ISBN: 978-3-95450-211-0 doi:10.18429/JACoW-SRF2019-MOP054

FABRICATION OF 3.0-GHz SINGLE-CELL CAVITIES FOR THIN-FILM STUDY

T. Saeki[†], H. Hayano, T. Kubo, SOKENDAI/KEK, 305-0801 Tsukuba, Ibaraki, Japan
H. Inoue, R. Katayama, KEK, 305-0801 Tsukuba, Ibaraki, Japan
F. E. Hannon, R. Rimmer, A.-M. Valente-Feliciano, Jefferson Laboratory, Newport News, VA, USA
Y. Iwashita, H. Tongu, Kyoto ICR, Kyoto University, 611-0011 Uji, Kyoto, Japan
H. Ito, SOKENDAI, 305-0801 Tsukuba, Ibaraki, Japan

Abstract

We fabricated 3.0-GHz single-cell cavities with Cu and Nb materials for testing thin-film creations on the inner surface of the cavities in collaboration between Jefferson Laboratory (JLab) and KEK. The cavity was designed at JLab. According to the design of cavity, the press-forming dies and trimming fixtures for the cavity-cell were also designed and fabricated at JLab. These dies and trimming fixtures were transported to KEK, and the rest of fabrication processes were done at KEK. Nine 3.0-GHz single-cell Cu cavities and six 3.0-GHz single-cell Nb cavities were fabricated finally. Two 3.0-GHz single-cell Cu cavities were mechanically polished at Jlab. Three 3.0-GHz single-cell Nb cavities were transported to Jlab for inner-surface preparation. All these Cu and Nb cavities will be utilized for the tests of various thin-film creations at JLab and KEK. This presentation describes details of the fabrication of these cavities.

INDRODUCTION

S-I-S (Superconductor-Insulator-Superconductor) thin-film multilayer structure has been proposed by A. Gurevich to enhance the effective H_{c1}, and T. Kubo has proceeded with an advanced theoretical study to predict an optimum thickness of each layer which achieves the maximum effective H_{c1} [1–3]. Alternative superconductors for thin-film structure, such as NbN, NbTiN, Nb_3Sn and so on, are proposed to achieve higher gradient and/or higher quality factor than bulk-Nb cavity. Nb thin-film on Cu cavity will provide drastic cost-reduction of SRF accelerators. Therefore, the thin-film technology will have an obvious and enormous impact to SRF accelerator facilities in terms of high-performance and/or cost-reduction. And the impact might be larger if the technology is applied to large-scale facilities, for example, the International Linear Collider (ILC), Continuous Electron Beam Accelerator Facility (CEBAF) and so on.

Series of studies have been done for the creation of thin-film structures with Nb, NbN, NbTiN, Nb_3Sn and so on, and also the measurements of superconducting characteristics of them at JLab and KEK [4–14]. If the good parameters of thin-film structures are found by sample experiments, we subsequently perform tests with cavities, which. are expensive compared with sample tests. Several experimental trials with thin-film test-cavities might be required to achieve the aimed extreme SRF performance. Consequently, we considered that the small-size 3.0-GHz cavity might be suitable for such thin-film experiments, because the Nb material procurement, facilities of cavity fabrication, setup of inner-surface preparation, film-creation, and performance tests can be done and obtained in relatively low-cost, compared with large-size 1.3-GHz cavity of ILC and/or 1.5-GHz cavity of CEBAF. We have good cavity-fabrication facilities at KEK and good companies for cavity fabrication in Japan in connection with KEK and Kyoto University. We have the inner-surface preparation and performance-test facilities for 3.0-GHz cavity at JLab. In such situations, the design and fabrication of 3.0-GHz cavities with Nb and Cu materials were done in collaboration between JLab and KEK.

PRESS-FORMING AND TRIMMING OF 3.0-GHz CU AND NB CUPS

The design of 3.0-GHz single-cell cavity was done at JLab. The total length of cavity is 170.8 mm with the cell length of 50.7 mm, and the inner equator diameter of the cell is 90.5 mm. The outer diameter of flange is 88.9 mm and the inner diameter of beam-pipe is 33.8 mm. The material of flange for Cu cavity is stainless steel and that of Nb cavity is NbTi. Cu disks were cut out from Cu plates (C1020) and the Cu disks were annealed in vacuum furnace (520 degrees C x 2 hours) at KEK. A picture of the Cu (C1020) disks set in the vacuum furnace for annealing process is shown in Fig. 1.

