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NITROGEN DOPING STUDY WITH 1.3 GHz SINGLE CELL SUPERCONDUCTING CAVITIES *

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Abstract

Nitrogen doping studies were carried out at Peking University. A series of 1.3 GHz single cell cavities fabricated with OTIC large grain niobium material were annealed and doped in the furnace of Peking University, and electropolished by a simple EP device. Light doping recipe and heavy doping recipe are both adopted for comparison. The results and analysis are presented in this paper.

INTRODUCTION

Impurity doping has been a hot topic in recent years to increase quality factor Q_0 of superconducting cavity. Especially for nitrogen doping, the effect is much more obviously. Nitrogen doping was discovered by FNAL in 2013 [1], and developed by FNAL, Jlab and Cornell University in the next few years [2]. There are two kinds of doping recipes, light doping and heavy doping. For light doping, the cavity is exposed in nitrogen for 2 minutes and annealed in vacuum for 6 minutes. While for heavy doping, the cavity is exposed in nitrogen for 20 minutes and annealed in vacuum for 30 minutes. Nitrogen doping studies were carried out at Peking University in recent years with 1.3 GHz single cell cavities. The cavities were fabricated with Ningxia OTIC large grain material. After mechanical fabrication, the cavities were eched 250 μm by buffered chemical polishing (BCP) to remove the surface mechanical damage layer. After high pressure rinsing (HPR), the cavities are annealed at 800 °C for 3 hours and nitrogen doping in the high temperature furnace. Following by slightly EP and HPR, the cavities were assembled in clean room and tested in vertical test system.

EXPERIMENTAL SETUP

Nitrogen Doping Furnace

After BCP and HPR, the cavities were annealed and doped in the furnace of Peking University, see Figure 1. The ultimate vacuum of the furnace is 1×10^{-5} Pa. Several 1.3 GHz single cell cavities can be annealed at the same time in the chamber. The cavities were supported by niobium holders and laid on the niobium plate.

Figure 1: High temperature furnace for cavities annealing and three single cell cavities in the chamber before annealing.

The chamber of the furnace is evacuated by cryopump and forepump, including roots pump and screw pump. In operation, the vacuum is reached to 2×10^{-4} Pa from atmospheric pressure in 1 hour. In nitrogen doping procedure, the nitrogen gas was evaporated from liquid nitrogen tank.

Surface Treatment

Figure 2a: Simple EP device.

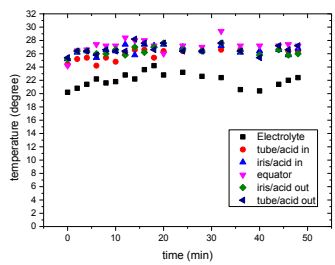

Figure 2b: The temperature in different places of the cavity during the process of EP.

After nitrogen doping, the cavity surface was electropolished with a simple EP device, see Figure 2a. The temperature of electrolyte was controlled under 25 °C. The temperature of the cavity was around 27 °C. Figure 2b shows the temperature in different places of the cavity. The rotation speed was about 1 rpm, and the acid flow rate was about 3 l/min. After EP, high pressure rinsing was used to clean the residual acid at the cavity surface.

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Vertical Test System

Vertical tests were carried out at the vertical test system at Peking University. Two single cell cavities were assembled together and tested at the same time, see Figure 3a and Figure 3b. The two cavities were connected by bellows and evacuated in slow rate by molecular pump to avoid turbulence. The antenna can be adjusted by stepping motor to achieve optimum coupling. Since nitrogen doped cavities are sensitive to trapping magnetic flux, fast cooling should be adopted to reduce the influence of magnetic flux [3]. The cavities were cooled down as fast as possible through critical temperature Tc. The temperature variation at the cavity equator during the cooling down is shown in Figure 4. The speed of cooling down is about 18.3 mK/s through transition temperature.

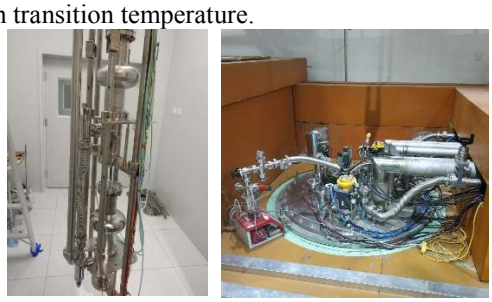

Figure 3a: Two single cell cavities were assembled together. 3b: Vertical test system at Peking University.

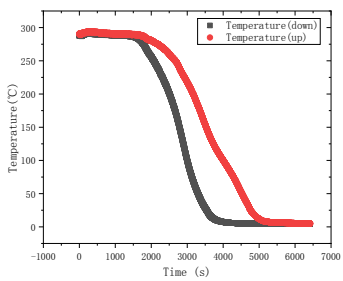

Figure 4: The temperature variation during the cooling down. Red and black curves are the temperatures at the equators of the top and bottom cavity, respectively.

NITROGEN DOPING AND VERTICAL TEST

Heavy Doping Recipe

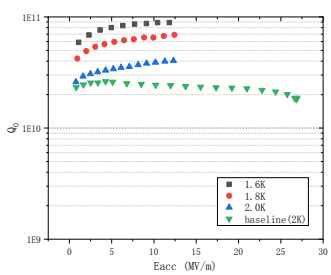

Figure 5: Q_0 vs Eacc for the large grain cavity LG1 after nitrogen doping.

