HIGH GRADIENT RESULTS OF ICHIRO 9-CELL CAVITY IN COLLABORATION WITH KEK AND JLAB

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Abstract

KEK and Jlab have continued S0-study collaboration on ICHIRO 9-cell cavities since 2008. In 2010, we have started S0 study on ICHIRO#7, full 9-cell cavity with end groups. Surface treatments and vertical tests have been repeated at Jlab. Maximum gradient of 40MV/m was achieved so far. We will describe the details of that and further plan of S0-study on ICHIRO 9-cell.

INTRODUCTION

We have succesfully demonstrated the principle proof of 50MV/m with ICHIRO single cell cavities in our high gradient R&D for ILC-ACD at KEK. For ICHIRO 9-cell, we have started S0-study in collaboration with Jlab from 2008. In S0 study, cavities will be exchanged and tested at each laboratory. We can cross check the data and also compare the facilities. In the S0-study on ICHIRO#5, which has no end group, we have achieved 36.5MV/m at Jlab and 33.7MV/m at KEK[1]. End group means HOM couplers, RF input coupler port, and RF pick-up antenna port. We confirmed that our KEK ICHIRO facilities are not so different from Jlab. After ICHIRO#5, we fabricated two full ICHIRO 9-cell cavities with fine grain Nb, ICHIRO#7 and #8. Our top priority is the proof of 50MV/m with full ICHIRO 9-cell cavity, so we decided to do S0-study with Jlab again with ICHIRO#7. Figure 1 shows the image of ICHIRO#7.

COMISSIONING OF ICHIRO#7 AT JLAB

At KEK, we processed ICHIRO#7 by our standard recipe which consists of centrifugal barrel polishing (CBP, ~100μm), light chemical polishing (CP, 10μm), annealing (750^{o}C x 3hrs), electropolishing (EP, 80 + 20μm), flash EP (3μm, fresh acid, no circulation), post EP cleaning [2, 3], HPR, and baking (120^{o}C x 48hrs). Pi-mode gradient was limited by field emission (FE) at 12MV/m. We found a defect on beam tube by inspection after VT; it might be a source of FE. We ground it off by mini-handy grinder before sending ICHIRO#7 to Jlab. KEK staff visited Jlab and had responsibility for process and test.

Installation

We prepared hardware in order to process ICHIRO#7 at

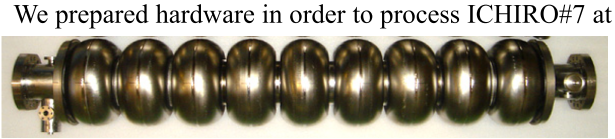

Figure 1: full ICHIRO 9cell cavity #7.

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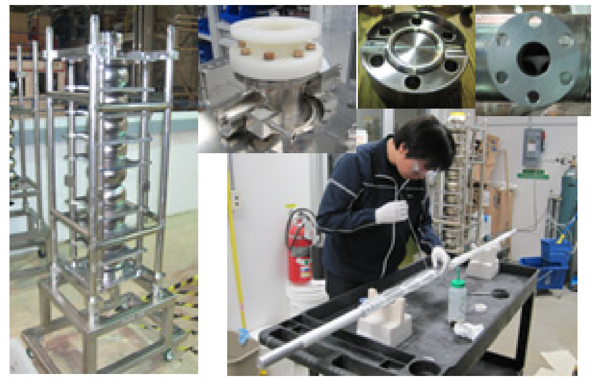

Figure 2: Installation of ICHIRO#7.

Jlab facilities. Jlab's cavity cage was modified to fix ICHIRO#7 with KEK's cage. ICHIRO#7 has MO seal on beam tube flanges [4], so we made adapters between MO flange and EP sleeves. We also made new EP cathode for ICHIRO#7. For HOM ports and Pt port, we used ILC standard Al gasket as sealing. Those ports of ICHIRO#7 were made of Nb. Leak tightness of this combination was successfully demonstrated in this S0-study. Fundamental RF input coupler port was sealed with indium wire because of the difference of flange shape. MO flange was sealed with indium plated Al gasket. Figure 2 shows some hardware installation.

