BASIC STUDY FOR DEGRADATION FREE FINAL HORIZONTAL CAVITY ASSEMBLY WITH HIGH GRADIENT NIOBIUM SC CAVITIES

K.Saito†, KEK Accelerator Lab, 1-1 Oho Tsukuba-shi, Ibaraki-ken, Japan

Abstract

We have succeeded to fabricated high gradient sc niobium cavities with Eacc=40 MV/m, and established fabrication method of the high gradient cavity in principle. Next issue is to realize such the excellent performance in a real accelerator. In the TRISTAN sc cavity production, we observed performance degradations after the final horizontal cavity assembly. We have made a basic study to understand which process made the degradations in that final cavity assembly. The breaking vacuum procedure with pure nitrogen after the vertical test is a cause of the degradation. The degradations are not related to particle contamination but reaction between nitrogen and niobium. In this paper, we will present the result of the basic research on the final cavity assembly.

1 INTRODUCTION

We have succeeded in fabrication L-band single cell sc niobium cavities with high gradient Eacc=40 MV/m, and established fabrication method of high gradient cavities in principle. Next issue is to realize such the excellent performance in real accelerator. We have to set sc cavities into horizontal cryomodule before installing them in an accelerator. By the experience of the TRISTAN, we observed performance degradations after the final horizontal cavity assembly. The maximum field gradient was degraded to 7 MV/m in average of the horizontal test from vertical test result of 9.7 MV/m. The Eacc of 7 MV/m seemed to relate with mulutipacting [1]. Qo value in the operation field was reduced to $1.7x10^9$ in average from $2.8x10^9$, and scattered into wide rage. The degradation of Qo value means an additional residual surface resistance of 60 nΩ. In the future applications, sc cavities will be operated with high Qo and high gradient. These degradations are very serious.

Recently we have made a basic study to understand which process made such degradations in the TRISTAN horizontal cavity assembly. In the TRISTAN final cavity assembly procedure, after the evaluation test in the vertical cryostat, the cavity was broken the vacuum with pure nitrogen gas in order to put on RF auxiliaries on the cavity, then to pair two cavities. In this procedure several steps are suspected: opening the vacuum, indium contamination, dust contamination so on. The effect of indium contamination is too serious to explain this degradation as reported in [2]. Here, we concentrated on the vacuum opening effect. As a result of this study, we made clear that the breaking cavity vacuum with pure nitrogen was the cause of the degradation. The degradations are not related to particle contamination but reaction between nitrogen and niobium. In this paper, we will present the result of the basic research on the final cavity assembly.

2 EXPERIMENT

In this study, at first a baseline performance was measured in vertical cryostat, then the cavity is proceed at room temperature: gas exposure or baking so on. Then the cavity is made cold test again and the resultant performance is compared with the baseline. The preparation for the baseline test is done by the KEK standard procedure: EP(50μm), HPR, 120°C bake for 2 days during vacuum venting. In Fig. 1 our vacuum evacuation system is presented. This system is used routinely in our R&D of L-band superconducting cavities and maintained very carefully. The vacuum evacuation system is classical. It uses the combination of a rotary forward pump with oil trapping on the head and a molecular turbo pump with evacuation speed of 50cc/sec for primary venting. These pumps do cavity bake. After baking the venting is switched to ion pump. The typical vacuum pressure is $1x10^{-9}$ torr. An oil free clean pumping system is not used. Introducing a gas into the cavity, it is passed a filter with molecular mesh size (MLLIPORE) through the inlet valve (V1). The gas inlet speed is about 900 cc/min. After venting, cavity is tested sealing the vacuum by the metal valve (V6).

