VERTICAL TEST RESULTS OF NITROGEN DOPED SRF CAVITIES AT KEK*

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Abstract

Nitrogen doping technique was attempted to single-cell cavities at KEK, in order to realize high-Q performance. Two different size of furnaces were used and three parameter sets were tried. After surface removal by electro polishing, vertical tests were carried out to investigate cavity performances. Contrary to expectations, Q-value became worse after doping. Vertical tests were also performed at FNAL to check effect of magnetic field. However, improvement was not much.

INTRODUCTION

For Superconducting RF (SRF) cavities, high-Q operation of cavities are very attractive, since it can largely reduce amount of He consumption. Recently Nitrogen doping technique during annealing process was proposed and drastic improvements of Q value were reported by FNAL, Jefferson lab and Cornell university [1-3].

Following their procedure, we tried Nitrogen doping to single-cell cavities, using furnaces placed in the mechanical center in KEK. After applying EP (Electro Polishing), the cavities were assembled and performances were tested by vertical tests.

EXPERIMENTAL SETUP

Nitrogen-Doping System

Two vacuum furnaces, small and large ones, operated at the KEK Mechanical center were used for Nitrogen doping. Large one, which is normally used for annealing process of 9-cell cavity, is shown in left of Fig. 1. As shown in right of Fig. 1, a cavity was installed into the furnace without a Ti box. Instead flanges were covered with Nb foils. The small furnace is originally used for annealing of single-cell cavities. Both of them are evacuated by diffusion pumps. Cryopumps are not used.

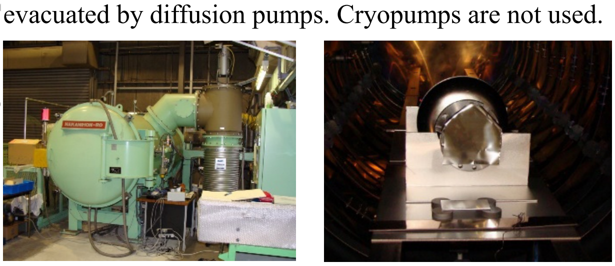

Figure 1: (left) A large furnace, basically used for 9-cell cavity. (right) A cavity installed into the furnace with Nb foil on beampipe flange.

Systems to feed Nitrogen gas were prepared for both furnaces. Pressure was controlled by a manual or a remote valve while monitoring vacuum gauges. Following three nitrogen doping parameters were applied to the cavities, after 3 hours of 800 degree annealing.

1) 3.3 Pa N_2, 2 min + Vacuum, 6 min (FNAL)
2) 5.5 Pa N_2, 20 min + Vacuum, 30 min (Cornell)
3) 2.7 Pa N_2, 20 min + Vacuum, 30 min (J-lab)

Surface Treatment

After nitrogen doping, cavity surface was polished by EP at KEK-STF. Relatively low temperature EP was applied to the cavity. Temperature at the cavity surface was controlled to be less than 25 degree. Typical EP parameters and temperatures are shown in Fig. 2.

After applying total of 3 hour HPR (high pressure rinsing), the cavity was assembled. 48 hours baking of 120 degree was sometimes applied and sometimes not.

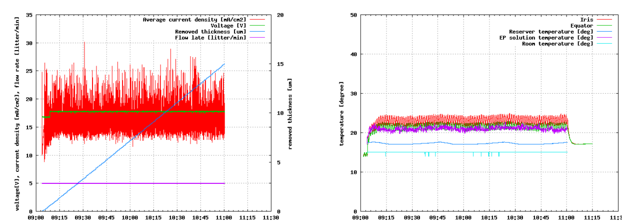

Figure 2: (left) Example of EP parameters. (Right) Temperature measured at the cavity surface during EP process.

Vertical Test System

Vertical tests were carried out at KEK-STF. Figure 3 show typical setup. Total of 44 carbon resisters are used to observe heating location on the cavity surface. Total of 22 Si PIN diode sensors are used to observe X-ray from field emissions. Two calibrated Si sensors are used to measure cavity temperature. Measurements are always done at matching condition using a variable input coupling system.

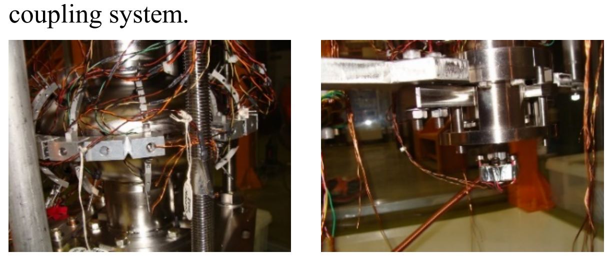

Figure 3: Vertical test setup. (left) Carbon resisters located on the equator part of the cavity. (right) Variable input coupler and Si diode X-ray sensors.

