High QE Photocathodes lifetime and dark current investigation

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Main Topics

• High QE photocathode lifetime
  - QE vs. time (measurements on several cathodes, FLASH data)
  - QE maps
  - Photocathode lifetimes (in operation and since their production)
  - Etc.

• Dark current investigation
  - Collected data of dark current measurement since 1998 (TTF, FLASH, PITZ machines)
  - Dark current images on screens (FLASH and PITZ machines)
  - Dark current interpretation: simulation results

• Photocathode productions status and future plants
  - Photocathode productions for FLASH and PITZ
  - A new transport box?
  - Safety interlock

• WorkShop on High QE Photocathodes
  - Information
Several pulsed QE measurements have been done at FLASH to check the photocathodes vs. time photoemissivity. Data have been compared with the CW QE measurement performed at FLASH and at LASA.

All cathodes show a drop of the QE over time, with different characteristics.

In the plot the end of cathode lifetime is also indicated: QE<0.5%

We can relate the drop in QE with the vacuum condition in the RF gun.

As an example, early this year, the RF gun has been operated with 300 μs long RF pulses, up to this, the pulse length was restricted to 70 μs. During this period, the pressure increased from $5 \times 10^{-11}$ mbar to $2 \times 10^{-10}$ mbar.
High QE photocathode lifetime(2)

Real pressure in the gun? An IG pump is used as gauge but a TSP is located between the IGP and the gun.
Gas composition? RGA?
High QE photocathode lifetime(3)

We have no indication, that the total amount of emitted charge limits the lifetime of the cathode.

The cathode lifetimes at FLASH is typically between 100 and 200 days (updated 1 September '06).

The cathodes produce an integrated charge between 1 and 2 C.

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High QE photocathode lifetime(4)

During the machine studies at FLASH also a tool to realize QE maps of cathodes has been done.
In this way it is possible to check the uniformity of the photoemissive surface.
For these 2D and 3D maps a thiny spot has been moving on the cathode surface to scan it.

Iris = 0.16 mm ($\sigma$)
The dark current investigation has been done organizing all the measurements performed in TTF, FLASH and PITZ machines, starting from 1998.

All dark current measurements have been organized and added in the cathode database taking into account also of the measurement conditions (solenoid currents, gradient, RF pulse lengths), of the RF GUN used and of the Faraday Cup (FC) positions.

<table>
<thead>
<tr>
<th>Where</th>
<th>Machine</th>
<th>RF gun</th>
<th>Cath. Used</th>
<th>Date</th>
<th>Faraday cup</th>
</tr>
</thead>
<tbody>
<tr>
<td>DESY-Hamburg</td>
<td>TTF</td>
<td>G3</td>
<td>13°</td>
<td>Nov-98/ Mar-02</td>
<td>FC(*)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>G4</td>
<td>1°</td>
<td>Jun-02/ Nov-02</td>
<td>FC(*)</td>
</tr>
<tr>
<td></td>
<td>FLASH</td>
<td>PITZ-G2</td>
<td>6°</td>
<td>Mar-04/ in use</td>
<td>2GUN(<strong>) 3GUN(</strong>*))</td>
</tr>
<tr>
<td>DESY-Zeuthen</td>
<td>PITZ</td>
<td>PITZ-G2</td>
<td>8°</td>
<td>Mar-02/ Oct-03</td>
<td>DC(***))</td>
</tr>
<tr>
<td></td>
<td>PITZ1.5</td>
<td>PITZ-G1</td>
<td>8°</td>
<td>Mar-04/ Sep-05</td>
<td>DC(***))</td>
</tr>
<tr>
<td></td>
<td>PITZ1.6</td>
<td>PITZ-G3</td>
<td>1°</td>
<td>Mar-06/ in use</td>
<td>DDG(<em><strong>)) DC(</strong></em>))</td>
</tr>
</tbody>
</table>

