REPORT ON STUDIES ON PHOTOCATHODE PERFORMANCES

P. Michelato, L. Monaco, P. Pierini, D. Sertore
INFN Sezione di Milano LASA, Italy

Abstract

We report here the organization of the information about cathode performances collected during the preparation process and during operation both at PITZ and TTF phase I and phase II. The data have been organized in a database with web based access pages. A first analysis of the data applying multivariate analysis is also presented.
Introduction
The improvement of the actual photocathode properties is an essential step towards an optimization of the overall electron RF gun performances. The limiting factors have been, up to now, dark current and the degradation of the photoemissive properties during usage in the gun. Moreover an increase in cathode performances, such as quantum efficiency, is desirable to loose the requirements on the laser characteristics.

The first step towards the photocathode improvement has been the analysis of the photocathode characteristics during both preparation and operation either in the PITZ guns or in the TTF (Tesla Test Facility) guns. Many parameters characterize the photocathode performances and many cathodes have been produced so far. The huge amount of data has been organized in a database, whose structure will be presented in the following section. The database interface has been developed using the ASP.NET language which allows to access the data, organized in predefined structures, via a web interface. The web interface provides information on preparation of photocathodes and their performances, status of the photocathodes used and their availability in the different labs, etc.

The usefulness of the database is also the possibility of data aggregation and statistics on all the stored information. We have implemented statistics on cathode quantum efficiency either measured at LASA or at PITZ/TTF, operation time, etc. The data available have finally been reviewed and studied applying Multivariate Analysis Techniques in order to highlight important parameters in the production process which influence the final quantum efficiency of the delivered photocathodes.

1 Database Design
The design phase is the more critical task in creating a database. The identification of a proper key parameter and classification of the data play an important role in the future possibility of data aggregation and structuring. Moreover, the possibility to expand the database to include further data has to be considered.

The first step has been to analyze the photocathode production process. A molybdenum plug is the substrate on top of which the photoemissive layer is evaporated. When a photoemissive layer is evaporated on the plug or the Mo plug itself is loaded in the preparation chamber, heated and shipped it becomes a cathode. The plug and the photoemissive layer are characterized by different parameters that are collected in the database. The plug properties depend on the Mo type (sintered or arc-cast, ), machining, polishing, surface finishing and they are characterized by their reflectivity. The photoemissive layer depends instead on the production process parameters (Te and Cs currents, evaporation rate, etc. ) and it is characterized by quantum efficiency (QE), QE spatial map, spectral response, colors, etc.

Fig. 1 presents typical relationships that describe the plug. The plug depends on the Mo rod from which is machined out, the machining process and its is characterized by its reflectivity and dimensional check. The cathode is identify by a ID number which is impressed on the back-side of the plug.

Similar relationships have been established for the photoemissive layer during the preparation process storing information about the Cs and Te sources and growing parameters. The resulting photoemissive layer properties are also stored to allow investigation of the interplay between growing parameters and layer performances.
Since on each plug many layers can be grown, we identify each layer by the plug number and the layer number, separated by a dot (#plug.#layer), finally obtaining the cathode name. For example, #11.2 is the second layer grown on plug #11. Also shipped uncoated plugs are defined as cathodes.

After the production, the cathodes are stored in transfer boxes which are then delivered to the labs. In the database, we follow then the boxes in the different labs. This enables to keep track of the boxes and the used cathodes. For each cathode, we store information about dark current and QE (the last only for photoemissive layers). Moreover, we also store information about the insertion and extraction of the cathode from the gun. These information are used to calculate the operative lifetime of the cathodes themselves.

2 Web Database Interface

The TTF Photocathodes Database is easily accessible by a simple and intuitive web page [1]. In Fig. 2 the main page of our database is shown. Stored information are relative both to the photocathodes production and to their use in different RF guns.

The followed strategy to the built-up of the database has been finalize for two mainly purposes: to be a simple tool for the machine operators and to be an on-line available “archive” for information on statistics and performances of cathode. The on-line information available for operators are relative to:

- cathodes availability
- cathodes in the transport box connected to the gun
- properties of the cathode inserted in the gun (Q.E., deposition date, etc.).

Referring to Fig. 2, from the main menu it is possible to access to different subsections:

- Current Status (2.1)
- Tracking info (2.2)
- Components (2.3)
- Statistics (2.4)
For each section, described in the following paragraphs, the relational database behind the web pages allows to reach other information related to the principal steps of the photocathodes life: production, transport, use in different guns, post-use diagnostic.

2.1 Current status

This section is mainly designed for machine operators, since it gives information on the actual status of different available photocathodes. Information are accessible in two different ways, ordered by transfer boxes or by labs. These two links allow to access information on the real position of different cathodes in the stacks (each transport box has a 5 slot stack), giving hints to the operator on the best cathode choice based on its lifetime, its QE, etc. Information relative to the photocathodes status at LASA laboratory in Milano are also shown, to inform the operators on the actual production status (new cathodes future availability, etc.). In both cases, by simply clicking the cathode name, it is possible to access the main characteristics of the different photocathodes loaded in the transfer boxes. Moreover, the boxes operation (cathode loading, unloading, etc) are accessible by clicking the box name.

2.1.1 Transfer boxes

Clicking this option, the actual status of the five boxes is presented in a compact view. This would be useful to easily know the status of the transfer boxes independently of their actual location (that is anyhow shown in the column “Connected to”). Moreover, the information relative to cathodes inserted in guns are reported. This page is shown in Fig. 3.
2.1.2 By LAB

In Fig. 4 the “by LAB” web page is shown. This page gives the same information presented in previous subsection but organized in different way to give a simple representation of the actual status (related to boxes and cathodes in the guns) referred to each laboratories (LASA, DESY-Hamburg, DESY-Zeuthen). This organization was done to highlight information relative to each lab (giving an immediate response to operators working in the relative lab).

**Status in the three Laboratories**

**Preparation chamber in LASA**

<table>
<thead>
<tr>
<th>Name</th>
<th>Data</th>
<th>Location</th>
<th>Connected to</th>
<th>C1</th>
<th>C2</th>
<th>C3</th>
<th>C4</th>
<th>C5</th>
<th>Last Event</th>
<th>Transferred from</th>
</tr>
</thead>
<tbody>
<tr>
<td>Long 3</td>
<td>18/05/2005 2:02 PM</td>
<td>LASA</td>
<td>Preparation chamber - LASA</td>
<td>Connected</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**TTF in DESY-Hamburg**

<table>
<thead>
<tr>
<th>Name</th>
<th>Data</th>
<th>Location</th>
<th>Connected to</th>
<th>C1</th>
<th>C2</th>
<th>C3</th>
<th>C4</th>
<th>C5</th>
<th>Last Event</th>
<th>Transferred from</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short 1</td>
<td>18/05/2005 6:09 AM</td>
<td>DESY-Hamburg</td>
<td>81.1</td>
<td>81.1</td>
<td>81.1</td>
<td>81.1</td>
<td>81.1</td>
<td>Connected</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Short 2</td>
<td>18/05/2005 3:30 PM</td>
<td>DESY-Hamburg</td>
<td>PITZ Gun</td>
<td>81.1</td>
<td>81.1</td>
<td>81.1</td>
<td>81.1</td>
<td>81.1</td>
<td>Cathode change</td>
<td></td>
</tr>
</tbody>
</table>

**PITZ in DESY-Zeuthen**

<table>
<thead>
<tr>
<th>Name</th>
<th>Data</th>
<th>Location</th>
<th>Connected to</th>
<th>C1</th>
<th>C2</th>
<th>C3</th>
<th>C4</th>
<th>C5</th>
<th>Last Event</th>
<th>Transferred from</th>
</tr>
</thead>
<tbody>
<tr>
<td>Long 1</td>
<td>18/05/2005 12:16 PM</td>
<td>DESY-Zeuthen</td>
<td>81.1</td>
<td>81.1</td>
<td>81.1</td>
<td>81.1</td>
<td>81.1</td>
<td>Connected</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Long 2</td>
<td>18/05/2005 4:52 PM</td>
<td>DESY-Zeuthen</td>
<td>PITZ Gun</td>
<td>81.1</td>
<td>81.1</td>
<td>81.1</td>
<td>81.1</td>
<td>81.1</td>
<td>Cathode change</td>
<td></td>
</tr>
</tbody>
</table>

**Fig. 3 Status of the transfer boxes.**

**Fig. 4 Status of the boxes and cathodes in different laboratories.**
2.2 Tracking Info

The aim of this section is to give a time ordered view of boxes operations (shipments, exchange of cathodes between the transport box and the gun, etc.) and cathode exchanges in different guns.

