H60VG4S17-1
Final Results
Structure High Gradient Performance
(Breakdown Rate -vs- Unloaded Gradient with 400 ns Square Pulses)
Breakdown Statistics for H60VG4S17-1 at 65 MV/m, 400 ns Pulse Width
After Revert to 400 ns Square Pulse from Ramped Pulse
Follow-up Studies

- On last night of run, tried to find pulsewidth threshold for breakdown.
  - However, structure ran well at 400 ns with a square pulse at 65 MV/m.
  - Increased pulse width to 600 ns and still ran reasonably well (took ~ 10 minutes for first breakdown – recovered afterwards).
- Examined structure with boroscope, although with reduced lighting.
  - Find pitting at bond joint in 3 of the 8 high current areas in cell 3 and in one area in cell 4.
  - Observed what looks like pits in 2mm radius transition to 2b area in cell 9.
H60VG4S17-1 Cell Contact Problem

Cell Cross-Section Illustrating Gap Between Cells Before Bonding

Resulting Field Attenuation After Bonding

‘Mesa’ Left After Machining (size exaggerated)
H60VG3-FXC1

- First slotted-cell structure built by FNAL.
- Copper from different vendor than that for FXB’s.
- Known problems with braze leakage and burrs on slots and braze dam.
- Did hydrogen bake as was done for FXB3 (not done for FXB6&7).
- No in-situ bake in NLCTA.
H60VG3S17-FXC1 Processing History
(Total Breakdowns ~ 5000)

Actual breakdown rate at 50 ns and 100 ns in 50 – 100 per hour range
Breakdown Statistics for H60VG3S17-FXC1

65 MV/m, 100 ns

60-66 MV/m, 170 ns
Breakdown Statistics for H60VG3S17-FXC1
240 ns Pulse Width

58-69 MV/m

65 MV/m

Phase of Reflected RF (degrees)

Position of Breakdown (ns)
Breakdown Statistics for H60VG3S17-FXC1
at 65 MV/m, 240 ns Pulse Width
After Processing to 69 MV/m
Trip Rate > 50 per Hour
Results from Examining First 39 Cells with Boroscope

1) Hard to distinguish etch pits from breakdowns – breakdowns sometime cluster, which helps to differentiate them, but no clusters seen in this case.

FNAL notes that it has changed its copper supplier:

- FXB’s made with Hitachi (Japan) extruded copper
- FXC’s made with Outokumpu (Finland) extruded copper
- FXD’s will be made with Zollern (Germany) forged copper

FNAL saw more etch pits with Outokumpu copper so switched to Zollern copper for FXD’s, which they found to have less etch pits than Hitachi copper.
2) Excess braze fillet in cells 1,2,3,8,9,10,12,14,15,17,21, which has a white color instead of the normal red or copper colored braze joints. The excess fillet is fairly uniform along the braze joint, covering the entire azimuth. There are generally 3-10, 1-mm-size black spots on this material, a few of which seem be associated with nearby pitting – the black spots occur at fairly random locations along the braze joint, including inside the manifold.

FNAL had boroscoped the structure after brazing and did note some dark spots on excess braze fillet, so these are not likely breakdown related.
Sectioned FXC Test Disks After Brazing

Tug Arkan
Cusil (Copper/Silver Alloy) on the Outside of FXC1
Sectioned FXC Test Disks After Brazing

CUSIL wire was put here

CUSIL wire melted & flowed in the brazing groove

Braze material leakage in the HOM

Braze material fillet around the corner of the iris

Tug Arkan
FXC1 Burr Problem On Braze Dam

- Burr on the rosette shape dam around the HOM feature
- Roller over Burr on the one side of the 0.020 inch radius around HOM due to machining sequence (milling + turning)
FXC1 ΔF (MHz) Before Tuning

Im(S), Before (red) & After Tuning (black)

Cells with Braze Fillet as Observed by Boroscope

Bead Pull Amplitude After Tuning

Gennady Romanov
3) There appears to be burrs in cells 19 and 32 and maybe 21 – they occur along the line where the 2b surface transitions into the 2mm radius for the manifold hole. However, do not see enhanced pitting around them. Would probably not see fine burrs on slots because of limited depth-of-field.
History of FXC-001 Structure

Disks were degreased with Fermilab procedure
Disks were single disk RF QC measured
Disks were pre-tuned
Disks were etched (SLAC C01 procedure)
Disk were baked at 1000 degree C for 1 hr
Disks were not hand deburred around the HOM keyhole radiuses and around the rosette shape dam

Bead-Pull showed some high frequency disks after brazing (refer to Gennady plots)
Borescope analysis showed some extra braze material in the problem disks. Cause of the problem was identified as the burrs on the rosette shape dam which allowed some small amount of braze alloy to leak into the RF volume
Structure was baked after final assembly at 500 degree C under 1 Torr 3% Hydrogen + 97% Argon gas mixture for 2 hrs
Structure was baked at 500 degree C under full vacuum for 72 hrs

Tug Arkan
4) None of the irises do not look excessively pitted – there is little variation in the amount of pitting iris-to-iris.

5) Cell 13 has small grain sizes in both the 2b area and iris surface, suggesting that it was not pre-baked.

6) There are several cells (21-24, 27, 32-36) that have a pattern of small grain sizes that cover one of the four quadrants of the 2b surface (the irises have normal grain sizes).

7) See distinct machining marks in manifold holes. Some of the 2 mm radii on in the 2 area look rough.

8) Some of the dimples look large, although this could be an optical effect. Also they look worse if have small grain sizes.
Comparison with Boroscope Observations

65 MV/m, 240 ns

- Small grain size on one 2b quadrant
- Burr near 2mm radius on 2b surface
Station 2 Vacuum Pressures During FXC1 Run
Station 1 Vacuum Pressures During First 10 Days of FXB6&7 Run
History of FXC-003 Structure

Disks were degreased with Fermilab procedure
Disks were single disk RF QC measured
Disks were pre-tuned
Disks were etched (SLAC C01 procedure)
Disk were baked at 1000 degree C for 1 hr

All disks were hand deburred around the rosette shape dam to prevent any braze material leakage into the RF volume.

Disks #28 and #44 were hand deburred around the HOM keyhole radiuses
Disks were re-etched for 60 seconds after hand deburring operations
Bead-Pull showed low frequency structure after brazing (refer to Gennady plots)
Structure was baked after final assembly at 500 degree C under 1 Torr 3% Hydrogen + 97% Argon gas mixture for 2 hrs
Structure was baked at 500 degree C under full vacuum for 72 hrs

Tug Arkan
Cell frequency after brazing.

Graph showing the frequency response for different cell numbers with three different markers.

- FXC001
- FXC002
- FXC003

Cell Number:
0 5 10 15 20 25 30 35 40 45 50 55

dF, MHz:
-30 -25 -20 -15 -10 -5 0 5 10 15 20 25 30 35 40 45 50 55

Gennady Romanov
FXC003. After final tuning. Field Amplitude

FXC003, Amplitude

Cell number

FXC003. After final tuning. Amplitude

FXC003, Phase

Cell number

FXC003. After final tuning. Phase

Gennady Romanov