(*) positioned at 0.62 m; (**) positioned at 0.78 m; (***) positioned at 1.27 m from the cathode surface
◊ Cs2Te, § KCsTe, ⊗ Mo

The analysis of the dark current data have been done selecting data obtained on Mo and Cs2Te at the standard operation conditions of FLASH:

- \( E_{\text{acc}} = 40\div42 \text{ MV/m at the cathode} \)
- \( I_{\text{main}} = 277 \text{ A (Main Solenoid)} \)
- \( I_{\text{buck}} = 20 \text{ A (Bucking Solenoid)} \)
- FC @ 0.78 m from the cathode front surface.
Dark current investigation (2)

- Decrease of dark current during each gun operation as effect of the gun cavity conditioning.
- A sharp increase of the dark current, for the same cathodes (#60.1, #61.1 and #500.1), due to the need for conditioning of the new gun. This effect was clearly seen also during TTF operation when G3 was substituted by G4. This increase was due to damaging of front surface during the conditioning of the new gun PITZ-G1 gun.
- Smoother behavior for PITZ-G1 to PITZ-G3 transition explained by previous baking of PITZ-G3 before operation.
- Uncoated Mo plugs (magenta colors), showed dark current emission levels comparable to the Cs₂Te cathodes, suggesting a dominant influence of the plug substrate or the gun conditions on the dark current emission mechanism.
- Cathode #53.1 (Mo) shows higher emission levels in the PITZ-G3 gun. This cathode was scratched at its border during handling causing uncontrolled local field enhancements.
- Cathode #80.1 (Mo) was a special one, with regular spot pattern on its surface. The experiment showed a dark current pattern similar to that of Mo plugs.
Only $\text{Cs}_2\text{Te}$ cathodes have been measured.

Dark current is quite low already from the beginning of operation due probably to the previous conditioning (@ PITZ).

Very sharp increase for cathode #37.2 (a factor of 5 in 2 days) due to a mechanical problem during the cathode handling.

After about one year of continuous operation, nearly the initial values have been restored.

Cathode #78.1 that has been electro and then optical polished: no significant effect on the dark current emission levels.
Dark current investigation(4)

Dark current images taken at different locations along the injector, varying solenoid or accelerating fields, are an important tool to study and understand the dark current origin.

Pictures taken at PITZ, in the same condition of gradient and focalization, of Mo (up, #56.2) and Cs₂Te (down, #54.2) cathodes.

The images looks similar except for the inner ring!

We observe:
- Three circular regions of different intensities
- Clear flares are visible

The flares spirals from the center outwards due to the large energy spread of the emitted electrons traveling in the solenoid magnetic fields. The flares seem to originate from the outer and middle rings.

The outer flares have been attributed, in the past, to dark current coming from the region between the plug and the gun body, where the RF contact spring is located.
Dark current investigation(5)

The "scratch" TEST (cathode #80.1)

The front surface of an optical polished cathode has been damaged with an intense ns laser beam in few controlled positions (cathode #80.1).

The experiment showed:

- a dark current pattern similar to that of regular cathodes.
- none of the damage locations on the front surface originated emission spots, even changing focusing and accelerating gradient parameters.

This could indicate that any field enhancement induced by the laser damage is substantially lower than the typical values at the gun/plug boundary.
Dark current investigation(6)

How to localize correctly the e- source?

Non monochromatic electron source
Chromatic focusing
Screen
Dark current investigation (7)

THE DARK CURRENT MODELING

We developed a simple computational model to reproduce the dark current patterns at the screen, with the aim to identify dark current sources. Below two cases are shown, using the ASTRA code.

- particles generated only on the plug border
- 25 azimuthal angles, in order to mimic the spring convolutions (~80 in the present design). Increasing the number of azimuthal positions results in a more defined outer ring image.
- the main features of the images are reproduced
- the plug border region, where the RF spring is located, could be responsible of the dark current emission.

