Post-Removal Examination of GTF Cathode #3

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Introduction

This photo-cathode (PC), Gun Test Facility (GTF) Cathode #3, was removed from the GTF injector, after operation, in March, 2003 (report LCLS-TN-03-1). It was examined originally by secondary electron microscopy in October, 2000, after polishing and degreasing, prior to insertion into the GTF injector. Images of the PC prior to insertion into the rf gun and after running are included in this report. The cathode fabrication and preparation steps were:

The cathode plate was conventionally-machined at SLAC, using class one OFE copper plate from Klystron Dept stock. A centrally-located ten mm through-hole was produced, and the plate was then cleaned in the SLAC Plating Shop (procedure C01A, no Oxyban). A tuning rod attachment nut was then 35-65 Au/Cu-brazed to the rear of the plate for in-situ attachment to the GTF transfer/tuning rod.

A two mm-thick (100) single-crystal ten mm diameter Cu disk-insert was oriented with Laue x-ray diffraction, and Au/Cu-brazed into the hole with Au/Cu. The plate was then polished to smooth flatness by J. Francis, initially using SiC and, finally, 0.25 micron diamond paste. The plate was then solvent-degreased, face-down on teflon edge supports with hot TCE, acetone and ethanol. The cathode surface was then imaged in the SEM and installed into the GTF rf gun.

This report covers the surface appearance before and after GTF running. It will address the following:

What is the general surface condition as a result of running?

What is the distribution of debris and breakdown features?

Is breakdown activity enhanced at the braze line or at the voids in the braze line?

Has rf heating, although minimal, affected the surface/braze line, perhaps through thermal expansion?

And finally, is laser or ion-feedback damage visible at the single crystal center and what is its nature?

General Cathode Appearance

A composite low magnification high resolution, high contrast image of the PC, after running, is shown in Figure 1. For linear scale, the braze circle is 10 mm in diameter. The performance of the single crystal cathode was very good and is discussed in a GTF Technical Note. Several types of features were found: surface debris, braze joint partial incompleteness (present at fabrication), and breakdown craters. Damage features extend out to ~12 mm radius from center. Located within a few tenths of a mm from axial center is a cluster of features that appear white in this secondary electron image.

Figure 1. Composite of 1024 x 1024 pixel SEM images. Center ring is braze line of a single-crystal copper disk, approximately ten mm diameter. The black spots are due to surface debris that has been charged by the SEM electron beam.

The PC surface in as-fabricated and polished condition is shown in Figure 2, for the single-crystal insert region.

Figure 2. PC before insertion into GTF injector. Faint vertical lines are video system artifacts. Voids in the braze line are evident between 6 and 9 O'clock. Otherwise, the surface was essentially featureless.

Surface Finish

The surface finish (Figure 3) before and after running was essentially identical, as was the braze line appearance (Figures 4-6), except for the occurrence of several craters on the braze, to be discussed later.

Figure 3. Central area single-crystal Cu surface finish, before and after running at GTF.

Braze-Line Appearance

Figure 4. Non-featured portion of the braze line before and after running. The composite image on the right contains an energy-dispersive x-ray spectrum from the small white marker box shown in the right hand image.

Figure 5. Incomplete region of braze line, before and after running.

Figure 6. Higher magnification of braze-line void shown in Figure 5, before and after running. Its appearance is unchanged.

Debris

Debris on the after-operation surface appeared to be randomly scattered about, containing Na/K-chlorides, carbon, or concrete (tunnel) dust. A few examples are shown in Figures 7 and 8.

Figure 7. Condensed NaCl crystals (perspiration), several mm from center. Right image is near-center evaporated stains from KCl (saliva).

Figure 8. Debris from near braze line, tunnel dust on left and Al oxide on right.

Breakdown Craters

No craters were located at the cathode center. However, there was a small number present further out (Figure 9) , with several on the braze itself Figure 10).

Figure 9. Craters located away from center. No residue of foreign material was found in the crater centers, e.g., see the spectrum of the right-hand panel.

Figure 10. Craters formed on a sharp-edged void region of the braze (left panel) and on an, apparently, featureless region (right panel) of the braze line. The EDX spectrum shows elemental peaks from the gold braze alloy. The braze runs lower left to upper right in the right-hand panel.

Cathode Center Damage

Closeups of the PC center show a cluster of features that, at low magnification, appear to be craters (Figure 11). However, they do not have the usual crater shape. Nor do they appear to be laser melt spots (too small, ~3-5 micron diameter). Analysis, based on the location of the secondary electron detector, suggests they are blisters (Figure 12).

Figure 11. Near-central PC area. Low magnification left-panel has debris (white spots, tunnel dust) and intact or broken blisters (magnified in right-panel).

Figure 12. Left-panel is electron backscatter image. This technique is sensitive to metal density, showing that blisters are hollow. Right-image of intact blister shows copper oxide, suggesting that material was molten and oxidized *in vacuo*.

Discussion

The “blisters” at axial center are very interesting. They are, in fact, features that are usually referred to as “hillocks” and are commonly formed during high-energy (hundreds of keV’s) ion bombardment. Recently, it has been shown (Ref. 1) that hillocks can also form under low energy (as low as 3 keV) bombardment with ion clusters formed from gases. On impact, the cluster breaks up and fragments penetrate the solid. Energy loss and nuclear recoil melt the solid, which is pushed away by the shock wave of the ion super penetration, and form a hillock. The melt is then thermally-quenches to produce a hollow interior. This picture seems to fit the data of Figure 12, namely the appearance of symmetric bubbles, which are shown to be hollow by backscatter electron microscopy.

Conclusions

- Debris is fairly uniformly-distributed over, and confined to, a central 25 mm diameter area. That suggests that the source of the debris is from downstream in the injector. The debris is of the expected nature: tunnel dust, carbon, and chlorides (presumably from human sources).
- No breakdown craters were found at, or very near, the axial center. That seems rather surprising.
- The copper surface finish and braze line appearance is unchanged by operation. A few breakdown craters were found on the braze line, apparently connected with braze void edges.
- No effect of rf heating was found (or expected) as might be manifested by thermal deformation or braze separation.
- Blisters were clustered very close to axial center. Their source appears to be ion feedback. No laser damage was visible.

Reference

1. “Nanohillock formation by impact of small low-energy ion clusters with surfaces”, V.N. Popok, S.V. Prasalovich and E.E.B. Campbell, Nucl. Instr. Meth. In Phys. Research **B207**, 145 (2003).