2.2.1 All transfers

This page is related to operations on boxes since 1998. In this section it is possible to have a short summary of all shipments with a description of the box type (long or short, depending on the carrier dimension), of the loaded cathodes (Cs$_2$Te, KCsTe or Mo) and of the destination of the box. Moreover, clicking the “show” link allows to have further information relative to the cathodes in the box and their deposition date. In Fig. 5 the main page of “All transfers” and of the “show” panel obtained are presented.

<table>
<thead>
<tr>
<th>Name</th>
<th>Date</th>
<th>From</th>
<th>To</th>
<th>Cathode 1</th>
<th>Cathode 2</th>
<th>Cathode 3</th>
<th>Cathode 4</th>
<th>Cathode 5</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short 1</td>
<td>6/20/1998 10:00:00 AM</td>
<td>LASA</td>
<td>DESY-Hamburg</td>
<td>21</td>
<td>11</td>
<td>12</td>
<td>21</td>
<td>21</td>
<td>show</td>
</tr>
<tr>
<td>Short 2</td>
<td>7/10/1998 10:00:00 AM</td>
<td>LASA</td>
<td>DESY-Hamburg</td>
<td>21</td>
<td>21</td>
<td>11</td>
<td>12</td>
<td>11</td>
<td>show</td>
</tr>
<tr>
<td>Long 1</td>
<td>8/20/1998 10:00:00 AM</td>
<td>LASA</td>
<td>DESY-Hamburg</td>
<td>21</td>
<td>11</td>
<td>21</td>
<td>21</td>
<td>21</td>
<td>show</td>
</tr>
<tr>
<td>Short 2</td>
<td>9/10/1998 10:00:00 AM</td>
<td>LASA</td>
<td>DESY-Hamburg</td>
<td>21</td>
<td>11</td>
<td>12</td>
<td>11</td>
<td>11</td>
<td>show</td>
</tr>
<tr>
<td>Long 1</td>
<td>10/10/1998 10:00:00 AM</td>
<td>LASA</td>
<td>DESY-Hamburg</td>
<td>21</td>
<td>11</td>
<td>21</td>
<td>21</td>
<td>21</td>
<td>show</td>
</tr>
</tbody>
</table>

In the same subsection it is also possible to track the information relative to a specific box. As an example in Fig. 6 the history of box “short2” is shown. The information reported are date, the box event and the location. For the “Cathode exchange” event, the cathodes position in the stack is updated each time a cathode exchange happens in the laboratories. Moreover, the “Connected to” column reports to which gun the box is connected while the “Gun” column gives information on the cathode inserted in the corresponding gun.
2.2.2 Gun operations

This section named “Gun operations” has been built with the main purpose of organize the cathodes used in different guns and laboratories. From a dropdown list, it is possible to select between the different guns used in the two laboratories (G3 and G4 used only at DESY- Hamburg and PITZ1 and PITZ2 used both at Hamburg and at PITZ). This information, as we report in see section 2.4, are used to calculate the statistics on the cathode operations. In Fig. 7 an example referred to some of the information relative to the PITZ1 gun at DESY – Zeuthen is shown.

![History of cathode operations in the DESY guns](image)

**Fig. 6 Example of a box history (box: short2).**

**Fig. 7 Gun operations page for gun PITZ1 at DESY-Zeuthen.**
2.3 Components

This section gives information on all rods, plugs and cathodes produced at LASA laboratory. Before giving a short description of each item, we summarize our definition for them:

- **Rods** (the Mo rods used for plugs creation; classified by integer number)
- **Plugs** (manufactured plug – substrates – used for cathode deposition; classified by integer number)
- **Cathodes** (coated and uncoated plugs; classified by the plug number and the coating type).

We label plug a Mo substrate BEFORE any deposition.

The cathode is “created” when a DEPOSITION is done for a photoemissive layer or after a THERMAL CYCLE for an uncoated plug.

2.3.1 Cathodes

In Fig. 8 the web page relative to photocathodes produced since 1998 for the collaboration is shown. For each photocathode, the table reports the cathode ID, the film composition, the deposition date, the plug on which the deposition has been done (the same as the first number of the cathode ID), the rod from which the plug was machined out and the plug Mo type.

<table>
<thead>
<tr>
<th>Id</th>
<th>Film</th>
<th>Deposited</th>
<th>Plug</th>
<th>Rod</th>
<th>Plug Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>Cs$_2$Te</td>
<td>6/17/1998</td>
<td>1</td>
<td>1</td>
<td>Sintered</td>
</tr>
<tr>
<td>2.1</td>
<td>Cs$_2$Te</td>
<td>6/18/1998</td>
<td>2</td>
<td>1</td>
<td>Sintered</td>
</tr>
<tr>
<td>3.1</td>
<td>Unc Coated Mo</td>
<td>1/23/2001</td>
<td>3</td>
<td>1</td>
<td>Sintered</td>
</tr>
<tr>
<td>11.1</td>
<td>Unc Coated Mo</td>
<td>1/23/1998</td>
<td>11</td>
<td>2</td>
<td>Sintered</td>
</tr>
<tr>
<td>11.2</td>
<td>Cs$_2$Te</td>
<td>1/23/2001</td>
<td>11</td>
<td>2</td>
<td>Sintered</td>
</tr>
<tr>
<td>12.1</td>
<td>Cs$_2$Te</td>
<td>11/24/1998</td>
<td>12</td>
<td>2</td>
<td>Sintered</td>
</tr>
<tr>
<td>13.1</td>
<td>Cs$_2$Te</td>
<td>11/23/1998</td>
<td>13</td>
<td>2</td>
<td>Sintered</td>
</tr>
<tr>
<td>13.2</td>
<td>Unc Coated Mo</td>
<td>12/19/2003</td>
<td>13</td>
<td>2</td>
<td>Sintered</td>
</tr>
<tr>
<td>21.1</td>
<td>Cs$_2$Te</td>
<td>10/14/1999</td>
<td>21</td>
<td>2</td>
<td>Sintered</td>
</tr>
<tr>
<td>21.2</td>
<td>Cs$_2$Te</td>
<td>10/11/2000</td>
<td>21</td>
<td>2</td>
<td>Sintered</td>
</tr>
</tbody>
</table>

* As an example: Rod #2, plug #13, cathode #13.1
2.3.2 Plugs

In Fig. 9 the plugs web page is shown. For this page, the information reported are the plug ID, the plug manufacturer, the type of machining used for plug realization, the production date, the rod to which the plug belongs, the Mo type.

### Plugs

Select the item ID to display further information.

<table>
<thead>
<tr>
<th>Id</th>
<th>Manufacturer</th>
<th>Machining Type</th>
<th>Date</th>
<th>Rod</th>
<th>Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>CINE061</td>
<td>Lathing and EDM</td>
<td>4/6/1998</td>
<td>1</td>
<td>Sintered</td>
</tr>
<tr>
<td>2</td>
<td>CINE061</td>
<td>Lathing and EDM</td>
<td>4/6/1998</td>
<td>1</td>
<td>Sintered</td>
</tr>
<tr>
<td>3</td>
<td>CINE061</td>
<td>Lathing and EDM</td>
<td>4/6/1998</td>
<td>1</td>
<td>Sintered</td>
</tr>
<tr>
<td>4</td>
<td>CINE061</td>
<td>Lathing and EDM</td>
<td>4/6/1998</td>
<td>1</td>
<td>Sintered</td>
</tr>
<tr>
<td>5</td>
<td>CINE061</td>
<td>Lathing and EDM</td>
<td>4/6/1998</td>
<td>1</td>
<td>Sintered</td>
</tr>
<tr>
<td>6</td>
<td>CINE061</td>
<td>Lathing and EDM</td>
<td>4/6/1998</td>
<td>2</td>
<td>Sintered</td>
</tr>
<tr>
<td>7</td>
<td>CINE061</td>
<td>Lathing and EDM</td>
<td>4/6/1998</td>
<td>2</td>
<td>Sintered</td>
</tr>
<tr>
<td>8</td>
<td>CINE061</td>
<td>Lathing and EDM</td>
<td>4/6/1998</td>
<td>2</td>
<td>Sintered</td>
</tr>
<tr>
<td>9</td>
<td>CINE061</td>
<td>Lathing and EDM</td>
<td>4/6/1998</td>
<td>2</td>
<td>Sintered</td>
</tr>
</tbody>
</table>

![Fig. 9 Plugs web page.](image)

2.3.3 Rods

In Fig. 10, the Rods web page is shown. The page give information on the rod ID, the rod supplier, rod fabrication date, the Mo type and, when available, also the batch number.

### Rods

Select the item ID to display further information.

