HIGH QE PHOTOCATHODES AT FLASH*

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Abstract

The RF gun-based photoinjector of FLASH (former VUV-FEL) at DESY continues to use high quantum efficiency (QE) photocathodes produced at LASA, Milano. To study the photocathode behavior during beam operation, an online QE monitoring tool has been installed. In this paper, we present the results of several measurements of the quantum efficiency (QE) during the lifetime of the cathodes. We compare the QE values taken in the RF gun with data measured just after production with a continuous UV light source.

INTRODUCTION

FLASH is a free electron laser user facility at DESY providing laser-like radiation from the VUV to the soft X-ray wavelength regime [1]. SASE free electron lasers require an excellent beam quality, which is achieved with an injector based on a laser driven RF gun. The electron beam is accelerated with TESLA superconducting modules.

A high quantum efficiency (QE) photocathode together with a synchronized mode-locked laser system is used to generate the electron beam structure typical for superconducting accelerators: some thousand bunches in a millisecond long RF pulse. Low QE cathodes would require a laser system of kW average power, cathodes with a QE in the percent range allow for a reasonable laser system of an average power in the few W range.

Important for FLASH as a user facility is also the typical lifetime of a cathode. Since the beginning of the user runs in summer 2005 we frequently measured the QE of the cathodes used. In this report, we give an overview of the measurements and compare them with measurements obtained with a Hg-lamp.

THE CATHODE SYSTEM

We produce Cs_2Te cathodes at INFN Milano-LASA, Segrate, Italy (see e.g. [2, 3]).

The emissive Cs_2Te film with a diameter of 5 mm is deposited onto a plug of pure Molybdenum. The plug fits to the backplane of the FLASH RF gun.

Fresh cathodes are shipped to DESY in a transport chamber. Since the high QE is only maintained by keeping the cathode in ultra-high vacuum, the transport chamber is continuously pumped; the vacuum is never broken. The transport chamber is attached to the cathode system at FLASH, a fresh cathode is picked and moved to the RF gun whenever required. The transport chamber contains 2 cathode plugs with a Cs_2Te film, one blank plug, and one plug with a scintillator. If required, the blank cathode can be used for RF conditioning of the gun, the scintillator eases the alignment of the UV laser beam onto the cathode.

The L-band 1 1/2-cell RF gun is operated with a 5 MW 1.3 GHz klystron. With a forward RF power of 3.2 MW, a gradient of 42 MV/m on the cathode surface is achieved on crest. The repetition rate is up to 10 Hz, FLASH presently runs with 5 Hz. The gun is operated with various RF pulse lengths from 70 µs to 900 µs depending on the requirements on the beam. To reduce dark current, the RF pulse length is always minimized (see [4]).

The RF gun uses a longitudinal RF power coupler. The gun is pumped through the coupler with a titanium sublimation pump and an ion getter pump. The pressure measured is below $3{\cdot}10^{-11}$ mbar without and 5 to $7{\cdot}10^{-11}$ mbar with RF. Note, that we cannot measure the pressure at the cathode directly. The Cs_2Te cathodes are easily contaminated by residual gases like hydrocarbons and oxygen with a pressure of $1{\cdot}10^{-9}$ mbar even for short term exposures [5].

CATHODE PREPARATION

The cathode plug is made out of pure Molybdenum with a surface of 16 mm in diameter. The surface is cleaned and polished to optical quality with an automated lapping procedure. For cathode 73.1, a manual lapping has been applied. In addition to normal cleaning, some cathodes have been cleaned with a buffered chemical polishing method (BCP) or with electro-polishing (EP).

Thin films of Tellurium and Cesium are then deposited in UHV. Tellurium and Cesium react to produce Cs_2Te. During the evaporation, the plug is heated to 120 °C. First, a thin layer of 10 nm of Tellurium is produced, then Cesium is evaporated at a rate of 1 nm/min. The film is illuminated with UV of a Hg-lamp to monitor the quantum efficiency. The evaporation is stopped, when the QE is at maximum. The final photoemissive layer thickness is some tens of nanometers. A mask with a diameter of 5 mm is used to restrict the formation of the film to the cathode center.

Table 1 summarizes selected data of the cathode used at FLASH since November 2004 (it follows up [3]). Cathodes

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have been used for a period of 100 to almost 200 days and produced an integrated charge in the order of 1 to 1.7 C.