The 1.3 GHz single cell large grain cavity LG1 was nitrogen doped with heavy doping recipe. Nitrogen was injected for 20 minutes and annealing in vacuum for 30 minutes, followed by EP of 15 μm. The details of treatment and results of vertical test are presented in [4]. The Q_0 reaches 4×10^{10} at 2.0K, 7×10^{10} at 1.8K and 9×10^{10} at 1.6K respectively when Eacc is around 12 MV/m, see figure 5. The Q_0 improvement and anti-Q-slope are obvious. However, the maximum Eacc is lower than 13MV/m. The main reason is probably that the surface of the cavity was contaminated during EP process with the simple EP device.

Light Doping Recipe

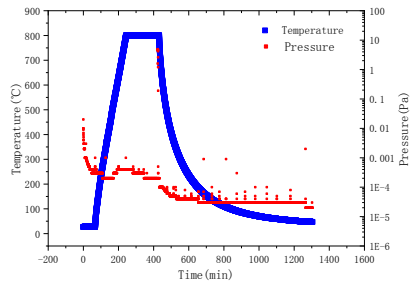

Figure 6a: Variation of temperature and pressure during high temperature treatment.

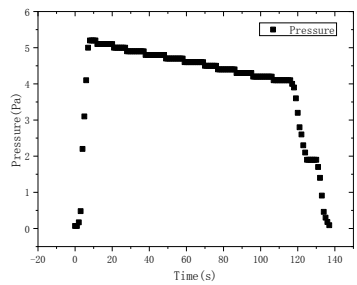

Figure 6b: Nitrogen pressure fluctuation during light N-doping process.

The Eacc is not high for heavy doping recipe. For comparison, we carried out light doping study in order to achieve high Q at higher accelerating gradient. Two 1.3 GHz single cell large grain cavities LG2 and LG3 were prepared. LG2 was light nitrogen doped and LG3 serves as the baseline cavity. Cavity LG2 was nitrogen doped for 2 minutes and annealed in vacuum for 6 minutes. The variations of temperature and pressure during doping and annealing are shown in Figure 6. Nitrogen gas was injected in the furnace chamber after 3 hours annealing. The pressure of nitrogen was about 4.5 Pa. After doping, the cavity was polished 6 μm by EP. As for baseline cavity, LG3 was treated nearly the same with LG2, except for nitrogen injection. LG3 was annealed for 3 hours and cooled down in vacuum, then followed by 6 μm EP and HPR. After treatment, two cavities were assembled together and tested at the same time. The results of vertical test are shown in Figure 7.

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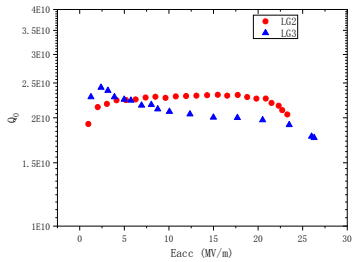

Figure 7: Q_0 vs Eacc at 2.0K for the large grain cavity LG2 and LG3.

After standard treatment, cavity LG3 behaved normally. The Eacc is 26 MV/m and the quality factor Q_0 is more than 2×10^{10} below 20 MV/m at 2 K temperature. For nitrogen doped cavity LG2, the Eacc is 24 MV/m and the quality factor Q_0 is 2.3×10^{10} at 20 MV/m. The Q_0 of light doping cavity LG2 is improved in comparison with cavity LG3. The anti-Q-slope performance is not as good as heavy doping cavity LG1. This might be due to too much trapped magnetic flux in LG2, which increases the residual resistance. Although the BCS resistance decreases with accelerating field because of nitrogen doping, the anti-Q-slope performance is not dramatically. More researches will be carried out for the next step.

SUMMARY

Studies of nitrogen doping with 1.3 GHz single cell cavities have been carried out at Peking University. Light doping recipe and heavy doping recipe are both adopted for comparison. For heavy doping recipe, the Q_0 improvement and anti-Q-slope are obvious in contrast to baseline. But the accelerating gradient is not high. For light doping recipe, accelerating gradient is as much as baseline cavity, reaching 24MV/m. However, the anti-Q-slope performance is not as good as heavy doping recipe. The main reason is probably that too much magnetic flux is trapped and residual resistance of nitrogen doping cavity is much higher. More experiments will be carried out and high Q_0 at high field is expected.

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REFERENCES

[1] Grassellino A, Romanenko A, Sergatskov D et al 2013 Supercon. Sci. and Tech. 26(10) 102001

[2] Grassellino A, Romanenko A, Posen S et al N Doping: Progress in Development and Understanding, in *Proc. 17th Int. Conf. RF Superconductivity (SRF'15)*, Whistler, Canada, Sep. 2015, paper MOBA06, pp.48.

[3] Romanenko A, Grassellino A, Melnychuk O *et al.*, 2014 *Journal of Applied Physics* 115(18) 184903

[4] Chen S, Hao J K, Lin L, *et al.*, Successful Nitrogen Doping of 1.3 GHz Single Cell Superconducting Radio-Frequency Cavities[J]. *Chinese Physics Letter*s, 2018, 35(3): 037401.