<table>
<thead>
<tr>
<th>Id</th>
<th>Supplier</th>
<th>Date</th>
<th>Material Type</th>
<th>Batch #</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Ponceoe</td>
<td>3/26/1995</td>
<td>Sintered</td>
<td>1502754</td>
</tr>
<tr>
<td>2</td>
<td>Ponceoe</td>
<td>3/26/1995</td>
<td>Sintered</td>
<td>1502209</td>
</tr>
<tr>
<td>3</td>
<td>Ponceoe</td>
<td>3/24/1997</td>
<td>Sintered</td>
<td>164518</td>
</tr>
<tr>
<td>4</td>
<td>Ponceoe</td>
<td>12/10/1999</td>
<td>Sintered</td>
<td>0050016569</td>
</tr>
<tr>
<td>5</td>
<td>CSM</td>
<td>1/6/1999</td>
<td>Arc cast</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Ponceoe</td>
<td>1/10/2001</td>
<td>Sintered</td>
<td>0001239284</td>
</tr>
<tr>
<td>7</td>
<td>Ponceoe</td>
<td>1/1/2000</td>
<td>Sintered</td>
<td></td>
</tr>
</tbody>
</table>

![Fig. 10 Rods web page.](image)
The data so far presented are also aggregated in a more useful view to allow following the entire cathode history, starting from the rod down to the cathode itself as explained in the following example and summarized in Fig. 11.

Selecting a ROD ID from the Rods web page (click1), we have access to all the information relative to the selected rod. The information are relative to the supplier, the material used, the Mo type (arc-cast or sintered), the rod dimensions, etc. Moreover in the same page there is a list of all plugs obtained from this rod. Selecting (click2) one of the plug IDs, the following page gives information about the plug, the manufacturer, the rod used, the type of manufacturing employed for the plug machining and the history relative to this specific plug. Click3 and click4 allow to have all the information relative to the plug measurement history (i.e. reflectivity) and also to the plug operation history (i.e. polishing, BCP, mechanical measurement, deposition, etc.). Images related to this plug, typically taken with a microscope, are shown on the same page.

From the plug page, clicking on the “cathode” ID is possible to go directly to the relative cathode page that includes its information (physical measurements, deposition, operation in a gun, shipments, photos, etc.). In Fig. 12 the web page for cathode #13.1 is shown with all the information and related web pages.
Starting from the plug page, it is possible to select (click 5) the cathode ID main page. For the case shown in the upper figure, the choices are between cathode #13.1 and cathode #13.2 (a Mo one). The cathode main page contains information on its history (physical measurements, etc.) and also pictures taken in different phases of the cathode life. Click 6, 7 and 8 refer to information contained in the database relative to the cathode operations before deposition, physical measurements (QE and dark current measurements) and operation in the gun.

2.3.4 1<sup>st</sup> example: Cathode #43.2

In this section an example is reported, to better explain the plug and cathode pages. We use in this case cathode #43.2 as shown in Fig. 13. In the upper part, a short description of cathode is presented, giving information on the history of the plug #43 and on its actual coating. This cathode is the second deposition on the plug #43 (as deducible from “.2” in its ID). On the same page appear different sections:

- “Physical Measurements” (QE and dark current measurements on this cathode done both just and after the production, during its operation in RF gun and after return to LASA)
- “History of the plug before deposition” (all operation done before the deposition of this film)
• “History of the cathode during operation” (number of uses in the gun).

The information relative to these three fields can be seen by simple clicking the relative cross symbol.

• “Data for the cathode transfers” (shipments related to this cathode).

• “Available pictures for this cathode” (all pictures taken on this cathode are shown with related comments).

**Photocathode #43.2 Datasheet**

This is the 2nd cathode on plug number 43.
The cathode is a Cs$_2$Te film, prepared in date 42/2004.

**Physical Measurements**

History of the measurements performed on this cathode.

**History of the plug before deposition**

History of the plug operation performed between last deposition (7/6/2000) and this cathode deposition (4/2/2004).

**History of the cathode during operation**

The following operations are available.

**Data for the cathode transfers**


<table>
<thead>
<tr>
<th>Date</th>
<th>From</th>
<th>To</th>
<th>Shipment</th>
<th>Box</th>
</tr>
</thead>
<tbody>
<tr>
<td>5/18/2004</td>
<td>LASA</td>
<td>DESY-Hamburg</td>
<td>Go to</td>
<td>3</td>
</tr>
<tr>
<td>7/28/2004</td>
<td>DESY-Hamburg</td>
<td>DESY-Zeuthen</td>
<td>Go to</td>
<td>3</td>
</tr>
</tbody>
</table>

**Available pictures for this cathode**

The following photographs are available.

![Digital photo. Cs$_2$Te coating. The cathode is in the transport box.](image1)

![Digital photo. Cs$_2$Te coating. The cathode is in the transport box.](image2)

![Digital photo. Cs$_2$Te coating. The cathode is in the transport box.](image3)

![Digital photo. This Cs$_2$Te cathode has been kept in](image4)

*Fig. 13 Cathode #43.2 web page.*
For cathode #43.2 we see that it was shipped to DESY-Hamburg on 18 May 2004 with the box number 3 and then shipped to DESY-Zeuthen on 28 July 2004 with the same box. No information on its travel back to LASA is reported, meaning that the cathode is still at Zeuthen. Moreover, there are two photos taken just after the deposition at LASA in the transport box and two more photos taken at Zeuthen during its use in the RF gun. Simple clicking on the photos give the possibility to enlarge images (see Fig. 14) and have them at high resolution.

Digital photo.

Cs$_2$Te coating. The cathode is in the transport box connected to prep. chamb. at LASA. The colour of coated surface is light gray.

Digital photo.

Cs$_2$Te cathode in the transport box connected to the DESY Z gun. This cathode has been used for about 1 month.

Digital photo.

Cs$_2$Te coating. The cathode is in the transport box connected to prep. Chamb. at LASA.

Digital photo.

This Cs$_2$Te cathode has been kept in vacuum for the long shutdown of PITZ.

Fig. 14 Some of the images available for cathode #43.2.

2.3.4.1 Physical measurement

In this section (see Fig. 15), measurements performed on the cathode are shown. First of all, after the deposition the QE is measured with a Hg lamp ($\lambda=254$ nm). For this cathode, other two measurements of QE are reported (due to the late shipment of the box). The other measurements are relative to pulsed QE measurement performed at DESY-Zeuthen about 5 months later. Typically, other information are stored in this section relative to QE in RF gun and dark current measurement performed during the cathode usage operation.
2.3.4.2 History of the plug before deposition

Clicking on the relative cross is possible to have all the information stored in the database relative to the plug history #43 before the deposition of cathode #43.2 (see Fig. 16). Before the deposition the plug has to be prepared following standard procedures. If the plug has been used in the past for a deposition, as in this case, we clean it and then we proceed with the lapping treatment. In this case the polishing technique was the newer one called “Lapping (automatic)”. After the lapping, the plug surface is checked performing reflectivity measurement with different wavelengths. For this plug, the wavelength was 543 nm with a measured reflectivity of 57% (as reported in the table). After typical cleaning procedure (with acetone and ethanol), the plug is loaded in the box carrier.

2.3.4.3 History of the cathode during operation

In this section (see Fig. 17) the operations of the cathode (insertion/removal) in the specific gun are summarized.
2.3.4.4 Plug #43 datasheet

If we are interested on the plug history, a simple click on the plug #43 (at the beginning of the “Photocathode #43.2 datasheet” sends you directly to the history of plug #43 (see Fig. 18).

In this page we find in:

- “Manufacturer” some information on the plug machining
- “Rod used for fabrication” information relative to the material and its supplier
- “History of plug measurement” and “History of plug operation” all the information relative to diagnostic on plug surface and to procedures applied to the plug itself (clicking on the relative cross it is possible to see data stored in the database).
- “Cathodes deposited on this plug” all cathodes obtained using this plug are indicated.
- “Available pictures for this plug”. Here we see two microscope photos, obtained after the automatic polishing, near the border and at the center of the lapped surface.

Referring to the web page again, we have cathode #43.1 (cesium telluride) and cathode #43.2 (cesium telluride too). The importance to summarize here the cathode history relative to the same plug is to give a direct access to these two cathodes information (simply clicking on the cathode name) and allow their comparison.
Plug #43 Datasheet

Manufacturer

The plug has been manufactured by CSPLAST, by means of Lathe and EDM in date 4/27/2000.

Rod used for fabrication

The plug was manufactured with the rod number 4, fabricated with Sintered material, supplied by Plansee on date 12/18/1998.

History of plug measurements

History of the measurements performed on this plug.

History of plug operations

History of the operations performed on this plug.

