Vertical EP Status at Marui/KEK

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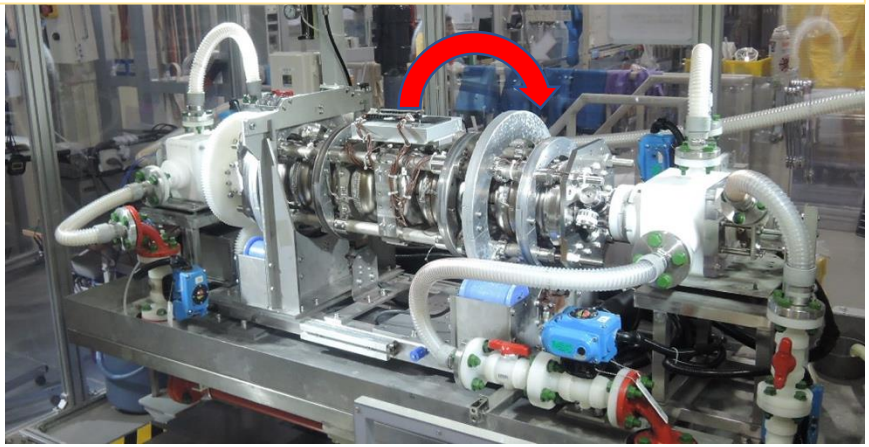
Contents

- Vertical EP Setup
- Progress on Single-Cell Cavities
- Progress on Nine-Cell Cavities
- Summary & Future Tasks

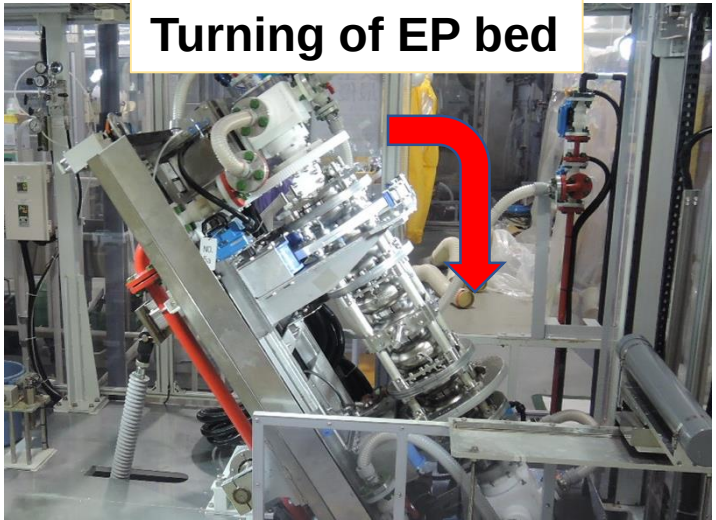
Objective

- The purpose of the work is to establish a successful vertical electropolishing (VEP) technique for surface treatment of Nb SRF cavities.
- VEP is performed with a cost-effective system.

Massive Horizontal EP Setup with Rotating Cavity

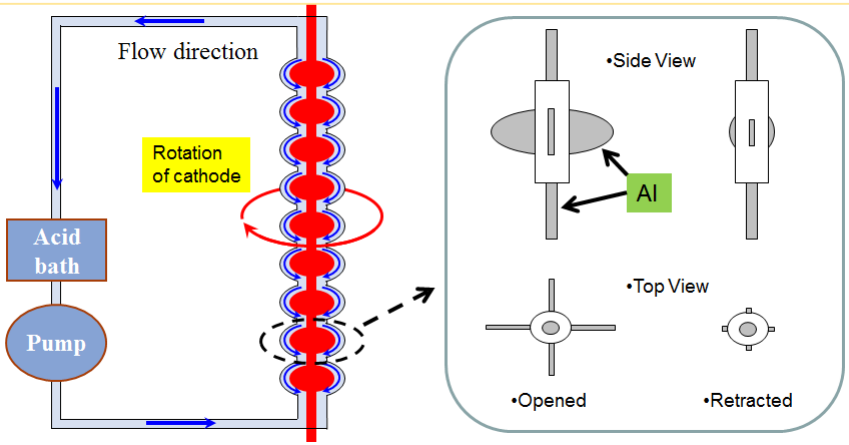


Turning of EP bed



Simple VEP setup with Fixed Cavity

Instead of the cavity rotation, cathode is rotated. No special rotating sealing is required

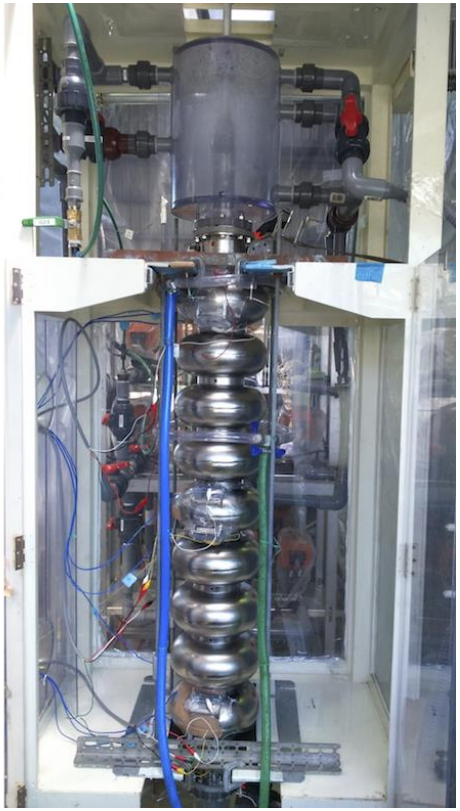


Special Ninja cathode by Marui Co. Ltd.

VEP System at Marui

Automated control valves (VEP Iwate collaboration)

VEP Stand for 9-Cell Cavity



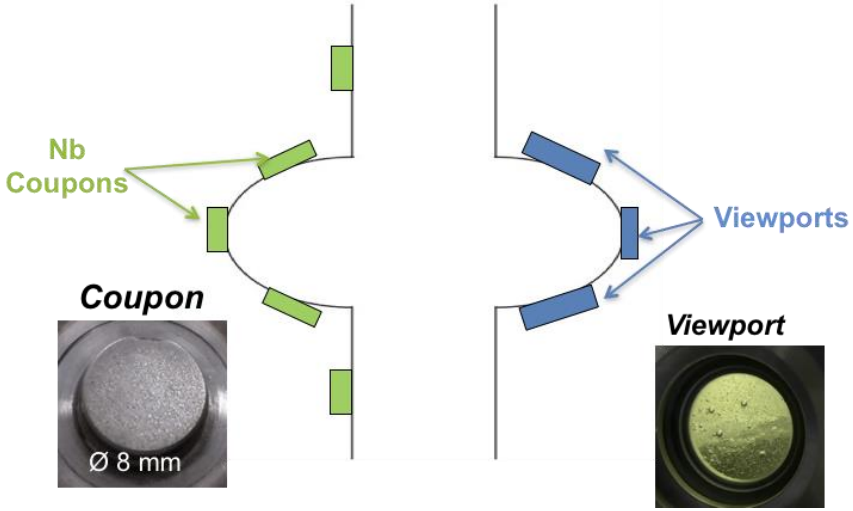
VEP Stand for 1-Cell Cavity

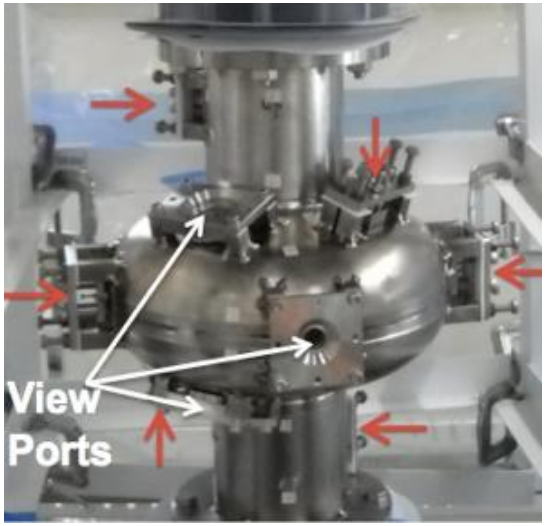
Touch Panel

System is equipped with auto-controlled electric valves, acid and water lines, acid tank with bubble filters, water spray system for cavity cooling, heat-exchanger in the tank, touch panel for remote operation, data logging system, motor with variable speeds for cathode rotation