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DOPING WITH PARAMETER (1)

Nitrogen-Doping (3.3 Pa N_2, 2 min + 6 min)

First we tried nitrogen doping with parameter (1). This parameter set is recommended by FNAL and called as "light doping". The small furnace was used. Pattern of temperature and pressure is shown in Fig. 4. After nominal 3 hours annealing procedure, the valve was opened and Nitrogen gas was fed. Pressure was controlled by opening of the manual valve while monitoring vacuum pressure inside the furnace. The vacuum system continued to evacuate during feeding Nitrogen gas.

A TESLA type single-cell cavity made of Tokyo Denkai fine grain Nb was used for this study [4].

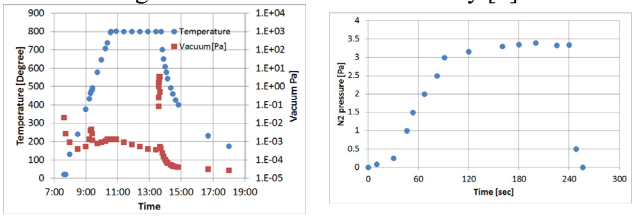

Figure 4: (left) Temperature and pressure of the furnace during N-doping. (right) Enlargement of pressure during Nitrogen filling.

Vertical Test Performance

History of the cavity is shown in Table 1 and results of vertical tests are shown in Fig. 5 and 6. Vertical test results before doping is shown in blue and after doping are shown in green and red. Both of Q-value and Eacc (accelerating gradient) degraded after doping. Estimated residual resistance was 11~14 nΩ. Feature of nitrogen doping, such as improvement of Q-value, could not be seen.

Table 1: History of the Cavity, which is Used for Nitrogen Doping with Parameter (1)

2015/Jan	VT2(Vertical test) before Nitrogen doping
2015/Feb	Nitrogen doping with parameter (1)
2015/Apr	EP(5um), HPR, Assembly → VT3
2015/May	EP(10um), HPR, Assembly, Baking→VT4

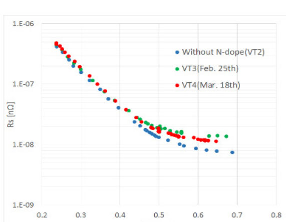

Figure 5: Rs-1/T curve of the cavity, on which Nitrogen doping was applied with parameter (1).

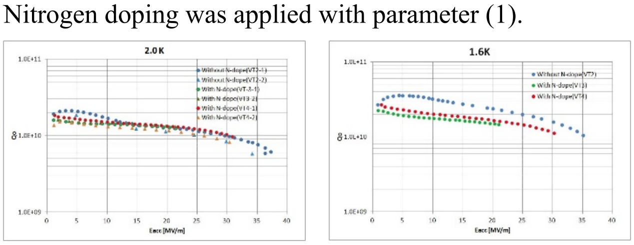

Figure.6: Q-E curve of the cavity at 2.0 K (left) and 1.6 K.

DOPING WITH PARAMETER (2)

Nitrogen-Doping (5.5 Pa N_2, 20min + 30min)

Another doping parameter was tested since the first parameter does not work for our cavity. Second parameter set was originally used at Cornell university and called "deep doping". In this case, 5.5 Pa Nitrogen was kept during 20 min and followed by 30 min post annealing, as shown in Fig. 7. The small furnace was used.

The cavity used for the doping parameter (1) is continuously used for the test with doping parameter (2).

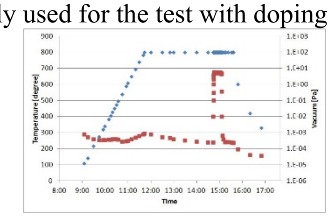

Figure 7: Temperature and pressure of the furnace during N-doping.

Vertical Test Performance

Table 2 shows history of the cavity after nitrogen doping. Vertical test results are shown in Fig. 8 and 9. Blue dots shows results before the doping and other colours shows after the doping. This time also, Q-value and Eacc degraded after the doping. Estimated residual resistance was ~16nΩ. Applying additional EP, performance became better, but could not exceed the one for before the doping.

Table 2: History of the Cavity, which is Used for Nitrogen Doping with Parameter (2)

	Continue from Table 1
2015/Apr	Nitrogen doping with parameter (2)
2015/Apr	EP(15um), HPR, Assembly, Baking→VT5
2015/May	EP(10um), HPR, Assembly, Baking→VT6
2015/Jun	EP(10um), HPR, Assembly → VT7
2015/Aug	EP(10um), HPR, Assembly, Baking→VT8

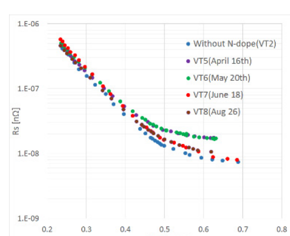

Figure 8: Rs-1/T curve of the cavity, on which Nitrogen doping was applied with parameter (2).