Figure 1: A picture of Cu (C1020) disks set in the vacuum furnace for annealing process.

† takayuki.saeki@kek.jp

ISBN: 978-3-95450-211-0 doi:10.18429/JACoW-SRF2019-MOP054

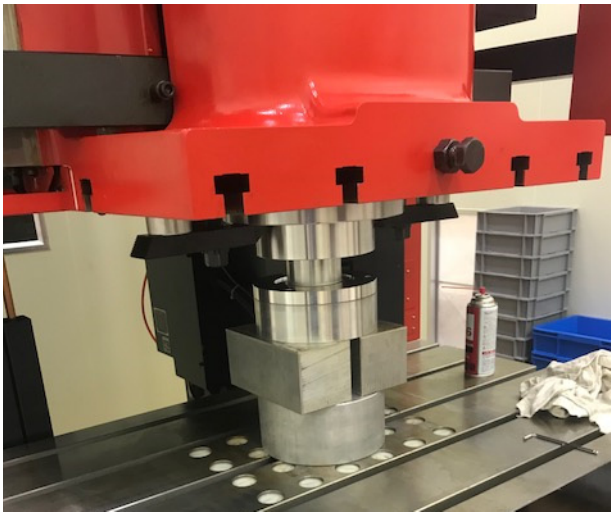

Figure 2: A picture of press-forming of cups at KEK.

Nb disks were cut out from Nb plates (RRR>300, Tokyo Denkai Co., Ltd.). Press-forming dies for the cups were designed and fabricated at JLab and transported to KEK. Using the dies, the press-forming of Cu and Nb cups were performed at KEK. A picture of press-forming of cups is shown in Fig. 2. Trimming fixtures were designed and fabricated at Jlab and transferred to KEK. The trimming of Cu and Nb cups were performed at KEK. The edge of cup at equator has the step for step-joint. The edge of cup at iris has also a step-joint shape. A picture of trimmed Cu and Nb cups is shown in Fig. 3.

Figure 3: A picture of trimmed Cu and Nb cups.

FABRICATION OF 3.0-GHz CU CAVITIES AT KEK AND SURFACE PREPARATION AT JLAB

Seven 3.0-GHz single-cell Cu cavities were assembled at KEK. Two of them were finished in April 2018 and five of them were finished in November 2018. We used brazing method to assemble the stainless-steel flange and Cu beam-pipe. The brazing materials were Ag (72.5 %) and Cu (27.5%) with other material < 0.15%. A picture of flanges and beam-pipes inside the furnace before brazing process is shown in Fig. 4.

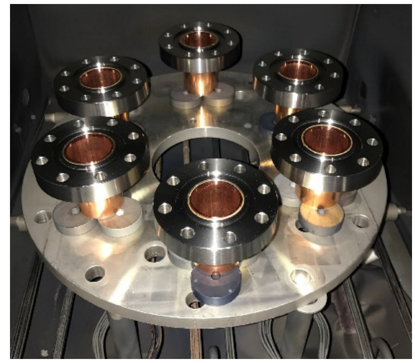

Figure 4: A picture of stainless-steel flanges and Cu beam-pips inside the furnace before brazing process.

Seven Cu cavities were assembled by the Electron-Beam-Welding (EBW) method by a NEC 6-kW EBW machine at KEK. EBW parameters are as follows: iris (V = 80 kV, Speed = 10 mm/sec, I1 = 15 mA, I2 = 29 - 31 mA), equator outside (V = 80 kV, Speed = 10 mm/sec, I1 = 15 mA, I2 = 23 - 25 mA), equator inside (V = 80 kV, Speed = 10mm/sec, I = 17 - 18 mA). Pictures of assembled Cu cavities are shown in Fig. 5 and 6.

Figure 5: A picture of 3.0-GHz single-cell Cu cavities which were assembled at KEK.

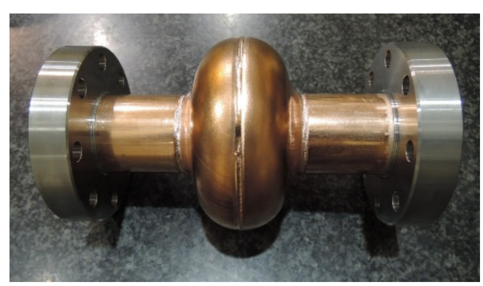

Figure 6: A size-view picture of 3.0-GHz single-cell Cu cavity which was assembled at KEK.