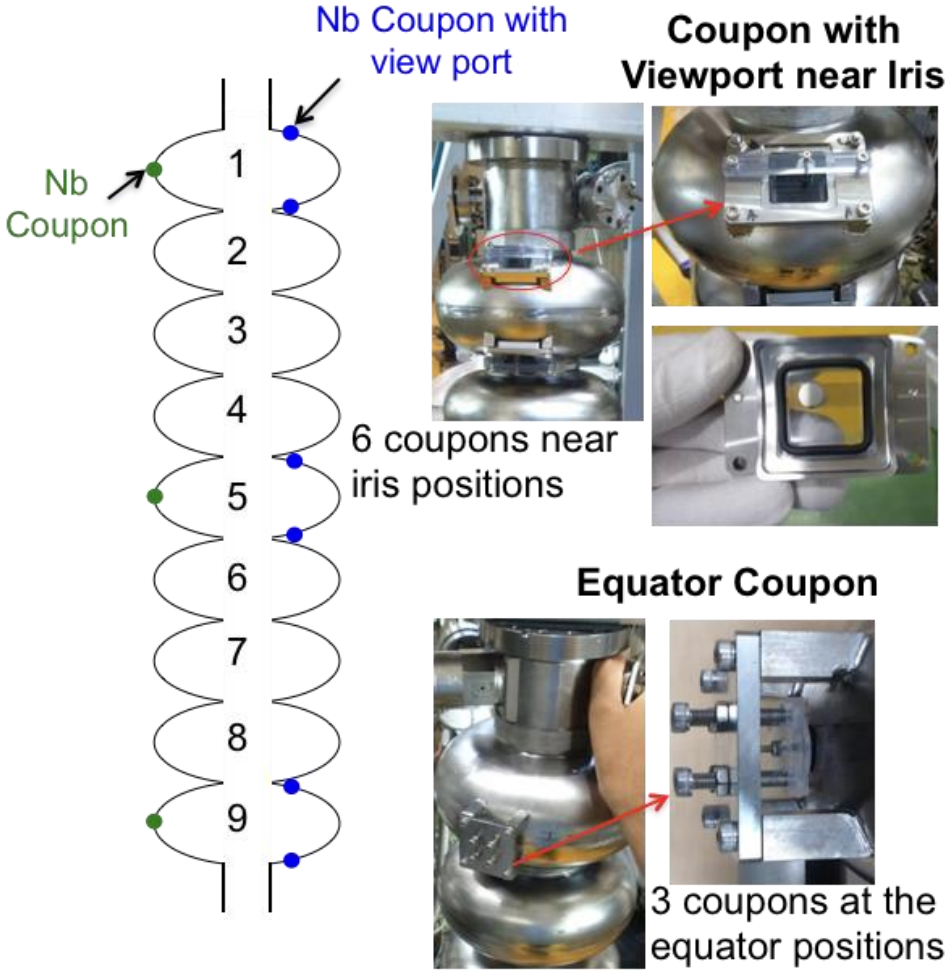
Single and Nine-Cell Coupon Cavities

Single-Cell Coupon Cavity



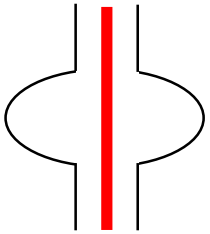


Nine-Cell Coupon Cavity



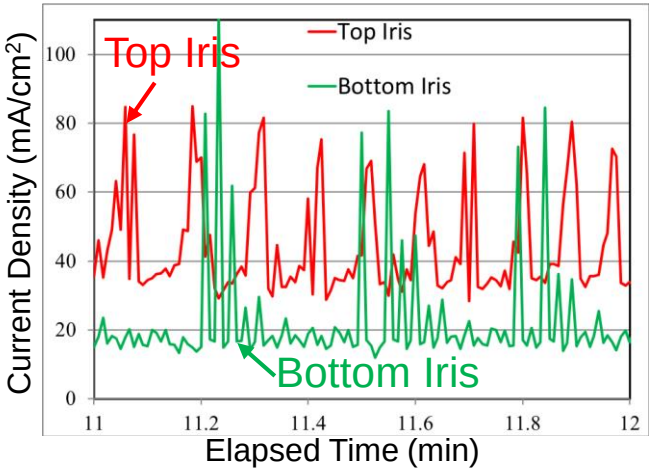
Measurable coupon current, in-situ observation, post VEP surface analysis

VEP with Conventional Rod Cathode



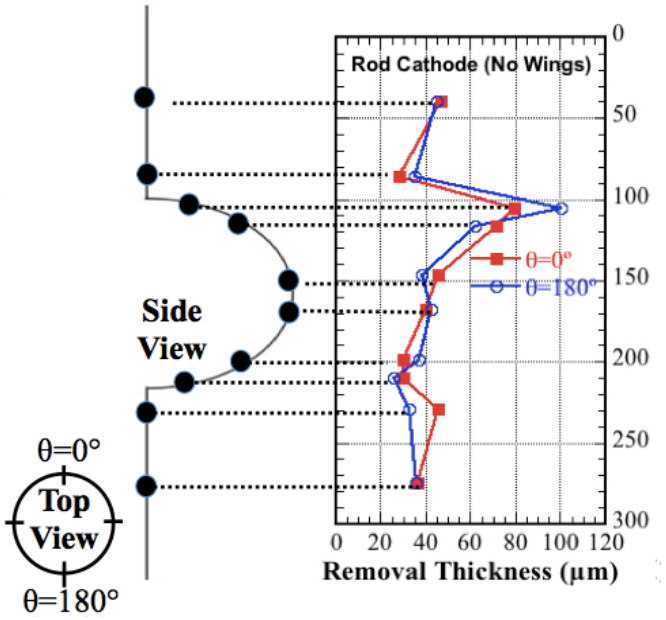
- Acid flow rate ~ 5L/min
- Voltage ~9 V

Coupon Currents

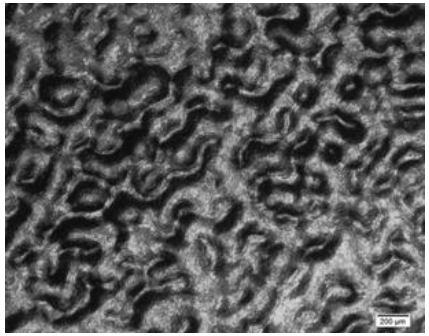


- Higher EP current at the upper half cell

Removal Trend



Bubble Footprints at Upper Iris



500 µm

Top Iris Viewport

Major Issues in VEP:

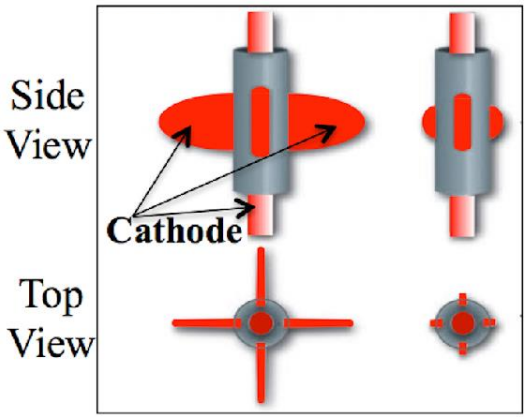
- Non-uniform removal
- Rough surface/Bubble traces

- The higher removal at the top iris is due to accumulation of H_2 gas bubble on the surface.
- It was confirmed with lab EP experiments.

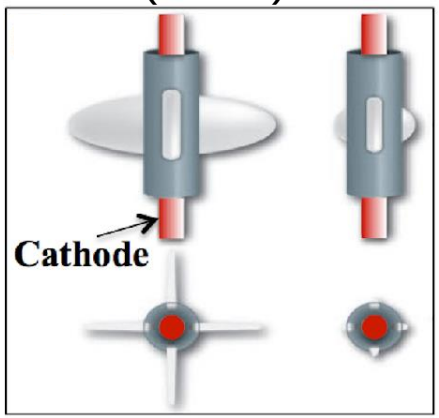
Ninja Cathodes for VEP

- We have applied several models of Ninja cathodes to find an optimized structure and VEP parameters.

