REVIEW OF THE PRODUCTION PROCESS OF TTF AND PITZ PHOTOCATHODES

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Abstract

In the present article, the production process of the photocathodes for the TESLA Test Facility (TTF) at DESY Hamburg and the Photo Injector Test Facility at DESY Zeuthen (PITZ) is reviewed in order to highlight key elements for the final photocathode performances. Since the first photocathode production in 1998, we have continuously collected relevant parameters of the cathode plugs and deposition process. These data are now critically analyzed in view of an optimization of the photocathode performances for the next generation of high brilliance sources.

INTRODUCTION

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

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. From the year 2000 on, we have also responsibility for the production of the PITZ photocathodes. 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 a 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 darkcurrent 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 discuss the preparation system. The sample preparation and the growing process will then be reviewed. We will then analyze the data so far collected to highlight possible key parameters that influence the photocathode characteristics. We finally report about the photocathode performances in the gun, mainly in terms of lifetimes and darkcurrent.

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Many of the data presented in this paper are available online on a web-based database [2], where cathode parameters and performances are archived.

PREPARATION SYSTEM

The preparation system consists of a UHV chamber whose base pressure is few 10^{-10} mbar. The pressure during cathode preparation reaches the low 10^{-9} mbar range. The chamber is equipped with a Residual Gas Analyzer for probing the gas desorption during cathode preparation. 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 caesium chromate. A circular masking system placed in front of the cathode shapes the round active layer 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 TTF or PITZ maintaining the UHV condition at all times [3].

PLUG PREPARATION

The photocathode layers are grown on a Molybdenum plug, properly machined, to allow the handling in UHV conditions and to prevent deterioration of the photoemissive layer.

The plug is cut out from a Mo rod (sintered or arc-cast) and machined to design specifications either with a lath or a mill. The plug is then cleaned by Buffered Chemical Polishing to remove residuals from the machining. To reduce the darkcurrent due to surface roughness, the piece is optical finished. We have used two lapping procedures up to now. The first ("manual") involved an initial step with SiC papers and then clothes with diamond powders. The second ("automatic") procedure uses 6 μm diamond powder with a "diamond embedded" disc and then clothes with diamond suspensions. The size of the final powder used in both cases is 0.1 μm. The plug finishing is checked by measuring its reflectivity at $\lambda = 543$ nm at normal incidence. A summary of measurement for the plugs used for Cs_2Te preparation is reported in Fig. 1. This plot shows that the plug reflectivity is independent from the procedure and its mean value is 56.3 %.

After the optical finishing, the plug is rinsed with acetone and alcohol, inserted in vacuum and then heated up to 425 °C to remove surface contaminants. The plug is then cooled down to 120 °C for cathode deposition.
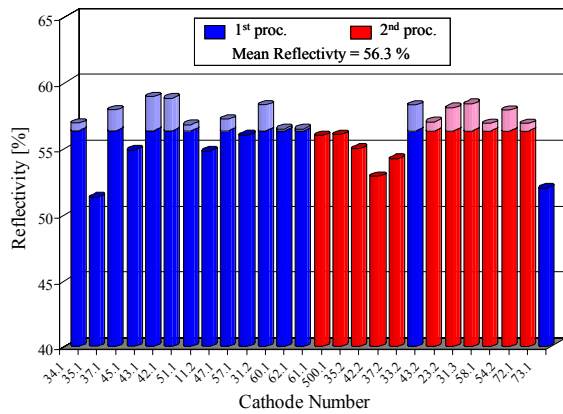
Fig.1 Reflectivity at λ=543 nm of cathode plugs after polishing. The theoretical reflectivity of Mo at this wavelength is 57.5 %.

PHOTOCATHODE DEPOSITION

Cs₂Te and KCsTe

The photocathode growth procedure has been studied in great detail during the past years, applying XPS techniques. First 10 nm of Te are evaporated and then Cs deposition starts, monitoring the QE. The Cs evaporation stops when the photocurrent reaches its maximum. The plug temperature is stable at 120 °C during the whole period. Different compounds with changing Te/Cs ratio develop during the growing process. The correct Te/Cs stoichiometric ratio 1:2 is reached when the maximum in photocurrent is achieved [4].