Cathodes deposited on this plug

The following cathodes were deposited on this plug:

<table>
<thead>
<tr>
<th>Date</th>
<th>Cathode</th>
<th>Film</th>
</tr>
</thead>
<tbody>
<tr>
<td>7/5/2000</td>
<td>43 1</td>
<td>Co,Te</td>
</tr>
<tr>
<td>4/2/2004</td>
<td>43 2</td>
<td>Co,Te</td>
</tr>
</tbody>
</table>

Available pictures for this plug

The following photographs are available:

Fig. 18 Plug #43 datasheet.

In Fig. 19 the two sections of the plug history are shown. In the first section, all reflectivity measurements on this plug are reported. In the second section, we summarized all the operations performed on this plug since its machining from the rod. This plug was cleaned by BCP in 2000 to clean its surface after the machining operation.
The first polishing was realized using the old technique (standard procedure until April 2003) called “Lapping (manual)”. Also in this case the lapping is qualified by reflectivity measurement (data reported in the history of plug measurements) @ $\lambda = 594$ nm. It follows the heating, the first coating deposition (#43.1 is created), the new lapping, etc.

### 2.3.5 2nd example: Cathode #11.2

This second example is presented only to highlight other information not present for cathode #43.2. The cathode considered is #11.2 and its main page is shown in Fig. 20. We immediately see that this cathode was shipped in different laboratories and that many photos available. In fact, it was shipped to DESY-Hamburg on 25 January 2001 with the box number 3, then shipped to DESY-Zeuthen on 26 March 2003 with the same box and finally send back to LASA on 2 October 2004. Its “lifetime” lasted for about three years.
Photocathode #11.2 Datasheet

This is the 2nd cathode on plug number 11.
The cathode is a Ce₂Te₃ film, prepared in date 1/23/2001.

Physical Measurements

History of the measurements performed on this cathode

History of the plug before deposition

History of the plug operation performed between last deposition (11/23/1996) and this cathode deposition (1/23/2001).

History of the cathode during operation

The following operations are available.

Data for the cathode transfers

Cathode transfers since 1/23/2001:

<table>
<thead>
<tr>
<th>Date</th>
<th>From</th>
<th>To</th>
<th>Shipment</th>
<th>Box</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/25/2001</td>
<td>LASA</td>
<td>DESY-Hamburg</td>
<td>Go to</td>
<td>3</td>
</tr>
<tr>
<td>3/29/2003</td>
<td>DESY-Hamburg</td>
<td>DESY-Zeuthen</td>
<td>Go to</td>
<td>3</td>
</tr>
<tr>
<td>2/02/2004</td>
<td>DESY-Zeuthen</td>
<td>LASA</td>
<td>Go to</td>
<td>3</td>
</tr>
</tbody>
</table>

Available pictures for this cathode

The following photographs are available.

Fig. 20 Cathode #11.2 web page.

Concerning the cathode pictures, all were taken when it came back to LASA. In this case the usual visual inspection was enriched with microscope analysis on selected area to study the surface aspect. Some of the cathode #11.2 images are shown in Fig. 21.
Fig. 21 Photos of cathode #11.2.

Interesting are the measurements performed on cathode #11.2 as shown in Fig. 22. The QE was measured just after the deposition at LASA and then at Hamburg in pulsed regime. Other measurements presented are dark current values taken during TTF phase 1 using both G3 and G4 guns. This cathode was the most performing cathode ever produced since it showed a low dark current and a high robustness (about 300 days of operative lifetime).

### Physical Measurements

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Value</th>
<th>Date</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>CIVQE [%]</td>
<td>9.6</td>
<td>1/03/20001</td>
<td>LASA</td>
</tr>
<tr>
<td>RF Dark Current [uA]</td>
<td>81</td>
<td>10/02/2001</td>
<td>DESY-Hamburg</td>
</tr>
<tr>
<td>Pulsed QE [%]</td>
<td>0.2</td>
<td>11/18/2001</td>
<td>DESY-Hamburg</td>
</tr>
<tr>
<td>RF Dark Current [uA]</td>
<td>20</td>
<td>11/19/2001</td>
<td>DESY-Hamburg</td>
</tr>
<tr>
<td>RF Dark Current [uA]</td>
<td>18</td>
<td>11/19/2001</td>
<td>DESY-Hamburg</td>
</tr>
<tr>
<td>RF Dark Current [uA]</td>
<td>37</td>
<td>2/1/2002</td>
<td>DESY-Hamburg</td>
</tr>
<tr>
<td>RF Dark Current [uA]</td>
<td>10</td>
<td>2/19/2002</td>
<td>DESY-Hamburg</td>
</tr>
<tr>
<td>RF Dark Current [uA]</td>
<td>257</td>
<td>7/17/2002</td>
<td>DESY-Hamburg</td>
</tr>
<tr>
<td>RF Dark Current [uA]</td>
<td>300</td>
<td>7/17/2002</td>
<td>DESY-Hamburg</td>
</tr>
<tr>
<td>RF Dark Current [uA]</td>
<td>325</td>
<td>7/30/2002</td>
<td>DESY-Hamburg</td>
</tr>
<tr>
<td>RF Dark Current [uA]</td>
<td>250</td>
<td>8/19/2002</td>
<td>DESY-Hamburg</td>
</tr>
<tr>
<td>RF Dark Current [uA]</td>
<td>761</td>
<td>8/27/2002</td>
<td>DESY-Hamburg</td>
</tr>
<tr>
<td>RF Dark Current [uA]</td>
<td>730</td>
<td>8/27/2002</td>
<td>DESY-Hamburg</td>
</tr>
<tr>
<td>RF Dark Current [uA]</td>
<td>810</td>
<td>8/27/2002</td>
<td>DESY-Hamburg</td>
</tr>
<tr>
<td>RF Dark Current [uA]</td>
<td>600</td>
<td>8/29/2002</td>
<td>DESY-Hamburg</td>
</tr>
<tr>
<td>RF Dark Current [uA]</td>
<td>624</td>
<td>8/29/2002</td>
<td>DESY-Hamburg</td>
</tr>
<tr>
<td>RF Dark Current [uA]</td>
<td>528</td>
<td>8/29/2002</td>
<td>DESY-Hamburg</td>
</tr>
<tr>
<td>RF Dark Current [uA]</td>
<td>470</td>
<td>8/29/2002</td>
<td>DESY-Hamburg</td>
</tr>
</tbody>
</table>

Fig. 22 Physical measurement of cathode #11.2.
2.4 Statistics

In this section, we have implemented a statistical analysis of some of the cathode information present in the database. New analysis will be added in the next future.

This section can be divided in different subsections (as indicated in the main menu of the web page):

- Total transfers
- Operation Lifetimes
- QE statistics

2.4.1 Total transfers

"Total transfers" (Fig. 23) gives a plot related to cathodes shipped since 1998 from LASA to the different laboratories grouped by type of cathode. In the summary, it is shown that the major number of cathodes shipped are the cesium telluride ones. In the plot also KCsTe cathodes are shown. These two cathodes were produced for their high QE (about 19%) and have been used for HOM experiments at TTF phase 1. The Mo cathodes are large in number and typically used for gun conditioning.

![Summary of all the cathodes transferred from LASA](image)

**Fig. 23** Summary of all cathode transfers (divided by material and destination).

2.4.2 Operation Lifetimes

This page gives information on the operative lifetime of all cathodes (Cs$_2$Te, KCsTe and Mo) used in different guns. In Fig. 24 an example is shown for DESY-Hamburg.

In this plot, the shutdown periods are NOT taken into account. Anyhow, they will be considered in the future, mainly for the DESY-Hamburg where there is a limited number of shutdowns. To give an example of the effect of the shutdown periods in the operative lifetime calculation, cathode #510.1 (Mo one) results used for about 360 days but, considering the long shutdown between TTF phase 1 and phase 2 (November 2002 - February 2004), the real days of operation are about 30.
Fig. 24 Cathodes operation lifetime in DESY-Hamburg.

2.4.3 QE statistics

The other simple summary discussed in this section is related to the QE of photocathodes measured at LASA just after the production (Fig. 25). At the end of the deposition process, the cathode QEs are measured using a Hg lamp at $\lambda = 254$ nm. It might happen that cathodes are shipped to Hamburg or Zeuthen only after some time and then more than one measurement is done to check the cathode status. In this case, the QE values reported in the summary are the mean value of all of these measurements. In the same figure, QE measurement done in the gun at Hamburg and at Zeuthen are reported.
Finally in Fig. 26, the summary plots relative to measured QEs for KCsTe cathodes are shown.