3 RESULTS

3.1 Argon gas exposure effect

In this study, dust contamination issue is not always swept off even using filter when we break cavity vacuum. Therefore we made sure the problem with this venting system. However, to make such an experiment the

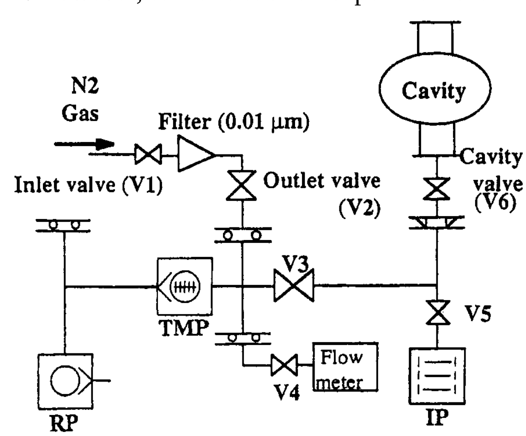

Figure 1: Vacuum evacuation system

†ksaito@post.kek.jp

introduced gas must have no influence on cavity performance, otherwise confusing will happen. Inert argon gas is the most conventional candidate. After a baseline test, the cavity was exposed to argon gas (99.9999%) for 10 days, and then made a cold test again. Bake was not carried out after argon gas exposure. The result is shown in Fig.2. Argon gas exposure made a better performance, which might be a argon gas discharge cleaning effect because we have no baking during venting after the exposure and the cavity is cold tested sealing the vacuum. Anyway, the result, which argon gas has no influence on sc cavity performance is very clear.

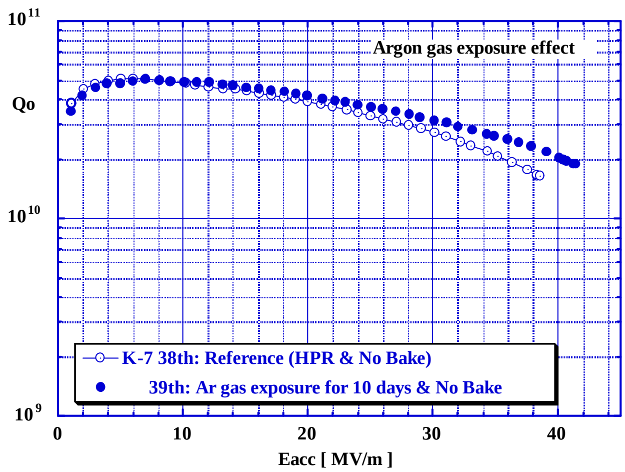

Figure 2 : Argon gas exposure effect

3.2 Opening vacuum effect

Since we confirmed argon gas has no effect on sc cavity performance, as a next step we investigated the dust contamination effect when cavity vacuum is broken using the gas. After above test, the cavity is connected to the venting system and the vacuum was broken with argon gas. The procedure including connecting vacuum, introducing the gas, venting cavity vacuum was repeated five times, and then the cavity was cold tested. The result is seen in Fig.3. These operations have no effect at all on the excellent cavity performance.

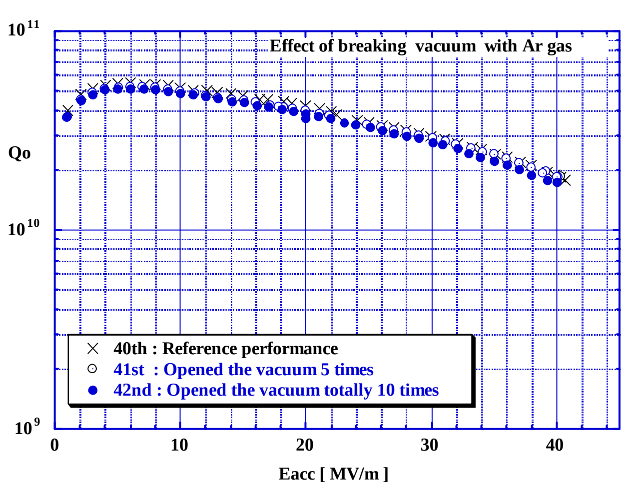

Figure 3: Effect of braking vacuum with argon gas

To see the reproducibility the breaking cavity vacuum procedure was repeated five times more and then the cavity was cold tested again. As seen in Fig. 3, the performance did not change. From this experiment we believe the dust contamination issue is not contained in following experimental results.

