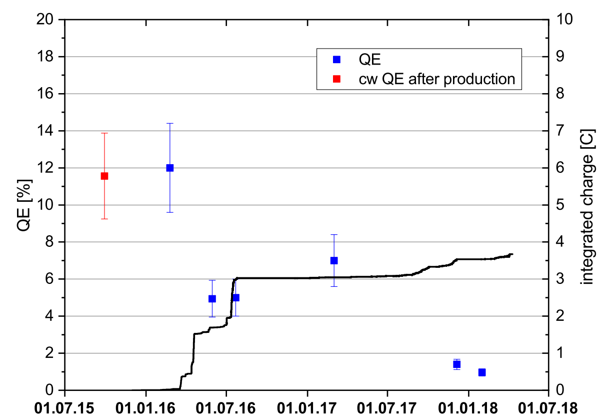

Figure 3: Quantum efficiency (blue squares) and integrated charge vs. time for cathode #680.1, operated at European XFEL. The red data point shows the QE right after production measured with Hg-lamp.

Figure 4 shows the QE and the integrated extracted charge over time for cathode #73.3 during operation of FLASH. This cathode was produced at INFN-LASA, Milano, in June 2013. It was inserted into the FLASH RF-gun in February 2015. Up to now the cathode is in operation for 1180 days, being the current lifetime record. During this time, a total charge of 18 C has been extracted from the cathode. Note, that FLASH is operated with beam 7500 hours per year.

QE-maps

The homogeneity of electron emission from the photocathodes at FLASH is regularly 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 by means of a toroid. The laser energy is adjusted to generate a maximum charge of 10 to 30 pC.

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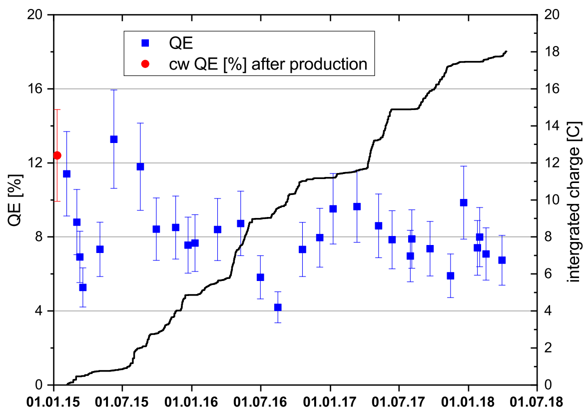

Figure 4: Quantum efficiency (blue squares) and integrated charge vs. time for cathode #73.3, operated at FLASH. The red data point shows the QE measured right after production with a Hg-lamp.

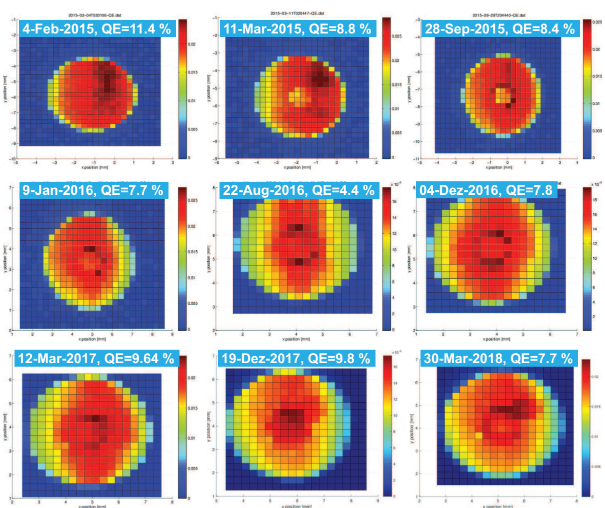

Figure 5: QE-map evolution of cathode #73.3 from February 2015 to March 2018.

In Fig. 5 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 decreasing QE at the place where the laser hits the cathode. Then the QE at this place becomes higher than on the surrounding areas. We assign this behavior to a rejuvenation effect caused by the UV light of the laser. The QE degrades over the complete Cs_2Te film because of temporary improper vacuum conditions. A small leak in the beamline section about 2 m downstream the RF-gun developed in September 2016 and was repaired December 2016. The vacuum pressure in the section increased from the usual 10^{-10} mbar to 10^{-8} mbar. Also the RF-window showed a small leak in July 2016 and has been quickly exchanged [16]. The UV light of the laser then partly regenerates the QE. This behavior has been observed already for cathode #618.3 [17] and supports the results from pollution studies [18] performed at INFN-LASA, Milano.

SUMMARY

The two Cs_2Te photocathodes currently operated at FLASH and the European XFEL show a remarkable life time. Cathode #680.1 is in operation for 872 days with a total charge of 3.7 C extracted. Cathode #73.3 even outperforms this with a lifetime record of 1180 days. The total charge extracted from this is cathode is 18 C.

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