![KCsTe cathodes Quantum Efficiency measurements](image)

In the future, we will implement also statistics for plug properties. For example (as shown in sections 3.1 and 3.2.2.1), all plugs are qualified after the polishing treatment measuring their reflectivity at different wavelengths. We would like to compare the old technique – “manual polishing” – and the new one – “automatic polishing” as well as the influence of different Mo type (arc cast and sintered).

3 Off-line information

In this section we present data not included in the online database or not yet available on the web pages. These information have been collected as part of our activity devoted to improve cathode performances and setup further diagnostic tools for cathode characterizations. In the following sections, a detailed analysis of the influence of the plug properties and preparation methodologies on the final QE and dark current is presented. Other sections present standard diagnostic tools like QE maps, cathode images in different operative conditions as well as new techniques like the multi wavelengths QE maps that promise to help in a deeper understanding of the cathode performances.

3.1 Plugs

As described before, the typical history of a plug starts from the material used for machining it (arc-cast or sintered), the machine technique used for its fabrication and the cleaning procedure followed before the surface polishing (BCP). From our experience, we have seen that these items do not influence the cathode performances significantly, except for the BCP treatment that can create difficulties during the polishing of the surface (thicker...
layer to be removed to obtain a good reflectivity). Referring to BCP, we have also noted some differences with arc-cast and sintered plugs that we are not yet able to explain. In Fig. 27 plug surfaces for the two materials after the BCP treatment are shown.

![Microscope photo](image1.png)  
Microscope photo (#80.1).  
Arc-cast Mo surface after the BCP.  

![Microscope photo](image2.png)  
Microscope photo (#72.1).  
Sintered Mo surface after the BCP.  

**Fig. 27** Plug surfaces after BCP cleaning: on the left arc-cast plug, on the right sintered plug.

Statistics concerning rods and plugs, are reported in the Table 1.

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td># rods</td>
<td>7</td>
</tr>
<tr>
<td># produced plugs</td>
<td>57</td>
</tr>
<tr>
<td># arc-cast</td>
<td>11</td>
</tr>
<tr>
<td># sintered</td>
<td>46</td>
</tr>
</tbody>
</table>

Table 1 Produced plugs

After cleaning, the plug are polished to optical finishing. This treatment is applied to all plugs (with the exception of the first cathodes produced for the TTF phase 1 start up) since 1999 to reduce the dark current emission. As presented in section 3.2.3.3 this idea reveals itself successful leading to a reduction of the dark current by one order of magnitude.

From 1999 to 2003 the used technique was the old one (manual lapping) described in Table 2 and since 2003 till now we have developed a different technique (automatic lapping, Table 3). The differences between the two procedures are both the materials and the polishing machine. After the polishing treatment, plug reflectivity is measured to qualify the surface. The reflectivity is measured at normal incidence using a Hg lamp ($\lambda = 254$ nm) and He:Ne lasers ($\lambda = 543$ nm, $\lambda = 594$ nm, $\lambda = 633$ nm) and compared with the theoretical value calculated using optical parameters from literature [2].

<table>
<thead>
<tr>
<th>step</th>
<th>papers/cloths</th>
<th>diamond suspension</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>abrasive papers</td>
<td>no suspension, only water</td>
</tr>
<tr>
<td>2</td>
<td>Cloths</td>
<td>3 $\mu$m</td>
</tr>
<tr>
<td>3</td>
<td>Cloths</td>
<td>0.1 $\mu$m</td>
</tr>
</tbody>
</table>

Table 2 Manual lapping procedure
step | papers/cloths | diamond suspension
--- | --- | ---
1 | diamond embedded disk | 6 μm
2 | Cloths | 3 μm
3 | Cloths | 0.1 μm

Table 3 Automatic lapping procedure

The first statistic analysis concern the reflectivity obtained on all polished plugs. In Fig. 28, we have reported the reflectivity measured @ 543 nm. We report measurements done on the "first time" polished plugs. Measurement are ordered referring to the plug number and different colors highlights the two polishing techniques.

![Graph showing reflectivity measurements](image)

**Fig. 28** Measured reflectivity after the first polishing procedure of several plugs. In the figure different colors indicate different polishing techniques.

From the plot, the two techniques do not show meaningful differences in the resulting reflectivity.

Another analysis has been done considering the measured reflectivity of all polished plugs (including different polishing on the same plug) distinguishing between the manual and the automatic technique. Even in this case, Fig. 29 shows that the two techniques give the same results independent from the number of polishing.
We have also analyzed two more aspects: the materials and the rods. Concerning the Mo type, we have analyzed the measured reflectivity with respect to the arc-cast and the sintered plugs. In Fig. 30 results obtained are reported. Also in this case the material type seems not to influence the surface finishing after the polishing treatment.

**Fig. 29** Statistical analysis of the measured reflectivity of polished plugs with the two techniques.

**Fig. 30** Statistical analysis of the measured reflectivity of polished plugs referred to different materials used for plugs.
In Fig. 31 we have plotted the 6 rods used up to now for plugs production and once more no clear influence on the final reflectivity is visible.

![Graph showing reflectivity of rods](image)

**Fig. 31** Measured mean reflectivity of all plugs referred to their rods.

Plugs, as explained before, can be reused (until their mechanical tolerances are compatible to the gun requests). In Fig. 32 a comparison of the measured reflectivity after different lapping sections is shown.

![Graph showing reflectivity after polishing](image)

**Fig. 32** Measured reflectivity after several polishing treatment on plugs. In the figure different colors indicate the treatment number (only plug #31 and #34 have been polished three times to be used for cathode deposition).

During the polishing procedure some photo of the surface finishing have been done. In Fig. 33 some pictures are presented.
Fig. 33 Some pictures of several plugs. Microscope photos have been done to check the surface finishing.

Some SEM analysis have been done to check if there are polishing residuals (i.e. diamond or silicon carbide). See as an example Fig. 34 relative to plug #45 after automatic polishing.

Fig. 34 SEM analysis on plug #45.
3.2 Cathodes

This section is relative to cathode diagnostics and performances in the RF guns. Information have been organized in the following main steps (representing the “cathode life” typical steps):

- deposition (QE, visual inspections)
- after production (QE, QE maps, visual inspections)
- during use (QE, QE maps, dark current, visual inspections)
- after use (QE, QE maps, visual inspections, SEM analysis).

As an introduction, in the first subsection a short description of the film growing processes, relative to Cs$_2$Te and KCsTe, is presented.

3.2.1 During the deposition

After the polishing procedure, the plug is cleaned and loaded in the carrier. After a high temperature treatment (maximum temperature 450 °C), the plug is ready for the deposition. The photocathode growth procedures have been studied in great detail during the past years, also applying XPS and AES techniques [3],[4]. Typically for Cs$_2$Te, firstly 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 maintained 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]. A similar procedure is used for KCsTe coating production. After the deposition of 10 nm of Te, about 30 nm of K are evaporated, followed by the Cs evaporation. As for the Cs$_2$Te, the Cs evaporation stops when the photocurrent reaches its maximum. The plug temperature during the first two steps is maintained stable at 120 °C, while it is increased up to 150 °C during the Cs evaporation. In Fig. 35 the deposition curve measured during the Cs$_2$Te growth is presented.

![Cs$_2$Te photocathode growth curve.](image)
For some specific experiments (such as the measure of the secondary emission coefficient of the cesium telluride, etc.[5]) we have produced cesium telluride films with different thickness. In spring 2003, a specific box was equipped with three cesium telluride cathodes grown with different thickness:

- #61.1: Te thickness 10 nm
- #35.2: Te thickness 15 nm
- #500.1: Te thickness 20 nm

In Fig. 36, the pictures relative to these cathodes are presented.

![cathode #61.1: Digital photo. Cs$_2$Te coated surface just after the deposition.](image1)

![cathode #35.2: Digital photo. Cs$_2$Te coated surface.](image2)

![cathode #500.1: Digital photo. Cs$_2$Te cathode in the transport box connected to the DESY Z gun.](image3)

**Fig. 36** Photos of Cs$_2$Te cathodes obtained with different Te thickness.

About the film size, the coating diameter has been changed three times starting from the beginning of cathodes production. The round coating shape is realized using a masking (Mo ring) positioned just in front of the Mo plug. In Table 4 the masking dimension, the period of use and the produced cathodes are summarized.