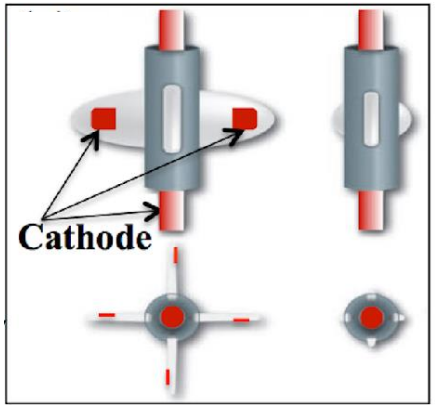
Metal Wings (Ver-1)



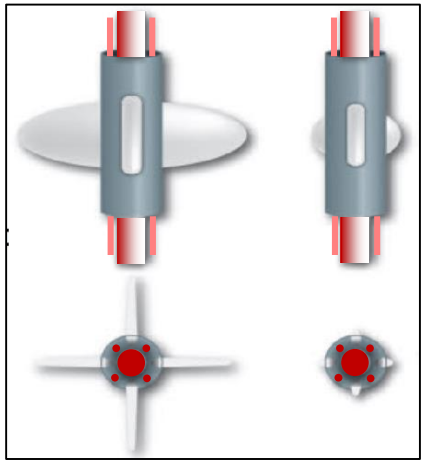
Insulating Wings (Ver-2)



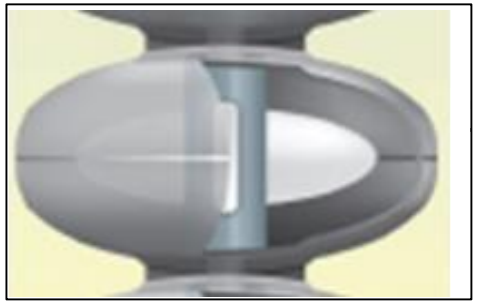
Partial Metal Wings (Ver-3)



Insulating Wings + Large Cathode Surface Area + Meshed Cover (Ver-5)

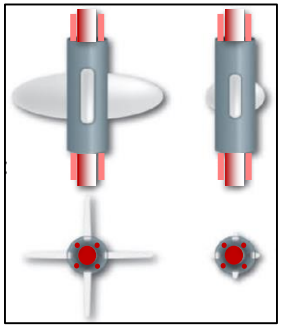


- Ninja cathode v5: Enhanced cathode surface area, cathode housing covered with meshed sheet, insulating wings

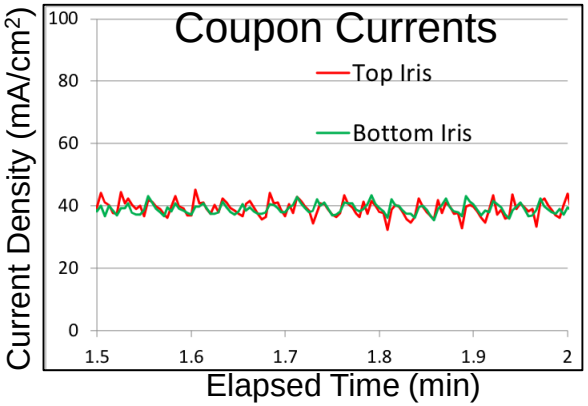


Ninja cathode is inserted in the cavity and then its blades are expanded.

VEP with Ninja Cathode

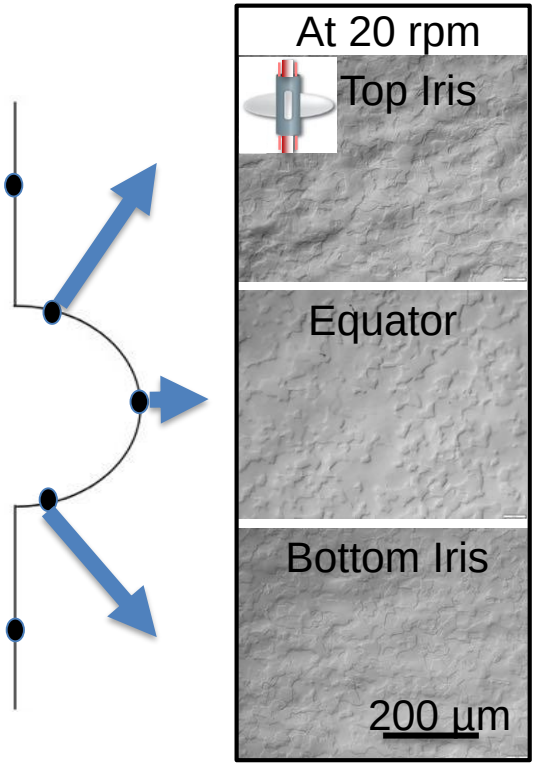


- Ninja cathode v5: Enhanced cathode surface area, cathode housing covered with meshed sheet, insulating wings

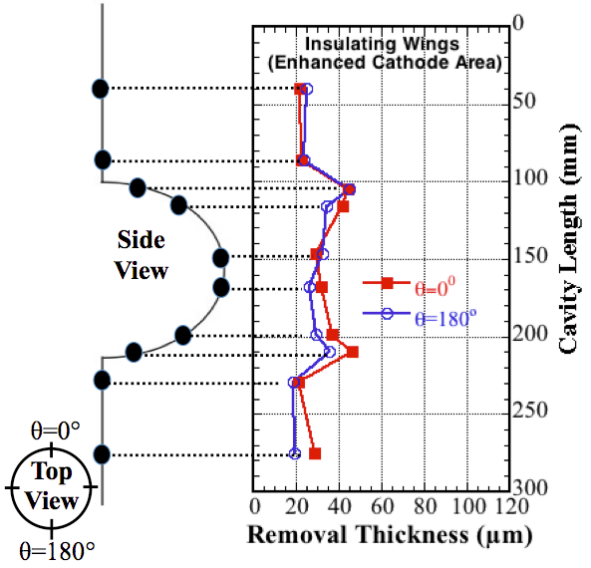


- Meshed housing: guides hydrogen bubbles along the cathode and reduces bubble accumulation in the cavity cell
- Cathode rotation might make uniform flow on the surface
- Larger cathode surface: reduces cathode screening by bubbles

Optical Images



Removal Thickness



Voltage: ~13 V, Acid flow rate: ~5 L/min,
Cathode rotation: 20 rpm, Temperature < 20 ºC,
Cavity cooling by water spray

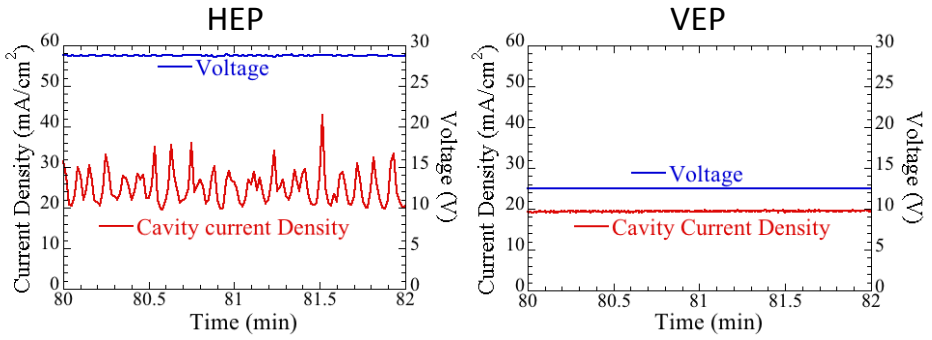
- The cathode and optimized parameters yield smooth surface and symmetric removal.
- Hence, the cathode was opted for further VEP and RF tests.

Comparison with HEP using Coupon Cavity

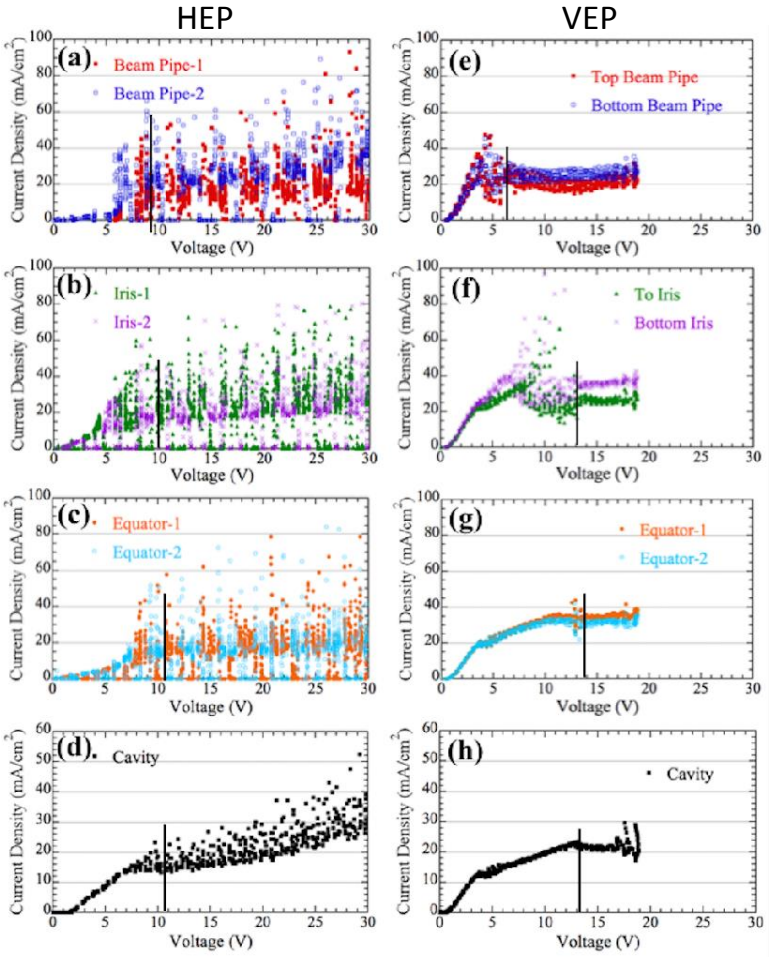
- HEP: with standard EP parameters at STF, KEK
- VEP: with Ninja cathode at Marui

