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INVESTIGATION OF SRF ELLIPTICAL CAVITIES MADE BY NEW Nb MATERIALS IN KEK

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Abstract

Two kinds of in-house 3-cell superconducting RF cavities were fabricated using two kinds of niobium in KEK. These materials are expected to reduce the cost for the cavity material since some processes in niobium production were skipped. Completed cavities were then RF tested in the vertical cryostat to measure their performance. One of them achieved maximum gradient of 40 MV/m with maximum Q_0 value of $1.87×10^{10}$.

INTRODUCTION

The International Linear Collider (ILC) is now under contemplation in Japan. Reducing the cost for cavity fabrication is presently one of the main issue to realize ILC. The Cavity Fabrication Facility (CFF) at KEK which enables the entire process of cavity fabrication approached this issue in terms of cavity materials.

The ratio of tantalum in niobium was first focused on to reduce the material cost. An additional chemical process is generally necessary to remove tantalum from niobium. This process arises niobium production cost. Thus niobium which contains high tantalum is cheaper than one contains low tantalum. The production processes of niobium were also focused on for the cost reduction. Several processes such as melting, forging and rolling are necessary to produce niobium sheets and tubes used for cavity. Skipping some of these process can also reduce material production cost.

The main purpose of this study is evaluation of new niobium for cavity materials which are expected to reduce the cost. Several cavities were fabricated and RF tested using these materials.

FABRICATION

CFF fabricated two types (“type1” and “type2”) of cavities using different materials. The shape of these cavities are all 3-cell Tesla-like [1] shape and designed to be used in 1.3GHz RF operation. Two 3-cell cavities (“cavity1” and “cavity2”) were fabricated for each type respectively.

Type1 Cavity

Figure 1 shows fabricated type1 cavities. Niobium which residual resistance ratio (RRR) is low and containing higher ratio of tantalum was used as start material for type1 cavities. This material was then forged and rolled into niobium sheets and seamless tubes. Niobium sheets were used for stiffener rings and tubes were used for beam tubes. Rest of this material was melted two times by electron beam welding in the vacuum chamber to purify. This melting process is normally done five or more times. Thus, production cost of this material was also reduced. This melted niobium was forged and rolled into niobium sheets and used for cavity cells. RRR of start material was 60~108 (ingot), and it recovered up to 277~298 (ingot). RRR of the sheets (after forge and rolling) used for cells was 293. RRR of ingot varies widely since measured samples were taken from both edges of ingot. RRR are summarised in Table 1. Chemical components of these materials are summarised in Table 2. In Table 2, “Ingot1” represents the value of start materials, “Sheet” represents the value of niobium sheets used for stiffener rings and “Ingot2” represents the value of ingot after two times melting. The start material was supplied by CBMM, and melting, forge and rolling process were done by ULVAC

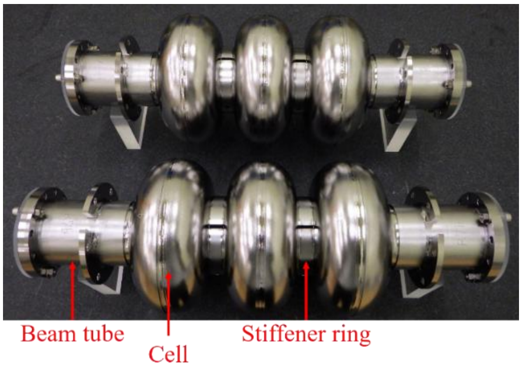

Figure 1: Fabricated type1 cavities and explanation of each parts.

Type2 Cavity

Figure 2 shows fabricated type2 cavities. Niobium sheets directly sliced from niobium ingot which is called large grain (LG) were used for this cavity. Production cost of LG niobium sheet is lower than normal sheet since forge and roll process are skipped. Used niobium sheet for type 2 cavity is shown in Figure 3. LG sheet has strong anisotropy as it has large crystal size which diameter is about 100~150 mm, as shown in Figure 3. This strong anisotropy leads some technical difficulties in fabrication. For example, the roundness of the inside equator is worse than one made of normal sheet due to large deformation after press forming. Hence, a special jig shown in Figure 4 which

