Materials Research related to W-band Cavity Construction*

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Abstract

Low power rf measurements, S11, of electro-discharge machined (EDM) diffusion bonded mm-wave traveling wave rf cavities were not in satisfactory agreement with electro-magnetic simulations. During subsequent mechanical inspection, the cell-to-cell iris were found to be distorted. This led to a series of systematic experiments to study the mechanical properties of oxygen free high conductivity Copper (OFHC) and Glidcop AL-15. Results of these studies which include cell-to-cell iris distortion, EDM machining accuracies, surface quality, and the results of different bonding techniques are presented.

The results of our mechanical studies are used to develop a set of mechanical design constraints for a second series of constant impedance W-Band structures that also used wire EDM and high temperature bonding for their manufacture.

I. Introduction

In this paper we shall present the results of mechanical studies as it relates to issues of mechanical fabrication of 90 GHz accelerating structures [1]. We shall present results from our material tests that indicate Glidcop AL-15, which is a dispersion strength material, is the material of choice when these materials must be exposed to temperature cycles greater than 1000°C. We present results that indicate that sinker EDM machining is capable of attaining the tolerances necessary to produce a tuned accelerator structure. Bonding studies are then presented. Finally, an overview of the available technology to mechanical inspect fabrication structures are presented.

These results have driven our efforts, to produce and test a W-band structures, away from bonded copper muffin tin structures to a novel rf zipper structure [2], that have no bond joints located in regions of large rf currents, produced from dispersion strengthened materials.

II. Materials Studies

Visual inspection of the first 25 cell constant impedance(CI) traveling wave accelerating structure mechanical deformation of the cell to cell iris was observed, as seen in Figure 1. Two possible effects might have caused the iris deformation. The yield strength of the base material was exceeded during the diffusion bonding cycle or during the beam pipe EDM machining step.

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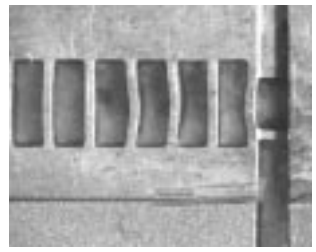

Figure. 1. Visual inspection of the cell to cell iris revealed distortion.

To identify the cause of this distortion, we constructed a series of test structure made from OFHC copper and AL-15, using wire EDM milling technology. The mechanical dimensions of these test structures are shown in Figure 2. These sample cavities were put through identical thermal cycles that mimicked the diffusion bond process used to produce Figure 1.

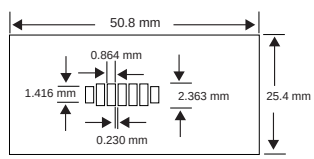

Figure. 2. Test structure used in the iris distortion studies.

Two subclasses of OFHC copper, annealed and work hardened, were investigated along with AL-15 as possible candidates for use as the base material for W-band structures.

Figure 3 shows a 30 μm iris distortion that was introduced in the the annealed OFHC copper after wire EDM milling of the test structure. It is thought that thermal induced crystal growth during the wire EDM milling process is responsible for this distortion. Further metallurgical studies are ongoing to verify this conjecture.

A identical series of test were also conducted on AL-15 and work harden OFHC copper, see Figure 3. To within the optical resolution of our microscope no distortion was observed in either the AL-15 or work hardened copper due to the thermal cycle of the diffusion bonding process. But our metallurgy analysis of the 25 cell work hardened diffusion bonded OFHC structure indicated that the OFHC base material plastically deformed during the bonding process and therefore is not a candidate as an acceptable material for thermal bonding.

To summarize, annealed and work harden OFHC copper are unacceptable base materials for mm-wave accel-

erating structures which are fabricate by thermal bonding and EDM wire machining technologies. This is due to the deformation induced in the rf cavities during the wire milling and diffusion bonding processes. AL-15 is an acceptable material to fabricate, thermally bonded and wire EDM milled, mm-wave accelerating structures.

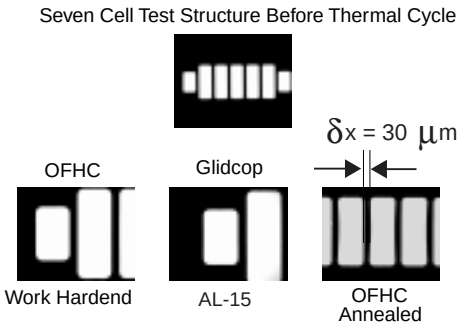

Figure. 3. View of material test structures before and after thermal cycle.

