HIGH QUANTUM EFFICIENCY PHOTOCATHODES FOR RF GUNS*

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Abstract

High Quantum Efficiency Photocathodes are nowadays routinely used as electron sources for laser driven RF guns. In this paper, we review the production, characterization and operation performances of the Cs_2Te photocathodes prepared at INFN Milano – LASA and operated at DESY for the FLASH and PITZ photoinjectors.

INTRODUCTION

Since the 90s, INFN Milano is involved in the study of the growth process of photocathodes based on alkali antimonide and more recently alkali telluride. The figure of merit for the photocathode characterization are the operative lifetime, the achievable current density, the extracted charge, the dark current, the sensitivity to gas exposition, the Quantum Efficiency (QE), and the uniformity of the cathode sensitive layer response.

The growth process was studied applying surface science techniques like XPS (X-ray Photoelectron Spectroscopy) and AES (Auger Electron Spectroscopy) [1]. We applied the same techniques also for investigating the response to gas exposition.

Since 1998, INFN Milano is in charge of the production of the photocathodes for TTF, now FLASH. From the year 2000, we have also responsibility for the production of the photocathodes for the PITZ facility. In the production process, we apply the knowledge gathered in previous years of R&D activities. Up to now, none of the cathodes has shown any limitation in the extracted charge, even after long periods of usage. The main reason to change cathodes during the gun operation is the growth of dark current to high values. Since the start-up of the cathode delivery, we have collected many parameters that characterize both the plug preparation and the growing process. In the following section we briefly review the preparation, characterization and operational performances of the cathodes, from their deposition at INFN Milano-LASA to their use at FLASH and PITZ.

PHOTOCATODES PRODUCTION

The Preparation System

The preparation system consists of a UHV chamber whose base pressure is few 10^{-10} mbar (low 10^{-9} mbar during cathode growing). A CF63 sapphire viewport allows the cathode illumination for photocurrent measurements. The sources for Te and Cs evaporation are hosted on a frame that holds up to 6 sources. The Te sources are made from pure Tellurium (99.9999 %). Cs is evaporated from SAES® sources based on Cesium chromate. A circular masking system, placed in front of the cathode, shapes the round active layer (Φ= 5 mm) and assures its centering on the plug. The cathodes are loaded in the transport box and moved into the chamber by a magnetic-coupled manipulator. The box is then sent to FLASH or PITZ maintaining the UHV condition at all times.

The Coating Growth Procedure

The cathode plug is made out of pure Molybdenum with a 16 mm front surface diameter. The surface is cleaned and polished to optical quality with an automated lapping procedure. 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 condition. 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, and then Cesium is evaporated at a rate of 1 nm/min. The film is illuminated with UV light (λ=254 nm) 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.

For special purposes, we produce also KCsTe photocathodes that have higher QE then Cs_2Te but shorter lifetime. After the preparation, the plug is heated to 120 °C for the deposition of a 10 nm layer of Te. The temperature is then risen to 150 °C for a K layer deposition. Also in this case we use UV light from an Hg lamp to monitor the quantum efficiency. Once the maximum of the photocurrent arrives, the plug is cooled down to 120 °C for the final Cs layer deposition, until the maximum QE value is reached.

Some Statistics on Produced Cathodes

So far we have produced 51 Cs_2Te photocathodes and 2 KCsTe. 37 Cs_2Te photocathodes have been delivered to FLASH and 14 to PITZ. The overall number of uncoated Mo plugs delivered to different labs is 28 (11 to FLASH and 17 to PITZ). They are used for gun conditioning and dark current measurements.

Fig. 1 reports a summary of the QE measured at LASA for the whole photocathode production. Green dots are QE measurement before the shipment and the magenta ones after their use in the gun and return to LASA from the different labs. These data are available on-line from the Web interface to a database [2]

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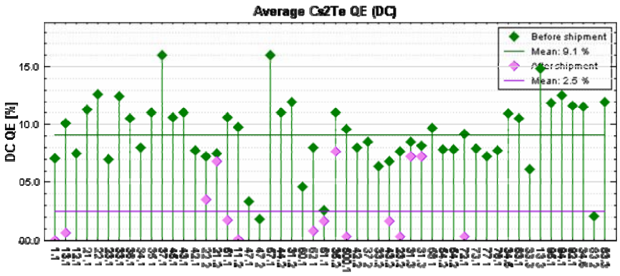

Figure 1: QE of the Cs_2Te photocathodes produced at LASA before and after their use at FLASH and PITZ.

