Stable Performance of 508 MHz Superconducting RF Cavities for KEKB

K.Asano, T.Furuya, S.Mitsunobu, T.Tajima and T.Takahashi
National Laboratory for High Energy Physics (KEK)
1-1, Oho, Tsukuba, Ibaraki, 305, Japan

We measured the performance of 508 MHz superconducting Nb cavities for KEK B factory (KEKB). After H_2O_2 rinsing, the cavity showed the maximum accelerating gradient, Eacc = 12.4 MV/m, but air exposure after the measurement enhanced the field emission at the higher gradient than 7 MV/m . Ozonized ultrapure water rinsing can form the stable and clean Nb_2O_5 layers, which act as the passive state to suppress the electron emissions, and to reduce sticking coefficient of gas molecules and photon stimulated gas desorption yield of synchrotron radiation. The cavity performance degraded by air exposure was recovered and the field emission was surpress greatly by ozonized water rinsing. The ozonized water rinsed cavity showed Eacc=14.4 MV/m. The air exposure up to for 4 days at 1 atm. did not show the degradation when it was compared with the 1st measurement of the ozonized water rinsed cavity. The effect of compositions of oxide layers without carbon and with less Nb hydroxides and NbO_X on stable performance are discussed.

1.Introduction

The use of superconducting (SC) RF cavities in a high current machine has the advantage because the higher accelerating gradients per cavity (5-6 MV/m with beam at the present time) can be used and number of the cavity cells can be decreased. Moreover, the SC cavities can have a lower impedance because of the larger permissible beam holes. Therefore, because there are fewer cavities of lower impedance, the threshold current for beam instabilities is increased.[1] With high current cavities, the power to be coupled to the beam is quite high. The accelerating gradient of most SC cavities are limited by the field emission from the high electric field regions of the cavity surfaces.

For KEKB, the intensity of the synchrotron radiation from high current beams in the bending section is two orders of magnitude higher than that of the TRISTAN MR.[2] The 508 MHz single cell SC cavity with large beam pipes for KEKB has been designed to propagate out and damp the HOM modes by the ferrite inside the beam pipes at room temperature. The cavity shape is also different from the TRISTAN 5-cell type. The beam test of 500 mA in TRISTAN AR is scheduled in 1996. If the RF trip of the SC cavities in TRISTAN MR are due to the discharging in the cavities, which is triggered by synchrotron radiation, the photon stimulated gas desorption (PSD) yield in addition to sticking coefficient of gas molecules especially hydrogen gas on Nb surfaces must be decreased in order to operate the SC cavities stably for long time with high current beams. The ozonized ultrapure water treatment can produce clean, stable, dense, thin, and amorphous Nb_2O_5 layers on Nb surfaces, which act as the passive state to suppress the electron emission and PSD from the active Nb surfaces. [3] We applied the ozone treatment technology developed for ULSI Si wafer [4] to the large area final rinsing ($10800\ cm^2$) of our electropolished Nb SC cavity for the first time in the world.

2.Effects of Nb Oxide Layers Formed by Ozonized Ultrapure Water Rinsing on the Cavity Performance

We tried the ozonized water as a final rinsing of the three 508 MHz SC Nb cavities for KEKB using ultrapure water including ozone of 3 ppm at a flow rate of 5 l/min for 20 min after 3 times rinsing. The stable oxide layers formed by ozone treatment improved the gas desorption characteristics induced by synchrotron radiation with critical energy of 26 keV.[5]

Fig.1shows the Q_0- Eacc curves of the 1atm air exposed cavity for 23 hours (2nd) and 69 hours (3rd) after the 1st measurement of ozonized ultrapure water rinsed cavity.The cavity performance is not degraded by air exposure for about total 4 days.