Parameters	HEP	VEP
Electrolyte (H_2SO_4:HF)	9:1	9:1
Acid Flow Rate	~5 L/min	~5 L/min
Cavity Surface Temperature (max)	40 °C	16 °C
Cathode	Al Pipe	Ninja-v5
Rotation	Cavity (1 rpm)	Cathode (20 rpm)
Applied Voltage	~29 V	~13 V
EP Rate	~0.26 μm/min	~0.28 μm/min
Removal Thickness	41 μm	33 μm

Current Profiles



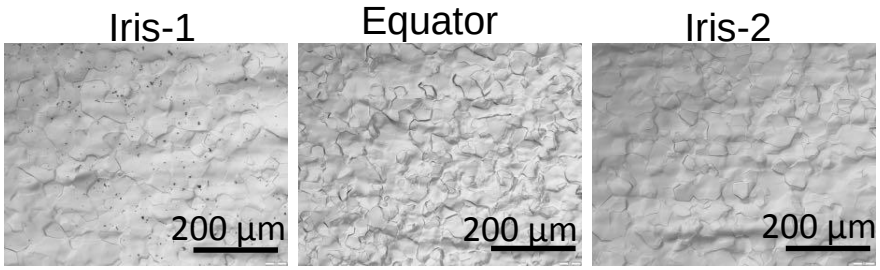
Coupon Currents



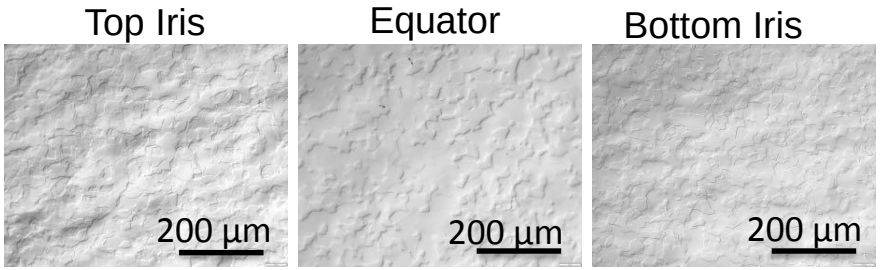
Apparent polishing plateaus in both the EP techniques.

Comparison with HEP using Coupon Cavity

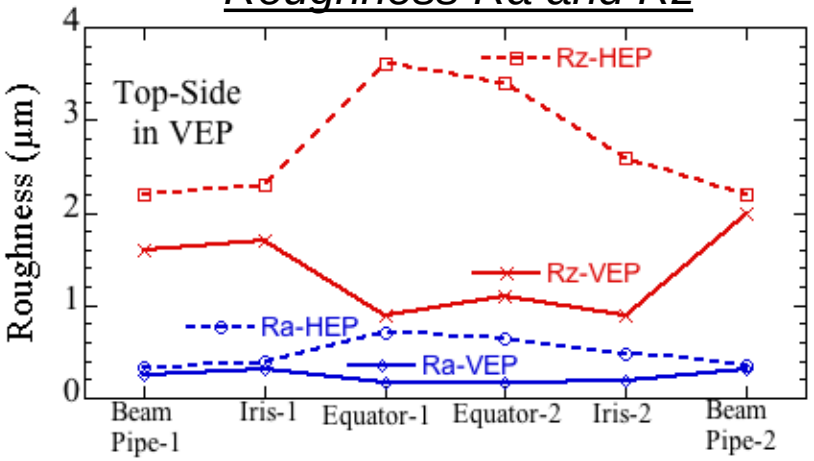
Coupon Surface after HEP



Coupon Surface after VEP

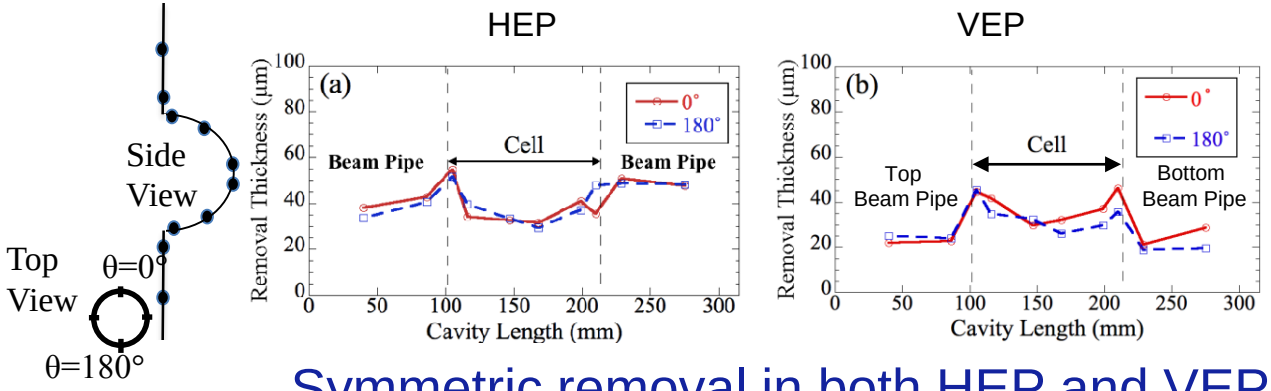


Roughness Ra and Rz



Smooth surface after VEP

Removal Thickness along the Cavity Length



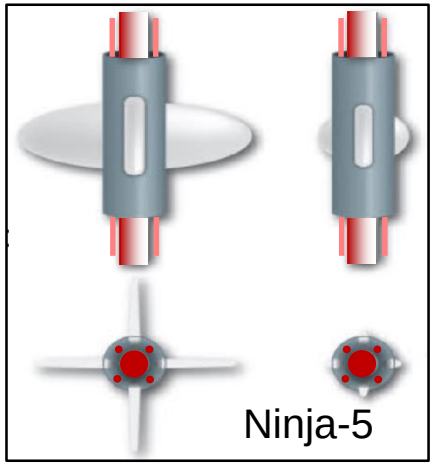
Symmetric removal in both HEP and VEP

VEP for RF Test Comparison

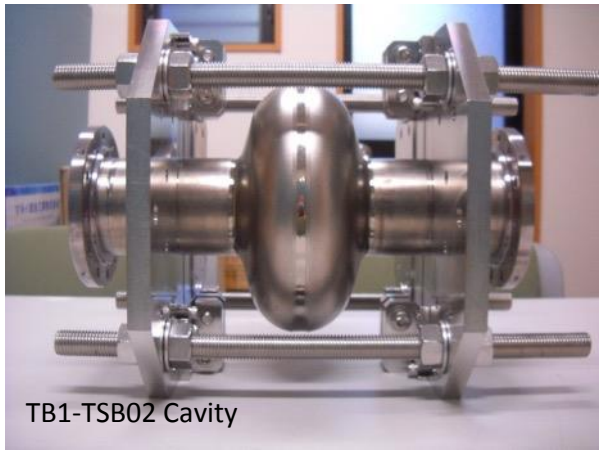
Ninja Cathode-v5

Side View

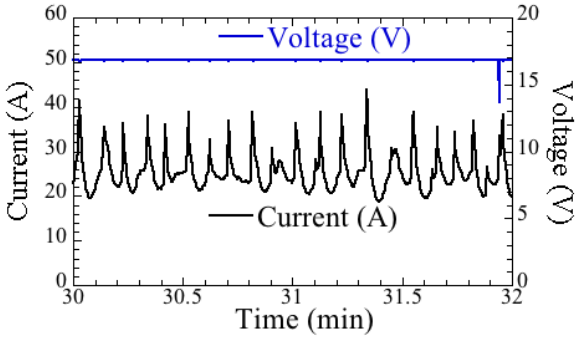
Top View



Single-Cell Cavity with Support-jig



VEP Current Profile



Voltage: 16-17 V

Cathode rotation: 20 rpm

Acid flow rate ~ 5 L/min

Temperature ~ 20 ºC

Process

VEP1（36μm）

↓

HPR &
120ºC baking

↓

Annealing
(750ºC)

