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HIGH POWER TEST RESULTS ON X-BAND COPPER AND MOLYBDENUM STRUCTURES, LOW POWER RF MEASUREMENTS OF COPPER ELECTROFORMED STRUCTURES AND TECHNOLOGICAL ACTIVITIES STATUS

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Abstract

X-band copper and molybdenum structures have been recently constructed at LNF using the brazing technique and have been tested at high power at SLAC. Electroformed copper structures have been also constructed at LNF and are now ready to be tested at high power. In this note we report the results of the first high gradient test done at SLAC on brazed Cu and Mo LNF structures and the results of the low power RF measurements on Cu electroformed structures. The technological activity status about the soft brazing bonding, electroforming and molybdenum sputtering are described, too.

1 INTRODUCTION

The three cell structures realized at LNF by brazing procedure and electroformed one are shown in Fig. 1. More details on the mechanical drawings and assembly are given in [1]. The Cu and Mo brazed structures have been sent at SLAC for high gradient tests. Fig. 2 shows the copper cavity (brazed) in the SLAC laboratory under low power RF tests (that had confirmed the results obtained at LNF [1]).

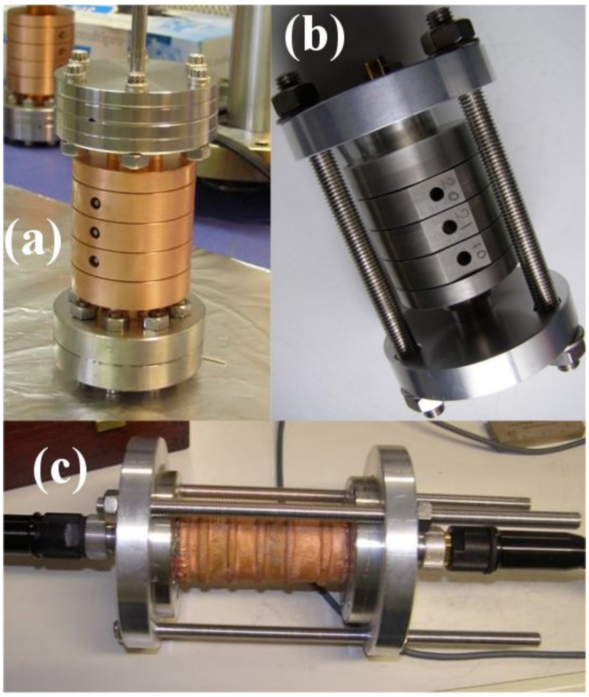

FIG. 1: pictures of the X band cavities constructed at LNF: (a) copper brazed; (b) molybdenum brazed; (c) copper electroformed.

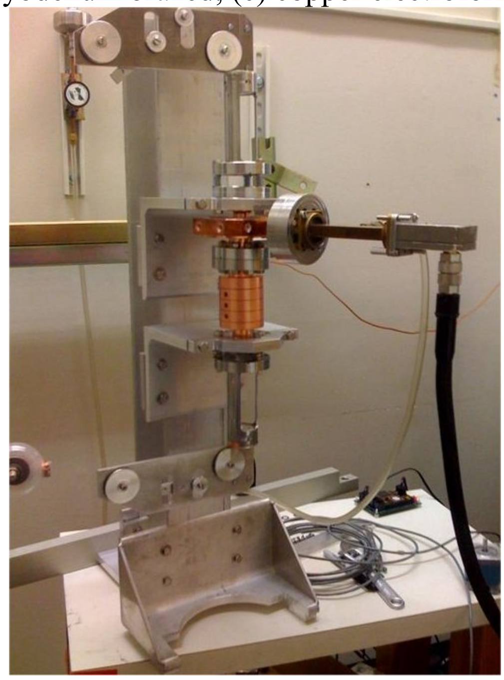

FIG. 2: copper cavity under low power RF test in the SLAC laboratory.