VT-1, as received

After shipping, ICHIRO#7 was inspected inside and confirmed flatness of 94%, no degradation during shipping. VT-1, as received test, was done after re-rinsed with ultrasonic cleaning (USC) with Liqui-Nox and HPR. The result is shown with blue dots (■) in Figure 3. Maximum gradient was improved from 12MV/m to 21MV/m; but limited by FE. Mechanical grinding mark still remains on beam tube, so this might have some responsibility for FE limitation. The flatness was kept with 93% through VT-1.

VT-2, after 1st EP (25μm) at Jlab

The processes for 2nd RF test were 25μm EP, post EP cleaning of wiping and brushing on end groups, USC, and 6cycles of HPR in total. Unfortunately, the indium seal at input coupler port was melted and leak was happened because of failure baking process. Cavity inside was contaminated by melted indium. We did nitric acid soaking to remove the indium contaminations and HPR again. Then cavity was baked with 120^{o}C for 48hrs successfully, and tested. The result is shown with purple dots (◪) in Figure 3. Severe FE was induced during the processing around 15MV/m, and gradient was limited

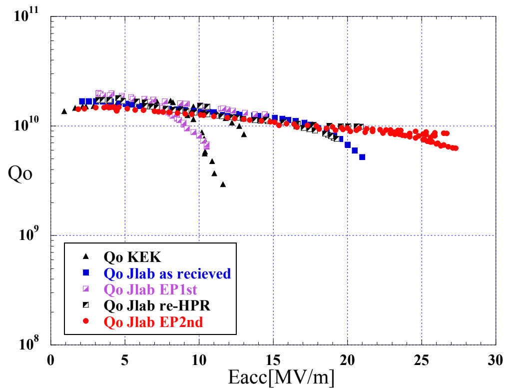

Figure 3: Summary of VT 1~4.

11MV/m. In this test, we did 2nd sound monitoring with Oscillating Superleak Transducers (OST) to identify the quench location. OST predicted the quench location was around the top end group.

VT-3, after re-HPR

Cavity was re-tested after HPR to confirm the limitation came from contaminations or defects. For the HPR, we disassembled bottom beam tube flange only. The result is shown with black dots (◩) in Figure 3. The maximum gradient was improved up to 21MV/m, but limited by severe FE again. After VT-3, we did inspection and found contaminations from top side HOM. The contaminants were sampled and analyzed by EDX and SEM. These contaminants consisted of Si, S, and Cl. Si and S were components of degreaser. But we did not found yet where Cl came from. So this contaminant was caused by poor rinsing after USC. We cleaned these contaminations by wiping with BCP acid. Flatness was 94% after VT.

VT-4, after 2nd EP (30μm) at Jlab

To avoid any affects of previous contaminants, we removed 30μm as 2nd EP at Jlab. Post EP cleaning and HPR cycles were same as VT-2. At the leak check, small leak was found at top HOM sealing. We disassembled the top HOM blank and found very small defect on the Nb flange surface. We sealed this flange with indium. HPR and final assembly were done again. Leak tightness was confirmed at room temperature. Cavity was baked and tested. The result is shown with red dots (●) in Figure 3. Maximum gradient of 27MV/m was achieved. 2nd sound monitoring with OST predicted the quench location was 3rd or 4th cell counted from input coupler port side. After VT-3 we found several issues. (1) The flatness was degraded from 94% to 87%. (2) A dog-born shaped discoloration area was observed near HOM can on Pt port side. This feature was not observed before VT. (3) Twin pit were also found on beam tube near the Pt port.

Summary for VT-1 to VT-4

We had many troubles during these tests. But reasons of those problems were almost understood and fixed. We made feedbacks for each steps. Figure 4 shows No. of VT vs. maximum gradient of Pi-mode up to VT-4. It shows the improvement was done step by step. We regard these VT were commissioning phase of S0-study on ICHIRO#7. All procedures for ICHIRO#7 at Jlab were checked and confirmed in this phase. We expected the high gradient should be achieved by next process.

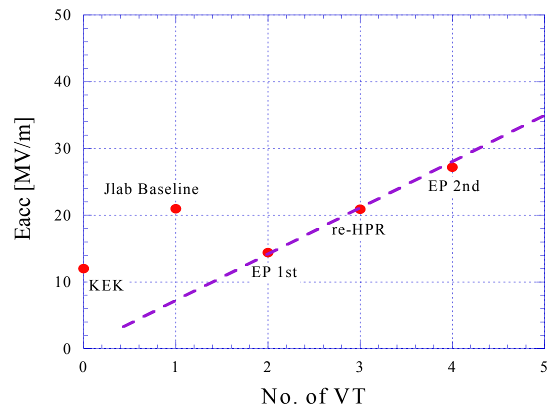

Figure 4: Summary of Qo vs. Eacc.