Table 1: Cathodes used at FLASH since Nov 2004. The cw quantum efficiency (cw QE) is measured right after preparation at 254 nm. Cleaning procedures: buffered chemical polishing (BCP) or electro-polishing (EP). Lapping is manually or with an automated procedure. The number of days in operation and the estimated integrated charge produced is given. Cathode 78.1 is still in operation (as of 20-Jun-2006).

nb	cw QE (%)	cleaning	lapping	operation (days)	charge (C)
42.2	8.0	normal	auto	123	1.1
23.2	9.6	normal	auto	195	1.7
72.1	9.2	BCP	auto	180	1.6
73.1	7.9	BCP	manual	114	1.0
78.1	7.7	EP	auto	62	0.5

QUANTUM EFFICIENCY

An automated set-up has been realized to measure the quantum efficiency frequently during the running of FLASH. We define the QE as the ratio of the number of photons incident on the cathode to the number of electrons measured at the exit of the RF gun. The number of photons is calculated from the laser pulse energy measured with a calibrated joulemeter (Molectron, ±5 %). The wavelength of the laser is 262 nm. The emitted charge is measured with a calibrated toroid (±1 %). The transmission of the laser beam through the fused silica vacuum window and the reflectivity of the internal mirror in the vacuum have been accounted for.

The RF gun settings have always been adjusted to the nominal working point of the gun: a forward power of 3.2 MW corresponding to an on crest field of 42 MV/m on the cathode, and a phase of the gun RF in respect to the laser pulse of 38 dg off zero crossing.

The charge is measured as a function of the laser energy for a fixed laser spot size of 2 mm in diameter (the laser pulse length is 4.4 ps (sigma)). The charge increases linearly with the laser energy until space charge effects lead to a saturation of the emitted charge. The QE is calculated from a straight line fit to the linear part.

As an example, Fig. 1 shows a measurement for cathode 78.1 after two month of usage. From the slope of a straight line fit to the data we obtain a quantum efficiency of 4.35 %.

The relative and systematic error of the measurements presented here are in the order of 20 %. The systematic error is mainly due to the uncertainty of identifying the linear part for the fit and due to the cross-calibration of the laser pulse energy monitor with the energy measured in front of the vacuum window.

The variation of the laser energy is done using a variable attenuator. A $\lambda/2$-wave plate is turned against a polarizing splitter. This method guarantees, that the properties of the laser beam with the exception of its energy are not altered.

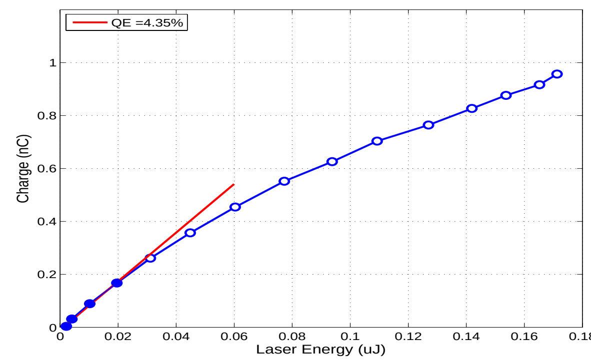

Figure 1: Measured charge output of the RF gun as a function of laser energy on cathode 78.1 as an example. The quantum efficiency is calculated from a straight line fit of the linear part.

As described above, during the production of the cathode, a high pressure Hg-lamp with a 254 nm filter is used to monitor the QE. In order to compare these type of measurements with the pulsed laser/gun data, a similar set-up has been realized close to the gun. The cathode chamber of the RF gun is equipped with a quartz window and a pick-up wire allowing a direct measurement of the cathodes used in the RF gun.

The light of a high pressure Hg-lamp illuminates the cathode through the quartz window. Several wavelength filters in the range of 220 to 334 nm are used. The light intensity is measured with a sensitive power meter, the photocurrent with a pico-ampere meter. A small bias voltage of 150 V is applied between the cathode and the pick-up wire to ensure, that all emitted electrons are collected. Figure 2 shows the measured response function of three cathodes 23.2, 72.1, and 73.1. The measurements with the pulsed laser energy in the RF gun at 4.7 eV (262 nm) is added.

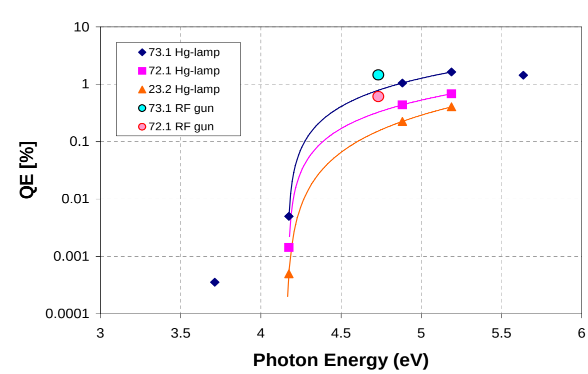

Figure 2: Measured quantum efficiency of cathodes 23.2, 72.1, and 73.1 with a Hg-lamp for different photon energies. Measurements in the RF gun with pulsed laser (4.7 eV) are included.