<table>
<thead>
<tr>
<th>Masking diameter</th>
<th>start</th>
<th>end</th>
<th>Cs$_2$Te cathodes</th>
<th>KCsTe cathodes</th>
</tr>
</thead>
<tbody>
<tr>
<td>13 mm</td>
<td>17-Jun-98</td>
<td>28-May-00</td>
<td>1.1, 2.1, 13.1, 12.1, 21.1, 22.1, 23.1, 33.1, 36.1, 34.1, 35.1, 37.1</td>
<td></td>
</tr>
<tr>
<td>10 mm</td>
<td>28-May-00</td>
<td>10-Mar-03</td>
<td>45.1, 43.1, 42.1, 22.2, 21.2, 51.1, 11.2, 47.1, 47.2, 57.1, 44.2, 31.2, 60.1, 62.1, 50.1, 54.1</td>
<td></td>
</tr>
<tr>
<td>5 mm</td>
<td>10-Mar-03</td>
<td>still in use</td>
<td>61.1, 500.1, 35.2, 42.2, 37.2, 33.2, 43.2, 23.2, 31.3, 58.1, 54.2, 72.1, 73.1</td>
<td></td>
</tr>
</tbody>
</table>

**Table 4** Masking and produced cathodes.

In Fig. 37 three cathodes produced with different masking are shown.
3.2.1.1 QE

The QE is a characteristic of the photoemissive film. In Fig. 38 a typical QE response obtained at different wavelengths on a Cs$_2$Te film is shown. In the same plot we have also indicated the TTF & PITZ laser working point.

The final QE value at $\lambda = 254$ nm is routinely in the range of 8 - 10 % for Cs$_2$Te, while for KCsTe the measured value is in the range of 18-20 % [6].

![Figure 38: Typical QE response of a cesium telluride cathode just after the deposition.](image-url)
3.2.1.2 Visual inspections
With “visual inspection” we classified all information related to cathode images. In Fig. 39 some picture during the deposition are shown.

![Cathode images](image)

- Fig. 39 Pictures taken during the Te deposition (left) and the Cs deposition (right).

3.2.2 Just after the deposition

3.2.2.1 QE
After the deposition, we measure the QE of cathodes at $\lambda = 254$ nm. These measurements are performed at room temperature for all photocathodes. In this section we search for correlations between QE and different parameters.

Fig. 40 shows a comparison between the QE and the plug reflectivity distinguishing the polishing procedures.

![Reflectivity vs QE](image)

- Fig. 40 Comparison between the measured reflectivity (on plugs) and Q.E. of Cs$_2$Te cathodes.
Fig. 41 shows that the QE is not correlated to the surface finishing, at least in the condition of the measurements done at LASA.

3.2.2.2 QE maps

The other typical analysis performed on cathode with a photoemissive layer is the QE map of the entire surface, necessary to check the film uniformity. The map is done using a Hg lamp with a small spot (about 1 mm diameter). The optical scanning is done by two mirrors mounted on a steering system. The usual map is done with light at $\lambda = 254$ nm. In Fig. 42 three QE maps performed on cathodes grown with different sizes (see Table 4) are shown. In the figure, QE maps have been plotted both in 3D and 2D. For each maps, the scanning range and the used step are reported.
Cathode #23.1 (13mm),
rang = +/- 10 mm, step = 0.5 mm

Cathode #43.1 (10mm),
rang = +/- 10 mm, step = 1 mm

Cathode #72.1 (5mm),
Range = +/- 4mm, step = 0.5 mm

Fig. 42 QE maps on three cathodes with different masking.
To improve the coating diagnostic, during 2004 we have analyzed four cathodes measuring QE maps at different wavelengths (from 239 to 436 nm). These maps provide information not only on the QE but also on the work function spatial distribution of the film. Fig. 43 shows an example for cathode #54.2.

Fig. 43 QE maps of cathode #54.2 with different wavelength.
3.2.2.3 Visual inspection

Digital photos of produced cathodes are taken just after the deposition both to improve their classification and to check the centering of coating position. The surface colors depend on the illumination angle and on the light spectrum. As an example, in Fig. 44 two cathodes that show different color are compared.

![Cathode #35.2: Digital photo. Cs₂Te coated surface. This cathode was not used in the gun.](image1)
![Cathode #62.1: Digital photo. Cs₂Te coated surface. This cathode was not used in the gun.](image2)

**Fig. 44** Comparison between cathodes with different thickness.

Finally, we have observed that some coatings show macroscopic irregularities even if they have a uniform QE map. In Fig. 45, the comparison between the digital photo and the QE map of cathode #54.2 is shown.

![Cathode #54.2: Digital photo. Cs₂Te coated surface.](image3)
![Cathode #54.2: QE map with 254 nm of cathode #54.2.](image4)

**Fig. 45** Comparison between QE and visual inspection.

3.2.3 In operation

In this section we present some of the measurements usually performed on cathodes during operation, either at TTF or at PITZ. The typical measurements are the QE and the dark current. For few cathodes, QE maps (done only at PITZ) are also presented.
3.2.3.1 QE

The measurement of the cathode QE during operation is used to evaluate the status of the photoemissive film. In fact, the cathode QE is influenced by the environment status (gases composition in the gun, presence of leaks, etc.) and tends to decrease vs. time.

The light used is the 4th harmonic of a Nd:YLF laser ($\lambda = 262$nm) and during the measurement the photoemitted charge per bunch, measured by a toroid or a Faraday cup, is kept lower (below 0.5 nC) if compared with the typical charge produced during operation (about 1 nC). This measurement is called RF or Pulsed QE.

Since two years, both at PITZ and at TTF, the QE measurement is also done with a CW Hg lamp like at LASA. For this measurement the cathode is put back to the transport box and the anode collects the photoemitted electrons: we call this measurement CW QE.

All these measurements, together with some statistics, are available in cathode pages of our cathode database. The difference in value between the CW and pulsed QE measurements, as shown in Fig. 25, is due partly to the cathode aging and also to a not correct measurement set up.

3.2.3.2 QE maps

Pulsed QE maps have been done only at the PITZ facility. Two examples of the QE maps obtained using Cs$_2$Te cathodes are shown in Fig. 46.

![Pulsed QE maps measured @ PITZ with $\lambda = 262$nm. The QE is plotted in arbitrary units.](image)

The two maps have been obtained scanning the cathodes surface with the laser ($\lambda = 262$nm). For these two maps the QE has not been calculated and values are in arbitrary units.

3.2.3.3 Dark current

Typically, a high dark current is a limiting factor in the gun operation. Considering that from the 1998, the accelerating field is grown from 35 MV/m to about 42 MV/m, with the plan to further improve it up to 60 MV/m, the dark current emission has to be deeply investigate.

The collection of several data on different cathodes (including Mo cathodes) has been done since the beginning of the gun operation.
The first cathodes used at TTF in 1998 were not polished and the dark current was higher than the one measured successively on polished plugs [6], [7]. In our online-database several dark current measurements have been stored. Up to now only the measurements relative to the TTF phase 1 are stored with limited information about the experimental conditions. We plan to add information about solenoid currents, accelerating field, RF power, RF pulse length and Faraday cups used. Moreover, we are going to add a summary plot of the dark current trend measured in the same condition on several cathodes.

**Dark current measurements in G3 & G4 gun @ TTF phase 1 (Pfor = 2.2 MW, Isol1 = 216A, Isol2 = 110A)**

![Graph showing dark current measurements](image)

*Fig. 47* Summary of the measured dark current during the TTF phase 1 operation.

In *Fig. 47*, an example of summary plot relative to dark current measurements performed during the TTF phase 1 operation (from 1998 to 2002) is presented. Dark current values are plotted ordered by date and labeled (also with different colors) by cathode name. In this plot also the dark current measured with KCsTe cathodes (#50.1 and #54.1) are shown.

During the TTF phase 1 two RF guns were used: G3 and G4. These guns operated at 35 MV/m. In the Table 5 the conditions used during these dark current measurements are collected.

<table>
<thead>
<tr>
<th>RF gun</th>
<th>Period</th>
<th>Isol1 [A]</th>
<th>Isol2 [A]</th>
<th>Eacc [MV/m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>G3</td>
<td>12 Dec 98 – 6 Mar 02</td>
<td>216</td>
<td>110</td>
<td>33.4 – 35</td>
</tr>
<tr>
<td>G4</td>
<td>17 Jul 02 – 18 Nov 02</td>
<td>216</td>
<td>110</td>
<td>33.4 – 35</td>
</tr>
</tbody>
</table>

*Table 5* RF guns parameter during the dark current measurements.

Referring to *Fig. 47*, cathode #1.1 presents the highest dark current due to its not polished surface. Only cathode #21.1 shows an higher dark current value (15 mA) respect to #1.1 caused by a strong field emitter on the gun backplane close to the cathode area [6]. For all the other cathodes, typically the dark current value at first tends to decrease with time (due
to the cathode conditioning) and then to increase (due to coating damaging). This is the
typical signal that force the cathode exchange. Moreover, considering all the cathode
measurements, we observed that the general trend of dark current is decreasing with time.
This can be explained considering that the continuous use of the gun conditions its
surface. The sudden dark current increase measured for cathode #11.2 from April to July
2002 is related to the gun exchange [6]. This is an hint that also the gun plays a role in
the dark current production. In Fig. 48 the measured dark current with cathode #11.2 in the
two guns is presented (G3 - conditioned gun, G4 – new gun).