The ozone rinsing has stronger and cleaner effect than H_2O_2 rinsing. The rates of Nb hydroxides and the lower oxides ($NbO + NbO_2$) which are weak superconductors in the surface oxides layers were decreased by ozone rinsing compared with those of H_2O_2 rinsing as shown in **table 1.** **Fig.**2 shows the comparison of the effect of air exposures for 4 days on cavity performances rinsed by ozonized water and H_2O_2. The clean and stable oxides layers (Nb_2O_5 40A) [3] with less Nb hydroxides and NbO_X on Nb surfaces formed by ozonized water can keep the higher cavity performance even after air exposures for 4 days. The reason is that Nb_2O_5 layers are negligible, whereas dielectric losses due to particulate contamination, adsorbates like hydrocarbons can significantly enhance the residual resistance and field emission. The surface work function is also increased by clean oxide layers.

CO, CO_2, CH_4 and other hydrocarbons including carbon , and H_2O desorbed by synchrotron radiation in e^+e^- strage rings have influence on beam lifetime and also on the long time operation of SC cavities.

Fig.3 shows the comparison of the cavity performance by ozonized water rinsing and H_2O_2 rinsing. The Q_0 values and Eacc without RF aging for ozonized water rinsed cavity are higher than those for the H_2O_2 rinsed cavity with RF aging. The decreased rate of weak superconductors (NbO_X) in the surface oxides layers raised the Q_0 values at all field ranges for the ozone rinsed cavity. The clean oxide layers without carbon remove emission souces and reduce secondary electron emission. Consequently, the RF aging time to get higher electric fields was decreased after ozone rinsing.The Eacc was 14.4 MV/m for the ozone rined cavity and 12.4 MV/m for the H_2O_2 rinsed cavity.

Improvement from 9.8 MV/m to 13.6 MV/m was obtained only by ozonized water rinsing for another cavity including Nb, Cu, stainless steel, In ribbons and Al_2O_3 ceramics, as shown in **Fig.4.** Ozone gas exposure to the cavity system with couplers, windows, extended beam pipes and dampers installed in a strage ring will recover the performance of the cavity with some degradation after long time operation.

The cavity (III) for a beam test in TRISTAN AR in 1996 was measured 3 times in a vertical cryostat. The maximum Eacc was 13.1 MV/m after grinding the equator welding regions 2 times and surface treatments to remove the heating spots on the EBW seam. Some grinding traces were observed on the inner surfaces of the cavity before the final electropolishing. The total removed thickness was 80 um by electropolishing 3 times after annealing at 700°C . This cavity (III) showed the lower Q_0 values than those for the other two cavities.[6] The results of the horizontal test will be published elsewhere.

3.Summary

We found that the compositions of Nb_2O_5 layers without carbon and with less Nb hydroxides and NbO_X on the Nb surfaces were very important to get stable performances of the SC cavity. Ozonized ultrapure water rinsing is effective to form such stable and clean Nb_2O_5 layers.

In order to operate the SC cavities at about 6 MV/m without RF trips for long time with high current beams for KEKB, the photon-stimulated gas desorption by synchrotron radiation which will induce the discharging in the cavities or input couplers, and sticking coefficients of gas molecules on Nb surfaces which will decide a period to warm up the cavities will be remarkably reduced by this ozone treatments. This result will be important for both crab cavities and accelerating cavities for KEKB. It is necessary to study the interaction of these surfaces of SC cavities with high current beams.