2 HIGH POWER RF TEST RESULTS ON THE COPPER AND MOLYBDENUM BRAZED STRUCTURES

High power RF test have been done in the SLAC National Accelerator Laboratory on the brazed Cu and Mo structures of type 1C-SW-A5.65-T4.6. The results are reported in Figs. 3-6 where the breakdown rate as a function of the accelerating field in the cavity is reported for different pulse length. “All breakdown rate” refers to the total number of breakdowns. “First breakdown rate” refers to a number of breakdown clusters. Breakdowns in the cluster occurres one after another with klystron repetition frequency of 60 Hz. If time interval between consequent breakdowns is more then 1/60Hz= 16.7 ms, they belong to different clusters. Typical number of breakdowns in a cluster is from 1 to 4. We speculate that this number represents damage done by first breakdown in the cluster. We speculate that “first breakdown rate” gives characteristics of the breakdown trigger, and “All breakdown rate” depends on both trigger and damage.
More details on the high power test procedure at SLAC can be found in [2]. Figs. 3 and 4 shows the results related to the Cu structure. In particular Fig. 4 report the comparison of the LNF Cu structure with similar Cu structure constructed in other laboratories. We note spectacular reproducibility of the results for structures made in different laboratories.
Results for the Mo brazed structure are reported in Figs. 5-6. To our knowledge, this was the first systematic measurement of the breakdown rate for whole-molybdenum standing wave structure. We note surprising result: the pulse dependence of the breakdown rate is similar to copper structures although material parameters (melting temperature, conductivity, etc) are very different.

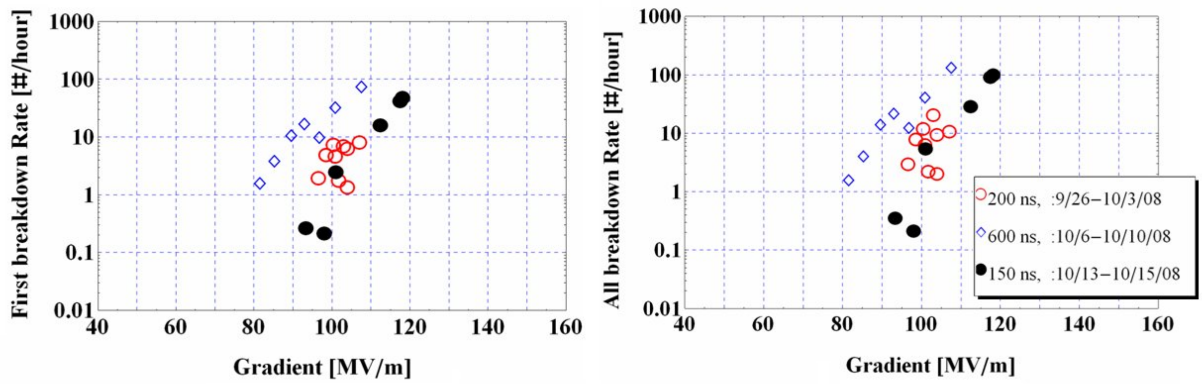

FIG. 3: Breakdown rate as a function of the accelerating gradient (brazed Cu Structure) 1C-SW-A5.65-T4.6-Cu-Frascati-#2.

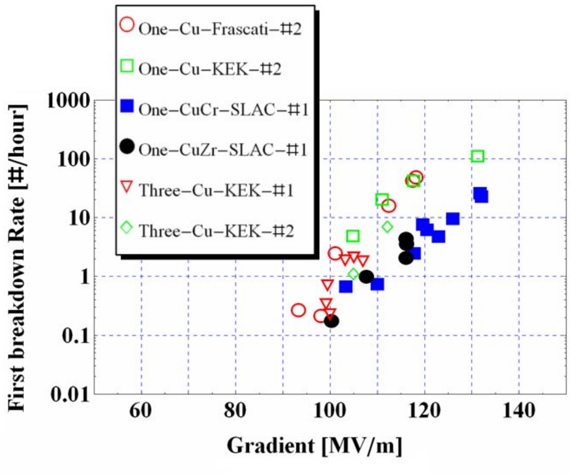

FIG. 4: Breakdown rate as a function of the accelerating gradient Cu-LNF structure compared with copper structures of same geometry, CuCr and CuZr structures of the same geometry and there-cell copper structures with same cell shape.

