EVALUATION OF COPPER SURFACE FOR X-BAND ACCELERATOR STRUCTURES

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Abstract

We have started evaluating the copper surfaces as of various stages of the recent X-band structure fabrication in order to find a cure to suppress the severe arcs during the high-field operation. The surface characteristics are firstly examined using scanning electron microscope. The copper as of machined already shows various other materials and particles on its surface but does not show any void nor other materials concentrated in the grain boundaries. Those after high-temperature heat cycles were found to be very different from those as of machined and the appearance depends on whether the treatment is in vacuum or in hydrogen. The surface after high-pressure (65-85kg/cm²) pure water rinsing shows many pits indicating much soft treatment is preferred replacing highly pressurized water.

1 INTRODUCTION

It was found recently that 1-2m long X-band accelerator structures suffered from a severe frequency change during a few hundred hours operation at an accelerating field over 50MV/m[1]. The frequency change comes from the erosion of copper surface around a high electric-field region. The erosion is severe in the upstream side of the structure where the group velocity is high. An idea of the affect of the breakdown to the erosion indicates the lower group velocity structures are less damaged even in the presence of the breakdowns. There is a development research changing geometries based on the idea above[1].

On the other hand, the surface of the structures which experienced breakdowns exhibits many pits and craters indicating the existence of the arcs on a limited area on surface. We need to understand how these arcs have been triggered so that we find cures. Possible origins might be such as some other materials covering the copper surface, particles on the surface, gas desorption from the copper material, some electronic state different from normal copper crystal, and so on.

There are various papers dealing with surface quality and preparation process as follows. Particle removal process in superconducting cavities was now widely applied in practice[2]. Other material concentration between boundaries was discussed in [3]. Gas desorption through baking or annealing process was found very effective to improve the breakdown performance on copper electrodes[4]. Careful diamond turning on copper surface reduces dark current while ozonized water rising degraded the FE performance indicating the importance of the chemical state of oxidized copper surface[5].

Taking the above information in mind, we have started with inspecting the copper surfaces as of various stages in our normal fabrication process, in order to study the mechanisms which cause arcs and to find a cure to escape from arcs.

2 FABRICATION PROCESS

Our present standard fabrication flow[6,7] is summarized here; 1-rough machining of class 1 OFC, 2-annealing at 500C, 3-diamond turning about 50µm in total, 4-rinsing in acetone ultra-sonic bath, 5-storage in air, 6-ozone-gas included pure-water rinsing, 7-storage in air, 8-stacking in a clean room, 9-pre-bonding in vacuum furnace at about 180C, 10-diffusion bonding at 890C in vacuum furnace, 11-brazing in hydrogen furnace around 1000C, 12-RF tuning and finally 13-vacuum baking before going into 14-high power feeding.

Typical parameters of the last diamond turning are summarized as 1-cutting with a single-crystal natural diamond with its radius 0.4mm and roundness of 0.1µm, 2-spindle rotation speed of 2800 rpm, 3-final cutting thickness of 2µm and 4-using kerosene oil as lubricant. The roughness is about 50nm P-V.

Just after diamond turning, the cells are rinsed in an acetone ultra-sonic bath for several minutes, then stored in a container with reduced humidity. These cells are rinsed in an ozone-gas included pure-water rinsing, 7-storage in air, 8-stacking in a clean room, 9-pre-bonding in vacuum furnace at about 180C, 10-diffusion bonding at 890C in vacuum furnace, 11-brazing in hydrogen furnace around 1000C, 12-RF tuning and finally 13-vacuum baking before going into 14-high power feeding.

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Just after diamond turning, the cells are rinsed in an acetone ultra-sonic bath for several minutes, then stored in a container with reduced humidity. These cells are rinsed in an ozone-gas included (3-4ppm) pure-water bath for 15 minutes and again stored in the same container until stacking.

The stacked cells are pre-bonded in a vacuum furnace at around 180C for one day. Then, the cell pillar is hanged vertically in the same furnace and diffusion bonded at 890C for a few hours[7]. The vacuum level of the furnace is usually a few 10⁻³ Torr. Periphery components are then brazed on the main body usually in a hydrogen furnace. Finally it is baked in a vacuum furnace before feeding high power.
3 SURFACE INSPECTION OF MACHINED COPPER

Firstly a scanning electron microscope (SEM) was used to see the surface as of machined. Some results are shown in Fig. 1. As shown in Fig. 1(a), particles are sometimes seen and some reactions along crystal boundaries are seen. Shallow hollows containing other materials such as chlorine, sulfur, calcium, etc. are also seen fairly frequently. Even an inclusion of carbon such as shown in Fig. 1(b) was found. It should be studied how these materials are integrated in the material or put on the surface so that we find how to escape from these other materials.