↓

VEP2（10μm）

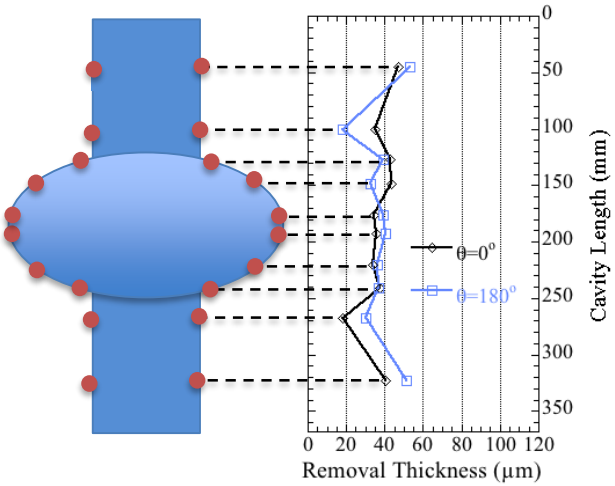
↓

HPR &
120ºC baking

↓

Vertical test

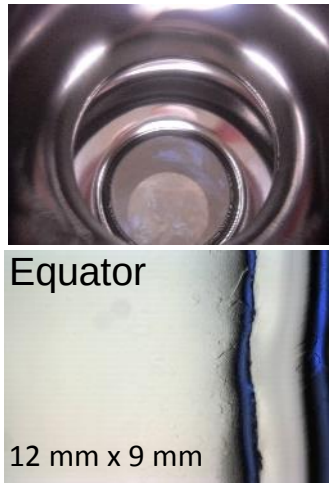
Removal Thickness in VEP-1



Uniform removal in the cell

Removal rate: 0.22 μm/min

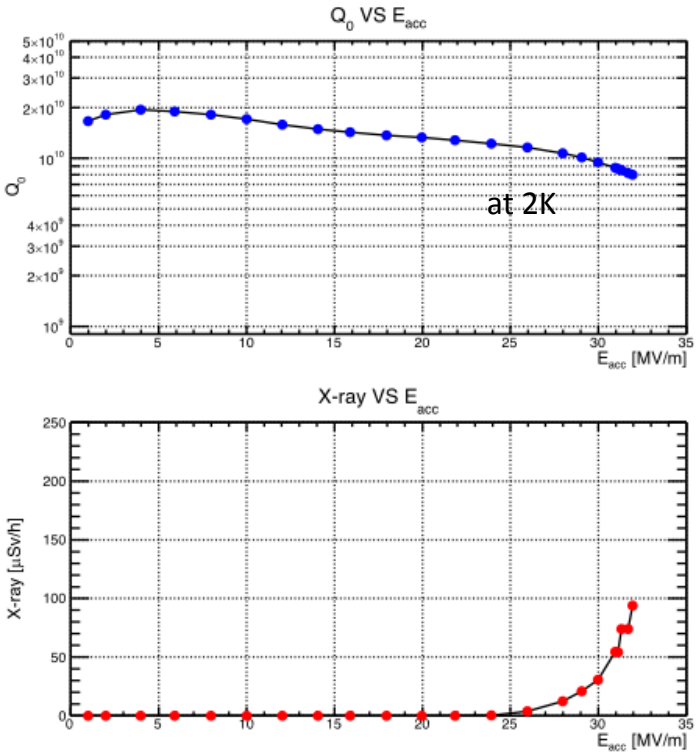
Cavity Surface after VEP-1



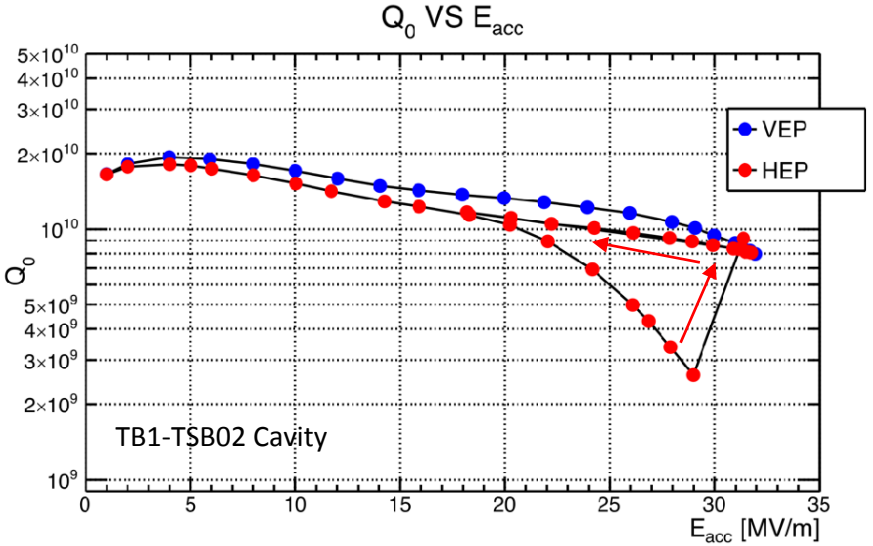
Smooth and glossy surface

RF Test Results after HEP and VEP

Cavity Performance after VEP



Cavity Performance after HEP and VEP



- 32 MV/m (Q_0=8.0E9) was achieved after VEP.
- The accelerating gradient after VEP was as good as achieved after HEP.

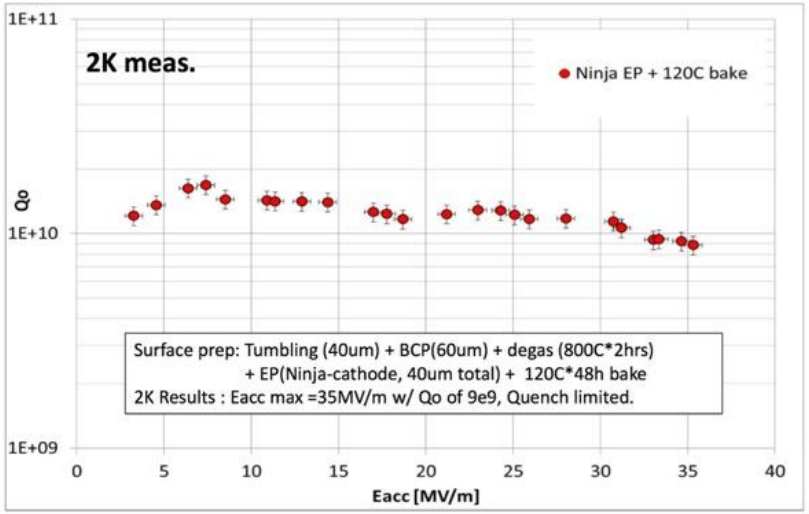
Collaborative Work with Cornell University

- Ninja cathode was tested with VEP setup at Cornell University.
- VEP for a single cell cavity was performed with Cornell's cathode and Ninja cathode for comparison.

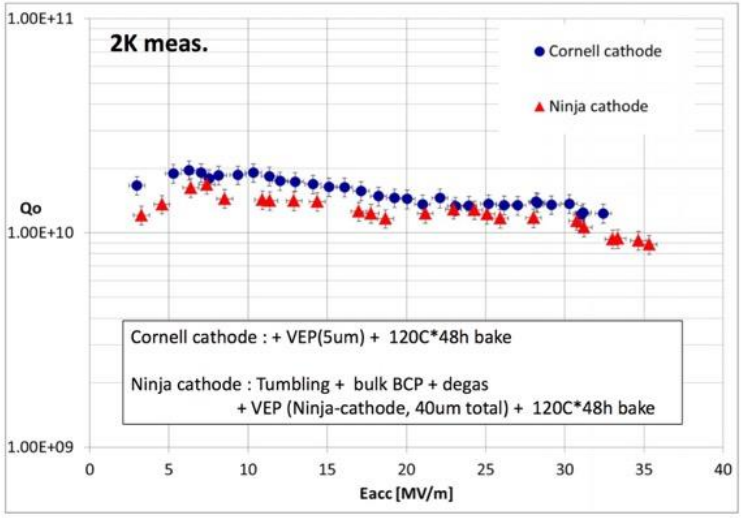
VEP conditions:
Voltage: 14 V, Cathode rotation: 50 rpm, Temperature < 20 ºC, Removal~40 µm

