Progress on Improving SC Cavity Performance for ILC

Rong-Li Geng
Jefferson Lab

PAC09, May 4-8, 2009, Vancouver, Canada
ILC SCRF Cavity Performance

Goal

- Operation
  - $E_{acc}$ 31.5 MV/m
  - $Q_0$ 1E10
- Vertical test acceptance
  - $E_{acc}$ 35 MV/m
  - $Q_0$ 8E9
- Gradient choice matters
  - High impact on project cost
  - Energy reach for fixed tunnel length
- 16,000 cavities
  - High yield required
  - Industrialization necessary
ILC Research and Development Plan for the Technical Design Phase

Release 3
February 2009

ILC Global Design Effort
Director: Barry Barish

Prepared by the Technical Design Phase Project Management

Project Managers: Marc Ross
                 Nick Walker
                 Akira Yamamoto
**ILC Research and Development Plan for the Technical Design Phase**

Release 3

February 2009

<table>
<thead>
<tr>
<th>Calendar Year</th>
<th>2008</th>
<th>2009</th>
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**Release 3**

**February 2009**

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**9mA full-beam loading at TTF/FLASH (DESY)**

**Demonstration of Marx modulator**

**Demonstration of cost-reduced RF distribution**
Globally Coordinated ILC Gradient R&D

- DESY
  - > 17 cavities reached > 35 MV/m since 2003
  - More cavity (6th production) testing coming...
  - XFEL 800 cavities to be manufactured

- JLAB
  - 7 cavities reached > 35 MV/m since 2006
  - Understand 9-cell limit by T-mapping & optical inspection
  - Large-grain cavity

- FNAL
  - Infrastructure ramp up (EP machine & VTA commissioned)
  - > 20 cavities received from industry, including US cavity vendor

- KEK
  - STF infrastructure ramp up (EP machine & VTA commissioned)
  - Low-loss shape cavity
  - 9-cell cavity T-mapping and optical inspection

- Cornell
  - Quench detection (second sound) instrumentation development
  - Re-entrant shape cavity
Shape, Material and Processing

• Baseline: TESLA-shape, fine-grain Nb, electropolishing
  • ~ 200 cavities manufactured (mostly DESY)
  • Tested in module and with beam
  • XFEL 800 cavities to be manufactured
  • EP required for 35 MV/m with fine-grain
  • Major global effort is to improve yield

• Alternative: Low-loss & Re-entrant shape, large-grain Nb
  • LL & RE shapes for higher gradient
  • Large-grain material for 35 MV/m without EP (lowering cost potential)
  • Excellent demonstration with many single-cells
  • 9-cell demonstration under way

• This talk focuses on baseline cavity and processing
Main Processing & Testing Steps

- Heavy EP for damaged layer removal (100-150 μm)
- Cleaning
- Vacuum furnace out-gassing for H removal (600-800 °C)
- Tune for field flatness and frequency
- Light EP for contamination layer removal (20-50 μm)
- Post-EP cleaning (alcohol or ultrasonic + detergent)
- High pressure water rinsing
- Clean room assembly
- Low temperature bake out (120 °C X 48 h)
- RF test
  - Optional T-mapping test
  - Optional optical inspection

understand gradient limit
DESY 6th Production Run Cavities
Successful Heavy EP in Industry

![Graph showing the maximum gradient in MV/m across different production runs. The graph compares EP, BCP + 1400°C, and BCP after EP.](image-url)
Alcohol Rinsing after Final EP Reduces Field Emission

Cavities since Jan 2006, 1st test

9-cell cavities, EP-treated, 1st test

alcohol rinsing after final EP introduced

EP in industry

XFEL design

both limited by field emission, i.e. very likely a problem of final HPR water rinsing

Hans Weise, DESY
TTC Meeting, New Delhi, October 20 - 23, 2008

Weise, TTC meeting at New Delhi, 2008
Rongli Geng

Van der Horst et al., SRF20

PAC09, May 4-8, 2009, Vancouver, Canada
Final preparation: Analysis of final test

No He-tank !!

With He-tank !!