- as previous case plus one “hot spot” of electrons to artificially enhanced the distribution.
- two bright spots are visible and a light blue flare crosses the whole image. Since many particles have been used for the hot spot generation, the underlining structure is fainter then before.

The emission process, in the simulations, does not take into account the Fowler-Nordheim dependence of the emitted current with the accelerating field on the cathode. This effect changes the relative intensity of the main features of the image, but not the overall structure.
Dark current and RF Spring contact(1)

Damages on used cathodes

We have observed damages on used cathodes in the RF contact region and the back part.

These burns indicate the presence of local “HOT” points in the spring region and a not correct path for the current flow.

...this is due to the SPRING??

This region has to be reconsidered and optimized?
Dark current and RF spring contact (2)

- Two spring technologies have been used, in the same groove geometry!
- The groove was first designed for a WELDED Watch bend type spring.
  - Spring used:
    - Watch bend type
    - Cantend coil spring
Dark Current and RF spring contact (3)

Watch bend type

• CuBe hard, silver coated spring
• Difficult to weld (becomes hard)
• Critical number of convolutions
Dark Current and RF spring contact (4)

Canted coil spring

- CuBe uncoated.
- Available coated with Ag, Au etc...
- Welded by the manufacturer.
Dark current investigation

conclusions

- The dark current data measured on several cathodes, and with different guns, at FLASH and at PITZ have been collected and critically analyzed.

- They show that the total dark current decreases both as the gun cavity conditioning proceeds and as a "local" conditioning of the cathode takes place.

- Improper handlings, generation of dust particles or mechanical damages at the front surface of the cathode lead to an increase of the dark current. There is not a significant difference in dark current emission between uncoated Mo and coated cathodes.

- The main features of the dark current images have been reproduced by particle tracking simulations in the RF gun.

- The simulations seem to confirm the hypothesis that the particles originate from the region between the plug and the gun body where the RF spring is located.

- Further tests are planned to confirm or invalidate this hypothesis.
Photocathode productions status (1)

- The preparation system maintenance has been completed in August (new thermocouple for cathode heating control)
- Vacuum is less then $4 \times 10^{-11}$ mbar
- One “spare” box (long2) has been sent to FLASH with a fresh Cs$_2$Te cathode
- The box short1 has been repaired (all metal valve replaced, new bayonet) after the mechanical accident occurred at PITZ
  - The box short1 has been equipped with 4 Mo plugs
  - The baking of the box is under way
  - During next weeks 4 Cs2Te cathodes will be grown (2 nominal thickness Cs2Te, + 2 thicker Cs2Te)
  - This box will be sent to FLASH in September
- Old box short2 has been shipped from FLASH to PITZ (?)
Photocathode production future (1)

- Assembling of a new transport box (number six) will increase system reliability (and our peacefulness)?
- New carrier is under test
  - In air behavior is ok
  - First bake out is foreseen in the next month.
  - Should be tested at Milano in one of the next transfer.
- Safety interlocks for avoiding accidents
Future plants: new carrier

New carrier assembled

No friction...
Many bearings...
Less particles!
Future plants: safety interlock for all metal valve activation

Displacement sensor to control the carrier position in the transportation box: it will be one interlock for the all metal valve control.

Can be installed in front of the transportation box viewport.

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Roughness measurement (1)

- Information from a “surface topography” optical instrument (no contact, c) from Taylor Hobson from a plug with air exposed cathode on Mo substrate.

Profile

![Profile Image]
Roughness measurement (2)

Roughness

![Graph of Profilo di rugosità](image1.png)

![Graph of Profilo di ondulazione](image2.png)
Roughness measurement(3): imaging
Roughness measurement(4): imaging
From October 4 to 6, we have organized @ LASA an international workshop dedicated on photocathodes.

Main items are:

- Preparation (recipes, etc.)
- Characterization (QE, etc.)
- Operation
- Secondary emission, thermal emittance, etc.

More information available at:
http://wwwlasa.mi.infn.it/WSPhotocathodes