The two Cu cavities which were assembled in April 2018 were immediately transported to JLab for inner-surface preparation. The mechanical polishing (CBP: Centrifugal Barrel Polishing) process was applied to the two cavities at Jlab. Pictures of inner-surface after CBP process are shown in Fig. 7. Plan is that we will perform Nb-film creation on the inner-surface of Cu cavities by KEK or Jlab. The performance tests (vertical tests) will be performed at Jlab.

ISBN: 978-3-95450-211-0 doi:10.18429/JACoW-SRF2019-MOP054

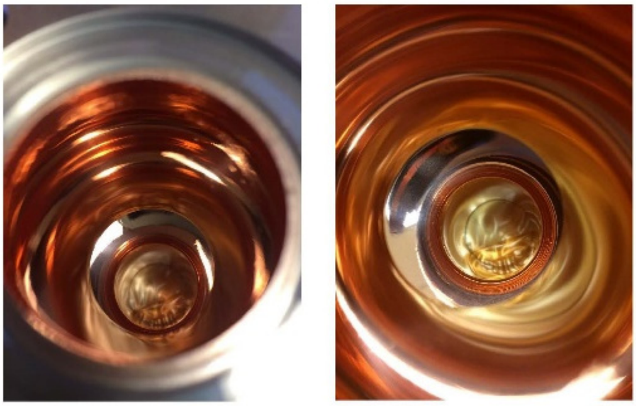

Figure 7: Pictures of inner-surface of 3.0-GHz single-cell Cu cavities after CBP process at JLab.

FABRICATION OF 3.0-GHz CU CAVITIES AT COMPANY

Additional two 3.0-GHz single-cell Cu cavities were assembled at a company in August 2018. For these two cavities, we used EBW method to assemble the stainless-steel flange and Cu beam-pipe as well as the assembly of cups and beam-pipes. The EBW machine that was used for the assembly was Steiger EBOCAM KS 150-G150KM-CNC. A picture of the joint seam of stainless-steel flange and Cu beam-pipe after EBW process is show

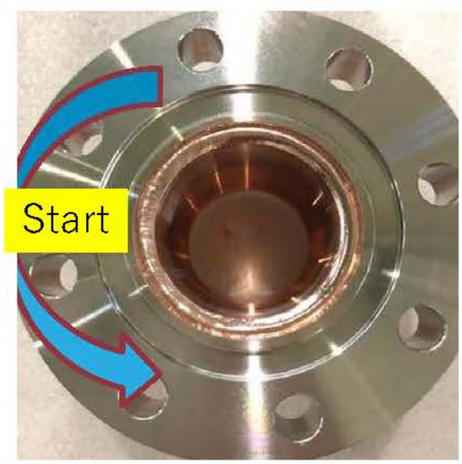

Figure 8: A picture of the joint seam of stainless-steel flange and Cu beam-pipe after EBW process.

EBW parameters are as follows: stainless-steel flange + Cu beam-pipe (I = 10 - 12 mA), equator inside (I = 14 - 17 mA), equator outside (I = 13 mA), iris (I = 26–29 mA). Pictures of assembly of Cu cups are shown in Fig. 9. A picture of assembly of Cu cavity and a picture of assembled Cu cavity are shown in Fig. 10.

Figure 9: Pictures of assembly of Cu cups in a company.

Figure 10: A picture of assembly of Cu cavity (left) and a picture of assembled Cu cavity (right) at a company.

FABRICATION OF 3.0-GHz NB CAVITIES AT COMPANY

Six 3.0-GHz single-cell Nb cavities were assembled at a company in January 2019. Before the assembly, all Nb parts and NbTi flanges were processed by Buffered Chemical Polishing (BCP) method to clean up the surface of the parts at KEK. A picture of the NbTi flanges and Nb parts which were being dried after BCP and pure water rinsing processes in a clean room is shown in Fig. 11.

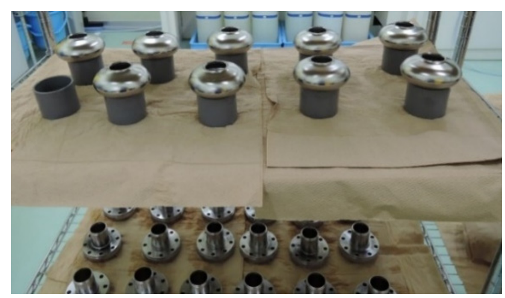

Figure 11: A picture of the NbTi flanges and Nb parts which were being dried after BCP and pure water rinsing processes in a clean room at KEK.