Final EP

final BCP

no FE

Eacc [MV/m]

no FE

Eacc [MV/m]

Final EP

final BCP

As expected: some improvement with respect to field emission

“final EP” gives higher $E_{\text{max}}$ than “final BCP”

Presented at TILC09 by L. Li

D. Reschke, to be published SRF 2009
DESY 9-cell T-mapping & Optical Inspection

Evolution of defects: Z137

Equator #1 at 23 deg.  Equator #1 at 20 deg.

Before treatment
• Equator #1 shows large steps and rough grains after main EP
• All other equators normal

After 108 μm main EP

S. Aderhold, TILC09

Rongli Geng  PAC09, May 4-8, 2009, Vancouver, Canada
Latest JLab Results of 9-cell from One Vendor

- 4 out of 5 reached > 35 MV/m after 1st light EP
- A15 quench limited by one defect in one cell

- A15 quench source identified by T-mapping and optical inspection
- A12 data after 1st light EP is not shown
- A12 data shown are after 2nd light EP

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PAC09, May 4-8, 2009, Vancouver, Canada

Crawford et al.
32 MV/m quench (A12) Study and Recover to 40 MV/m by Re-EP

T-map during quench

Cell 7 equator EBW seam

No gross defect observed at quench location
JLab Surface Studies Reveal Nb-O Granules to be Field Emitting.

- Nb sample EP'ed together w/ 9-cell cavity
- Now JLab EP lower temp. to reduce Nb-O granule formation
JLab Basic EP Studies

PSD of Profilometry and AFM Data
for Ground Sample with 5 Mins BCP

- Dot: AFM
- Square: Profilometry
- 20μm*20μm
- 50μm*50μm
- 100μm*100μm
- 200μm*200μm
- 1000μm*1000μm

Rotation Disk Electrode Studies Confirms The
Diffusion-Limited Mass Transport Control Mechanism

Current Density (mA/cm²)

Voltage (V vs. MSE)

HF(49%)H₂SO₄(50%)=1:10
T=30 °C

Current density (mA/cm²)

T=40.9 °C
slope=5.683

The non-zero intercept may indicate the presence of a parallel non-diffusion-limited electrode mechanism

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PAC09, May 4-8, 2009, Vancouver, Canada

H. Tian
JLab Large-Grain Nb Cavities

Single Crystal
- A thick sheet of a large crystal from a large grain ingot provided by CBMM has been enlarged at DESY (X.Singer, W.Singer)
- Six sheets could be prepared, large enough to deep draw half cells for TESLA/ILC – type single half cells
- We are in the process of fabricating 3 single cell cavities

Multi-cell Cavities for ILC
- The fabrication of two LL/Ichiro-type 9-cell cavities has started; niobium from CBMM and Tokyo-Denkai will be used
- The 20 sheets of TD material were sliced simultaneously by multi-wires – development done by K.Saito with Japanese industry – with very good tolerances and surface quality.
- The sheet slicing produced very smooth surface finishes and small deviations in thickness. Appr. 60 sheets were sliced simultaneously in only 40 hrs.
FNAL Vertical Cavity Test Facility

- 35 cavity tests in FY08/FY09, where “test” = cryogenic thermal cycle
  - 9-cell & single-cell 1.3 GHz elliptical cavities and 325 MHz HINS single-spoke resonators
  - instrumentation development, variable coupler, thermometry, cavity vacuum pump system, cavity vendor development
  - Many cavity tests dedicated to ANL/FNAL CPF commissioning

Monthly VCTF Test Activity - FY08/09

Average test cycles/month: 1.8
FNAL EP single cell cavity performance

<table>
<thead>
<tr>
<th>BCP</th>
<th>EP</th>
<th>Ethanol</th>
<th>$E_{acc} [MV/m]$</th>
<th>Notes</th>
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<td>NR-1</td>
<td>150</td>
<td>93</td>
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<td>Oxidation by acid residual</td>
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<tr>
<td>TE1AES004</td>
<td>107</td>
<td>65</td>
<td></td>
<td>Equator large pit present</td>
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<tr>
<td>TE1AES005</td>
<td>104</td>
<td>100</td>
<td>Yes</td>
<td>Oxidation by HPR water</td>
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<tr>
<td>TE1ACC002</td>
<td>112</td>
<td>Yes on second</td>
<td>37.1</td>
<td>FE appeared after 120°C baking</td>
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<tr>
<td>TE1ACC001</td>
<td>99</td>
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<td>FE present</td>
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<td>TE1ACC003</td>
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<td>TE1ACC004</td>
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EP at ANL/FNAL

