Advances in Large Grain Resonators

• material and fabrication aspects
• preparation and RF test results

Advances in Seamless Resonators

• 3-cell and 9-cell cavities
• new seamless tube fabrication

Presented by W. Singer, DESY
Advances in Seamless Resonators

What was happened in last 2 Years

Welding seam is critical even without pits problematic

Example of welding connection of EP treated cavity. Up to 75 µm steps
Hydroforming activities at KEK

Three cells of LL type from Cu

After Necking of Nb bulk pipe that is made from plate

KEK hydroforming and necking machines

Fabrication of Nb multi cells is in progress at KEK

W. Singer, THOAAU04, 14th International Workshop on RF Superconductivity, September 20-25, 2009, Berlin-Dresden, Germany
Hydroforming activities at DESY

Necking equipment

Hydroforming machine
HYDROFORMA

Several 3-cell TESLA type units are build at DESY using earlier constructed equipments
JLAB completed with beam tube/flange assemblies surface treated and cryogenically tested three 3-cell cavities, which had been manufactured at DESY by hydroforming (SRF2009 Poster THPP0058, P.Kneisel et al) All three cavities after BCP and post-purification with titanium at 1250°C for 3 hrs. achieved of Eacc = 32 MV/m, 34 MV/m and 35 MV/m limited by “Q-drop” in the absence of field emission.

These 3 x 3 cell units will be completed at ZANON to 9-cell cavity # Z163 (contract are allocated)
Another hydroformed at DESY 3 x 3 cell units will be completed at ZANON to 9-cell CV Z164 (contract allocated)
DESY Z145: 9-cell as 3x3 cell cavity hydroformed and completed at Fa. ZANON in 2007
New method of tuning with profile ring was proposed and applied to Z145 at DESY (I. Jelezov, G. Kreps, A. Ermakov).

**It works**

Radius change: up to 1.5 mm

Frequency change: up to 10 MHz
Z145: 9-cell cavity RF test results (ca. 30 MV/m)

Surface treatment at DESY: 40 µm BCP, 800 °C 2h, tuning; 170 mm EP, ethanol rinsing, 800 °C 2h; 48 µm EP, HPR.

The cavity is welded into the He vessel, will be installed in one of next acc. cryomodules at DESY.

Mode limits of cavity Z145 measured on 23-Jul-2008 13:08

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<th>Pi</th>
<th>8/9 Pi</th>
<th>7/9 Pi</th>
<th>6/9 Pi</th>
<th>5/9 Pi</th>
<th>4/9 Pi</th>
<th>3/9 Pi</th>
<th>2/9 Pi</th>
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<th>Limit</th>
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<td>27.34</td>
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<td>15.79</td>
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<td>35.24</td>
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<tr>
<td>Limit</td>
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</table>
DESY spun, flow formed, 800°C annealed tube, ca. 800 mm long
Data of T. Bieler, MSU

Spin+ff + 800°C ann 1 hr

Colors are parallel to radial direction

W. Singer, THOAAU04, 14th International Workshop on RF Superconductivity, September 20-25, 2009, Berlin-Dresden, Germany
T-map on 3-cell hydroformed cavities at $E_{\text{acc}} = 27$ MV/m, $Q_0 = 4.5 \times 10^9$ (JLab) indicating several hot-spots in the equator area, mostly on the top cell (relation to the tube fabrication method).
The seamless tubes can be produced better and longer

New tube fabrication in length sufficient for 9-cell cavity

Status of Tube Processed for Hydroforming
Black Laboratories, L.L.C. and ATI Wah Chang

Roy Crooks
Black Laboratories, L.L.C., Newport News, VA

This work was performed under the support of DOE SBIR DE-FG02-04ER83909
High purity Nb tube production developed and coordinated with ATI Wah Chang

Heavily deformed billet, processed for fine grain structure
Shaped by extrusion and flow-forming

- 150 mm I.D. RRR Tubes
- For DESY Hydroforming Machine Size
- 1.65 m length, ~ 3 mm wall
- 3 Recrystallized
- Set-up tubes (varying wall thickness) to establish flow-forming parameters
Microstructure and Properties of Tube B1B, Flow-formed + recrystallized

Uniform, fine, equiaxed grain size through wall thickness (one scan shown).