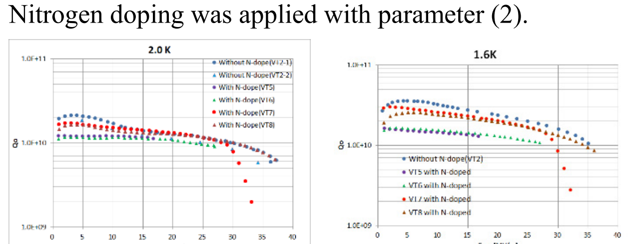

Figure 9: Q-E curve of the cavity at 2.0 K (left) and 1.6 K..

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DOPING WITH PARAMETER (3)

Nitrogen-Doping (2.7 N_2, 20min + 30min)

Third parameter set of nitrogen doping was tested. This parameter set was used by Jefferson lab. This is also deep doping, but Nitrogen pressure is almost half of parameter (2). This time, the large furnace was used for doping. Nitrogen pressure was controlled by using the remote valve. Behaviour of temperature and pressure in the furnace is shown in Fig. 10.

A TESLA type single-cell cavity made of ULVAC fine grain Nb was used for this study [4].

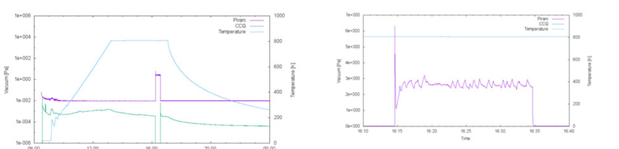

Figure 10: (left) Temperature and pressure of the furnace during N-doping. (right) Enlargement of pressure during Nitrogen filling.

Vertical Test Performance

History of the cavity is shown in Table 3. Results of vertical tests up to third test are shown in Fig. 11 and 12. Blue dots shows results before the doping and others are after the doping. Q-value and Eacc became drastically worsen. Quench field became even less than 15 MV/m. Estimated residual resistance was 20~30 nΩ.

Table 3: History of the Cavity, which is Used for Nitrogen Doping with Parameter (3)

2015/Feb	VT1 before Nitrogen doping
2015/Mar	Nitrogen doping with parameter (3)
2015/Jun	EP(15um), HPR, Assembly, Baking→VT2
2015/Jun	EP(15um), HPR, Assembly, Baking→VT3
2015/Dec	EP(5um), HPR, Assembly→VT4
2016/Mar	HPR, Assembly→VT5 (FNAL)

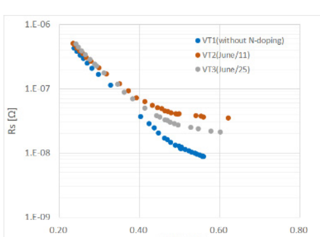

Figure 11: Rs-1/T curve of the cavity, on which Nitrogen doping was applied with parameter (3).

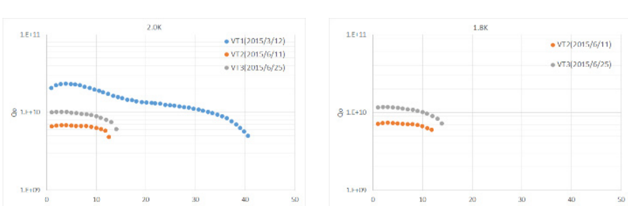

Figure 12: Q-E curve of the cavity at 2.0 K (left) and 1.8 K (right).

VERTICAL TEST AT FNAL

Recently it is known that residual resistance of nitrogen-doped cavities is sensitive to magnetic flux trapping [5]. There is ~10mG of remaining field inside the vertical test cryostat at KEK [6]. Bad Q-values were expected to come from not sophisticated magnetic field circumference.

The cavity doped with parameter (3) was sent to FNAL. Their vertical test dewar has less magnetic field, and furthermore cancellation can be done by coils. Figure 13 shows the results of vertical tests at FNAL, compared with results at KEK. These tests are described in Table 3 as VT4 and VT5. Measurements were done at 2.0 K and 1.6 K. Q-values improved twice. However, it is still too low. Drop of Q-value at high field is caused by field emission.

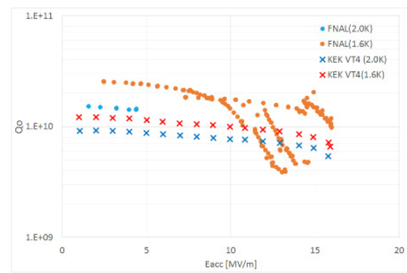

Figure 13: Vertical test results performed at FNAL and KEK, for the cavity doped with parameter (3).

DISCUSSION

At present, it is difficult to understand these results, why Nitrogen doping does not work at KEK. Remaining difference is furnaces and their pumping systems. Typical vacuum level during annealing process at KEK is order of 10^{-4} Pa. This should be higher than other facilities, who use cryopumps. We will check details of data related to vacuum and also conduct surface analysis of Nitrogen-doped Nb samples.

SUMMARY

Nitrogen doping systems were constructed in KEK. Three doping parameters were applied to the single-cell cavities and their performances were investigated by vertical tests. Expected high Q-value was not obtained for all cases. Results were not good, even in good magnetic circumference. The reason of these poor performances is not clear. We will continue investigations.

ACKNOWLEDGEMENT

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