III. Electro-Discharge Machining (EDM)

In this section we studied the surface finish attained by EDM machining techniques, wire milling and sinker EDM, using non-destructive inspection techniques.

During SEM analyses of the our first 25 cell structure zinc (Zn) was found to have contamination the structure. Clearly, this is a byproduct of the Brass coated EDM wire used during fabrication. It should be pointed out that there was limited flushing due to the constrained geometry of this structure. Our future design and step by step manufacturing process eliminates the problem of limited flushing action.

A. Wire EDM

Previous attenuation studies of EDM OFHC copper waveguide [3] measured an attenuation of -0.2 dB for Cu waveguide, manufactured using wire EDM technology. Since results in Section II indicate that the base material should be AL-15, we have extended the previous work to include the effect of different EDM wire base material used to fabricate structures out of AL-15.

In these studies, the surface finish of WR-10 waveguide, constructed out of AL-15, was investigated non-destructively, by measuring the attenuation of the rf power, in the frequency range of 85 to 95 GHz, as a function of EDM wire base material. Three 2 inches long W-band waveguides were wire EDM milled out of AL-15 using a Brass coated wire, trade name Cobra Cut A, pure Copper wire, and a Molybdenum wire.

Comparing the attenuation factor of pure copper, -0.13 dB, to that of AL-15, -0.29 dB. We find that Al-15 is satisfactory base material for accelerator structure in the mm-wavelength. No variation in the AL-15 attenuation factor was measured before or after cleaning.

Dimension (mm)	Mean (mm)	σ (mm)
1.000	0.99970	0.00232
0.250	0.24964	0.00200
2.000	1.99259	0.00136
2.400	2.39083	0.00170

Table I
Optical inspection results of a series of 6 Sinker EDM 7 cell test structures.

B. Sinker EDM

Previous planer structure design at W-band have limited themselves to only utilized wire EDM. We have investigated the use of sinker EDM machining to produce the cavity structure similar that that shown in Figure 2. This technique would eliminate the need to bond the cavity structure in the region of large rf currents.

This test was conducted with a single electrode, produced by a precision wire EDM machine, with the negative of the 7 cell cavity structure we wanted to produce. In this manner we were able to transfer the precision of the wire EDM machine to the sinker EDM machine and the 7 cell test structure. Optical comparison techniques were utilized to inspect the surface finish of the cavity walls and bottom. The cavity walls and bottoms were found to have a RMS surface finish of 0.41 μm and 0.82 μm, respectively. Dimensional accuracy attained by the sinker EDM technique are tabulated in Table I. In conclusion, we find that sinker the EDM machining technique can attain the dimensional tolerance required by mm-wave accelerating structures. Improvements in the surface finish are possible with the use of higher quality cathode material.

IV. Bonding Studies

During the course of our studies into the cause of the iris distortion, see Figure 1, the iris to cavity bond was studied. Metallurgy analysis indicated that they was no significant epitaxy crystal growth in the iris region of the bonding surface. This is the region where large rf currents flow perpendicular to the bond joint. This has caused us to pursue a novel rf design [2] that does not necessitate any physical bond in the regions of large rf currents. But it should be noted that we are studying different bonding techniques, since the ability to bond metals together without physically distorting the structure allows for a larger range of rf structures to be envisaged and fabricated.

Therefore, we are investigating diffusion brazing with silver plated alloy, ultra thin alloy brazing, and also diffusion bonding of diamond fly cut surfaces. We shall discuss each of these process in the following subsections.

A. Diffusion Bonding

Initial diffusion bonding of W-band structures at SLAC utilizes hand lapping of all bonding surfaces, that are flat and parallel to 0.5 μm. A pressure of 20 psi was applied to

the structure with a temperature plateau of 1020°C held for 1 hour. The metallurgy analysis indicated that they was no significant epitaxy crystal growth across the bonding surface and in some case no physical contact in the region of coupling iris where rf current flow.

The lack of bonding in the iris region could possible be due to the lose of surface flatness in the iris region due to preferential chemical etching used to clean the surfaces prior to bonding, or roll off in iris region induced during the lapping process.

