IHEP 1.3 GHz Low Loss Large Grain 9-cell Cavity R&D

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On behalf of the IHEP 1.3 GHz SRF Team

SRF2011, Chicago

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Outline

- IHEP 1.3 GHz SRF Program
- Large grain low loss 9-cell cavity
- Other components progress
- Summary
IHEP 1.3 GHz SRF R&D Program

• **Develop 1.3 GHz SRF Tech**
  – key components and infrastructures
  – short cryomodule (HTS) with ILC spec.
  – 2009-2012

• **Team (led by J. Gao)**
  – Input coupler: W. M. Pan, T. M. Huang, Q. Ma
  – Cryomodule: S. P. Li, R. Ge, C. H. Li
  – RF Power Source: Y. L. Chi
  – SRF Infrastructure: J. P. Dai, Q. Y. Wang
Large Grain Niobium

- ultrasonic and eddy current scanning tests
- mechanical behavior sample test at room temp. and 4K
Single Cell Cavities

- 3 Ningxia large grain cavities, made by KEK, in 2007: 48 MV/m (CBP + EP)
- 2 Ningxia large grain cavities, fabricated and processed in IHEP, tested at KEK in 2008 40 MV/m (CBP + BCP)
- 1 fine grain cavity for reference study
Low Loss large grain 9-cell Cavity

• **Research frontier**
  – Low loss shape: KEK 40 MV/m with end groups (FG, EP)
  – Large grain EP: DESY 46 MV/m with end groups
  – Large grain BCP: ~30 MV/m (DESY and KEK)

• **IHEP-01 without end groups**
  – Fabricated in Beijing with Ningxia OTIC large grain Nb
  – 2009 ~ 2010
Fabrication

- Fabrication and EBW challenges
  - Low loss shape
  - Large grain
- Precise freq. and length control
Processing

- CBP + bulk BCP + anneal + tune + light BCP + HPR + bake
  - 1\textsuperscript{st} pass: CBP 190 μm + BCP 130 μm
  - 2\textsuperscript{nd} pass: CBP 150 μm + BCP 110 μm (10 μm in JLAB)
  - totally ~ 600 μm removed in the equator area, 4 kg Nb
  - annealing: 750 C, 3 hours, 1E-4 Pa
  - field flatness
    - 1\textsuperscript{st} pass: 98 % vertical bare, 94 % v. with jig, 92 % horizontal with jig after VT
    - 2\textsuperscript{nd} pass: 99 % h. bare, 92 % v. bare, 90 % after VT
    - 10 μm BCP < 1 % F.F. reduction, flip up and down to reduce F. F. change
    - relative passband frequency change in VT2: RT to 2 K 4%, 2 K to RT 50%
    - passband field profile measurement after VT2, cell gradient correction?
1st Pass Processing

CBP → 1st BCP → Annealing

Pre-tuning & 2nd BCP → Ultrasonic Cleaning (at IHEP & KEK)

HPR → Assembly and Pumping → Baking

(IHEP) (KEK)
1st Vertical Test at KEK on July 2010

STF T-mapping system
2nd Pass Processing

CBP, bulk BCP, Annealing, Pretuning, Inspection, Ultrasonic, light BCP, HPR at IHEP

Field flatness check, Ultrasonic, flash BCP, HPR, Assemble, Baking at JLAB
2nd Vertical Test at JLAB, July 2011

Thermometry near VT1 quench location
OST (2nd Sound) setup
He Pressure Frequency: 335 Hz / Torr
Lorentz detuning factor: 6 Hz / (MV/m)^2
1\textsuperscript{st} and 2\textsuperscript{nd} Test Results

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{test_results_graph.png}
\caption{Graph showing the results of 1\textsuperscript{st} and 2\textsuperscript{nd} tests. The graph plots radiation (mSv/h) against $E_{acc}$ (MV/m), with several markers indicating initial, final, and quench points for VT1 and VT2. The graph also highlights passband processing and F. E. turned on events.}
\end{figure}
Cell Gradient and Analysis

- Pi mode VT1: 20 MV/m
- Pi mode VT2: 13 MV/m
- 5 cells > = 30 MV/m

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**Eacc (MV/m)**

- Cell 1
- Cell 2
- Cell 3
- Cell 4
- Cell 5
- Cell 6
- Cell 7
- Cell 8
- Cell 9

**VT1**

**VT2**
Cell Gradient and Analysis

![Graph showing cell gradient and analysis with Eacc in MV/m and cell numbers 1 to 9.]

- **6 cells no quenching yet**
- **5 cells > = 30 MV/m**
- **Pi mode VT1 20 MV/m**
- **Pi mode VT2 13 MV/m**

Legend:
- VT1
- VT2
Cell Gradient and Analysis

6 cells no quenching yet

5 cells
>= 30 MV/m

Pi mode VT1
20 MV/m

Pi mode VT2
13 MV/m
- cell#2 quenched in VT1 at 32 MV/m
- bump found by T-mapping & inspection
- eliminated by CBP
- cell#5 quenched first in VT2
- no way to push cell#2 higher
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Typical equator pictures for cell #2, 3, 4, 5, 6, 7, 8

EBW company asked us to anneal the dumbbells to get rid of hydrogen. But why cell #1 & 9 equators, single cell equators and dumbbell iris EBW no sputtering?

Although so many sputtering spots, we can reach 30 MV/m in at least five cells by CBP. No underneath bubbles.
#3 & 7 increased because we didn’t test 2Pi/9 mode in VT1. Two defects were removed after VT1 by CBP, but we will never know if it matters or not above 20 MV/m. At least for 20 MV/m is OK.
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Cell#5 quench (equator 105 deg): 3Pi/9 29.4 MV/m (1 mSv/h) & Pi/9 24 MV/m
Cell#7 quench (equator 20 deg): 2Pi/9 32.3 MV/m (0.7 mSv/h)
No apparent defect by inspection before VT2, will inspect again.