3.3 Nitrogen gas exposure effect

1) The case without bake after nitrogen gas exposure

This kind of experiment was repeated many times using several different cavities. Very pure nitrogen gas from a cold evaporator was used in this experiment. Results are summarized with K-7 cavity in Fig.4. The results are all for one-day nitrogen gas exposure not followed by bake. The baseline performance is plotted by solid line with a marker. For one pair data the same markers are used but opened maker for the baseline and filled one for after the nitrogen exposure. The sc cavity performance is very scattered in this case. By Dr. R. Palodi's simulation [3], one point multipacting is foreseen at following levels:

$$Hp[Gauss]/f[MHz] = 0.28/n \qquad (1).$$

Here, Hp is the surface peak magnetic field and f is the resonant RF frequency of a cavity, n is a positive integer. For our cavity the ratio Hp/Eacc is 43.8 [Gauss m/MV] and f=1300 MHz. This formula suggests the multipacting at Eacc=8.3 MV/m. In the worst cases (▲, ■) of Fig. 4, the performance will be limited by the one point 1st order multipacting. Two-point multipacting also appears after the exposure. It is foreseen at the following levels [4]:

$$Hp[Gauss]/f[MHz] = 0.6/(2n-1) \qquad (2).$$

In our case it is foreseen at Eacc=18 MV/m. One can see it in Fig.5. This is a result of the nitrogen exposure for 3 days not followed by baking. At first stage in taking excitation curve one point multipacting appeared. After it was processed out, then two point multipacting levels appeared. This processing level was also finally processed out, and the field was quenched at 27.3 MV/m. Thus, nitrogen gas exposure makes a harmful influence for only one day, if baking is not followed in the venting after the exposure.

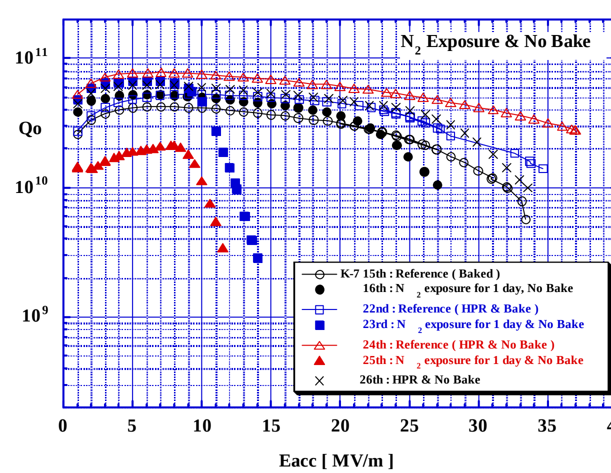

Figure 4: Effect of nitrogen exposure not followed by baking

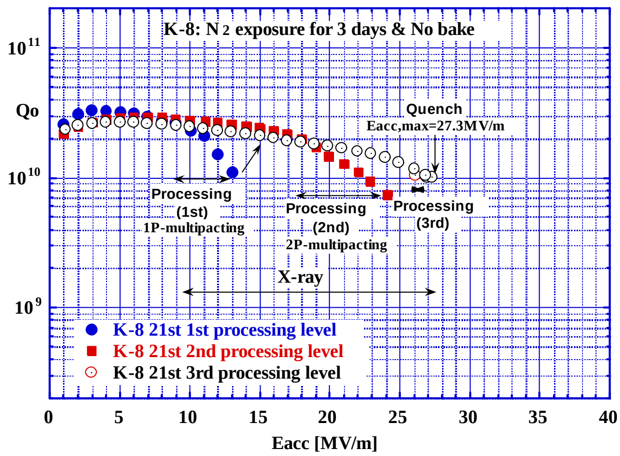

Figure 5: Appearance of two point multipacting

2) The case of nitrogen gas exposure followed by baking

On the other hand, if we bake cavity during evacuation after nitrogen gas exposure, the degradation is much relaxed. Experimental results are summarized in Fig.6. With K-8 cavity, exposing time was prolonged by every one day totally up to 3 days. For every exposing, baking was carried out at 120°C for 2 days. Any degradation is not observed up to 3 days. On the other hand, K-11 cavity was exposed nitrogen gas directly for 4 days and baked. A obvious degradation started (see ▽ , ▼). Baking is not effective any more for 4 days exposure. It has been confirmed by similar experiments with other cavities.