Due to the success of diffusion bonding of diamond turned surfaces for X-band structure development [4] we are pursuing this technology with respect to W-band structures. To date, we have been able to utilize this technology with a W-band cavity plate without physically damaging precut irides. For this to be a viable technology for W-band structure, it must be applicable to AL-15.

B. Diffusion Brazing

To overcome the drawbacks of the solid-state diffusion bonding process in fabricating mm-wave accelerating structures, we began exploring an alternative bonding method called Liquid Interface Diffusion (LID) bonding. LID bonding is a metallurgical bonding technique commonly used in the aerospace industry for applications as diverse as the assembly of honeycomb structures and the assembly of jet turbines. In this technique, a low-melting point metal is inserted as an interlayer between the two metals to be bonded. The interlayer is chosen from among the metals that readily alloy with the metals to be bonded; for LID bonding of copper, the optimum low-melting alloy to use is silver. Upon heating, a liquid forms as the interlayer melts. As a result of liquid formation, a combination of wetting and capillary attraction insure that the mating surfaces are drawn closely together. By holding at the liquid-forming temperature, inter-diffusion between the interlayer and the higher-melting parent metal results in isothermal solidification of the bond line. When the bond-line is subsequently examined metallurgical, no evidence of a distinct low-melting phase can be observed. This is the principal difference between LID bonding and traditional brazing. Processing variables such as interlayer thickness, masking to limit deposition to only the interface to be bonded, and selection of joining temperatures and pressures are currently under investigation. A major advantage of LID is its significantly lower brazing temperature of 800°C versus that of 1020°C for conventional H^2 Brazing with Au-Cu alloys.

C. Ultra Thin Alloy Brazing

S-Band structure normally utilize 40 μm thick Au-Cu alloy to bond surfaces together. At higher frequency, the fillet produced by this technique would significantly detune a resonant structure. We have been able to bond copper surfaces together with 35-65 Au-Cu alloy that is 2.5 μm thick. No detuning fillet was observed. This same process is being studied with AL-15, as the base material of the structure.

Machine	cell width (μm)	cell length (μm)
DMM 12-106	837.04 ± 0.43	2368.71 ± 0.90
M48	828.71 ± 0.50	2363.04 ± 0.81
Apex 200	828.43 ± 0.83	2361.54 ± 0.64

Table II
41 cell muffin tin structure baseline and optical inspection results.

V. Mechanical Inspection Techniques

Dimensional tolerance at W-band are on the order of 2.5 μm. Contact measurements are capable of attaining measurement tolerance of ± 0.25 μm. It has been observed that contact measurement can cause significant damage to W-band structures constructed out of work hardened OFHC material [5]. Similar damage was observed on a Al-15 test fixture. We report, the results of our investigation into optical inspection techniques that would eliminate the surface damage induced by more invasive techniques.

To provide a calibrated baseline, SLAC's Leitz PMM 12-106 coordinate measuring machine was used to measure a 41 cell muffin tin structure. These results are accurate to within $\pm .25$ μm.

The 41 cell muffin tin structure was then sent to Sandia National Laboratory and was inspected on a Moore M48 optical inspection machine. The 41 cell structure was also inspected on an Optical Gauging Products Apex 200 machine. The results of these inspection are listed in Table II. The optical measurement technique under estimated the cell physical dimensions by 10 μm. This is due to the edge finding schemes getting confused by shadow effects at the wall edge. Whereas the contact method depends on physical force to find an edge of a cavity wall. It should be noted that during all optical inspection, the 41 cell structure was back lit with low intensity white light.

VI. Conclusions

We find the Glidcop AL-15 is an acceptable base material for use in fabricating W-band accelerating structures. Problem with thermal bonding of planar structures must be overcome to increase the diversity of exotic structure that may be envisaged by accelerator physicists. We have bypassed this problem with a novel rf structure design that eliminates bonding metal surfaces together perpendicular to the rf current flow. Sinker EDM machining is capable of achieving the tolerances necessary to fabricate mm-wave structures. Optical inspection techniques under estimate the absolute dimensions due to lighting and edge effects.

References

[1] P.J. Chou et al., PAC97, page 464
[2] Kroll et al., PAC99, FRA92
[3] M. Hill, ARDB Technical Note 126
[4] C. Pearson, Personal Communication
[5] P.J. Chou, ARDB Technical Note 115