Quench location around large grain boundaries (sharp edge due to BCP)? Inspect
Cell #  Pi mode VT1  20 MV/m
cell#9 290° heating zone (20 MV/m quench in VT1)

as received incomplete penetration?

after CBP

after VT1 2nd Pass CBP removed

CP stains in VT1
Not found in VT2

F. E. induced quench?

Pi mode VT1 20 MV/m

cell#9 300° heating zone

after VT1 2nd Pass CBP removed

Pi mode VT1 20 MV/m
cell#9 290° heating zone (20 MV/m quench in VT1)

CP stains in VT1
Not found in VT2

Cell#9 8Pi/9 quench: 2cm inner away from the equator, 80 deg (1 mSv/h): 17 MV/m (field emission caused?)

VT2 OST and thermometry didn’t find heating at the old quench location.

F. E. induced quench?

as received incomplete penetration?

after CBP

after VT1 2nd Pass CBP removed

Pi mode VT1 20 MV/m

Pi mode VT2 13 MV/m
Field Emission Induced Iris Quenches

- **OST:** iris cell#7&8, ~ 90 - 120 deg
  - T-mapping can’t reach iris area

- **Passband test quench gradient***:
  
  - $Pi$ : 12.9 MV/m (5 mSv/h)
  - $5Pi/9$ : 14.6 MV/m (0.3 mSv/h)
  - $4Pi/9$ : 13.8 MV/m (5 mSv/h**)

  * for $5Pi/9$ and $4Pi/9$ mode, the gradient is equivalent Pi mode gradient of the end cell (#9)
  ** highest radiation of the passband modes
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- **Inspection:** iris pit cell#8&9, 90 deg

Field pattern

• #7
• #8
• #9
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• Pit azimuthal positions, cell gradients, field patterns & radiation levels are correlated, pointing to field emission induced iris quench. The defects may be uncovered after intensive hand and machine grinding and BCP.

• This is why the Pi mode gradient is limited at 13 MV/m, while all cells are higher than 20 MV/m.

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*Field pattern* 

![Field pattern diagram with cell gradients and radiation levels](image)
Cavity Quench and Defects Summary

1. quench around 40 MV/m (in BCP single cell)
2. 30 MV/m quench without F.E. (cell#2 defect, VT1)
3. 30 MV/m quench with F.E. (cell#5&7, VT2)
4. 20 MV/m equator quench with F. E. (cell#9, VT1)
5. 13 MV/m iris quench with F.E. (iris#7-8, VT2)
Next Steps

- Inspect to identify defects (iris and equator)
- Reduce low field field emission
  - HPR again and test
  - EP
  - iris repair (?)
- Higher gradient
  - BCP limit: 30 MV/m or 40 MV/m?
  - EP
- IHEP-02 large grain low loss with end groups
  - will finish fabrication in Nov. 2011, test in Feb. 2012
High Power Input Coupler

- Two double-choke-window input couplers
  - uniform copper plating on bellows and coaxial parts
  - TiN coating on ceramics
  - finished fabrication of two couplers
  - high power test: October 2011

Refer to E. Kako (KEK)
Welded Coupler Parts

Warm and Cold Window, based on the experience of BEPCII 500 MHz 400 kW CW power input coupler (W. M. Pan etc.)

Warm outer part

Warm inner part

Cold outer and inner parts
Tuner and LLRF

• Home-made slide jack tuner
• Performance test with MHI-04 from KEK
  – Tuner stroke
  – Piezo
  – Stability
• Cold test planned
• Motor inside cryomodule

Refer to S. Noguchi (KEK)
LLRF Performance @ RT

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency stability</td>
<td>± 1 kHz (room temperature)</td>
</tr>
<tr>
<td>Amplitude stability</td>
<td>± 0.05 % (peak to peak)</td>
</tr>
<tr>
<td>Phase stability</td>
<td>± 0.035° (peak to peak)</td>
</tr>
<tr>
<td>Response time</td>
<td>70 μs</td>
</tr>
<tr>
<td>Dynamic range</td>
<td>20 dB</td>
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</tbody>
</table>
Cryomodule for the 9-cell Cavity

- Based on PXFEL1 success and XFEL cryomodule mass production
- Design finished, fabricate and assemble in 2011-2012
- Horizontal test with IHEP’s new cryogenic system
IHEP SCRF Infrastructures
Refer to A. Rowe of FNAL
High Pressure Water Rinsing (HPR)

- Nozzle fixed, Cavity rotate and move
Cavity process and test with IHEP SRF Facility

- BCP, HPR, clean room and vertical test system were verified by the BEPCII 500 MHz cavity processing and test at IHEP
- Facilities may need improvement for higher gradient cavity
Cavity RF and LLRF Lab
High Resolution Inspection Camera

NEXT STEPS

Better image: clearer
• improve the lighting and optical lens system

Automatic:
• install motors for cavity moving & rotation
• better camera moving base
• auto photo-taking and focusing

Refer to M. Ge
Vertical Test Dewar and Heat Exchanger

Refer to FNAL
Summary

• Three 9-cell cavities (LG LL, FG TESLA-like) R&D
  – IHEP-01 two tests, continue to lower F. E. and higher gradient
  – IHEP-02 1st VT in 2012, install to IHEP cryomodule for HT
  – IHEP-03 in fabrication, for beam test

• Various SRF facilities were developed

• International collaborations with KEK, FNAL and JLAB are productive.
Acknowledgement


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Thank you!

And welcome to the TTC meeting
IHEP, Beijing, December 5-8, 2011