Then, a scanning auger microscope (SAM) was used to investigate whether there is any concentration of other materials between crystal boundaries. Sputtering with argon ions of 3 KV impinging at 30 degrees was performed by the amount equivalent to Silicon crystal of 800 Angstroms. Then carbon and oxygen contents were mapped around a triple junction of the copper crystal boundaries shown in Fig. 2. No sign of these materials was found indicating that the present diamond turning did not stuff any lubricant into crystal boundaries.

Particles, larger than 1 micron, sitting on the copper surface as of machined was counted by using SEM. All of the area of a 100 micron-wide strip traversing the diameter of the front face of a sample with 25mm in diameter was scanned. The measured population was shown in Fig. 3. How to evaluate particles smaller than 1 micron should be developed.

4 SURFACE CHANGE

4.1 High-pressure pure-water rinsing

High-pressure pure-water rinsing (HPR) is one of the most efficient ways to remove dust particles from the niobium surface of super conducting cavities[2]. It was also applied to reduce dark current in an S-band copper cavity[3].

Before really applying this technique on copper for X-band structure application, we started with inspecting the copper surface by SEM after HPR of various conditions. Firstly, a copper electrode with a spherical front shape with its radius of 30mm was irradiated by pure water through a nozzle set at 20mm apart. One of the water jets was directed normal to the copper surface under test. The alignment was performed by eye. The nozzle was moved up and down by +-2mm during irradiation for realizing a better uniformity of irradiation.

Fig. 4 shows one of the SEM views of the copper surface irradiated at a pressure of 65kg/cm² for two hours. In the figure, we observed many pits of the order of a few microns in diameter. The surface was inspected by Talystep of Taylor Hobson, Co. Ltd. to see the change of surface shape. It was seen that the tool mark of diamond turning was blurred a little showing a finite amount of copper material was removed.

The surface irradiated at the pressure at 85 and 65kg/cm² for 10, 40 and 120 minutes were inspected. Those at 85kg/cm² showed the same quality as those of 65kg/cm². The number of pits and the size seem smaller for the case of shorter period.

The surface without rinsing but with the same drying process, dripping alcohol and drying in a filtered air flow, showed few pits indicating the pits were mainly due to HPR process. We will try to reduce the pressure to see how the diamond-turned surface is kept.
4.2 Heat cycle in vacuum furnace

The copper sample was put in the same vacuum furnace for diffusion bonding. The sample was inspected by SEM as shown in Fig. 5(a). Pits and inclusions were observed in addition to forming valleys along crystal boundaries.

The same-shape sample was put in another vacuum furnace. The SEM view is shown in Fig. 5(b). Here we see much clear grain boundaries and different surfaces depending on the direction of the crystal axes.

From these figures, we realized that the bonding process in a vacuum furnace should be improved though we do not know at this moment how these surfaces affect the high-field performance.

4.3 Heat cycle in hydrogen furnace

The same-shape copper sample was put in the brazing cycle at about 1000°C in a hydrogen furnace. The surface is shown in Fig. 6. As shown in the figure, the surface was much smoother than that of vacuum furnace. Grain boundaries were also developed valleys. Some particles were also found. The high-field performance should be studied also on this type of copper surface.

5 DISCUSSIONS

The copper surfaces were inspected after various stages of our nominal fabrication flow. Following understandings were obtained and some future study directions were under consideration.

- Other material was found embedded in copper body.
- Neither carbon nor oxygen concentration was observed along grain boundaries even diamond turning with oil as lubricant.
- The HPR treatment results in many pits if the pressure is too high. Parameters such as pressure and irradiation period should be optimised to keep the surface quality but removing particles.
- Evaluation method of particle population should be improved to study particles smaller than 1 micron.
- Copper surface changes dramatically through high-temperature heat cycle. Evaluation of high-field performance on copper surface after high-temperature heat cycle, either in vacuum furnace or hydrogen one, should be performed.

REFERENCES