PHOTOCATODES CHARACTERIZATION

After production, the photocathodes are qualified by measuring their QE uniformity over the active layer, taking pictures and measuring their spectral response.

A typical QE map over the cathode area (Φ = 5mm) is reported in Fig. 2. The UV beam (λ=254 nm) was focused onto a small spot (Φ = 1 mm). A well defined area corresponding to the active layer with QE uniformity within 10 % can be clearly seen. Similar uniformities are achieved for larger diameter active layers as well.

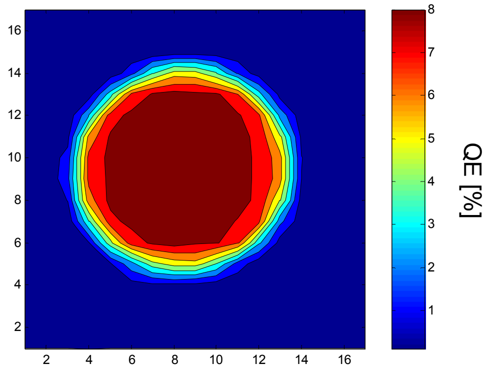

Figure 2: QE map of a typical photocathodes measured at λ=254 nm. Each tick represents 0.5 mm.

The spectral response is useful to study aging effect and to determine the physical properties that are helpful for modeling the photoemission process and estimate the thermal emittance. Fig. 3 shows a typical response for a Cs_2Te photocathodes.

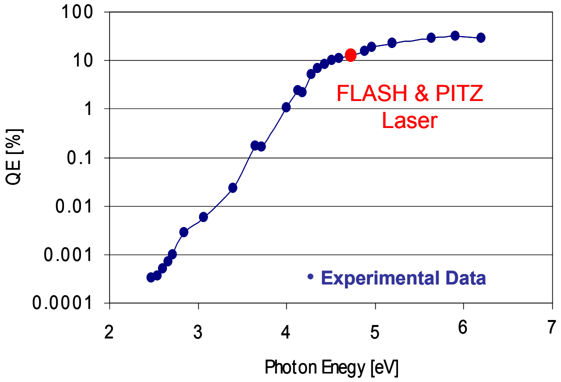

Figure 3: Spectral response of a typical Cs_2Te photocathode. The red dot represents the QE value at the photon energy of the laser used at the photoinjectors.

PHOTOCATODES PERFORMANCES DURING OPERATION

After production, the cathodes are loaded in the transport chamber that typically 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 FLASH L-band 1 1/2-cell RF gun is operated with a 5MW 1.3GHz klystron. With a forward RF power of 3.2MW, a gradient of 42MV/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.

At PITZ a similar configuration is used but the L-band gun is operated with a 10 MW klystron aiming to reach 60 MV/m on the cathode surface.

During operation in both photoinjectors, the main parameters we are interested in are quantum efficiency and dark current but also secondary emission [3] and multipacting effect [4] have been studied.

Quantum Efficiency

Given a constant charge output from the gun, the quantum efficiency determines the laser pulse energy. The two main effects that influence QE are the aging and the effect of cathode operation in a high electric field region. At FLASH, an automated procedure has been set-up to frequently monitor the QE during operation [5]. We record, with a calibrated toroid (± 1%), the emitted charge versus the laser energy measured with a calibrated joulemeter (Molectron ± 5%). 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. 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 (see fig. 4).

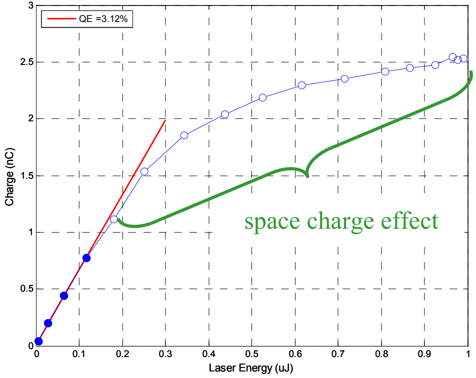

Figure 4: typical measurement of charge vs. laser energy at λ=262 nm. The QE is calculated considering the linear dependence of the extracted charge from the laser energy.