From a fit to the response curve we can evaluate the $(E_g + E_a)$ = 4.16 $\pm$ 0.01 eV, being the same for all three cathodes. For a fresh Cs_2Te the energy gap is expected to be E_g = 3.2 eV and the electron affinity E_a = 0.5 eV [6].

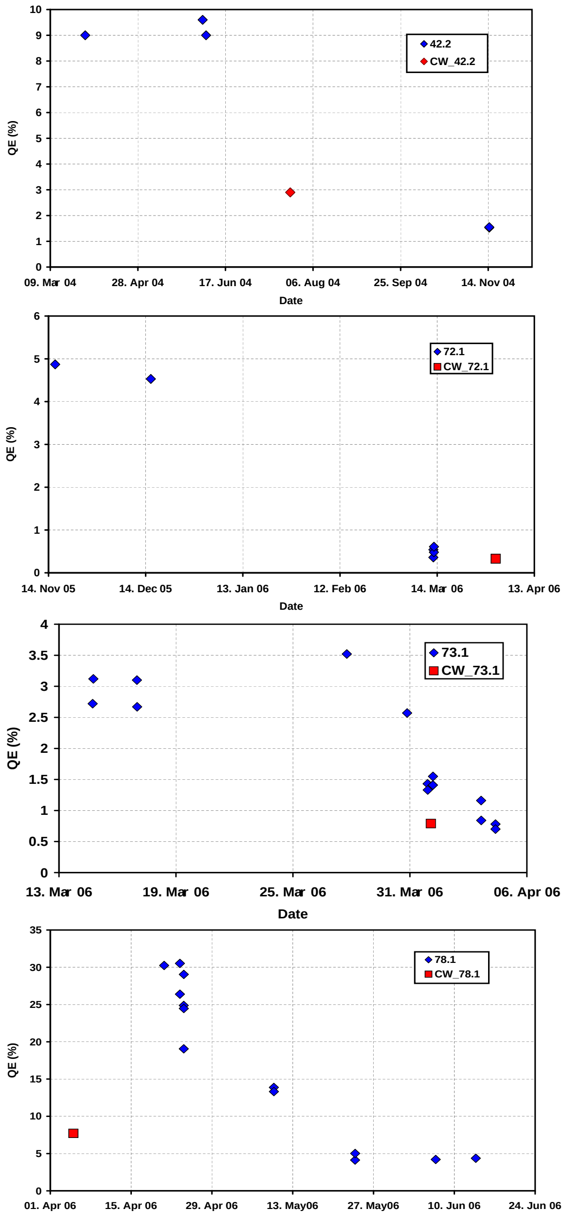

Figure 3: Quantum efficiency measured for cathodes 42.2, 72.1, 73.1, and 78.1 several times during their lifetime in the RF gun.

Fig. 3 shows the quantum efficiency measured for cathodes 42.2, 72.1, 73.1, and 78.1 several times during their lifetime in the RF gun. All cathodes show a drop of the QE over time, however, the characteristics differ. The high values of cathode 78.1 are under investigation.

We can relate the drop in QE with the vacuum condition in the RF gun. Although we cannot directly measure the vacuum at the cathode, the vacuum measured at the gun exit gives a good estimate of the change in vacuum condition. As an example, early this year, the RF gun has been operated with 300 µs long RF pulses, up to this, the pulse length was restricted to 70 µs. During this period, the pressure increased from 5 to $7 \cdot 10^{-11}$ mbar to $2 \cdot 10^{-10}$ mbar. This coincides with the drop of QE of cathode 73.1 at the same time.

We have no indication, that the total amount of emitted charge limits the lifetime of the cathode. At FLASH, we presently produce an integrated charge of about 0.2 C per month.

CONCLUSION

During the last two years, high QE Cs_2Te cathodes have successfully been used in the RF gun of FLASH. The operational lifetime of a cathode is between 100 and 200 days. A transport box contains 2 or 3 Cs_2Te cathodes, so that one box is good for at least a year of continuous running. During their lifetime, the cathodes produce between 1 and 2 C. We consider cathode at the end of its lifetime, when the quantum efficiency decreases below 0.5 %. From our present understanding we believe that the vacuum condition in the RF gun determines the cathode lifetime rather then the extracted charge.

ACKNOWLEDGEMENT

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