Vertical EP at Marui & KEK

November 2016
TTC High-Gradient WG Meeting

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Outline

• VEP setups
• Coupon cavity & Ninja cathode
• Optimization of cathode design and VEP parameters
• Vertical test results
• Fabrication of 9-cell coupon cavity
• Summary
Both setups were prepared with PVC materials in order to reduce cost of surface treatment of cavities in mass production.
Cavity contains 6 coupons at beam pipes, irises and equator.
- An EP current can be measured for individual coupon.
- Coupon surfaces are analyzed with several surface analytical tools.
- The cavity is having 4 view ports on the top iris, bottom iris and equator for light introduction and in-situ observation.
• Ninja cathode was developed in order to agitate EP acid.
• The wings are either insulating or metallic/partially metallic which act as a cathode.
VEP with Rod and Ninja Cathode (Al Wings)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\text{H}_2\text{SO}_4:$HF</td>
<td>9:1</td>
</tr>
<tr>
<td>Electrolyte Flow Direction</td>
<td>Bottom to Top</td>
</tr>
<tr>
<td>Flow Rate</td>
<td>5 L/min</td>
</tr>
<tr>
<td>Cathode Rotation Speed</td>
<td>1 rpm</td>
</tr>
<tr>
<td>Applied Voltage</td>
<td>~9 V</td>
</tr>
<tr>
<td>EP Current Density</td>
<td>25-30 mA/cm$^2$</td>
</tr>
<tr>
<td>Target Removal Thickness</td>
<td>50 µm</td>
</tr>
<tr>
<td>Cavity Surface Temperature</td>
<td>~25 °C</td>
</tr>
</tbody>
</table>

**Upper Iris Coupon**

- **Ninja Cathode (Al wings)** results in:
  - Smooth surface
  - Asymmetric removal similar as rod cathode
Ninja Improvement

- Al wings were replaced with insulating and partial metallic wings.
The top iris coupon current was the highest at 1 rpm because of accumulation of H₂ bubbles on the top iris.

Ninja cathode rotating at 50 rpm displaced the bubbles and might make uniform acid flow in the cavity cell.
An I-V curve gives an information about phenomenon occurs on Nb surface based on applied voltage.

A particular range of voltage (in polishing region) needs to be applied for EP.
Effect of Partial Cathode Wings

- H₂ bubbles can screen the cathode and reduce ion migration to the cathode.
- A distance between anode and cathode might be important for a small area of cathode.
- Electric field on equator was obviously lower due to a large distance from cathode.
- Wing cathode enhanced ion transportation and electric field on equator surface.
Removal thickness was measured with ultrasonic thickness gauge.

Ninja wings were found to be effective as a stirrer in order to minimize longitudinal asymmetry of Nb removal.

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Surfaces of Coupons

- Rough equator surface of equator with rod cathode and insulating wings might be due to Nb removal in etching region. (Since equator remains in etching region at the applied voltages.)
- Ninja with partial metal wings resulted in smooth surface of the equator.
What We Learned

• Ninja cathode with Insulating Wings:
  – Cannot be used since it resulted in rough equator surface due to cathode screening by H$_2$ bubbles.

• Ninja cathode with Partial Metal Wings:
  – May not be appropriate for VEP of a 9-cell cavity because bubbles generating on the wings will finally accumulate in the upper cells of a cavity.

The problem of cathode screening by H$_2$ bubbles should be solved.
Ninja with Enhanced Cathode Area

- Cathode surface area was enhanced to reduce the screening effect.
- The cathode was covered well with a meshed shield to trap H₂ bubbles and guide them along the cathode.
Effect of Enhanced Cathode Area

- EP plateau for equator was obtained with Ninja cathode having larger cathode area.
The enhanced cathode area resulted in smooth surface of the equator surface.
• Since the Ninja cathode was prepared with bubble guide, the rotation speed of the cathode was reduced.

• VEP was carried out at 20 rpm.

Partial Metal Wings

<table>
<thead>
<tr>
<th>At 50 rpm</th>
<th>At 50 rpm</th>
<th>At 20 rpm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Top Iris</td>
<td>Top Iris</td>
<td>Top Iris</td>
</tr>
<tr>
<td>Equator</td>
<td>Equator</td>
<td>Equator</td>
</tr>
<tr>
<td>Bottom Iris</td>
<td>Bottom Iris</td>
<td>Bottom Iris</td>
</tr>
</tbody>
</table>

Enhanced Cathode area

• Surface roughness of equator was reduced in case of 20 rpm.

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Almost symmetric removal was obtained with the Ninja cathode due to bubble guide and uniform acid flow in cavity cell.

Based on the concept of the Ninja cathode (enhanced cathode area), a Ninja cathode for VEP of 9-cell cavities has been fabricated.
Vertical Test Results

- Two single-cell cavities (NR1-2 and C1-19) were VEPed with the Ninja cathodes and tested in vertical cryostats.

**NR1-2 Cavity (Cornell Cavity)**
- **Pre-treatment**: Tumbling, BCP, degassing at 800 °C
- **Cathode**: Ninja cathodes (partial metal wings and enhance area) with the VEP setup of Cornell University
- **VEP**: VEP with each cathode (20+20 µm removal)
- **Ninja rotation speed**: 50 rpm
- **VT**: Performed at 2K at Cornell after 120 °C baking

**35 MV/m at Q₀=9×10⁹**

**C1-19 Cavity (Saclay Cavity)**
- **Pre-treatment**: BCP
- **Cathode**: Ninja cathode (enhanced area) with Marui VEP setup
- **VEP**: Two VEP for 31 and 55 µm removal, degassing at 750°C and final VEP for 11 µm removal
- **Ninja rotation speed**: 30 rpm
- **VT**: Performed at 1.6K at Saclay

The both cavities showed good performance in the vertical tests.
9-Cell VEP Experiment

- **Parameter** | **Value**
- $\text{H}_2\text{SO}_4$:$\text{HF}$ | 9:1
- Electrolyte Flow Direction | Bottom to Top
- Flow Rate | 5 L/min
- Cathode Rotation Speed | 50 rpm
- Applied Voltage | ~11 V
- EP Current Density | 30-35 mA/cm$^2$
- Cavity Surface Temperature | ~20 °C
▫ Removal thickness at iris is around 2-3 times larger than that at the equator.
The world’s first 9-cell coupon cavity was fabricated to optimize VEP parameters.

- **Nb Coupon with view port**
- **Coupon with View Port near Iris**
- **Equator Coupon**

6 coupons near iris positions
3 coupons at Equator positions

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Summary

✧ VEP setup and unique Ninja cathodes were developed for surface treatment of Nb cavities.
✧ VEP parameters and design of the Ninja cathode were optimized for single cell cavity.
✧ Smooth surface and symmetric removal of Nb along cavity length were obtained with the Ninja cathode.
✧ The Ninja cathode and optimized VEP parameters were applied to two single-cell cavities which showed good performance in a vertical tests performed at Cornell University and CEA-Saclay.
✧ The world’s first 9-cell coupon cavity has been fabricated.
✧ Based on the VEP results of 1-cell cavity, 9-cell Ninja has been fabricated.
Conference Presentations

- V. Chouhan et al., THPP098, LINAC2014.
- K. Nii et al., TUPP101, LINAC2014.
- V. Chouhan et al., MOPB105, SRF2015.
- V. Chouhan et al., THBA02, SRF2015.
- K. Nii et al., MOPB098, SRF2015.
- V. Chouhan et al., MOPLR037, LINAC2016.
- K. Nii et al., MOPLR039, LINAC2016.
Thank You