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THE CRYOSTAT RESULTS OF CARBON CONTAMINATION AND PLASMA CLEANING FOR THE FIELD EMISSION ON THE SRF CAVITY*

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Abstract

The field emission effect is the mainly limitation for the operating of SRF cavities in higher gradient with stability. The hydrocarbon contaminant was proved one of the field emitter sources that presented on the cavity inner surface and induced the degradation of work function. In addition, the plasma cleaning was an effective method to solve this issue [1-2]. However, the mechanism of hydrocarbon contamination on the niobium surface was still unclear. In this paper, the experiments were conducted to evaluate the impact of the carbon contaminants and plasma cleaning on the performance of SRF cavity.

INTRODUCTION

Mechanism of contamination was classified by the bonding strength that between the carbon components and niobium surface. Thus, the weaker and stronger bonding strength were taken into consideration.

For the weaker bonding strength condition, the cryogenic adsorption was the mainly contribution because the SRF cavities were acted as the cryogenic pumps at liquid helium temperature region that will lead to the adsorption of residual gas and contaminants. These cryogenic contaminants maybe desorb from the inner surface by warming up cavity to higher temperature.

However, the field emission cannot be relieved in the most instances by thermal cycle the SRF system to room temperature and pump the residual gas out. This situation indicated that there was a stronger bonding strength between hydrocarbon contamination and niobium surface, and the NbC was detected by XPS on outmost surface of niobium samples in our previous study [3]. Therefore, the carbon contamination by chemical deposition with stronger bonding strength was assumed as the one of reason for field emission. In addition, oxygen activation plasma cleaning might be the efficient solution for this kind of contamination.

EXPERIMENT SETUP

A HWR015 cavity, which developed at IMP for CiADS project, was used for experiment study. The standard surface treatment was completed for this cavity including the BCP with 150 um, annealing treatment under temperature of 650 ºC for 10 hours, light BCP for 30 um and HPR by deionized water at class 100 clean room. Then, the performance was tested as the experiment base line in the vertical Dewar.

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The methane was employed as the hydrocarbon contaminants to pollute SRF cavity. Firstly, the methane was inlet into the cavity at vertical test stand to make a cryogenic adsorption layer on the inner surface of the cavity. For the strong strength condition, the chemical deposited dirty layer of carbon contamination was produced by using of Ar/CH_4 plasma with PECVD method. Finally, carbon deposited cavity was treated by the Ar/O2 plasma to remove the contamination.

Cryogenic Adsorption

The schematic diagram of experiment for cryogenic adsorption was shown in the Figure 1 and the experimental procedure as follows:

- Vertical test at 4K after the standard surface treatment to obtain the base line.
- Warm up the system to room temperature, then inlet methane into cavity and the vacuum was 9.2 Pa.
- Close the valve II to isolate cavity from pump system, and cooling down Dewar to 4 K.
- Two tests were conducted at 3 and 24 hours after cooling to 4 K.
- Warm up the Dewar to room temperature and open the valves to pump the methane out from the cavity.
- Re-cooling down to 4 K after the methane pump out and test the performance for fourth time.

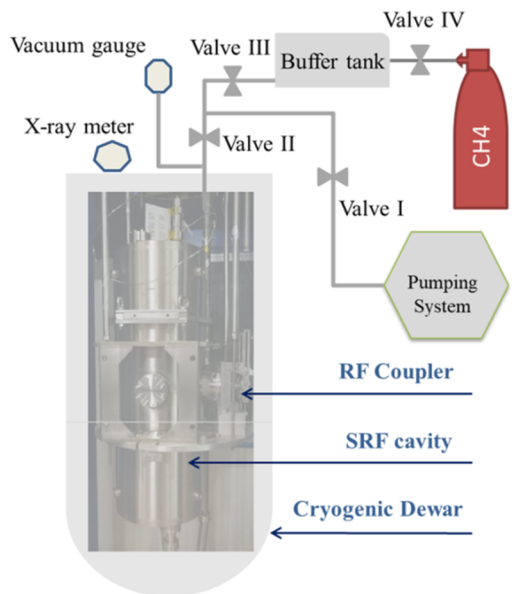

Figure 1: schematic diagram of experiment for cryogenic adsorption.

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Chemical Deposition

The plasma ignition technique of argon and oxygen mixed gas in the HWR cavity was developed in the previous investigation [4]. The 3 precepts of methane was mixed with argon to instead of oxygen and ignition parameters for Ar/CH_4 plasma, such as RF power and gas pressure were similar with plasma cleaning processing. The active species of CH_3, CH, C_2H_2 and so on were normally generated with the presence of methane in the inert gas plasma. In the meantime, these active hydrocarbon species were affinitive for the metal surface to induce the carbon chemical deposition [5]. In this study, about 8 mins of total effective Ar/CH_4 plasma was ignited to make the carbon deposited layers on the inner surface cavity.

RF Condition and In-situ Plasma Cleaning

The traditional RF condition was carried out for the carbon deposited HWR015 to eliminate field emission, but it was not effective, the detail results see the next section. Therefore, the in-situ Ar/O_2 plasma was utilized to remove the carbon layers, and the technique parameters were duplicated from the previously study in the reference [4]. The RF power was about 60-80 W, the plasma pulse on and off time was 10-30 seconds and 2-5 mins respectively, and the total efficient cleaning time was 90mins.