3.3 Effective baking temperature against the degradation

Baking is effective against the degradation of nitrogen gas exposure. A question is the effective temperature. Fig.7 is a result of the experiment. Baking effect was investigated for one-day nitrogen gas exposure. The bake at temperature of 70°C for 2 days kept still a good performance but the degradation started at 60°C. The

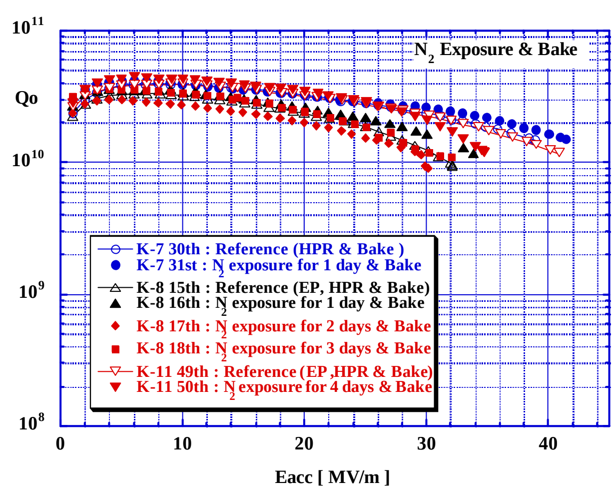

Figure 6: Baking effect against degradation of nitrogen exposure.

degradation occurred once is not recovered by additional baking at 70°C, even at 120°C. Only HPR could eliminate the degradation. To see the reproducibility we baked again at 55°C after the nitrogen gas exposure for one day, and then the degradation occurred again.

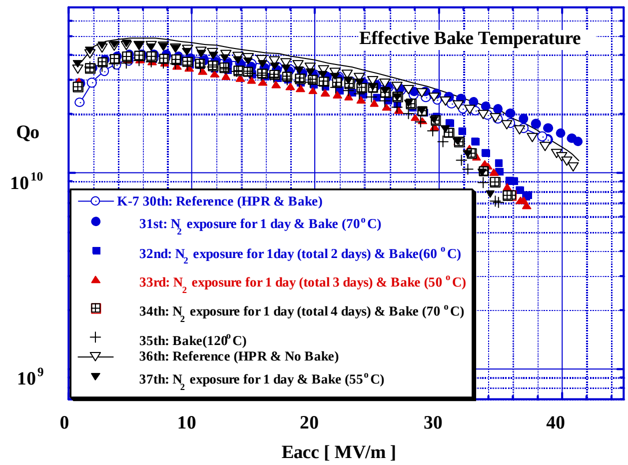

Figure 7: The effective baking temperature

3.4 Air exposure effect

Recently L.Lulje et al. at DESY have found the electropolished niobium cavity surface has no bad effect against a long-term air exposure followed by HPR, e.g. for 2 months. This new finding was also reconfirmed in our experiment. The result is presented in Fig.8. The baseline performance is for argon gas exposure (see in Fig. 2). Here, considering a period of horizontal final cavity assembly procedure, the exposed term is set at 10 days. The cavity was disassembled after the baseline measurement, then rinsed by HPR at 85kg/cm2 for 1 hr, dried in the KEK class 10 clean-room for one nigh, then assembled and sealed the air and holed for 10 days, then evacuated without baking and cold tested in the vertical cryostat. The wonderful performance is no changed by this procedure. The inverse order of HPR with air exposure: after 10 days air exposure, then HPR, is also no effect on the cavity performance (not presented in Fig. 8.

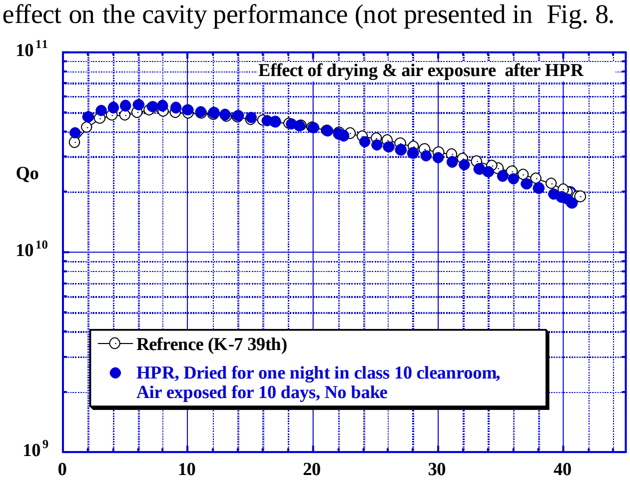

Figure 8: Effect of air exposure followed by HPR

4 DISCUSSIONS

4.1 Scenario of the degradation

From the experimental results described above, we can understand which procedure made the degradation in the TRISTAN horizontal cavity assembly. The use of pure nitrogen gas in braking cavity vacuum after vertical test occurred an enhancement of secondary emission coefficient and resulted in serious two-point 1st order multipacting. It limited the field at Eacc=7 MV/m. Really at 508 MHz, the formula (2) calculates the two-point first mutipacting at 7MV/m.

