Performance of Large Grain and Single Crystal Niobium Cavities

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Jlab/CBMM Technology(1)

- Development started with the need for understanding mechanical properties of niobium from different manufacturers (G. Myneni)
- Ingot material supplied by CBMM with large grains (T. Carneiro)
- Mechanical properties—especially elongation—excellent, permitting forming of cavity cells
- Investigate influence of grain boundaries on “Q-drop”

*Comparison of Single and Poly Crystal RRR niobium*

![Graph showing comparison of single and poly crystal RRR niobium](image)

- **Y-axis**: Load (Pounds)
- **X-axis**: Percentage of elongation

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- Since the first ILC workshop we have fabricated and tested 5 single cell cavities (1300 MHz - 1500 MHz) from sliced material (wire EDM and saw cut) from 3 different ingots (“A”, “B”, “C”), 3 different shapes, CBMM
- We have fabricated and tested 2 single crystal cavities from ingot “A” at 2.3 GHz, CBMM
- We have fabricated two 2.3 GHz cavities with material from a second vendor (WC) with somewhat smaller grains (not yet tested)
- We have fabricated a single cell cavity from large grain niobium from China-Ningxia (not yet tested)
- We have fabricated a 7-cell HG-Jlab-Upgrade cavity, which has been tested with problems so far (leaks, FE)
- We are in the process of fabricating an ILC_LL 7-cell cavity and intend to present results at the Snowmass meeting
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Ingot “B”

HG Single Cell Cavity - "Single Crystal "-B

$Q_0$ vs. $E_{acc}$

"150 micron bcp, post-purified, 100 micron bcp"

"In-situ" baked at 120C, 40 hrs

Test

Quench
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Ingot “A”

HG Single Cell Cavity - "Single Crystal "-A
$Q_0$ vs. $E_{acc}$

Test #4/4a

after baking
before baking

Quench

$E_{acc}$ [MV/m]
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Discs from Ingot

Cavity

$E_{\text{peak}}/E_{\text{acc}} = 1.674$

$H_{\text{peak}}/E_{\text{acc}} = 4.286 \text{ mT/MV/m}$
Single Crystal Niobium Cavity (1)

Test #1a: Treatment 100 μm BCP, 800C hydrogen degassing, 100 μm BCP, high pressure rinsing for 30 min

2.2 GHz Single crystal single cell cavity

$Q_0$ vs. $E_{acc}$

$T=2K$  $T=1.7K$  $T=1.5K$
Single Crystal Niobium Cavity (2)

Test #2: T-dependence (before baking)

2.2 GHz Single crystal single cell cavity after post-purification, 70mm BCP 1:1:1, 30min HPR

\[ \frac{\Delta}{kT_c} = 1.827 \pm 0.032 \]

\[ R_{\text{res}} = 0.8 \pm 0.4 \text{ n\Omega} \]

\[ l = 291 \pm 83 \text{ nm} \]

\[ \lambda_L = 32 \text{ nm} \]

\[ \xi = 62 \text{ nm} \]

\[ T_c = 9.25 \text{ K} \]
Single Crystal Niobium Cavity (3)

Test #1b: Treatment 100 \(\mu\)m BCP, 800C hydrogen degassing, 100 \(\mu\)m BCP, high pressure rinsing, "in situ" baked at 120C for 48 hrs

2.2 GHz Single crystal single cell cavity, 120C 48h bake

\[ Q_0 \text{ vs. } E_{\text{acc}} \]

\( Q_0 \) vs. \( E_{\text{acc}} \) graph showing data points for temperatures of 2K and 1.5K.

Transmitted signal

Field emission

Pulsed
Test #2: post-purification heat treatment at 1250 °C for 10 hours, 100 μm BCP, high pressure rinsing

2.2 GHz Single crystal single cell cavity after postpurification

$Q_0$ vs. $E_{acc}$

T=2K
T=1.84K
T=1.84K scaled to 1.3 GHz

ERL gradient
XFEL gradient
ILC gradient
Quench
Jlab/CBMM Technology (6)

Nb Discs

LL cavity 2.3GHz

$E_{\text{peak}}/E_{\text{acc}} = 2.072$

$H_{\text{peak}}/E_{\text{acc}} = 3.56 \text{ mT/MV/m}$
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ILC_LL Cavities: no Q-drop w/o baking

Large Grain ILC_LL_Cavity

Can't follow the resonance!

Quench @ 33 MV/m

1500 ppm Ta

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Surface Roughness (1)

BCP provides very smooth surfaces as measured by A. Wu, Jlab.

RMS: 1274 nm fine grain bcp

- 53 nm after ~ 35 micron, single Crys
- 27 nm after ~ 80 micron, single Crys
- 251 nm fine grain ep

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Surface Roughness (2) (A. Wu)

- Nb Single Crystal As-cut
  Average RMS 1591 nm

- 20 min BCP112
  Average RMS 870 nm

- BCP112 60 min
  Average RMS 459 nm

- BCP112 10 min
  Average RMS 1199 nm

- 50 min BCP112
  Average RMS 575 nm

- BCP 112 70 min
  Average RMS 424 nm

- BCP112 Using an Improved Agitation Method RMS 202 nm

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With a single cell cavity of the OC shape and fabricated from ingot “A” material we are investigating the “improvements” in cavity performance as a function of material removal employing T-mapping with the goal to:

- understand the loss mechanisms in the cavity, especially in the region of the “Q-drop”
- “streamline” the surface treatment by BCP with respect to the amount of material removal, which might result in cost savings
T-Mapping (1)

T-mapping system: ~600 Allen-Bradley C-resistors
**T-Mapping (2)**

Eacc = 25.9 Mv/m  
Q = 4.9 x 10⁹

Eacc = 27.6 Mv/m  
Q = 3.1 x 10⁹

Eacc = 29 Mv/m  
Q = 1.9 x 10⁹

70 micron  
bcp 1:1:2

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T - Mapping(3)
Add. 25 micron bcp 1:1:2

$E_{acc} = 28.5 \text{ MV/m}$
$Q = 3.6 \times 10^9$

Large grain CEBAF Single cell cavity 25µm BCP 1:1:2
What are the potential advantages of large grain/single crystal niobium?

• Reduced costs
• Comparable performance
• Very smooth surfaces with BCP, no EP necessary
• Possibly elimination of “in situ” baking because of “Q-drop” onset at higher gradients
• Possibly very low residual resistances (high Q’s), favoring lower operation temperature (B. Petersen)
• Higher thermal stability because of “Phonon-Peak”
• Good or better mechanical performance than fine grain material (e.g. predictable spring back..)
• Less material QA (eddy current/squid scanning)
Cavities awaiting testing

Wah Chang
2.2 GHz, HG shape
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China
1.5 GHz, OC shape
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CBMM
1.3 GHz ILC, LL shape
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