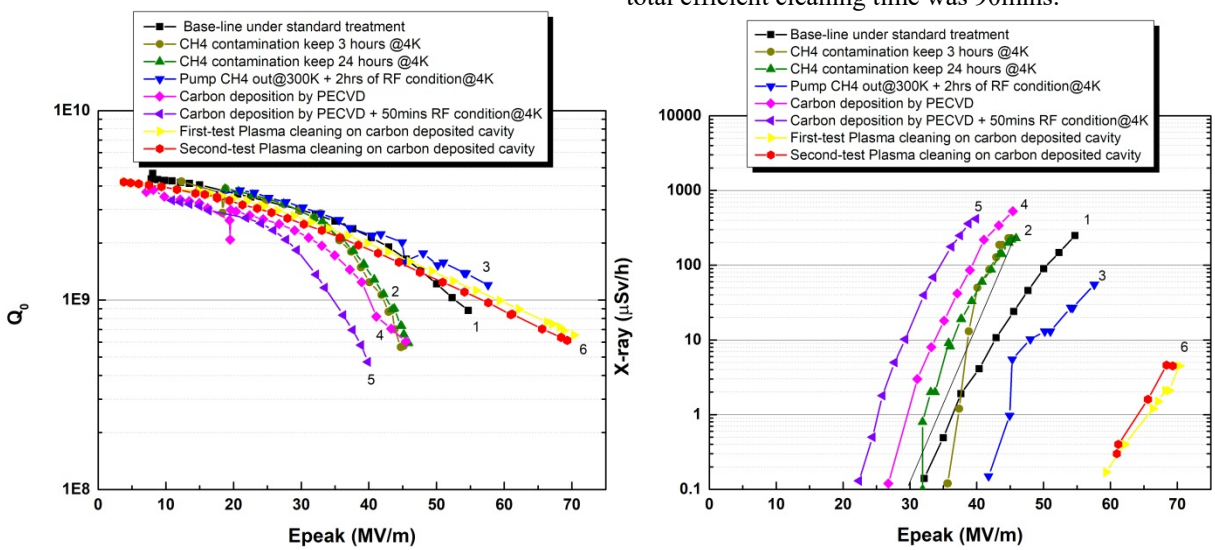

Figure 2: Experiment results under different surface treatment, the left and right was the dependence of Q0 value and X-ray radiation dose on the surface peak electric field, respectively.

EXPRIMENTAL RESULTS

The experimental results of Q_0 value and X-ray radiation dose were shown in the Figure 2. The performance of SRF cavity was degraded by methane cryogenic adsorption, the field emission effect inside the cavity was enhanced with the dose onset point decreased from 32 to 28 MV/m, and the maximum gradience was aslo deteriorated from 55 to 45 MV/m, as shown in the curve 2. Fortunately, the performance degradation can be recovered by thermal cycle the cavity to 300K and pump methane out, as shown in the curve 3.

For the strong strength condition, the carbon chemical deposition was one of the causes of feild emission. The maximum Epeak and FE onset was decreaed to 46 and 27 MV/m, respectively, shown as the curve 4. And then, additional 50 mins of RF condition was conducted to relieve the field emission. However, the performance was degrated further as shown in the curve 5.

The in-situ oxygen plasma cleaning was very effictive to cover the shortage of traditional RF condition that can remove the deposited carbon layers and the field emission was decreaced greatly with the increasing of onset point to 59 MV/m, as shown in the curve 6.

CONCLUSION

The hydrocarbon contaminants including the cryogenic adsorption and chemical depostion were source of field emission. The cryogenic adsorption can be solved by warming up the SRF system to room temperature and pumping residual gas out. However, the warming up method was not effective for most situation of on-line operation. Thus, there was a reasonable assumption can be deduced that carbon chemical deposition was existed in really SRF cavity operation online and it was difficult to terminate the field emission in this condition. In addition, the plasma cleaning was essential to eliminate the deposited hydrocarbon contamination that hardly removed from the SRF inner surface.

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REFERENCES

[1] P. V. Tyagi *et al.*, Improving the work function of the niobium surface of SRF cavities by plasma processing, *Applied Surface Science*, vol. 369, pp. 29-35, 2016.

ISBN: 978-3-95450-211-0 doi:10.18429/JACoW-SRF2019-THP064

[2] M. Doleans *et al.*, In-situ plasma processing to increase the accelerating gradients of superconducting radio-frequency cavities, *Nuclear Instruments and Methods in Physics Research Section A*, vol. 812, pp. 50-59, 2016.

[3] Z. Y Zhang *et al.*, The mechanism study of mixed Ar/O2 plasma-cleaning treatment on niobium surface for work function improvement, *Applied Surface Science*, vol. 475, pp. 143-150, 2019.

[4] A. D Wu *et al.*, In-situ plasma cleaning to decrease the field emission effect of half-wave superconducting radio-frequency cavities, *Nuclear Instruments and Methods in Physics Research Section A*, vol. 905, pp. 61-70, 2018.

[5] T. Kouichi and H. Kichinosuke, Studies on carbon deposition in Ar-CH4 plasmas with optical emission spectroscopy and X-ray photoelectron spectroscopy, *Applied Surface Science*, vol. 59, pp. 31-37, 1992.