From a common sense, nitrogen gas makes a bad influence on sc cavity performance is an unbelievable result. A question is why nitrogen acts badly with niobium at such a room temperature. Our scenario about the degradation is described in Fig. 9:

1) Introducing nitrogen gas to the clean niobium surface, nitrogen molecules get quickly in physical adsorption on niobium surface,
2) then a little bit of the molecules changes locally to chemical adsorption by quantum fluctuation effect or quantum tunnelling effect, and come to more close niobium surface,
3) the molecule transits a lower state, then cuts the molecular bond by the transition energy, and results in radical free nitrogen atoms,
4) the active nitrogen atoms react with niobium, and get niobium nitride,
5) the locally generated niobium nitride enhances the secondary emission coefficient and multipacting become more serious.

Recently the secondary emission coefficient of niobium surface has been evaluated by Dr. R.Noer at KEK corresponding to the TRISTAN or the KEKB preparation procedure, of which result shows a rather enhancement in the secondary emission coefficient after nitrogen gas exposure [5]. Our speculation is very consistent with the result.

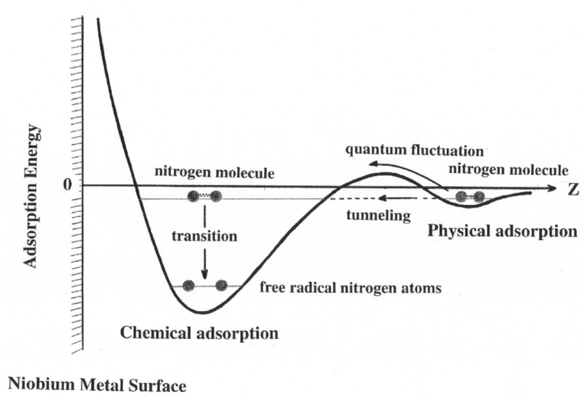

Figure 9: Process of the reaction between nitrogen and niobium

4.2 Degradation free final assembly

From this basic study, we get a guideline about degradation free final cavity assembly: use pure argon gas instead of pure nitrogen gas when one breaks the cavity vacuum after vertical test. Other question is the dust contaminations during cavity disassembling after the vertical test or from RF auxiliaries to be put on the cavity: high power input coupler, HOM couplers so on. The former is rather simply solved by changing indium sealing to aluminium sealing [6]. To remove the latter problem, it is necessary to make auxiliaries as clean as cavities.

5 CONCLUSIONS

Here, we summarize the experimental conclusion about degradation free horizontal cavity assembly.

1) The performance degradation seen in the TRISTAN horizontal cavity assembly is explained by the nitrogen gas breaking the cavity vacuum.
2) Argon gas has no bad effect on sc cavity performance. Use pure argon gas is strongly recommended.
3) Present filter technology for gas handling is fine for the 40 MV/m high gradient cavities.

6 REFERENCES

[1] K.Saito et al.,"R7D of Superconducting Cavities at KEK", Proc. of the 4th Workshop on RF Superconductivity, August 14 – 18, 1989, Tsukuba, Japan, pp.635 – 694.

[2] K.Saito et al., " Basic Research on Horizontal Assembly Method of SC Cavities with High Q and High Gradient", Proc. of the XIX International LINAC Conference, August 23 – 28, 1998, Chicago, Ilinois, USA, pp.294 – 296.

[3] R.Parodi, in the presentation of the advisory committee about SNS cavity design in Jlab, March 2000.

[4] K.Saito, "Experimental Formula of the On-set Level of Two-point Multipacting Over the RF Frequency Range 500MHz to 1300 MHz", in this workshop.

[5] R.Noer, in this workshop.

[6] K.Saito et al., "Stainless Flange Bonded to Niobium Tube and Simple Aluminium Sealing", in this workshop.