The average QE of each cathode and of the overall production - 8.9 % - is reported in Fig. 2 as available from the Web interface to the database.
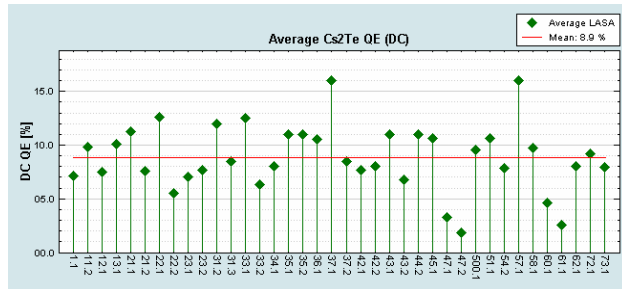

Fig. 2. QE at λ=254 nm of Cs_2Te photocathodes after production and before delivering to either DESY or PITZ.

The very low QE values of cathode 47.1 and 47.2 are due to inconveniences related to Cs sources at some stage of deposition: a source finished during cathode 47.1 growth and then we had an electrical short during evaporation of 47.2. Cathode 61.1 was instead produced with a thin 5 nm Te layer for R&D purpose.

The total number of Cs_2Te cathodes delivered respectively to TTF and PITZ is 29 and 9.

We have also produced two KCsTe photocathodes for dedicated experiments at TTF where high QE was necessary. The QE for cathode 50.1 was 20 % while for cathode 54.1 was 18 %.

PHOTOCATHODE DIAGNOSTICS

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. 3. 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 a QE uniformity within 10 % can be clearly seen. Similar uniformities are achieved for larger diameter active layers as well.
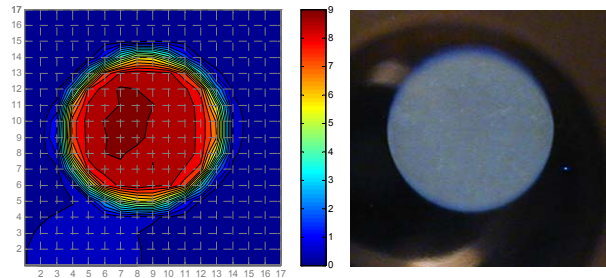

Fig. 3. On the left, cathode 73.1 QE map. Each tick represents 0.5 mm and each contour line 0.5 % of QE. On the right, a picture of the active layer taken just after deposition.

DEPOSITION PROCESS ANALYSIS

A PCA (Principal Component Analysis) [5] of the data samples has been carried out in order to explore correlations between the process parameters and the resulting QE, which is defined as the goal of this optimization. The purpose of this kind of multivariate analysis is to decompose the data into a "structure" and a "noise" part in order to detect any "hidden phenomena". Every sample is represented as a point in a multidimensional space where the coordinates are the values assumed by the measurements and process parameters. The main directions with maximum variation PCs (Principal Components) are identified by the PCA, in a similarity to the principal inertial axis of set of material points. The new reference coordinates system composed by the PCs can suggest if there are variables or parameters that covary in the main variance of the data.

Fig.4 shows an important trend in the data distribution highlighted by the PCA analysis. When plotted against the PC1&PC2 (accounting for 21% and 13 % of the samples variance), the cathodes are clearly separated into distinct groups corresponding to the different masking used for shaping the cathodes photoemissive layer. In particular, the 5 mm photocathodes are well separated from the 10-13 mm. Corresponding to the masking change, we implemented also the "automatic" lapping procedure which is another strong contributor to PC1 (horizontal axis). The presence of this strong grouping might hide other important correlations and indeed none of the many process variables considered in the analysis at this stage has a major influence on the final QE behaviour of the photocathodes.
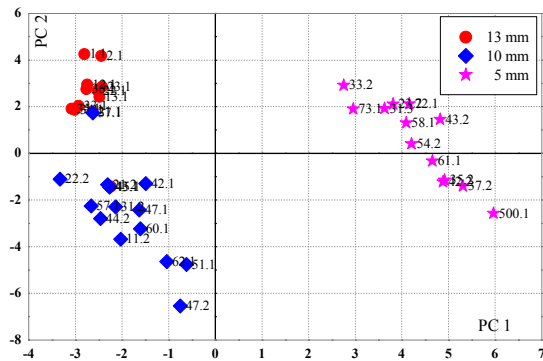
Fig.4 PCA analysis. The main trend is determined by the masking diameter represented with different colors.