Average Diameter 13.76 μm

Crystal axes parallel to circumferential direction

<table>
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<tr>
<th>Material</th>
<th>Grain Size, μm</th>
<th>Recrystallized</th>
<th>YS/elongation, axial</th>
<th>YS/elongation, circum. or transv.</th>
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<td>Sheet</td>
<td>25</td>
<td>90 %</td>
<td>79.3 MPa / 60%</td>
<td>75.1 MPa / 68%</td>
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<tr>
<td>BL/AWC Tube</td>
<td>14</td>
<td>90 %</td>
<td>84.8 MPa / 51%</td>
<td>84.1 MPa / 55%</td>
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</table>

New hydroforming activities are going on
Possible advantages (hope):

• Cost effective
• Higher purity. RRR=600 of ingot is achievable
• No danger that during many steps from ingot to sheet the material will be polluted.
• Simplified quality control (reduced number of measurements: grain size, eddy current scanning etc.)
• Higher thermal conductivity at low temperatures (phonon peak)
• Seems to be less susceptible to field emission (Univ. Wuppertal)
• Seems that the baking at 120°C works better after BCP (compare to fine grain BCP)
Discs Slicing:

1. The multi-slicing of discs was done within the framework of the R&D program of DESY and the Co. W. C. HERAEUS (B. Spaniol et al, LINAC 2006, TUP024)

2. **Successfully Multi-sliced 59 sheets (3.2t) from 201 mm long Nb Ingot**

More details in presentation of Kenji Saito
Thinning or ripping at grain boundary in iris if the grains “meet” in these areas

Safety margin is not big. Large central single crystal is very desirable

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**Ingot fabrication W.C. Heraeus:**

Development of LG disc production was done within the framework of the R&D program of DESY and the Co. W. C. HERAEUS.

Melting-/cooling behavior was investigated: beam figures (different numbers, position and shape); energy entry (different focusing of the beam and stay time); refrigeration parameters (bottom, crucible wall, split).

The complete process is not sufficiently stable or reproducible in order to create a central crystal of big diameter and required orientation along the whole ingot.

**JLab solution: deep draw.– annealing - second deep draw.**

allows LG CV fabrication without big single crystal in the disc centre

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Multi cell LG DESY: Fabricated 11 LG 9-cell cavities at ACCEL(RI) from HERAEUS material (AC112-AC114, AC151-AC158)

Fabrication:
- Discs scanned only for two cavities.
- Deep drawing
- Machining
- EB welding
- Grinding of grain boundaries on 4 cavities for comparison

In discs for AC151-AC154, the main orientation of the central crystal is (100), for discs of AC155-AC158 (211) or (221). For the disc with (100) orientation, a more pronounced anisotropy and quadrangular shape after deep drawing was observed. The assembling of half cells and dumb-bells for welding have been done using a special tool.

Large single crystal in the centre of the LG disc was available.
Multi cell LG activities: Several Labs are working on LG multi cell cavities

JLab: Two Jlab upgrade 7-cell cavities are completed from Ningxia/ CBMM large grain Nb
Jlab: Two LL/Ichiro 9-cell ILC cavities are in fabrication from Tokyo-Denkai and CBMM material

Pekin Univ: LG two cell cavity

IHEP works on two 9-cell LG 1.3 GHz CVs

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**RF performance**: reasonable $E_{acc}$ and reproducibility is demonstrated on single cell LG cavities with BCP by JLAB, DESY, and KEK/IHEP.

All cavities treated:
- 100 micron bcp (1:1:1)
- 600 C, 10 hrs
- 30 micron bcp, HPR

RF-Test
If no FE, baking at 120C for 20 hrs
Re-testing

Reproducibility Tests of LG Niobium Cavities (P. Kneisel, JLab).