HIGH GRADIENT RESULTS OF ICHIRO#7

VT-5, after 3rd EP (20μm) at Jlab

Before 3rd EP, we fixed the issues mentioned before. Twin pits were polished by Scotch-Brite, no visible defects were on beam tube after polishing. Flatness was tuned again up to 96%. Then 3rd EP (20μm), post EP cleaning, USC, HPR and baking were applied. A dog-born shaped discoloration was removed by 3rd EP. Figure 5 shows the results. ICHIRO#7 reached 36MV/m with Qo value of 7.4e9 at 2K. Very high radiation was monitored during the test. We decided to re-HPR this cavity to decrease the radiation.

VT-6, after re-HPR

For the VT-6, we did several modifications on the process. (1) Additional HPR for end groups were applied prior to whole cavity HPR. (2) Put a metal isolate valve at the bottom beam tube to prevent the contamination during cavity attachment to VT stand. (3) Short baking to degas the residual gas on the cavity inside surface. After all

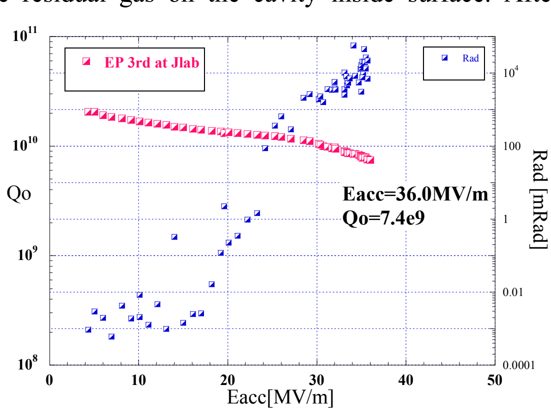

Figure 5: Result of VT-5 at 2K after 3rd EP.

these efforts to reduce the radiation, cavity was tested at 2K. Figure 6 shows the result. ICHIRO#7 achieved 40MV/m with Qo value of 8.0e9. This result was satisfied ILC-ACD requirement. Figure 7 shows the result of pass-band measurements analysis. It shows all cells reached more than 40MV/m, it is also consistent with Pi-mode measurement. Cavity was limited by high radiation and quench.

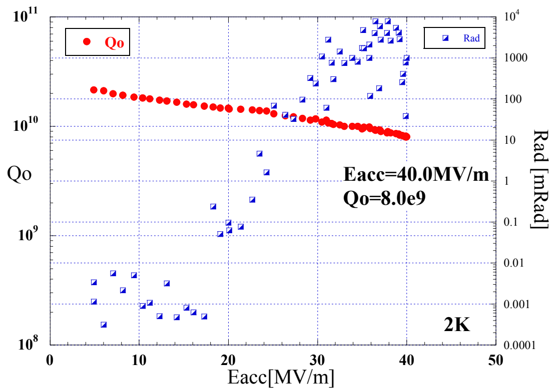

Figure 6: Result of VT-6 at 2K, after re-HPR.

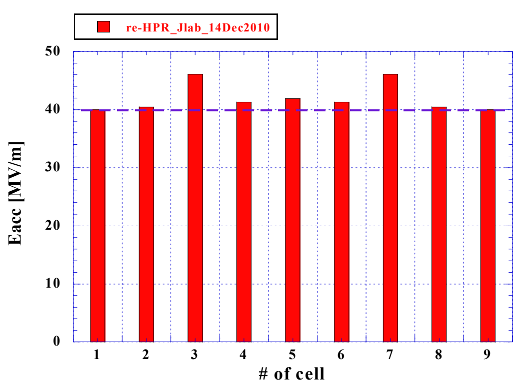

Figure 7: Analysis of pass-band measurements.

VT-7, with OST

ICHIRO#7 was once warmed up to room temperature and set OST for 2nd sound monitoring. Cavity was cooled down again and tested at 1.8K. Maximum gradient was same as before. OSTs predicted the quench location was on the cell#8 in Pi-mode. After VT-7, we inspected cavity inside and found a feature (~0.5mm) at the predicted area of cell#8. Figure 8 shows the image of feature, but it seems not so critical. We think it can be easily removed by additional EP process. In other pass-band mode, we found no features on the area OSTs predicted as quench locations.