Table 1: RRR Values of Materials Used for Each Part of Type1 and Type2 Cavities

	Type1	Type2
Cells	293	242~298
Beam tubes	60~108	60~108
Stiffener rings	60~108	-

Table 2: Chemical Components of Each Material

Cavity		C	N	O	H	Zr	Ta	Fe	Si	W	Ni	Mo	Hf	Ti	S
Type1	Ingot1	<30	33	26	<2	<1	1194	3	<20	<5	<1	<1	<2	7	<10
	Sheet	<10	30	<10	1	<10	1210	<10	<10	<10	10	<10		<5	
	Ingot2	<10	<10	<10	<1	<10	1430	<10	<10	<10	10	<10		<5	
Type2	ingot	<30	6	5	2		1191	<3		<5		1			<10

forces equator into an exact circle is necessary for electron beam welding (EBW) of an equator. This process is only necessary for LG cavity. Non-uniform thicknesses at the edge of half-cell especially around grain boundaries are observed. This leads an EBW failure such as creation of a hole and not enough penetration. An iris part (constricted part of a cavity) was welded from both outside and inside however it is normally welded only from outside. Such difficulties of fabricating LG cavity is also described in [2].

The chemical components of this material are shown in Table 2. The ratio of tantalum in this niobium is also high.

Figure 2: Fabricated type2 cavities.

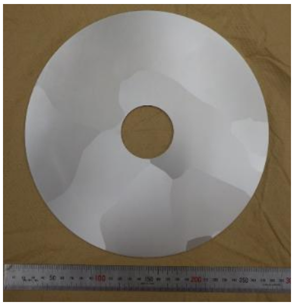

Figure 3: LG niobium sheet used for type2 cavity. The outer diameter is 260 mm.

Figure 4: Special jigs set at equator for EBW.

RRR value varies from 242~298 which is listed in Table 1. LG ingot were supplied by CBMM, and cut by wire saw.

A same material as type1 cavity was used for beam tubes. Recycled niobium from scrapped niobium was used as stiffener rings of type2 cavity.

PERFORMANCE MEASUREMENT

Preparation

Completed cavities were measured its performance in a vertical cryostat. Several surface treatments have been applied to the cavity before measurement in KEK [3]. Brief surface treatment flow is listed below.

1. 100 μm of electropolishing (EP) of inside cavity
2. Ultrasonic rinsing with neutral detergent at 50 ◦C for 15 min and high-Pressure Rinsing (HPR) of the inside cavity with 8 MPa of ultrapure water for 1 h with open flanges
3. Annealing of cavity for 3 hours at 750 □ in a vacuum furnace for hydrogen degassing
4. Frequency tuning
5. 30 μm of EP
6. Ultrasonic rinsing with neutral detergent at 50 ◦C for 15 min and HPR
7. Assembly for the performance measurement in Class 10 clean room
8. Baking for 48 h at 120 ◦C (after assembly)

Measurement

Cavity is cooled down by liquid helium in a vertical cryostat and its performances were measured after surface treatment.

Top two plots in Figure 5 show results of performance measurements of type1 cavities in π-mode. Measurements were done at 1.5 K, 1.8 K and 2 K respectively. Measurement in 1.5 K and 1.8 K were stopped at 15 MV/m intentionally to avoid Q_0 drop due to flux trapping caused by quench. Measurements at 2 K were done twice; first and final. The first 2 K measurement was done after 1.5 K and 1.8 K measurement. The final 2 K measurement was done after other passband mode measurement done after first 2 K measurement. The performance of type1-cavity1 (left top in Figure 5) was limited to 23 MV/m at 2 K due to quench. The performance of type1-cavity2 (right top in Figure 5) was limited 35 MV/m. Q_0 value was dropped over 25 MV/m due to x-ray radiation. Cavities are required to reach accelerator gradients of 35 MV/m and Q_0 value of 0.8×10^{10} at 35 MV/m in ILC technical design report [4]. Both of type1 cavities could not satisfy these requirements.

