# Microwave Performances of Two Cavities Fully Coated by YBCO

Bi Zhang, P.Fabbricatore, G. Gemme, R.Musenich, R. Parodi

Natianal Nuclear Physics Research Institute(INFN) in Section of Genova,

Via Dodecaneso 33, 16146, Genova, Italy

## I. Introduction

We studied the electrodynamic properties of the high Tc superconducting materials at rf fields in various temperatures and magnetic fields. Two different full high Tc superconducting cavities are fabricated by different eletrophoretical processes. Microwave measurements were carried out at TE011 mode of the cavity with resonant frequency at 7.9GHz. Among the results for the first superconducting cavity fabricated, the most interesting is the observation of an anomalous behaviour of the temperature dependence of the surface resistance. To understand well the mechanism of the anomalous dissipation, a second superconducting cavity has been fabricated by a improved electrophoretic method. The microwave performance of the second cavity are tested and the results are discussed and analysed comparing with the BCS theoretical calculations.

## II. The Fabrication of Full HTCS Cavities by Electrophoretic Deposition

The electrophoretic deposition technique has been developed and successfully applied to coat various shapes of silver substrates including the whole cylindrical cavity, made of two identical silver disks (55 mm diameter) and a cylindrical body (50 mm inner diameter), with high Tc thick films. In spite of the electrophoretical deposition of many ceramic materials is a well known process, the dynamics of deposition and the charging mechanism of YBCO powders were not well understood yet. Therefore a detailed studies on the electrophoretic deposition processes of high Tc materials has been carried out. and the effects of processing parameters on the quality of the films are also investigated(1).

## III. Microwave Results of the First Full YBCO Cavity

The microwave performance of the fully superconducting cavities were carried out as the function of the temperature, frequency and magnetic fields. The detailed results have been published elsewhere(2).

Among the results for the first superconducting cavity fabricated, the most interesting is the observation of an anomalous behaviour of the temperature dependence of the surface resistance. As shown in Fig. 1 the unexpected increasing of temperature dependent Rs(T) in rf fields took place at near the transition temperature Tc ≈ 90K and at lower temperature near 50K after the superconducting transition. This behaviour was fully reproducible under repeated cool-down and warm-up cycles; In the same figure, tests made at different RF field levels showed that the curve shape in the region $T \approx T_c$ did not depend on field level while, on the contrary, the unusual rising of Rs at T≈50 K, was strongly field dependent.

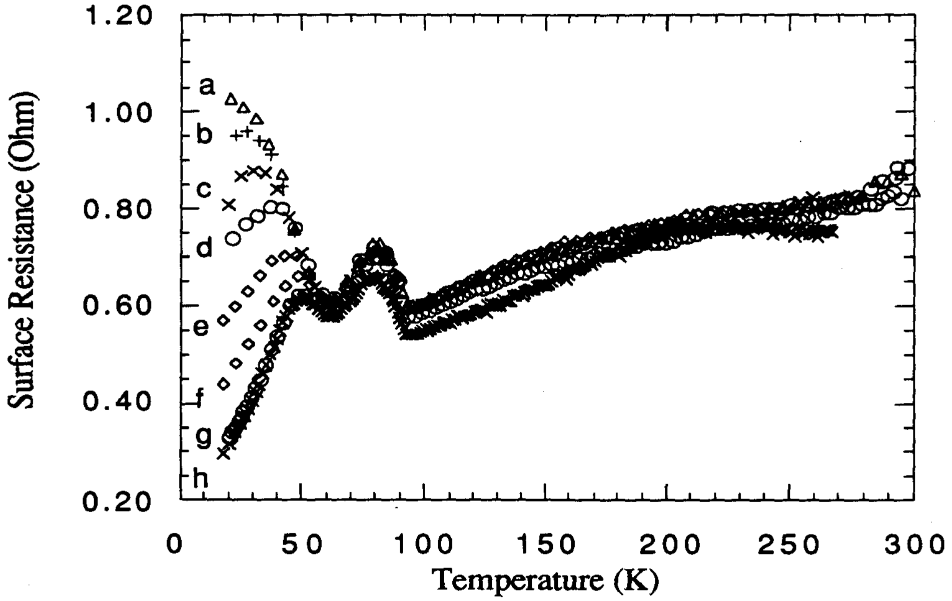

**FIG. 1-** Temperature dependence of the surface resistance of the YBCO coated cavity in the $TE_{011}$ mode for an input power of (a) 1 W; (b) 600 mW; (c) 270 mW; (d) 100 mW, (e) 50 mW (f) 20 mW, (g) 3 mW and (h) 0.3 mW