NR1-2 VT results

The first breakthrough of Ninja-cathode EP with single cell cavity



Cornell VEP and Ninja cathode VEP

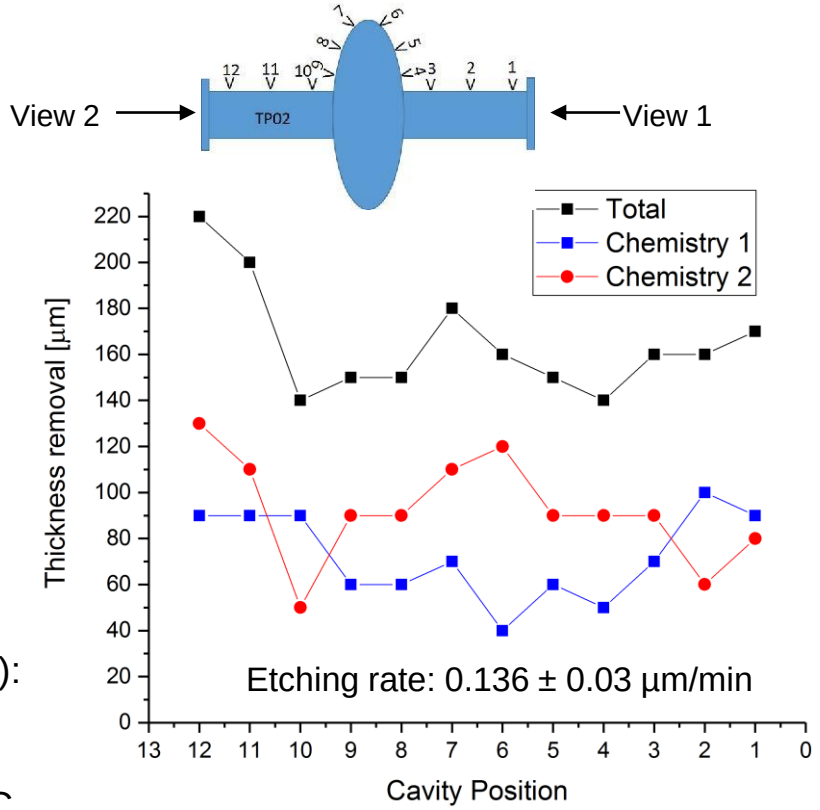


Similar cavity performance was attained with Cornell's cathode and Ninja Cathode.

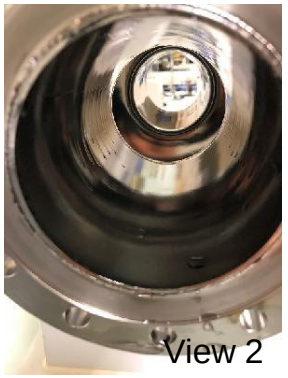
Collaborative Work with CEA-Saclay

- Ninja cathode and optimized VEP parameters with the coupon cavity were applied on two cavities at CEA-Saclay.

VEP setup with Ninja cathode



After Final EP



Targeted Vertical EP conditions (Cavity-1):

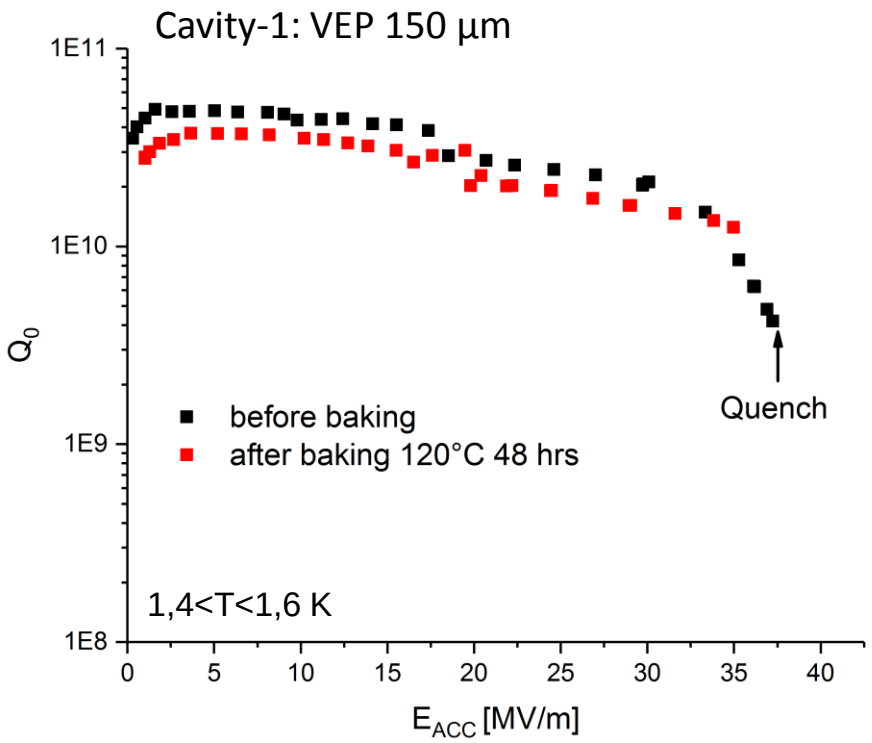
- Thickness removal 150 µm
- Acid Temperature in tank: 18°C
- External Cool down Temperature: 12°C
- Acid flow: 10L/min
- Rotation cathode: 20 rpm
- Voltage cathode: 17.3 V
- N_2 flow: 6L/min
- Cavity: TESLA design 1.3 GHz
- Volume acid Tank: 200L

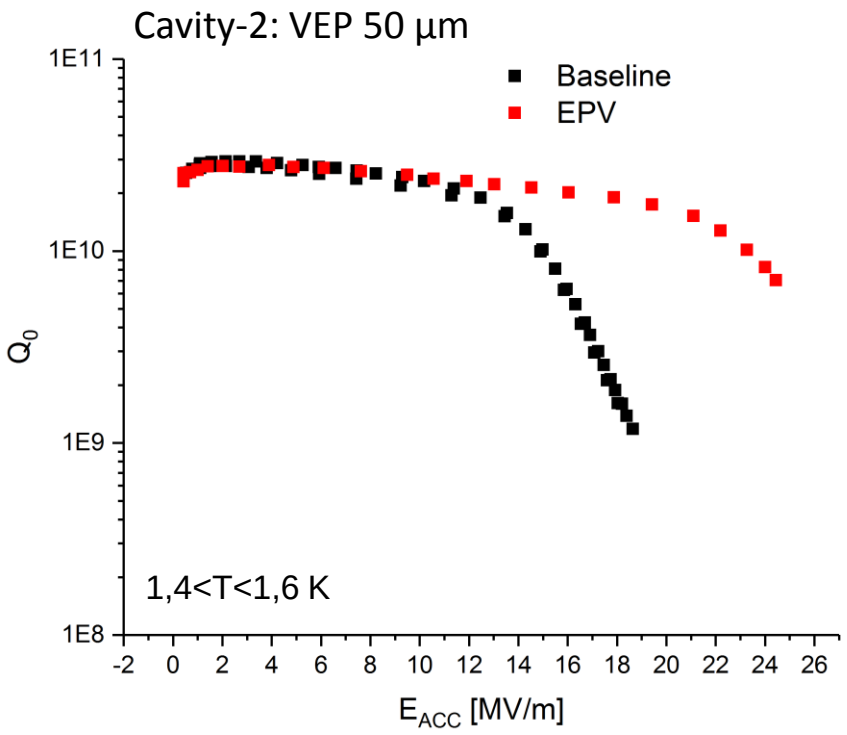
VEP conditions (Cavity-2):

- VEP process: 50 µm, same conditions as for cavity-1

Effect of cathode and optimized parameters was confirmed at CEA-Saclay

RF Test Results





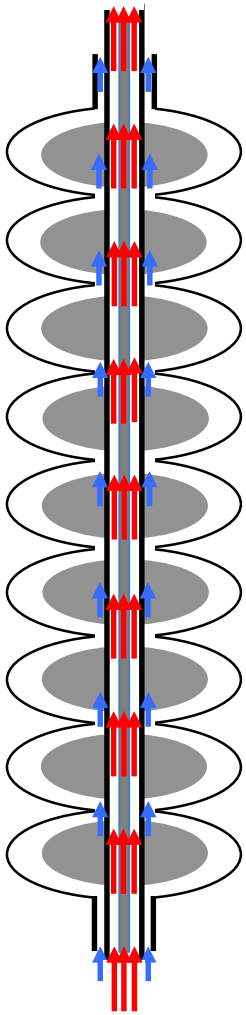
- Quench at 37.2 MV/m and 35 MV/m with Q_0 = 1.26 x10^{10} before and after baking
- Future: High temperature annealing 650°C – 10 hrs with Nb caps