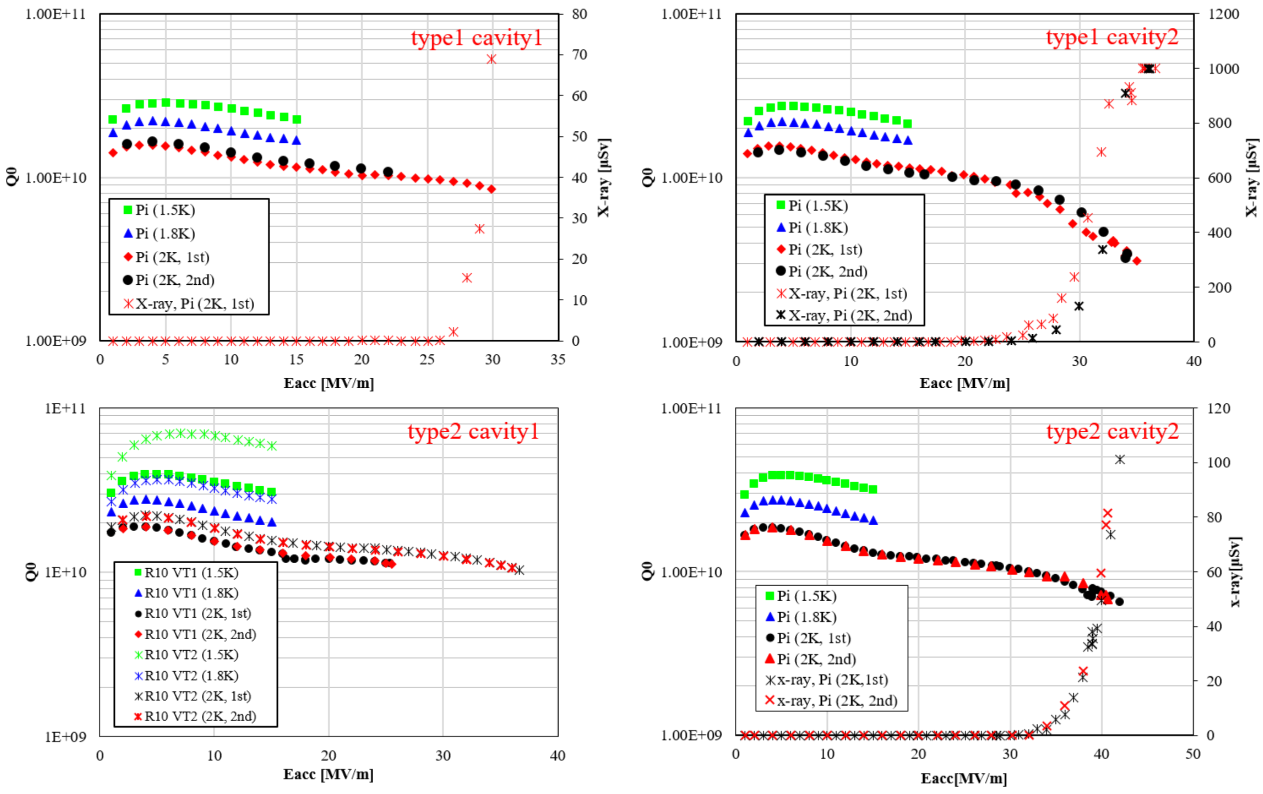

Figure 5: Results of performance measurements.

Bottom two plots in Figure 5 show results of performance measurements of type2 cavities in π-mode. Measurements were done in same sequence as type1 cavities. The performance of type2-cavity1 (left bottom in Figure 5) was limited to 25 MV/m at 2 K due to quench. A suspicious defect was found around quench region by inspection done after performance measurement. This defect was removed, and the cavity was electropolished in 50 µm. The performance of this cavity was then reached to 36 MV/m in the second measurement. The remaining magnetic field around cavity was cancelled by solenoid coil surrounding cavity in the second measurement. Other measurements were done in the remaining magnetic field of 5~10 mG. And, temperature gradient which was made by heater surrounding top beam tube was applied during superconducting transition. The Q_0 value in the second measurement is higher than one from first measurement due to magnetic cancelation and temperature gradient. The performance of type2-cavity2 reached to 40 MV/m in 2K measurement. Both of typ2 cavities satisfied ILC requirements.

CONCLUSION

Two types of niobium were used to fabricate superconducting RF cavities to study cost reduction in terms of cavity materials. Two 3-cell Tesla-like shape cavities were fabricated with each niobium. Completed cavities underwent performance measurement via several surface treatments.

Type1 cavities made of niobium which RRR is around 300 and contains high ratio of tantalum reached 23 MV/m and 35 MV/m respectively.

Type2 cavities made of LG niobium which RRR is around 300 and contains high ratio of tantalum reached 36 MV/m and 40 MV/m which satisfy ILC requirements.

In both cases, beam tubes made of low RRR and high tantalum contained niobium did not affect to cavity performance in the measurement where liquid helium directly cooled down the beam tubes. But further study about an effect from heat conductivity to a beam tubes should be done since the cavity is not directly put into the liquid helium in the practical usage.

LG niobium is expected to achieve more efficient cost reduction. And CFF is fabricating 9-cell cavities using this LG niobium in 2018.

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