The dried parts were packed in plastic bags and transported from KEK to a company for EBW assembly. A picture of packed parts is shown in Fig. 12. We used Mitsubishi Electric Low-Voltage-type EBW machine for the assembly at the company. EBW parameters are as follows: NbTi flange + Nb beam-pipe (V = 60 kV, I = 12 mA), iris (V = 60 kV, I = 48 mA), equator outside (V = 60 kV, I = 27 mA), equator inside (V = 60 kV, I = 30 mA).

ISBN: 978-3-95450-211-0 doi:10.18429/JACoW-SRF2019-MOP054

Figure 12: A picture of packed NbTi flanges and Nb parts for a cavity at KEK.

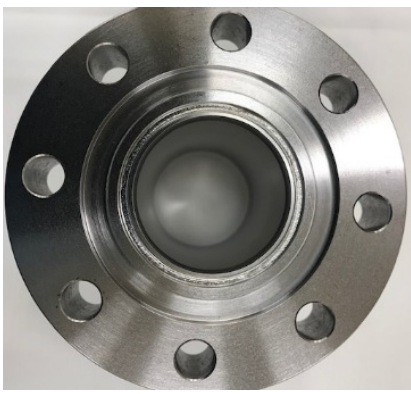

Figure 13: A picture of the joint seam of NbTi flange and Nb beam-pipe after EBW process at a company.

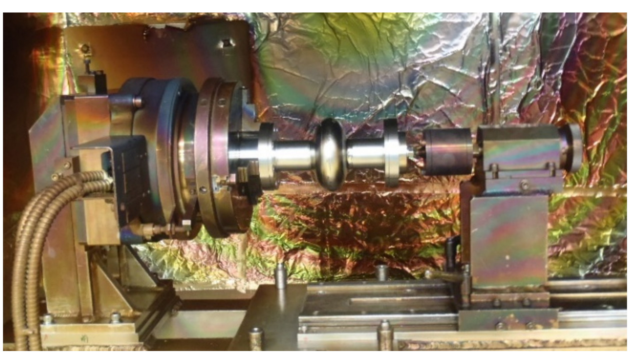

Figure 14: A picture of assembly of 3.0-GHz single-cell Nb cavity at a company.

A picture of the joint seam of NbTi flange and Nb beam-pipe after EBW process is shown in Fig. 13. A picture of EBW assembly of 3.0-GHz single-cell Nb cavity at a company is shown in Fig. 14. Six 3.0-GHz single-cell Nb cavities were completed finally. Three of them were transported to Jlab for inner-surface preparation. Plan is that Electro-Polishing (EP) process will be performed for the inner-surface preparation and Vertical Tests (VT's) will be performed at JLab to determine the base-performance. After observing the base-performance, various thin-film creations on inner-surface of the Nb cavities will be performed at Jlab and/or KEK

COUPON CAVITY

In the film-creation process of cavity, it is important to keep the uniformity of film all over the inner surface of cavity. To investigate the film-quality at several positions of cavity, like beam-pipe, equator, and cell-wall, we designed the 3.0-GHz single-cell cavity with detachable coupons. The 3D schematic view of the coupon cavity is shown in Fig. 15. A coupon Cu-cavity is under fabrication at Kyoto University. If it is successful, a coupon Nb-cavity will be fabricated subsequently. The coupon disks can be made of Cu or Nb, and these are set into the coupon cavities. The films created on the coupon disks can be analyzed in various methods to test the SRF characteristics.

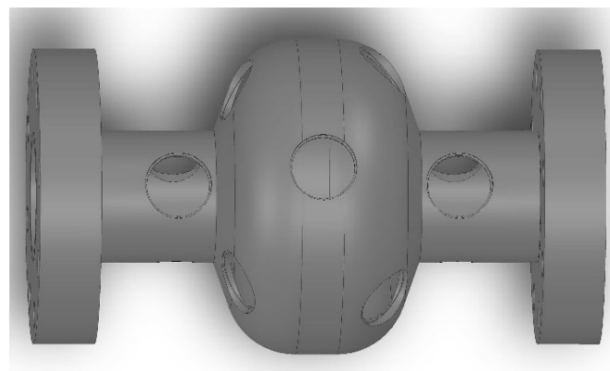

Figure 15: The 3D schematic view of the 3.0-GHz single-cell coupon cavity.