Data cross-check

After VT-7, flatness of 94% was confirmed. Other data cross-checks for Lorentz detuning factor, cable calibration factors, RF parameters were also done and consistent with previous measurements. So we had confident of 40MV/m of ICHIRO#7.

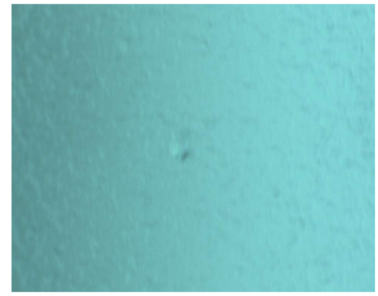

Figure 8: Feature at cell#8 predicted by OST.

DISCUSSION AND FURTHER CHALLENGES

ICHIRO#7 was reached 40MV/m, but still high radiation was monitored. On-set gradient of radiation was around 15~18MV/m. This number was almost same through the all VT. We think there might be some source of radiation we did not find out yet. For the 50MV/m with ICHIRO#7, we should understand the source of radiation and eliminate it. One concern is ICHIRO#7 has new challenge on beam tube sealing, MO flange. We used Indium plated Al gasket for this flange. Reliability of leak tightness was confirmed with all 7 VTs at 2K. After VT-7, we have started R&D using single cell cavity with MO flange at KEK to confirm this gasket will make contaminants during the assembly and cause FE or not.

Reduction of radiation by assembly with air flow

We did particle count monitoring during the assembly of MO flange, and monitored several hundred particles. We applied air flow from cavity inside to outside to prevent particles go into cavity during assembly. This worked well and no particles were counted after applying air flow. The VT result of MO single + In/Al gasket + assembly with air flow is shown in Figure 9 with red dots (▲). Still radiation was monitored, but FE on-set was improved up to 25MV/m. Air-flow will help ICHIRO#7 to reduce the high radiation. More R&D was done with single and 9-cell cavities. The details are presented in this conference [5].

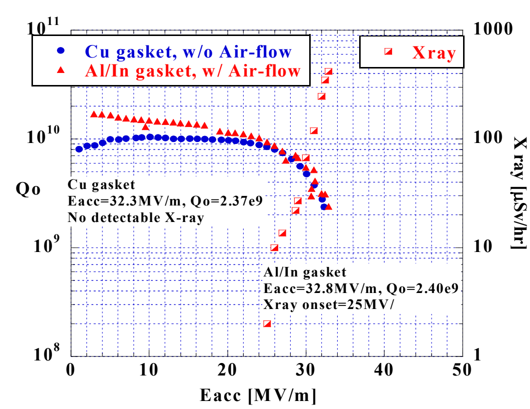

Figure 9: Comparison of In/Al and Cu gasket.

Feasibility of radiation free with Cu gasket

In plated Al gasket is reliable for 2K leak tightness but make particles during assembly. Original MO flange was designed with Cu gasket, so we tried it on our MO flange single cell. The result is shown in Figure 9 with blue dots (●). Qo vs. Eacc curve was almost same and no radiation. In this case, air flow was not applied during assembly. This suggested that if we apply Cu gasket and air flow on ICHIRO#7, radiation free maybe possible and gradient will be improved much also. We need more statistics against 2K leak tightness of the combination of MO flange and Cu gasket in super-fluid liquid helium.

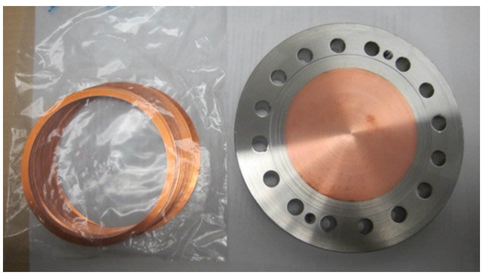

Figure 10: Image of Cu gasket and Cu/SUS flange.