Baking works
DESY: BCP of first three 9-cell LG cavities (100 µm rough BCP, annealing at 800°C for 2h followed by fine BCP of 20 µm). The same BCP treatment is now applied to the recently fabricated 8 LG cavities AC151-AC158. 100 µm BCP done at Company RI. RF test is ongoing.
DESY: Q(Eacc) curve of the LG nine cell cavities AC113-AC114 at 2K after additional 20-30 µm BCP and 125°C, 50 h baking

- Very similar behavior, good reproducibility
- Baking does not work?? More results needed. New 8 LG CVs in work
What treatment EP or BCP??

DESY data on single cell cavities; it seems that EP works better

DESY: $Q(E_{acc})$ curve of the LG single cell cavity1AC4 after EP and BCP treatment. EP at Henkel, preparation at DESY (D. Reschke et al)

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DESY 3 LG cavities: additional EP of 50 -100 µm, combined with additional “in situ” baking. Enhancing the acceleration gradient by approx. 10 MV/m can be seen on two cavities (AC112 and AC113). AC113 installed into cryomodule No. 7, achieved excellent result (talk H. Weise)

Surprisingly, significant degradation of Eacc from 28 to 14 MV/m for the cavity AC114 (quench without field emission)
Large groups of small craters on the entire surface of all cells found by optical inspection with high resolution camera in AC114.

Depends the pits creation on the crystal orientation?

More results needed. New 8 LG CVs in work.

T-maps of AC114: for π-mode, the quench in cell 2 above and near equator. In other modes, quench was also found in cell 1 and 9. In addition, many other smaller hot spots were found.
Is LG good enough, or do we have to have single grain?

AFM image of LG Nb, BCP etched up to 100 µm

Profile and step heights of the three grain sample at the grain boundary intersection

AFM roughness measurement (X. Singer, A. Dangwal-Pandey). Roughness of fine grain Nb after EP is 251 nm (A. Wu).

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One large grain (single crystal) is still a very perspective option that allows stably reach very high gradient by simple BCP treatment

Summary of test results on single crystal single cell cavities
P. Kneisel et al EPAC2008

<table>
<thead>
<tr>
<th>Cavity #</th>
<th>$E_{\text{acc, max}}$ (MV/m)</th>
<th>$B_{\text{peak, max}}$ (mT)</th>
<th>$Q_0(B_{\text{peak, max}})$</th>
<th>Treatment</th>
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<tbody>
<tr>
<td>1</td>
<td>38</td>
<td>162</td>
<td>$4 \times 10^9$</td>
<td>200μm BCP, 800°C 3h, HPR, 120°C 48h</td>
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<tr>
<td>2</td>
<td>45</td>
<td>160</td>
<td>$7 \times 10^9$</td>
<td>200μm BCP, 800°C 3h, HPR, 120°C 24h</td>
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<tr>
<td>3 (1AC6)</td>
<td>41</td>
<td>177</td>
<td>$1.2 \times 10^{10}$</td>
<td>250μm BCP, 750°C 2h, 120μm EP, HPR, 135°C 12h</td>
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<tr>
<td>4 (1AC8)</td>
<td>38.9</td>
<td>168</td>
<td>$1.8 \times 10^{10}$</td>
<td>216μm BCP, 600°C 10h, HPR, 120°C 12h</td>
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<tr>
<td>5</td>
<td>38.5</td>
<td>166</td>
<td>$7.6 \times 10^9$</td>
<td>170μm BCP, HPR, 120°C 12h</td>
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</table>
Single Crystal Cavity option is going on

**JLAB:** Three single cell single crystal cavities of three different crystal orientation have been fabricated from enlarged by DESY method single crystals of CBMM niobium and are in the “pipeline” for testing.
Thank you to all colleagues who provided me with information for this summary:

T. Bieler, R. Crooks, H. Hayano, P. Kneisel, M. Liepe, G. Mueller, K. Saito, B. Spaniol, K. Ueno,