SUMMARY

We fabricated 3.0-GHz single-cell cavities with Cu and Nb materials for testing thin-film creations on the inner surface of the cavities in collaboration between Jefferson Laboratory (JLab) and KEK. The cavity was designed at JLab. According to the design of cavity, the press-forming dies and trimming fixtures for the cavity-cell were also designed and fabricated at JLab. These dies and trimming fixtures were transported to KEK, and the rest of fabrication processes were done at KEK. Nine Cu cavities and six Nb cavities were fabricated finally. Two 3.0-GHz single-cell Cu cavities were mechanically polished at Jlab. Three 3.0-GHz single-cell Nb cavities were transported to Jlab for inner-surface preparation. All these Cu and Nb cavities will be utilized for the tests of various thin-film creations at JLab and KEK.

ACKNOWLEDGEMENT

This work is supported by JSPS KAKENHI JP17H04839, JSPS KAKENHI JP26600142, Japan-US Research Collaboration Program, and the Collaborative Research Program of ICR Kyoto Univ. (2018-13).

ISBN: 978-3-95450-211-0 doi:10.18429/JACoW-SRF2019-MOP054

REFERENCES

[1] A. Gurevich, "Enhancement of rf breakdown field of superconductors by multilayer coating", *Appl. Phys. Lett.*, vol. 88, p. 012511, 2006.

[2] T. Kubo, "Multilayer coating for higher accelerating fields in superconducting radio-frequency cavities: a review of theoretical aspects", *Supercond. Sci. Technol.*, vol. 30, p. 023001, 2017.

[3] T. Kubo *et al.*, "Radio-frequency electromagnetic field and vortex penetration in multi-layered super-conductors", *Appl. Phys. Lett.*, vol. 104, p. 032603, 2014.

[4] R. Ito *et al.*, "Nb3Sn Thin Film Coating Method for Superconducting Multilayered Structure", presented at the SRF'19, Dresden, Germany, Jun.-Jul. 2019, paper TUP077, this conference.

[5] H. Ito *et al.*, "Lower Critical Field Measurement of NbN Multilayer Thin Film Superconductor at KEK", presented at the SRF'19, Dresden, Germany, Jun.-Jul. 2019, paper TUP078, this conference.

[6] R. Katayama *et al.*, "Evaluation of the Superconducting Characteristics of Multi-Layer Thin-Film Structures of NbN/SiO2 on Pure Nb Substrate", presented at the SRF'19, Dresden, Germany, Jun.-Jul. 2019, paper THFUA2, this conference.

[7] A-M. Valente-Feliciano *et al.*, "RF Behavior of ECR Nb/Cu Films", presented at the SRF'19, Dresden, Germany, Jun.-Jul. 2019, paper TUP069, this conference.

[8] A-M. Valente-Feliciano *et al.*, "Material and Superconducting Properties of NbTiN/AlN Multilayer Films", presented at the SRF'19, Dresden, Germany, Jun.-Jul. 2019, paper THFUA3, this conference.

[9] Md. N. Sayeed *et al.*, "Deposition of Nb3Sn Films by Multilayer Sequential Sputtering for SRF Cavity Application", presented at the SRF'19, Dresden, Germany, Jun.-Jul. 2019, paper TUP079, this conference.

[10] M. C. Burton, A. D. Palczewski, C. E. Reece, and A-M. Valente-Feliciano, "Progress with Nb Hipims Films on 1.3 GHz Cu Cavities", presented at the SRF'19, Dresden, Germany, Jun.-Jul. 2019, paper THFUB2, this conference.

[11] R. Katayama *et al.*, "Evaluation of superconducting characteristics on the thin-film structure by NbN and Insulator coatings on pure Nb substrate", in *Proc. IPAC'18*, Vancouver, Canada, Apr.-May 2018, pp. 3653-3655. doi:10.18429/JACoW-IPAC2018-THPAL015

[12] R. Katayama *et al.*, "Precise Evaluation of Characteristic of the Multi-layer Thin-film Superconductor Consisting of NbN and Insulator on Pure Nb Substrate", in *Proc. LINAC'18*, Beijing, China, Sep. 2018, pp. 391–394. doi:10.18429/JACoW-LINAC2018-TUPO030

[13] H. Ito *et al.*, "Lower Critical Field Measurement of Thin Film Superconductor", in *Proc. LINAC'18*, Beijing, China, Sep. 2018, pp. 484-487. doi:10.18429/JACoW-LINAC2018-TUPO066

[14] H. Ito, H. Hayano, T. Kubo, and T. Saeki., "Lower Critical Field Measurement System based on Third- Harmonic Method for Superconducting RF Materials", arXiv e-prints, arXiv:1906.08468, Jun 2019.