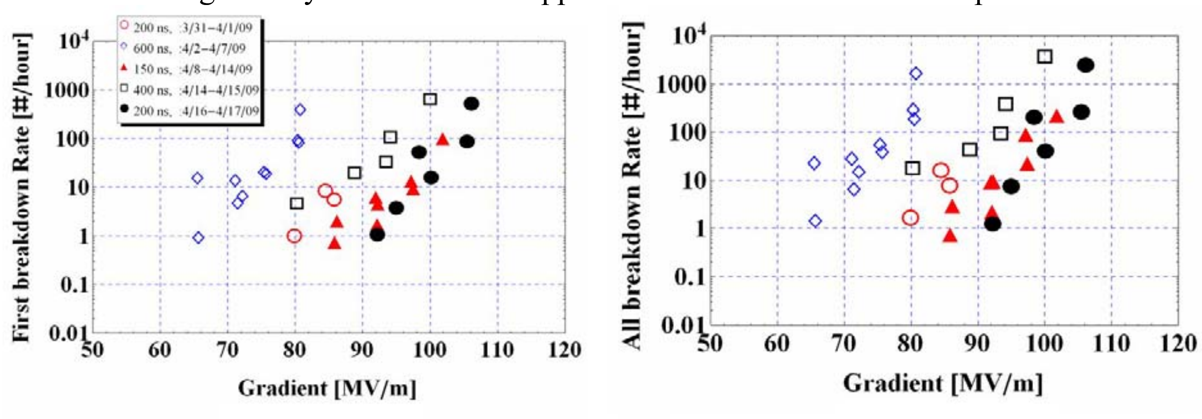

FIG. 5: Breakdown rate as a function of the accelerating gradient (Brazed Mo Structure), 1C-SW-A5.65-T4.6-Mo-Frascati-#1.

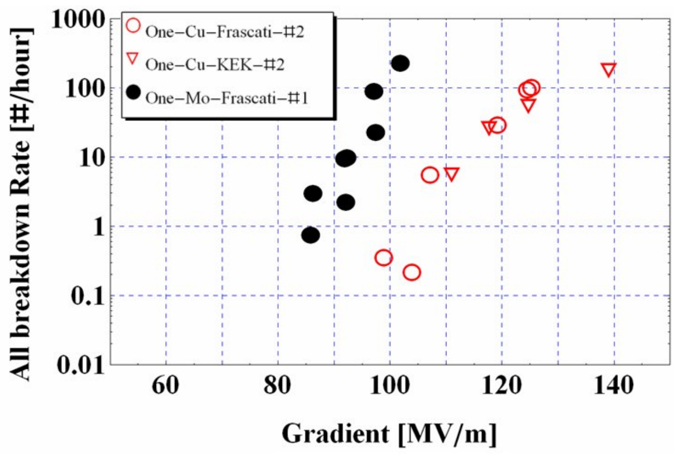

FIG. 6: Breakdown rate as a function of the accelerating gradient Mo-LNF structure compared with cooper structures of same geometry.

3 RF MEASUREMENTS RESULTS FOR THE COPPER ELECTROFORMED STRUCTURE

Details on the electroforming procedure to construct X Band structures are given in [3]. The results of the low power RF measurements are reported in Table I and Fig. 7. The mode characterization is that already discussed in [1]. In Table I we also report, for comparison, the results of the Cu brazed structure. The results show the good agreement between the theoretical values and are comparable with the results of the Cu brazed structure. Fig. 7 shows the measured field profile of the π-mode by bead pull technique. About the electroformed section, additional tests carried out at SLAC gave a quality factor Q greater of the (5-6)%.

TABLE 1: mode frequencies and quality factors (given by SUPERFISH) and measurements results of copper electroformed and brazed structures.

MODE	Res. Frequency [MHz] (simul.)	Res. Frequency [MHz] (meas. Cu Brazed)	Res. Frequency [MHz] (meas. Cu Electrof.)	Quality factor (simul.)	Quality factor (meas. Cu Brazed)	Quality factor (meas. Cu Electrof.)
1	10980	10983	10977	8478	7700	7600
2	11118	11127	11113	8889	7600	7000
3	11433	11429	11418	8380	7200	7700