Improvement of Qo by Cu/SUS flange

In the R&D on MO flange single, low Qo problem was happened and we found it was caused by the loss of SUS flange on top beam tube. To reduce that loss, we tried to replace SUS flange to Cu/SUS flange. Cu plate and SUS ring were welded together by electron beam welding. MO sealing edge was machined on SUS surface. Figure 10 shows the image. Cu has 10 times higher thermal conductivity than SUS, that means the loss of Cu can be lower about one third of SUS. This will help to improve Qo at vertical test. Figure 11 shows the MO single cell results of surface resistance vs. Temperature for SUS flange and Cu/SUS flange respectively. In this trial, the beam tube length of MO single was 105mm and surface resistance at 2K was reduced about half by Cu/SUS flange, so Qo was improved about factor 2. In the 9-cell case, beam tube is 108mm. The surface resistance at 2K

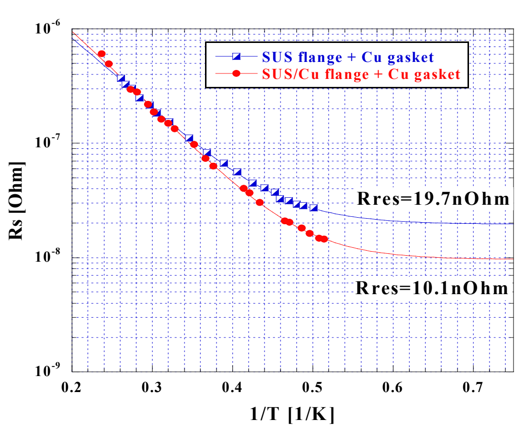

Figure 11: Comparison of SUS and Cu/SUS flange with MO single cell cavity (beam tube 105mm).

will be reduced from 14nΩ to 9n nΩ, so Qo will improve from 2e10 to 3e10 at low field. This will also help ICHIRO#7 to improve the gradient.

SUMMARY AND ACKNOWLEDGMENT

S0 study on ICHIRO#7 has continued in Jlab and successfully demonstrated high gradient of 40MV/m so far. Figure 12 shows summary of VT. In addition to high gradient, it should be noted that the leak tightness of the combination of Nb flange and ILC standard Al gasket was also demonstrated at HOM and Pt ports. Current limitation of ICHIRO#7 is high radiation. We have found that some reduction of field emission might be possible by improvement on MO flange procedures. Figure 13 shows the improvement of maximum gradient through of ICHIRO#7. That graph encouraged us that more than 45MV/m might be possible by next EP process and our feedbacks from R&D on MO flange. In addition to ICHIRO#7, we have already sent ICHIRO#8 to Jlab for next S0 study. It will start soon.

We would like to thank to Jlab and Jlab staffs for collaboration of S0 study on ICHIRO#7.

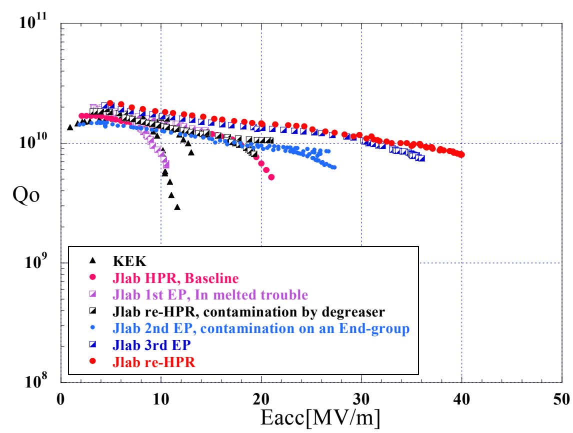

Figure 12: Summary of VT.

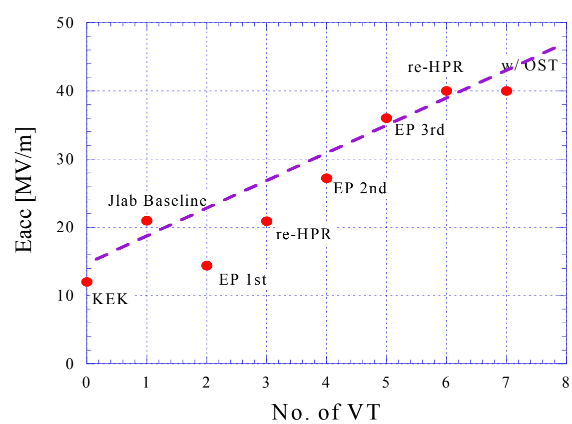

Figure 13: Improvement of Eacc max.

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