The aging effect has been valuated taking different QE measurements during the operative lifetime of several cathodes. Different phenomena affect the QE aging. In particular, long pulse operation (900 µs) and ion back bombardment play a critical role. Fig. 5 shows the behavior of cathode 78.1.

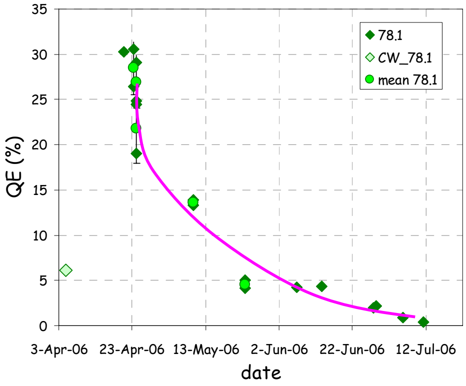

Figure 5: QE aging of cathode 78.1.

As mentioned before, also the analysis of the high electric field influence on the QE is important mainly for its impact on the thermal emittance that plays a key role for the future high brightness electron sources.

To extrapolate the field enhancement factor, we have studied the charge versus laser energy curve. We have model the curve, including different effects like laser spot shape, field enhancement, space charge and a typical example is reported in Fig. 6.

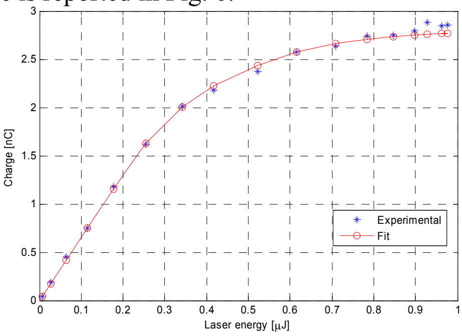

Figure 6: Analysis of the charge versus laser energy taking into account for example space charge, field enhancement and laser spot shape.

Dark Current

Dark current emission is one of the limiting factors in the operation of RF gun-based linear accelerators, due to possible activation and damage of accelerator components and the possibility of inducing quenches in superconducting cavities. The presented data are available from the Web interface of the database [2]. We present here a summary of the data collected in many years of operation and an attempt to identify the dark current source by its modeling.

Fig. 7 shows the dark current trend at PITZ for several photocathodes and three different guns. A main trend to notice is the decrease of dark current during each gun operation. This effect is more pronounced for PITZ-G1 and PITZ-G3 and can be explained as an effect of the gun cavity conditioning. Further explanation has been presented at EPAC06 [6].

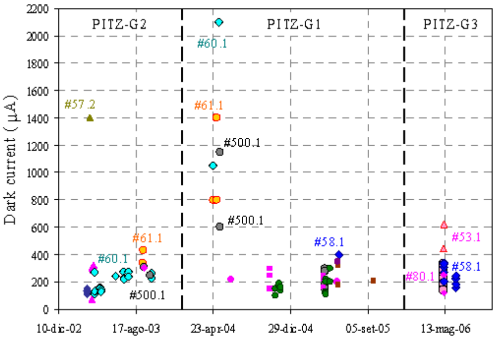

Figure 7: Dark current trend at PITZ from 2002 to 2006.

In order to identify the source of the dark current in the region of the cathode/gun backplane, we have set-up a model that assume a source of dark current in the transition region cathode/gun. Fig. 8 shows the image taken on a screen (left) and simulated (right). The reproduced flares structure is due to the combined effect of dark current energy spread and chromatic effect of the solenoidal field in which the emitted electron flight.

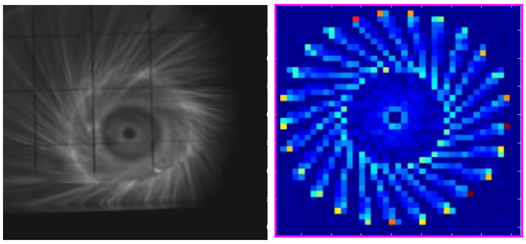

Figure 8: Comparison between screen and simulated dark current (not proper scaled).

CONCLUSIONS

In this paper, we have reviewed the complete photocathode process from the production at INFN Milano–LASA to their use in the FLASH and PITZ photoinjectors. We have consider mainly QE and dark current that up to now are the limiting factor in assuring a very long operational lifetime of the photocathode, today limited to about 90 days.

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