- Quench improved from 18 MV/m to 25 MV/m after VEP (50 µm)
- Future: Further EP for 50 µm

Parameter Study with 9-Cell Coupon Cavity

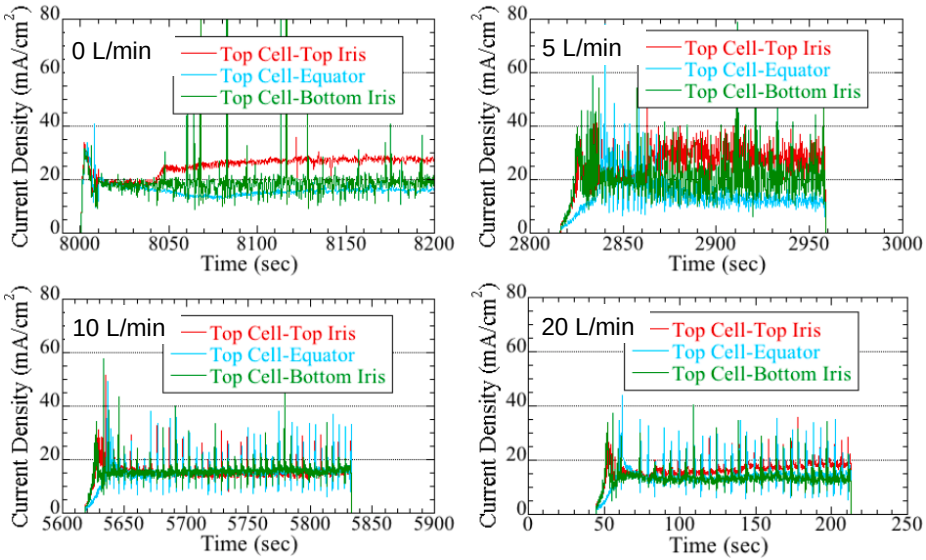
Separate Flow in Cavity and Cathode

- Removal of bubbles quickly from a multi-cell cavity is more difficult and challenging.

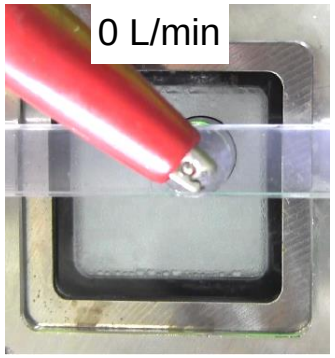


Separate Acid Flow in Cathode and Cavity

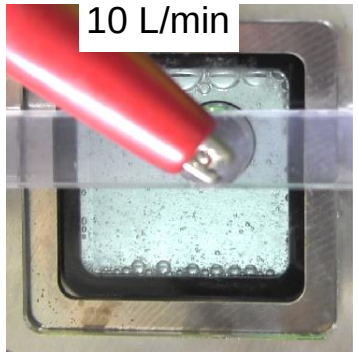
Coupon currents at 5 L/min in Cavity & Different Flow Rates in Cathode Housing



Viewport (Top Cell) at 0 and 10 L/min in Cathode Housing



Filled with bubbles



With reduced bubbles

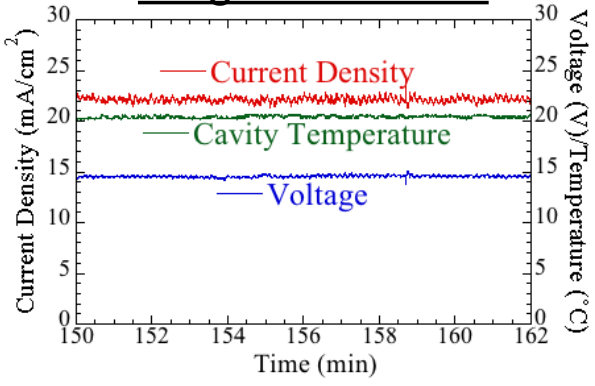
Adequate acid flow:
Cathode housing ~ 10 L/min & Cavity ~ 5 L/min

Separate acid flow in the cavity and cathode housing reduced bubble accumulation in the cavity cells.

VEP of 9-Cell Cavity with Combined Flow

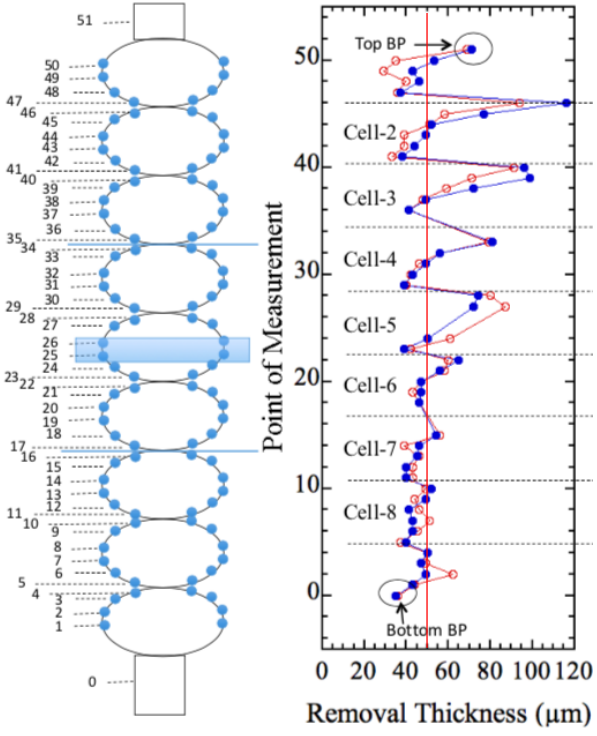
- VEP test was conducted with combined acid flow in the cathode housing and the cavity.

Single Acid Flow



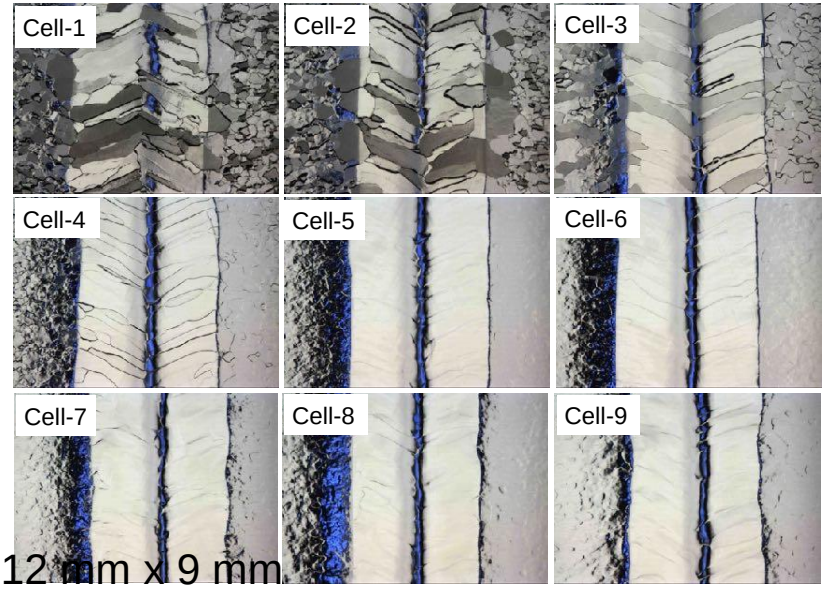
Single flow at 5 L/min from bottom to top,
Cathode rotation at 20 rpm

Removal Trend



Avg. removal: 50 μm

Equator Surface after VEP



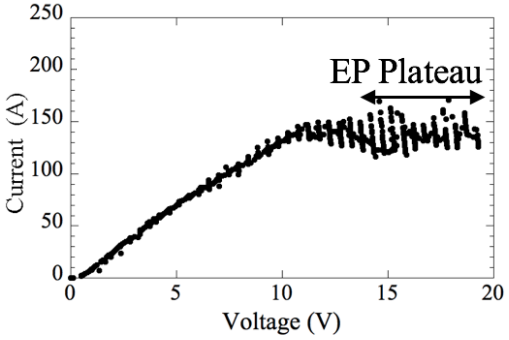
12 mm x 9 mm

- Asymmetric removal along the cavity length.
- Rough surface in the upper cells.
- Strong cathode screening with H_2 gas bubbles in the upper cell.