![Graph showing dark current measurements for cathode #11.2 in G3 and G4.]

**Fig. 48** Measured dark current with cathode #11.2 in G3 and G4.

For all the other dark current measurements not included in the database, we have
collected only data taken at PITZ and at TTF phase 2, with fixed condition of accelerating
field or solenoid focalization (Table 6). We have chosen as reference the typical condition
of the guns during standard operation at TTF phase2: $I_{buck} = 20A$, $I_{main} = 277A$, $E_{acc}$
between 40 and 42 MV/m.

<table>
<thead>
<tr>
<th>Machine</th>
<th>RF gun</th>
<th>Period</th>
<th>$I_{buck}$ [A]</th>
<th>$I_{main}$ [A]</th>
<th>$E_{acc}$ [MV/m]</th>
<th>FC</th>
</tr>
</thead>
<tbody>
<tr>
<td>PITZ</td>
<td>PITZ2</td>
<td>8 Mar 02 – 7 Oct 03</td>
<td>0 - 20</td>
<td>277, 300</td>
<td>40 – 42</td>
<td>FCDiagCross</td>
</tr>
<tr>
<td>TTF phase2</td>
<td>PITZ2</td>
<td>17 Mar 04 – in use</td>
<td>20</td>
<td>277</td>
<td>40.8 – 42.2</td>
<td>FC3GUN, FC2GUN</td>
</tr>
<tr>
<td>PITZ</td>
<td>PITZ1</td>
<td>26 Mar 04 – 22 Sep 05</td>
<td>0 - 30</td>
<td>277, 300</td>
<td>40 – 42</td>
<td>FCDiagCross</td>
</tr>
</tbody>
</table>

**Table 6** RF gun parameters during the dark current measurements for TTF phase 2 and PITZ.

In Fig. 49, Fig. 50 and in Fig. 51 the summaries of dark current measurements in the
different laboratories and with different guns are shown.
Fig. 49 Measured dark current at PITZ with PITZ2 RF gun.

Fig. 50 Measured dark current at TTF phase2 with PITZ2 RF gun.
Only some comments on these figures. In these plots we show the dark current measured not only with coated cathodes but also with uncoated ones (Mo cathodes, magenta markers). In first approximation, data indicate that the dark current measured for coated and uncoated cathodes is comparable.

The other consideration is relative to the dark current behavior vs. time. Also in these summary plots it is evident that for all guns the dark current decreases vs. time due to the gun conditioning.

Finally, it is worthwhile to mention the influence of the Faraday cup location on the dark current measurements due to different solenoid focalization. As an example, referring to TTF phase2, in Fig. 50 the recorded measurements using FC3GUN (full markers) and FC2GUN (empty markers) are plotted together. It is evident that FC2GUN records higher dark currents than the FC3GUN in the same experimental condition. This is mainly due to its position respect to the RF gun: FC2GUN is at 2 meters from the gun and FC3GUN is positioned at 3 meters from the gun.

3.2.3.4 Visual inspection

About visual inspection, pictures of cathodes in transport boxes connected to Zeuthen and Hamburg guns are collected starting from 2003. These photos, stored in our database, are collected to check the surface status during the machine operations. The interesting thing is that these images can be compared with the one taken both just after the deposition and after cathodes are coming back to LASA. In Fig. 52 an example of this comparison is shown for cathode #61.1.
Fig. 52 Comparison between cathode just after the deposition and during its operation in PITZ gun.

From the picture it is clearly visible that during the cathode operation in the gun its surface can be damaged (usually due to discharges).

A further example is the photo of cathode #37.2 taken after the accident occurred at TTF phase 2 last year (Fig. 53). The manipulator bayonet coupling was bended due to the valve closing and a picture of cathode showed some dust on its surface. For this reason the cathode was changed.

Fig. 53 Visual inspection after the bending of the manipulator Some dust is present on the cathode #37.2 surface.

3.2.4 After use

When cathodes come back to LASA the transport box is reconnected to our system for final diagnostic.
3.2.4.1 QE and QE maps

The usual diagnostic is the cathode QE measurements. We typically make the QE map to have information both on the QE distribution over the cathode surface and on the average QE value.

In Table 7 we report the average QE measurement done on some cathodes after their shipment back to LASA; they are compared with QE values measured at LASA before the shipment and during operation in RF guns.

<table>
<thead>
<tr>
<th>Cathode</th>
<th>CW QE @ LASA (λ=254nm) before shipment</th>
<th>Pulsed QE in guns (λ=262nm) during operation</th>
<th>CW QE (λ=254nm) during operation</th>
<th>CW QE @ LASA (λ=254nm) when cathode is back</th>
</tr>
</thead>
<tbody>
<tr>
<td>21.2 (Cs₂Te) (11 Oct 00)</td>
<td>7.5 % (11 Oct 00)</td>
<td></td>
<td></td>
<td>6 % (6 Aug. 04)</td>
</tr>
<tr>
<td>42.2 (Cs₂Te) (16 Dec 03)</td>
<td>8 % (16 Dec 03)</td>
<td>9 % (5 Jun 04), 1.6 % (14 Nov 04)</td>
<td>2.9 % (24 Jul 04)</td>
<td>Still @ DESY Hamburg</td>
</tr>
<tr>
<td>54.1 (KCsTe) (30 Jul 02)</td>
<td>18 % (30 Jul 02)</td>
<td>3 % (18 Nov 02)</td>
<td></td>
<td>0.43 % (24 Feb 04)</td>
</tr>
<tr>
<td>43.2 (Cs₂Te) (2 Apr. 04)</td>
<td>6.85 % (5 Apr. 04)</td>
<td>3.4 % (27 Sep. 04)</td>
<td></td>
<td>1.65 % (8 Feb 06)</td>
</tr>
</tbody>
</table>

Table 7 CW and pulsed QE measurements vs. time.

Only one comments on the noticeable QE stability of cathode #21.2, never used in the RF gun. It maintained a stable QE value (7.5 % just after the production, 6 % after its shipment back from DESY Hamburg) after about four years staying in the transport box.

About the QE maps, in Fig. 54 a comparison between the two maps (measured just after the production and after coming back to LASA) is shown for cathode #11.2 (Cs₂Te film, 10mm diameter).

Fig. 54 Comparison between CW QE maps done on cathodes before and after their operation in RF guns.
### 3.2.4.2 Visual inspection and SEM analysis

After their use in RF guns, cathodes are analyzed to check their surface status with visual inspection and SEM analysis. The visual inspection includes photos with a scanner, with a digital camera, with an optical microscope.

In Fig. 55 pictures of several cathodes just after the deposition, during operation and when they come back to LASA are presented.

<table>
<thead>
<tr>
<th>Deposition</th>
<th>Operation in RF guns</th>
<th>Back to LASA</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Digital photo (#43.2). Cs$_2$Te coating. The cathode is in the transport box connected to prep. chamb. at LASA. The colour of coated surface is light gray." /></td>
<td><img src="image2" alt="Digital photo (#43.2). Cs$_2$Te cathode in the transport box connected to the DESY Z gun. This cathode has been used for about 1 month." /></td>
<td><img src="image3" alt="Scanned photo (#44.2). Cs$_2$Te coated surface. This cathode back from DESY Z and it was used in the gun." /></td>
</tr>
<tr>
<td><img src="image4" alt="Digital photo (#34.4). Uncoated Mo cathode in the transport box." /></td>
<td><img src="image5" alt="Digital photo (#61.1). Cs$_2$Te cathode in the transport box connected to the DESY Z gun. This cathode was used 4 days in the gun (Sept-Nov 2003)." /></td>
<td><img src="image6" alt="Digital photo (#54.1). KCsTe coated surface back from DESY Z, used in the gun. Cathode is still in the transport chamber." /></td>
</tr>
<tr>
<td><img src="image7" alt="Digital photo (#61.1). Cs$_2$Te coated surface. This cathode was not used in the gun." /></td>
<td><img src="image8" alt="Digital photo (#60.1). Cs$_2$Te coated surface. The cathode is in the transport box connected to the DESY Z gun. The surface looks totally damaged." /></td>
<td><img src="image9" alt="Scanned photo (#47.3). Damaged Mo surface. This cathode was used for gun conditioning in DESY Z." /></td>
</tr>
</tbody>
</table>

**Fig. 55** Pictures of several cathodes during their life.
Some cathodes have been observed using an optical microscope at LASA. In Fig. 56 some pictures on Cs$_2$Te, KCsTe and Mo cathodes are shown. We typically check the burnings (due to discharge in the gun), scratches on the plug and coating surface and we look for the presence of “extraneous” particles such as Cu or Ag (coming respectively from the gun itself and from the spring used for the electric contact).