G. Wu
# FNAL Cavity Inventory

## Tesla-shape nine-cell cavities

<table>
<thead>
<tr>
<th>Description</th>
<th>No. Cavities</th>
<th>Status</th>
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<tbody>
<tr>
<td>AES 1-4</td>
<td>4</td>
<td>tested</td>
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<tr>
<td>AES 5-10</td>
<td>6</td>
<td>received; testing in progress</td>
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<tr>
<td>AES 11-16</td>
<td>6</td>
<td>due Oct 2009</td>
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<tr>
<td>Accel 6-9</td>
<td>4</td>
<td>tested</td>
</tr>
<tr>
<td>Accel 10-17</td>
<td>8</td>
<td>received Mar 2008; testing in progress</td>
</tr>
<tr>
<td>Accel 18-29</td>
<td>12</td>
<td>due May 2009</td>
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<tr>
<td>Jlab fine-grain 1-2</td>
<td>2</td>
<td>fabrication complete; testing in progress</td>
</tr>
<tr>
<td>Niowave-Roark 1-6</td>
<td>6</td>
<td>due Oct 2009</td>
</tr>
<tr>
<td>Stimulus Procurement</td>
<td>xx</td>
<td>still in the planning stages; assume first cavities ~April 2010</td>
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Total: 48  
Already Received: 24

## Tesla-shape single-cell cavities

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<tr>
<td>AES 1-6</td>
<td>6</td>
<td>tested at Cornell; further testing in progress</td>
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<tr>
<td>Accel 1-6</td>
<td>6</td>
<td>received Dec 2008; testing in progress</td>
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<tr>
<td>Niowave-Roark 1-6</td>
<td>6</td>
<td>received Jun 2008; testing in progress</td>
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<tr>
<td>PAVAC</td>
<td>4</td>
<td>requisition in progress</td>
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Total: 22  
Already Received: 18
We have demonstrated that 2\textsuperscript{nd} sound detection can locate multiple quench locations in a single 9-cell cavity cold test.

By exciting different TM\textsubscript{010} pass-band modes of a 9-cell cavity different cells can be driven to quench.

This technique is simple, low cost, and quick to implement.
We have successfully repaired an AES 9-cell cavity with tumbling and VEP.
This cavity originally quenched at $E_{acc} = 15 \text{ MV/m}$ at a weld pit in the first cell, after tumbling and reprocessing $E_{acc} > 30\text{MV/m}$.
When excited in the $5\pi/9$-mode a peak fields of $89 \text{ MV/m}$ and $1400 \text{ Oe}$ were reached in the center cell. This corresponds to $E_{acc} > 37 \text{ MV/m}$.
This test demonstrates that tumbling is an effective option to repair weld defects, e.g. pits.

$E_{pk}/E_{acc} = 2.4$
• We have demonstrated gradients >35 MV/m in individual cells of two 9-cell cavities processed with vertical EP.
• In each test the $\pi$-mode was limited by quench.
A Cycle of Vertical Test at STF KEK

Infrastructure in the STF Hall

System check with AES#1 cavity was carried out in Oct., 2008.

Flange-CP → EP → Hot bath Rinsing → HPR → Assembly (Class 10)

Pre-tuning for adjustment → Inspection of Inner Surface → Vertical Test

Hanging Stand → Baking (Class 1000)

E. KAKO (KEK) 2009' April 18

TILC’09 @Tsukuba Global Design Effort

Rongli Geng
New vertical test system was completed in July 2008.