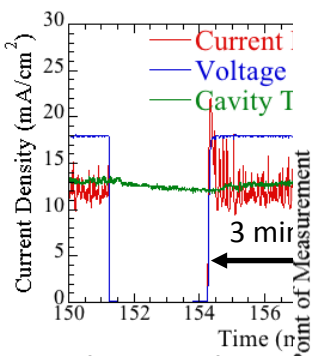
VEP with Separate Flow (Dual-Flow)

Flow rate: Cathode housing-10L/min, Cavity-5L/min

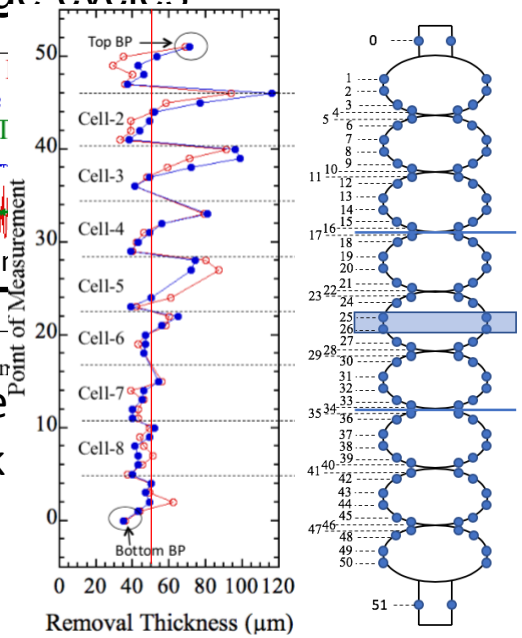
I-V Curve



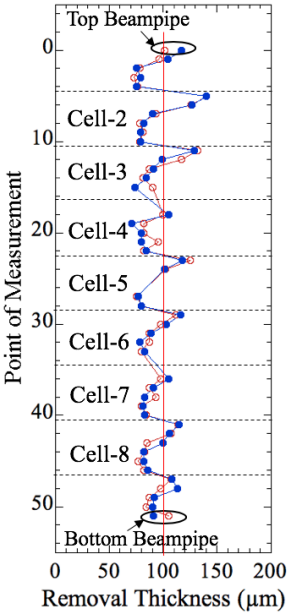
On-Off voltage cycles



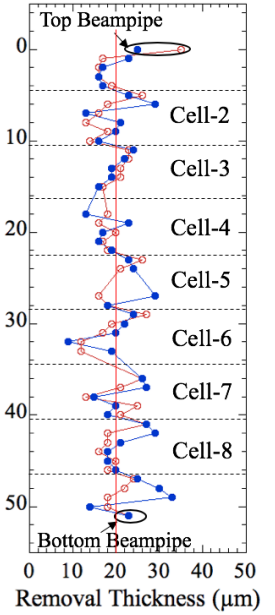
On-Off cycles were selected to reduce circulating bubbles from the acid tank

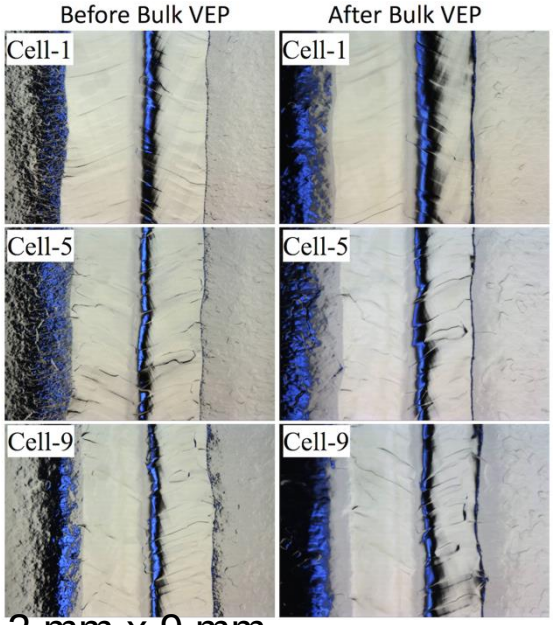


VEP for 100 μm

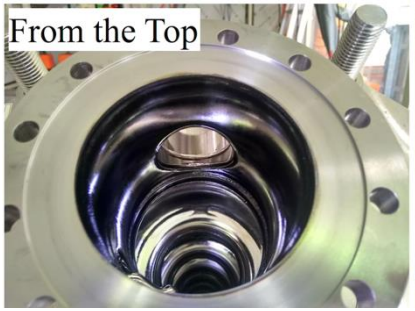


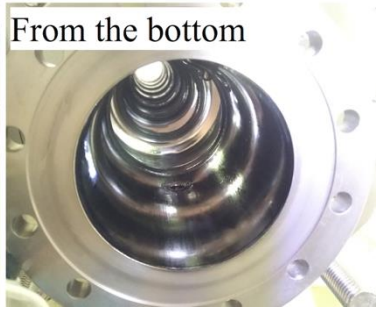
VEP for 20 μm





12 mm x 9 mm





- Removal asymmetry significantly reduced.
- Surface was smooth in all the cells.

RF Test after Bulk Removal of 9-Cell Cavity

Horizontal EP (baseline RF test)

↓

VEP for 100 µm

↓

750ºC bake

↓

VEP for 20 µm

↓

750ºC bake

↓

Field Flatness Tuning (99%)

↓

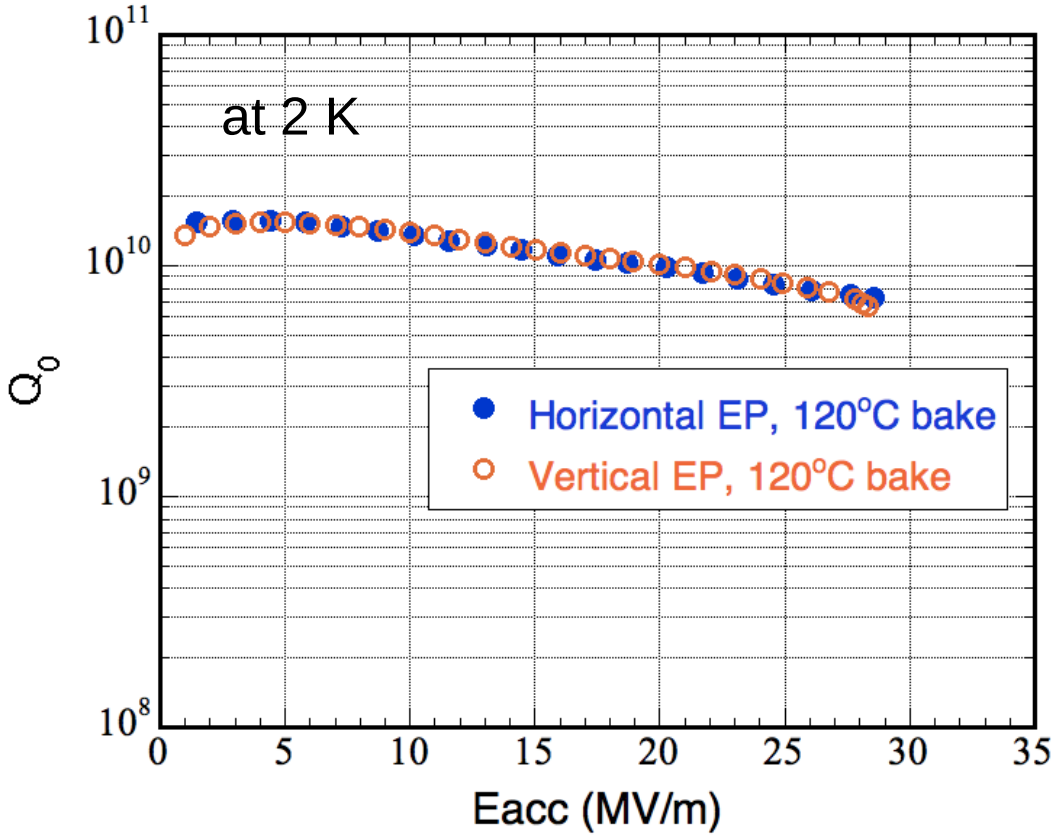
VEP for 10 µm and 120ºC

↓

RF Test

↓

Field Flatness: 99%



Cavity performance after VEP is the same as achieved after HEP.

Field flatness was the same (99%) after 10 µm removal and RF test.

Summary & Future Work

- VEP process was successfully optimized with the single-cell coupon cavity. The optimized parameters and cathode yield desired surface and removal uniformity.
- The asymmetry was significantly reduced and smooth surface was attained for the 9-cell cavity as well.
- The single and 9-cell cavities showed good RF performance in vertical tests.
- VEP of single cell cavities has been successfully done with the Ninja cathode at Cornell university and CEA-Saclay. The cavities showed good RF performance after the VEP treatments.
- The VEP parameters for 9-cell cavity will be further tuned to improve removal uniformity.
- VEP operation for 9-cell cavity(ies) will be performed with the Ninja cathode at CEA-Saclay by the end of this year.

Thank you for your Attention