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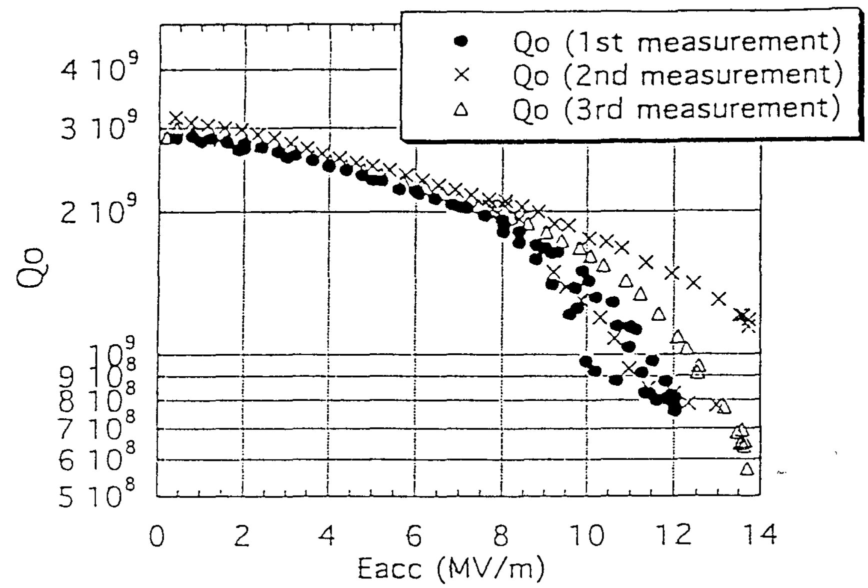

Fig. 1 Stable performance of the 508 MHz Nb cavity rinsed by ozonized ultrapure water. The 2nd and 3rd tests were measured after 1 atm air exposures for 23 hours and 69 hours, respectively.

Table1 The comparison of weak superconductors ($NbO+NbO_2$) and hydrides of Nb for ozonized ultrapure water rinsed and H_2O_2 rinsed Nb surfaces after electropolishing

	$\frac{NbO_x}{Nb + NbO_x}$	$\frac{Nb(OH)_x}{Nb_xO_y + Nb(OH)_x}$
EP + O_3	0.9 %	24 %
EP + H_2O_2	4.0 %	53 %

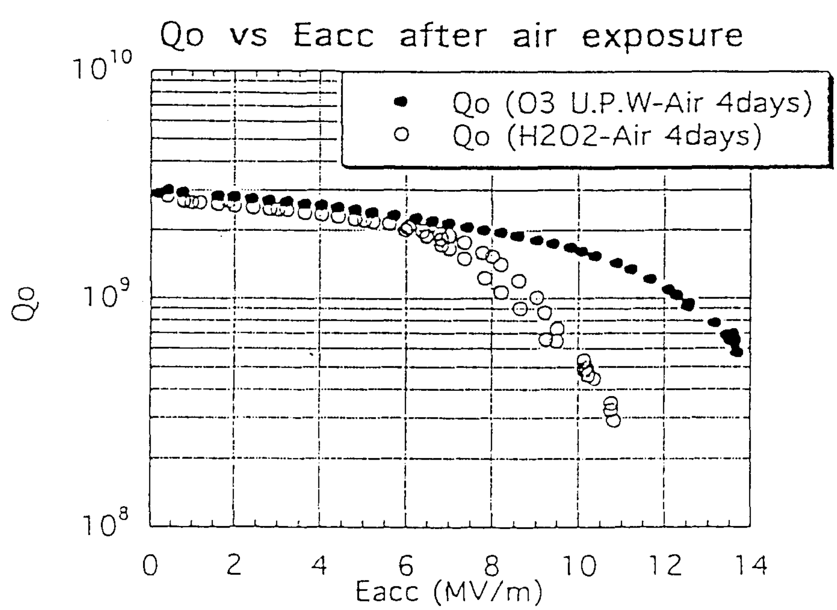

Fig. 2 The comparison of the effect of air exposures on cavity performance rinsed by ozonized water and H_2O_2. The clean and stable oxide layers on Nb surfaces formed by ozonized water can keep the cavity performance after air exposures.