1. Surface Inspection System
2. Temperature Mapping System
3. Passband-modes Measurement
Summary of V.T Results at STF

April, 2009

Study of Mag. Shield (no EP)

Apr.17

5th VT in May

June ~ Nov. 2009

6 tests

E acc,max [MV/m]

AES#1 MHI-05 MHI-06 MHI-07 MHI-08 MHI-09

1st VT 2nd VT 3rd VT 4th VT 5th VT

E. KAKO (KEK) 2009' April 18

TILC’09 @Tsukuba
Global Design Effort

Rongli Geng PAC09, May 4-8, 2009, Vancouver, Canada
KEK T-mapping New 9-cell Cavities

Fish-bone structure

~300ch for C.R.
0.1sec sampling time

First Test

Potential Max. Gradient for STF B.L. #5 @2008/12/4

Y. Yamamoto et al.
KEK Optical Inspection new 9-cell Cavities
Before & after EP – reveals unstable weld possible cause for quench

Rongli Geng
PAC09, May 4-8, 2009, Vancouver, Canada

K. Watanabe et al.
KEK Rinse Effect to Remove Sulfur precipitation/contamination

Teflon texture

Before rinse

Many white dots are sulfur contamination

After rinse

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PAC09, May 4-8, 2009, Vancouver, Canada
KEK New ICHIRO 9-cell Cavities

- Two bare cavities tested
- One reached 36.5 MV/m so far (KEK/JLab collaboration)
- Two full cavities fabricated (one sent to JLab)
- One full cavity fabricated with large-grain Nb

Single-cell results
Recent Gradient Yield Progress at JLab

Best Gradient Yield Feb 09 vs Oct 08
One Vendor Cavities

Best Gradient Yield Feb 09 vs Oct 08
All Vendor Cavities

Yield vs Eacc [MV/m]

Rongli Geng
PAC09, May 4-8, 2009, Vancouver, Canada
Recent Progress in Yield at DESY
Data provided by D. Reschke, and reassembled by M. Ross

- 25 cavities with two vendors,
- Mostly only one chemical process
- Field emission not observed: 64%
Two Big Pushes Ahead...

Past yield curves show best gradient of JLab data set.
Two Big Pushes Ahead...

Push Quench Limit:
- Defects from material
- Defect from fabrication (EBW)
- Renewed studies

Past yield curves show best gradient of JLab data set.
Two Big Pushes Ahead...

- Push Quench & field emission Limit
  - Classical defect/field emitter
  - EP specific...

Push Quench Limit:
- Defects from material
- Defect from fabrication (EBW)
- Renewed studies

Graph:
- Y-axis: Yield
- X-axis: Eacc [MV/m]
- Lines:
  - Blue: All vendor cavities (12) - Nov08
  - Red: All vendor cavities (14) - Feb09
  - Purple: ILC TDP1 goal
  - Green: ILC TDP2 goal

Past yield curves show best gradient of JLab data set.
Summary

- Progress being made pushing yield curve
  - Shown by both DESY data and JLab data
  - Several cavities demonstrated > 35 MV/m after first light EP
  - Expect more statistics (> 60 cavities) 2009-2010

- Field emission much reduced
  - Shown at DESY (alcohol rinsing) and at JLab (ultrasonic + detergent)
  - 1st demonstration of 40 MV/m w/o detectable Bremsstrahlung X-ray
  - Further understanding needed for further improvement

- Quench understanding improved
  - Yield drop 15-20 MV/m partly due to defect in equator EBW HAZ
  - Most cases at JLab: one defect in one cell; other cells 32-44 MV/m
  - Local repair seems to be the way to go for raising yield (besides QA)
Summary (cont.)

- **Global effort ramping up**
  - FNAL infrastructure (EP, VTA) commissioned; excellent 1-cell results
  - KEK STF infrastructure commissioned
  - > 60 cavities expected 2009-2010

- **Laboratory-Industry collaboration ramping up**
  - European industry heavy EP demonstrated
  - First America cavity vendor meeting at FNAL – feedback info to cavity vendor
  - ILC PM's visit to ACCEL, ZANON, MHI, AES, NIOWAVE/ROARK, PAVAC

- **Outlook encouraging**
  - Further progress along base line seems possible
  - Great potential along alternative line

A Canadian company to be visited during PAC09