The unusual behaviour near Tc can be explained taking into account the effect of the silver substrate which plays an important role due to the large field penetration in normal YBCO. In fact we estimated that skin depth in normal YBCO is approximately 50-100 μm, while film thickness is around 30 μm.The solution of the boundary value problem for the surface impedance of the composite system film-substrate yields :

$$Z_{meas} = Z_{film}\frac{\sinh(\gamma_{film}d)+\rho\cosh(\gamma_{film}d)}{\cosh(\gamma_{film}d)+\rho\sinh(\gamma_{film}d)}$$

where d is the film thickness, ρ is the ratio between substrate and film surface impedance (i.e.$\rho=Z_{S(subs)}/Z_{S(film)}$ ) and γ is the propagation constant of the fields inside the film material, defined as for a normal metal:

$$\gamma=(1+j)\frac{\pi f\mu_0}{R_s}$$

and defined as

$$\gamma=2\pi f\mu_0\frac{X_s+jR_s}{X_s^2+R_s^2}$$

for a superconductor in the framework of a two fluid model, which is generally accepted to hold for ceramic superconductors due to the large value of field penetration depth compared to the short coherence length. The implicit equation defining $Z_{meas}$ can be solved numerically to find film parameters from measured data once film thickness and substrate surface resistance are known. The film thickness corrected results of Rs is presented in figure 2 where a critical temperature of 85 K was assumed for the film. This is probably a too simplifying assumption since it is conceivable that the superconducting transition develops gradually on the film area with a broad temperature dependence, starting around 90 K and ending at a certain lower temperature. Our calculations show that the presence of the substrate let us underestimate by a factor of three the surface resistance of YBCO in the normal state due to the lower surface resistance of silver, while the measurements in the superconducting state are practically unaffected due to the shorter field penetration depth. The corrected data show also a semiconductor-like behaviour of YBCO surface resistance in the normal state which can be a signal of dominant electrical conduction along the c-axis.

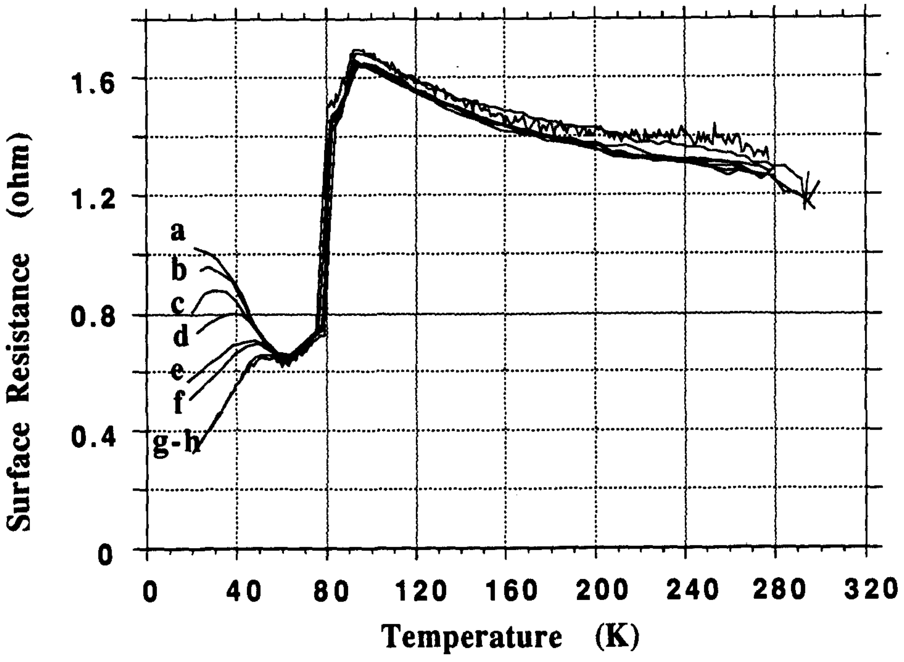

**FIG.2-** Temperature dependence of the corrected surface resistance of the YBCO coated cavity for different power levels: a) 1 W; b) 600 mW; c) 270 mW; d) 100 mW; e) 50 mW; f) 20 mW; g) 3 mW; h) 0.3 mW;

However, the anomalous increasing dissipation (near 50 K) as the temperature decreasing in the superconducting state is not well understood. Particularly, in fig.2 the observation of field dependence of Rs at T<50 K indicates that the dissipation mechanism in this temperature range is in some way related to the behaviour of networks of weakly linked superconducting grains in RF magnetic field. In addition, some similar phenomena were also addressed to be observed by other groups in recent microwave measurements on HTc thin films(3). Nevertheless, the anomalous dissipation mechanism was not well understood. The possible causes responsible for it are proposed as:

*Impurity inclusions;

*Granular structure of the materials;

*Deficiency of oxygen;

*Quality of CuO chains;

*Multi gap behaviour etc.