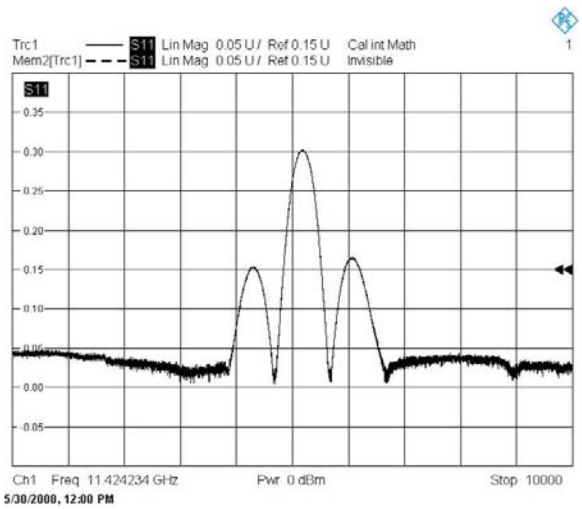

FIG. 7: Cu electroformed structure: measured π-mode field profiles by bead-pull technique.

5 Technological activity status [4,5,6]

a) Soft Brazing bonding

Low temperature brazing can be adopted when the metal used for the RF structures can not sustain high temperature .

Soft brazing permits creating joints from similar or dissimilar base materials at temperatures below 450°C and at any rate such as to permit the fusion of the brazing alloy while maintaining the base materials integral if they are temperature sensitive.

Soft brazing is utilized for creating joints on copper tubing in heating and sanitary fitting plants, and in general plants that operate at maximum working temperatures of 100 - 120°C; higher temperatures require strong brazing.
The quality of the joint depends on various factors:
- joint design, normally spigot and socket joint;
- flow ability of alloy;
- appropriate activity of deoxidizer to be applied to joint surfaces;
- distance between the two surfaces to be brazed, recommended from 0.05 to 0.13 mm;
- stress studies, if necessary provide for expansion joints.

About the sputtering approach, the Molybdenum material deposition on the Copper one in order to improve the surfaces quality, some tests and checks using an Atomic force microscopy to understand the morphological aspect have been made.
In order to avoid mechanical stress and morphological one induced into the material during high temperature treatment (high temperature brazing) the soft brazing like is required. This method can be adopted when using metal for the RF accelerating structures construction which cannot be to sustain high temperature.
The alloy Sn/Ag 95/5 (melting point 230°C) is under investigation. The procedure is the same we adopt for the high temperature brazing replacing Cusil alloy with the Sn/Ag one.
Preliminary tests on COPPER have given good vacuum tight results but also some problems due to the fact that Sn/Ag alloy doesn't act like Cusil regarding capillarity; in other words the Sn/Ag diffusion is not homogeneous on each contact surface so in some tests we found an unwanted alloy diffusion inside the cells. For this reason, we also studied the possibility of using Sn, as gasket, to joint the cells.
The procedure is quite simple, by plating a Sn layer on one of the surfaces we want to joint, making a temperature treatment close to the Sn melting point in order to make a vacuum tight boundary layer between the cells. The deposition is so called "brush plating".
The electrolytic parameters can be used to estimate the thickness of the deposited material: in order to deposit 1 μm of Sn on 1 dm^2, we need 36 mAh and knowing the density of Sn, we can estimate the thickness.
By brazing bonding at temperature a little less than 230°C we obtain a good mechanical structure stability. Some tests with copper OFHC remade with different shapes among the contact surfaces gave good results in term of helium vacuum leak. As a next step , the realization of the Cu-Zr three cells section , applying the above procedure, electrolytic plating plus temperature treatment, has been scheduled and is going to be completed in a couple of months.
If contact surfaces are machined at a very low roughness, in our case order of 70 nm, the thermal treatment after Sn deposition could be unnecessary. Vacuum tight of about10^{-10} *mbar*l/sec* has been obtained with a proper pressure applied to the structure with three bars.
As a first prototype we use a soft brazing bonding with six bars, tight with a proper torque , in order to improve uniformly the pressure among cells. This structure is close to be completed and sent to SLAC for tests with RF higher power.
However we propose that standard model will be realized with the soft brazing bonding plus electroforming technique. In this case bolts will be replaced by electrolytic encapsulation.the model will be ordered to the Company in the next days.

b) Electroforming

The electroforming procedure is presently use for the encapsulation of the RF structures. In detail the whole procedure would consist in :
-machining the single cells, the end parts and the flanges
-assembling and strengthening together al the components
-covering the structure with a Cu thick electrolytic layer

