High Q Cavities at Cornell University

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Motivation

• Most important figure of merit for CW machines is $Q_0$
• We investigate the impact of preparation on cavity residual resistance
• We apply these techniques to the first Cornell ERL 7-cell cavity and show record results for a cryomodule test
  – $Q_0 = 6 \times 10^{10}$ at 1.6 K
Single Cell Preparation Methods

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- Large-Grain
  - BCP
    - 120°C, 48 h bake
      - Test
  - 120°C, 48 h bake

- Fine-Grain
  - BCP
    - 120°C, 48 h bake
      - Test
  - 120°C, 20 h bake
    - Test
  - 120°C, +28 h bake
    - Test

- EP
  - 800°C Heat Treatment
    - Test
  - uEP
    - Test
# Summary of Cavity Tests

<table>
<thead>
<tr>
<th></th>
<th>AES02</th>
<th>AES06</th>
<th>NR1-2</th>
<th>NR1-3</th>
<th>LR1-3</th>
<th>LR1-5</th>
<th>LR1-6</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Shape</strong></td>
<td>ILC</td>
<td>ILC</td>
<td>ILC</td>
<td>ILC</td>
<td>Reentrant</td>
<td>Reentrant</td>
<td>Reentrant</td>
</tr>
<tr>
<td><strong>Grain</strong></td>
<td>Fine</td>
<td>Fine</td>
<td>Fine</td>
<td>Fine</td>
<td>Fine</td>
<td>Large</td>
<td>Large</td>
</tr>
<tr>
<td><strong>Manufacturer</strong></td>
<td>AES</td>
<td>AES</td>
<td>Niowave</td>
<td>Niowave</td>
<td>Cornell</td>
<td>Cornell</td>
<td>Cornell</td>
</tr>
<tr>
<td><strong>Main Chem.</strong></td>
<td>300 um VEP</td>
<td>300 um VEP</td>
<td>200 um VEP</td>
<td>300 um VEP</td>
<td>VEP after CBP</td>
<td>BCP</td>
<td>BCP</td>
</tr>
<tr>
<td><strong>800 C bake [h]</strong></td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td><strong>120 C bake [h]</strong></td>
<td>20</td>
<td>48</td>
<td>48</td>
<td>48</td>
<td>--</td>
<td>48</td>
<td>48</td>
</tr>
<tr>
<td><strong>Bpk [mT]</strong></td>
<td>120</td>
<td>130</td>
<td>120</td>
<td>150</td>
<td>150</td>
<td>90</td>
<td>86</td>
</tr>
<tr>
<td><strong>Highest Q₀</strong></td>
<td>5x10^{10}</td>
<td>9x10^{10}</td>
<td>3x10^{10}</td>
<td>7x10^{10}</td>
<td>8x10^{10}</td>
<td>3x10^{10}</td>
<td>6x10^{10}</td>
</tr>
<tr>
<td><strong>Temp [K]</strong></td>
<td>1.8</td>
<td>1.4</td>
<td>1.8</td>
<td>1.4</td>
<td>1.6</td>
<td>1.4</td>
<td>1.4</td>
</tr>
<tr>
<td><strong>Quench</strong></td>
<td>1 location</td>
<td>2 locations</td>
<td>1 location</td>
<td>Large region</td>
<td>Global</td>
<td>1 location</td>
<td>1 location</td>
</tr>
<tr>
<td><strong>Optical Inspection</strong></td>
<td>No visible defects</td>
<td>No defects near quench</td>
<td>No defects near quench</td>
<td>No visible defects</td>
<td>Discolored spots</td>
<td>Rough area near weld</td>
<td>Rough area near weld</td>
</tr>
</tbody>
</table>

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‘Low Temperature’ Maximum Q’s

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‘Low Temperature’ Maximum Q’s

Break down of treatment and maximum Q

- 800°C Bake
- Electropolish
- Buffer Chemical Polish

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Residual Resistance

Break down of treatment and residual resistance

- 800°C Bake
- Electropolish
- Buffer Chemical Polish

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• Bulk BCP
• After fabrication, heat treated cavity at 650°C for 12 hr
• Final BCP
• High pressure rinse
• 120°C bake for 48 hr
Cryomodule Test Results (1.8 K)

- Initial $\max(Q_o) = 3.18 \times 10^{10}$
Cryomodule Test Results (1.8 K)

- Initial max($Q_o$) = $3.18 \times 10^{10}$
- Warmed > 10 K
  - max($Q_o$) = $3.52 \times 10^{10}$
  - max($Q_o$) increased 11%
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Cryomodule Test Results (1.8 K)

- Initial $\max(Q_o) = 3.18 \times 10^{10}$
- Warmed $> 10$ K
  - $\max(Q_o) = 3.52 \times 10^{10}$
  - $\max(Q_o)$ increased 11%
- Warmed $> 100$ K
  - $\max(Q_o) = 3.67 \times 10^{10}$
  - $\max(Q_o)$ increased 4%
Cryomodule Test Results (1.8 K)

- Initial max($Q_o$) = $3.18 \times 10^{10}$
- Warmed > 10 K
  - max($Q_o$) = $3.52 \times 10^{10}$
  - max($Q_o$) increased 11%
- Warmed > 10 K
  - max($Q_o$) = $3.67 \times 10^{10}$
  - max($Q_o$) increased 4%
- Warmed > 100 K
  - max($Q_o$) = $4.37 \times 10^{10}$
  - max($Q_o$) increased 19%
Cryomodule Test Results (1.8 K)

- Initial $\max(Q_o) = 3.18 \times 10^{10}$
- Warmed > 10 K
  - $\max(Q_o) = 3.52 \times 10^{10}$
  - $\max(Q_o)$ increased 11%
- Warmed > 10 K
  - $\max(Q_o) = 3.67 \times 10^{10}$
  - $\max(Q_o)$ increased 4%
- Warmed > 100 K
  - $\max(Q_o) = 4.37 \times 10^{10}$
  - $\max(Q_o)$ increased 19%
- Warmed > 100 K, fast cool down
  - $\max(Q_o) = 4.06 \times 10^{10}$
  - $\max(Q_o)$ decreased 7%
Comparison 1.6, 1.8 K Q vs E

Maximum $Q_o = 6 \times 10^{10}$ at 1.6 K
($R_{res} \sim 4.5 \text{ n}\Omega$)

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Conclusions

• High quality factor cavities can be produced through several different methods
  – Final surface chemistry (EP, BCP) after heat treatment not necessarily required for high Q’s (At least for fine grain)
  – High Q’s can be obtained without 120°C bake

• More tests are needed for good statistics

• Thermal cycling can help to boost Q-factors
  – Above 10 K needed to release trapped flux (?)
  – Above 100 K needed to remove adsorbed gas (?)

• ERL cavity reached $Q_0 = 6 \times 10^{10}$ in cryomodule