According to the PCA practice, we then proceed analysing the two groups separately in order to explore correlations to QE. Fig. 5 reports the load or influence of the different process variables to the first two PCs of one of the two groups (similar results are achieved for the other group). This loading plot shows that the process variable which is primarily correlated to the QE (46) is the number of uses of the Cs sources (30).
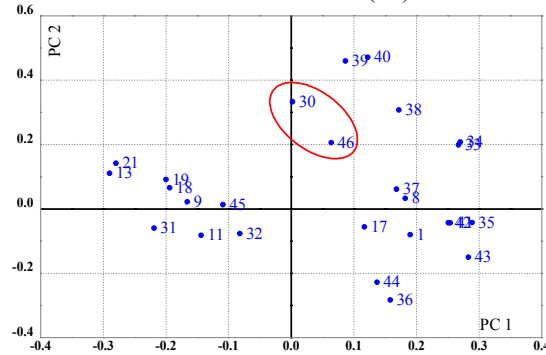

Fig.5 Correlation between QE (46) and the number of use of the Cs sources (30). Two variables close each other on the same side of the origin have a positive correlation.

A possible interpretation is that the aging of the source requires an increase in the current to keep a constant deposition rate. This implies an increase of the source temperature, and, consequently, of the thermal load on the cathode surface. Moreover a decrease of the evaporation uniformity is foreseen. Thus the growing conditions are different from the nominal case previously described and a direct influence on the final QE is expected.

OPERATING PERFORMANCE

Up to now, the darkcurrent is the limiting factor in the cathode usage and hence in its operative lifetime. To the present understanding, the darkcurrent is coming both from the gun itself and from the cathode [6]. Experiments indicate that the darkcurrent is dominantly emitted at the interface between the Cs_2Te and the Mo substrate and from the transition between the cathode plug and the RF gun backplane [7]. Fig. 6 shows the history of the darkcurrent measurements at TTF with a Faraday Cup after the RF gun. The solenoids and accelerating field values are at standard working point of the linac.

The darkcurrent is constantly in the 50-100 μA range since the operation of this gun at TTF. The high darkcurrent value of cathode 37.2 originated from an improper cathode handling, leading to its contamination. An R&D program is in progress to reduce the darkcurrent to some tens of μA. In the past, this has already been achieved only for few photocathodes [6].
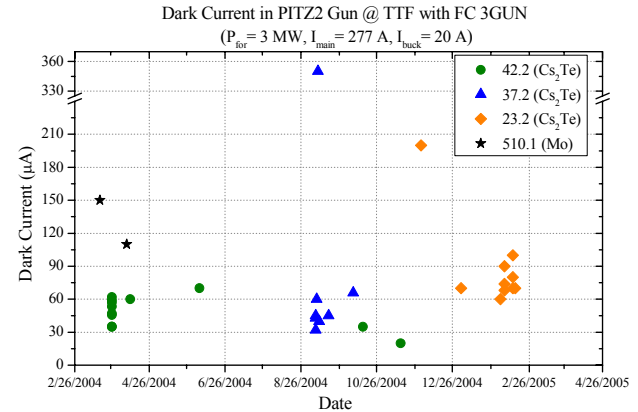

Fig. 6. Darkcurrent vs. time for Cs_2Te and Mo (conditioning) photocathodes during operation at TTF.

CONCLUSIONS

The production process of the photocathodes delivered to TTF and PITZ has been reviewed along its main phases: plug preparation, deposition process and final methods for the photocathode characterization. The preliminary outcome of a multivariate analysis of the production process parameters and of the resulting QE suggests primarily a correlation between the QE and the number of usage of Cs sources. The same analysis will be applied in further studies to the darkcurrent properties of the cathode in the gun and to the QE during operation.

ACKNOWLEDGEMENTS

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