![Microscope photo: 200 x (#11.1). Burning on the Mo surface close to the border.](image1)

![Microscope photo: 200 x (#13.1). Hole in the coating surface deep 12um with melted material on the bottom.](image2)

![Microscope photo: 200 x (#11.2). Exfoliation of Cs$_2$Te near the coating border with Cu particle in the middle.](image3)

![Microscope photo: 100x, int. contr. (#34.3). Spark on the border of Mo cathode.](image4)

![Microscope photo: 100x, int. contr. (#54.1). Detail of the big hole in the center of KCsTe coating.](image5)

![Microscope photo: 200 x (##62.1). Detail of the boundary between the Cs$_2$Te coated surface and the Mo polished surface.](image6)

**Fig. 56** Microscope pictures of several cathodes when they come back to LASA.

SEM analysis have been done at the Istituto Scientifico Breda on few plugs (after the polishing treatment) and on few cathodes (both of cesium telluride and molybdenum) after their use in the RF guns. Mo plugs have been analyzed mainly to check the residual presence of the polishing procedure. The SEM analysis on cathodes has been done to understand the nature of extraneous particles (copper or silver from the gun or the RF spring material), the behavior of the coating after a discharge and its composition, the Mo surface damaging due to discharge during the RF gun conditioning.

In Fig. 57 we present images of cathode #44.2 (Cs$_2$Te). Its surface aspect, after its shipment from DESY Zeuthen, is shown in Fig. 55 (top right position).

In particular, Fig. 57 shows the image of a coating explosion (probably caused by a discharge in the RF gun) positioned in the center of the cathode. On the left the entire explosion area is shown, while on the right a zoomed image of a selected zone (as indicated with the blue circle) is presented. In the zoomed image, we clearly see several big white particles, one dark particle with different shape and the smooth gray background. With SEM we simply analyzed these three components to understand their composition.
(see Fig. 58, Fig. 59 and Fig. 60). Results indicate that the big white particles are cesium telluride, the dark one is carbon and the gray background is molybdenum.

Results indicate that the big white particles are cesium telluride, the dark one is carbon and the gray background is molybdenum.

Fig. 57 SEM images of cesium telluride cathode (#44.2) after its arrive at LASA from DESY Zeuthen.

Fig. 58 SEM analysis of the coating explosion: dark particle (carbon).

### Table: SEM Analysis of Dark Particle

<table>
<thead>
<tr>
<th>Element</th>
<th>Net Counts</th>
<th>Weight Concentration %</th>
<th>Atom Concentration %</th>
<th>Compound Concentration %</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>24394</td>
<td>66.99</td>
<td>85.07</td>
<td>66.99</td>
</tr>
<tr>
<td>O</td>
<td>5566</td>
<td>12.73</td>
<td>12.14</td>
<td>12.73</td>
</tr>
<tr>
<td>Al</td>
<td>459</td>
<td>0.11</td>
<td>0.06</td>
<td>0.11</td>
</tr>
<tr>
<td>Si</td>
<td>1095</td>
<td>0.22</td>
<td>0.12</td>
<td>0.22</td>
</tr>
<tr>
<td>P</td>
<td>297</td>
<td>0.07</td>
<td>0.03</td>
<td>0.07</td>
</tr>
<tr>
<td>V</td>
<td>1111</td>
<td>0.56</td>
<td>0.17</td>
<td>0.56</td>
</tr>
<tr>
<td>Mo</td>
<td>12623</td>
<td>3.87</td>
<td>0.62</td>
<td>3.87</td>
</tr>
<tr>
<td>Te</td>
<td>10571</td>
<td>9.67</td>
<td>0.69</td>
<td>9.67</td>
</tr>
<tr>
<td>Cs</td>
<td>16693</td>
<td>5.78</td>
<td>1.11</td>
<td>5.78</td>
</tr>
</tbody>
</table>

Zoom of the coating explosion. The SEM analysis on different particles indicates that:

- Dark particle: carbon
- White particle: Cs₂Te
- Gray background: Mo

SEM analysis of the dark particle: carbon particle.

From SEM analysis we see also small peaks of Mo, Cs, Te and oxygen.
SEM analysis of the white particle: Cs₂Te particle.

From SEM analysis we see main peaks are due to Te and Cs. There are also two lower peaks of oxygen and molybdenum.

**Fig. 59** SEM analysis of the coating explosion: white particle (Cs₂Te).

<table>
<thead>
<tr>
<th></th>
<th>C</th>
<th>O</th>
<th>Mo</th>
<th>Te</th>
<th>Cs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Net Counts</td>
<td>1654</td>
<td>10147</td>
<td>12419</td>
<td>43634</td>
<td>34523</td>
</tr>
<tr>
<td>Weight Concentration %</td>
<td>10.17</td>
<td>16.07</td>
<td>6.80</td>
<td>36.89</td>
<td>30.07</td>
</tr>
<tr>
<td>Atom Concentration %</td>
<td>34.74</td>
<td>41.21</td>
<td>2.91</td>
<td>11.86</td>
<td>9.28</td>
</tr>
<tr>
<td>Compound Concentration %</td>
<td>10.17</td>
<td>16.07</td>
<td>6.80</td>
<td>36.89</td>
<td>30.07</td>
</tr>
</tbody>
</table>

SEM analysis of the gray background: Mo.

The Mo peak is the higher in intensity. Anyhow other peaks due to oxygen, Te and Cs are visible.

**Fig. 60** SEM analysis of the coating explosion: gray background (Mo).

<table>
<thead>
<tr>
<th></th>
<th>O</th>
<th>Mo</th>
<th>Te</th>
<th>Cs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Net Counts</td>
<td>3137</td>
<td>197602</td>
<td>2556</td>
<td>7272</td>
</tr>
<tr>
<td>Weight Concentration %</td>
<td>11.85</td>
<td>79.97</td>
<td>2.15</td>
<td>6.03</td>
</tr>
<tr>
<td>Atom Concentration %</td>
<td>45.26</td>
<td>50.93</td>
<td>1.03</td>
<td>2.77</td>
</tr>
<tr>
<td>Compound Concentration %</td>
<td>11.85</td>
<td>79.97</td>
<td>2.15</td>
<td>6.03</td>
</tr>
</tbody>
</table>
4 Multivariate Data Analysis

A PCA (Principal Component Analysis) [8] 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 [9]. 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 co vary in the main variance of the data.

Before starting the PCA analysis, all parameters involved during a film deposition were labeled and organized in a table. Some of the parameters are:

- rod: name, material
- plug: machining type, BCP, polishing technique, reflectivity
- cathode: temperature treatment, masking, sources (current, number of its use, evaporation rate), Te thickness, time spent for the deposition, cathode temperature
- QE monitoring: Hg lamp power, spot size, photocurrent

Fig. 61 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 behavior of the photocathodes.

According to the PCA practice, we then proceed analyzing the two groups separately in order to explore correlations to QE. Fig. 62 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. 62](image)

**Fig. 62** 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.

## 5 Conclusions

The large amount of data relative to cathode production, operation, performances, etc. collected during these years, have been organized in a database web accessible. These data have been analyzed, also using a PCA analysis, trying to find possible correlations between cathode performances in RF guns (with particular interest in QE and dark current) and the procedure followed for their productions.

The production process has been analyzed starting from the Mo plug (material, surface finishing, etc.) and also reviewing the main steps during the deposition of the photoemissive films (Cs$_2$Te, KCsTe). As an example, our analysis shows that the plug material (sintered and arc cast molybdenum) and the two lapping techniques (manual and automatic) have no significant influence on the final QE value. On the contrary, cathodes grown on polished plugs show a lower dark current respect to the one measured with the unpolished one. Results from PCA analysis, mainly devoted to the correlation between QE and the main steps of the Te and Cs evaporation, shows an influence on QE due to the Cs source aging. Moreover, we have presented a description of all the diagnostic techniques
applied on plugs and cathodes during their life (QE maps, visual inspection, SEM analysis).

For the future, we want to proceed further with this activity, enriching the collected parameters and completing the insertion of lacking information in our cathode database. Moreover, the PCA analysis, together with new diagnostics, will be applied for the dark current investigation.

6 Acknowledgements

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7 References

[1] Database address: http://wwwlasa.mi.infn.it/ttfcathodes/