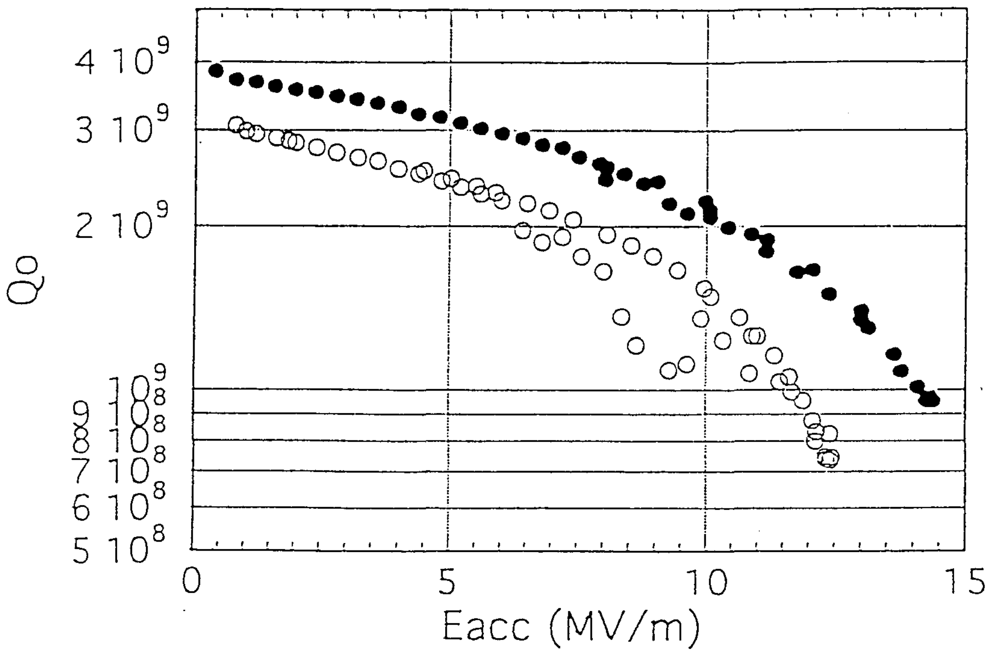

Fig. 3 The comparison of the cavity performance between by ozonized water rinsing and H_2O_2 rinsing. The Q_0 values and E_{acc}^{max} without RF aging for ozonized water rinsed cavity are higher than those for the H_2O_2 rinsed cavity with RF aging.

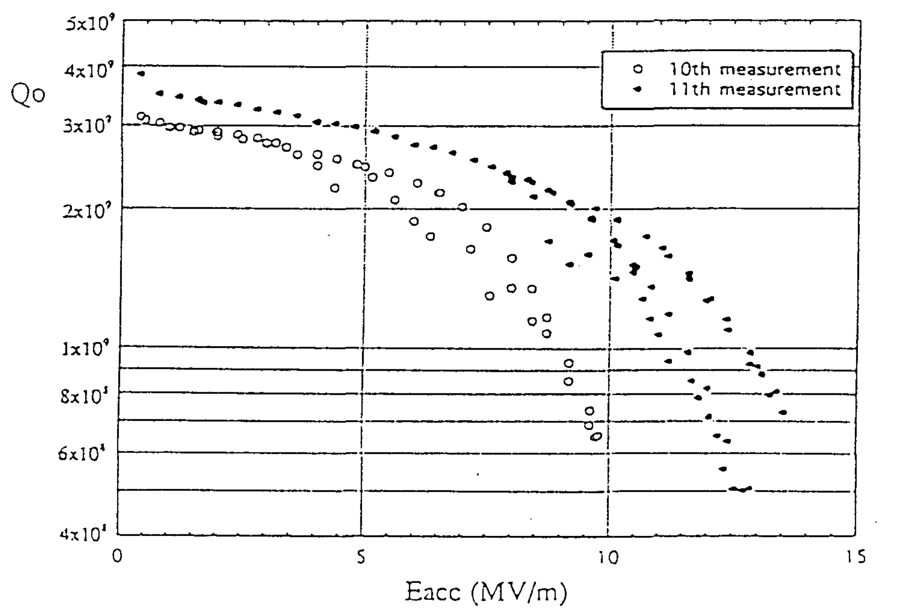

Fig. 4 Performance recovery of the 508 MHz Nb cavity with Cu plated SUS extended beam pipes, SUS flanges sealed by In ribbons and Al_2O_3 ceramics. 10th and 11th measurements show before and after ozonized ultrapure water rinsing, respectively.