A couple of bolts with a proper torque are used to maintain fixed all the components .They are eliminated after the electroforming procedure. One of the points under investigation for the above procedure is the contact among cells before electroforming. This contact must be

very good not only for the RF field but also because when the structure is put into the galvanoplastic bath , this one has not to penetrate inside the cells . Fortunately the low roughness obtained (at least for Cu) gives a vacuum tight contact , as it has been seen from some preliminary tests on Cu component machined at very low roughness. The surfaces in contact are vacuum tight with a leak of about 10^{-10} *mbar*l/sec* when a pressure of some *N/mm*^{2}. is applied. In addition, we also are studying the possibility of depositing tin by galvanoplastic or the alloy Sn/Ag 95/5 by sputtering procedure on contact points of cells in order to decrease the roughness at joints to reduce or eliminate RF energy power losses due to electric field discharge. Some tests have been done on Copper. For the sputtering procedure a dedicated system has been realized and optimised in order to deposit thin materials layer , like gold , copper , nickel , titanium molybdenum , Sn/Ag 95/5 and so on. A three cells , Cu OFHC structure has been delivered to us by the company specialized in the high precision machining (Ra <0.1µm).
It has been tightened at a proper torque ; vacuum and RF tested and finally encapsulated by means of an electroforming, ready for the RF power tests. The preliminary results, before RF power tests are good, in the sense positive, a leak rate of about $5*10^{-10}$ *mbar*l/sec* has been measured. We are studying and testing this procedure (low Ra machining plus electroforming) because it absolutely avoids any thermal stress on the material, that can preserve the roughness and the quality of the machining surfaces. Obviously the goal is to apply this procedure to metals or alloy different from Cu , for example to the molybdenum and to the alloys Cu/Zr and W/Cu. If we want to get a successful in higher power tests of clamped joint or electroformed structures, we need to work on this. Since we think that copper oxides could generate breakdowns in clamped joint, we are studying the possibility of depositing gold or rhodium in the clamped joint region, too.

c) Molybdenum sputtering

It is known that the Molybdenum material could be an interesting choice for making RF linear accelerating structure since its melting point is higher than the copper giving higher performances under RF higher power.
Unfortunately it is very difficult to be machined with a good roughness (not less of 350 nm can be obtained) and could trap residual gas by limiting the sections performances in terms of breakdown effects, as it was observed at SLAC during the high power tests on dedicated and brazed three cells section.
For this reason we started the study to make the cavity resonators in copper with an excellent roughness and then to deposit Molybdenum by sputtering technique in order to reduce the breakdown phenomena.
To estimate the surfaces quality some tests under an Atomic force microscopy to understand the morphological aspects or the topic ones was used.
Studies on the molybdenum sputtering on the copper surfaces are in progress.
The results obtained with Atomic Force Microscopy show the surfaces of the machined copper with a very low roughness, of the 70 nm order, after and before the molybdenum sputtering.
The undulations of the surface due to the step of lathe machine, about 700nm, with a lots of spikes overlapped , spikes that disappear when a layer of about 100 nm molybdenum is deposited on. It seems to be that molybdenum on the copper surface acts like a smooth layer, in other words the roughness improves. Further studies are in progress in order to verify this statement.
Since the materials have different thermal coefficients, the deposited molybdenum on the copper could be not stable rising temperature. One possible solution consists in depositing a

film and make a thermal treatment, about 800 Celsius degree, in order to fix the film on the substrate (a similar treatment has been adopted for other applications).

4 CONCLUSIONS

Copper and Molybdenum X-band RF structures have been constructed at LNF using two different techniques: the brazing and the electroforming procedure. The brazed Cu and Mo structures have been tested at high power at SLAC. The performances in term of breakdown rate for the Cu structure are the same as those of similar structures constructed at SLAC or in other laboratories. The breakdown rate of the brazed Mo structure is higher than that of coppers structure for same rf parameters. We have done low power RF tests on copper structure constructed with the novel electroforming technique. The results are comparable with those of the Cu brazed structure. This structure is now ready to be tested at high power at SLAC. Additional studies on the technological activities in collaboration with Y. Higashi (KEK) are in progress and they will be described in a forthcoming paper.

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