## IV. Microwave Results of the Second Full YBCO Cavity

Regard to our first HTCS cavity fabrication procedure by electrophoresis, since suspension of the YBCO powder was prepared through a wet-milling process using $Al_2O_3$ milling balls, the corrosion powder of $Al_2O_3$ milling balls during the milling process is most probably to contaminate the materials.Therefore, to clarify the source of the unusual dissipation, a second superconducting cavity has been fabricated by a improved electrophoretic method, where the very fine superconducting powder was chose intently. In consequence, the suspension of the powder was successfully prepared by grinding it for a long time about 20 hr but without using $Al_2O_3$ milling balls. By means, the impurities contamination of the suspension was eliminated.

The microwave performance of the second cavity are tested and the results are discussed and analysed comparing with the BCS theoretical calculations.

Fig.3 illustrated the surface resistance of the superconducting cavity through quality factor measurements as temperature-dependence at low field. It turned out that the surface resistance, as expected, decreased monotonically with temperature going down. The anomalous increase of Rs at low temperature near 50K observed before has been eliminated in this case by the improved manufacture process and quality of the films obtained. The experimental results of the surface resistance are consequently compared with the numerical calculation in the framework of BCS theory as shown in fig.3 with the solid line. In the best fit to the experimental data a temperature independent residual resistance of 35 mΩ.was added. They are well agreement. The best fit of experimental data to BCS theory gives a set of characteristic parameters of $YBa_2Cu_3O_7$ films as: $T_c$=91K, $\Delta(0)/kT_c$=1.8, $\lambda_L(0)$=6µm, $\xi_0$=7Å, and l =16nm.

*The large zero temperature penetration depth of 6µm resulted from the granular structure of the film. The electromagnetic fields intend to penetration more deeply into the boundary regions between the superconducting grains.

*the superconducting coherence length $\xi_0$ is much smaller that the electron mean free path l, which is one of the HTCS characterisation known now.

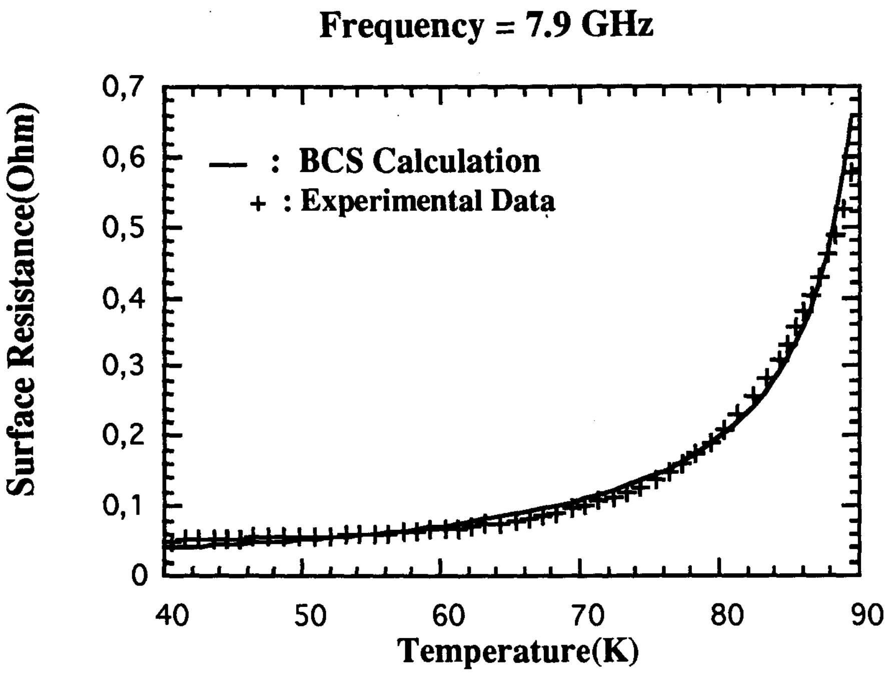

**FIG. 3-** Surface resistance of the YBCO coated cavity as function of temperature. (+): experimental data; the continued line is the best fit calculated by BCS theoty

The magnetic penetration depth λ(T) has been evaluated from the measurements of frequency shift Δf(T) according to the following relation:

$$\Delta\lambda(T) = \lambda(T) - \lambda(T_0) = -\gamma\Delta f(T)$$

where

$$\gamma = \frac{\Gamma}{\pi\mu_0 f^2}$$

In Fig.4 the temperature dependence of penetration depth λ obtained by experiment was plotted. On the other hand, the penetration depth λ(T) based on the BCS theory has been calculated by using the same values of material parameters obtained in the fitting process of surface resistance before. The calculation of λ are made for two regimes where the electrons is assumed to be scattered at the surface specularly and diffusely. It is interesting to note that the experimental data fall into theoretical values between the two regimes, as shown in fig4.

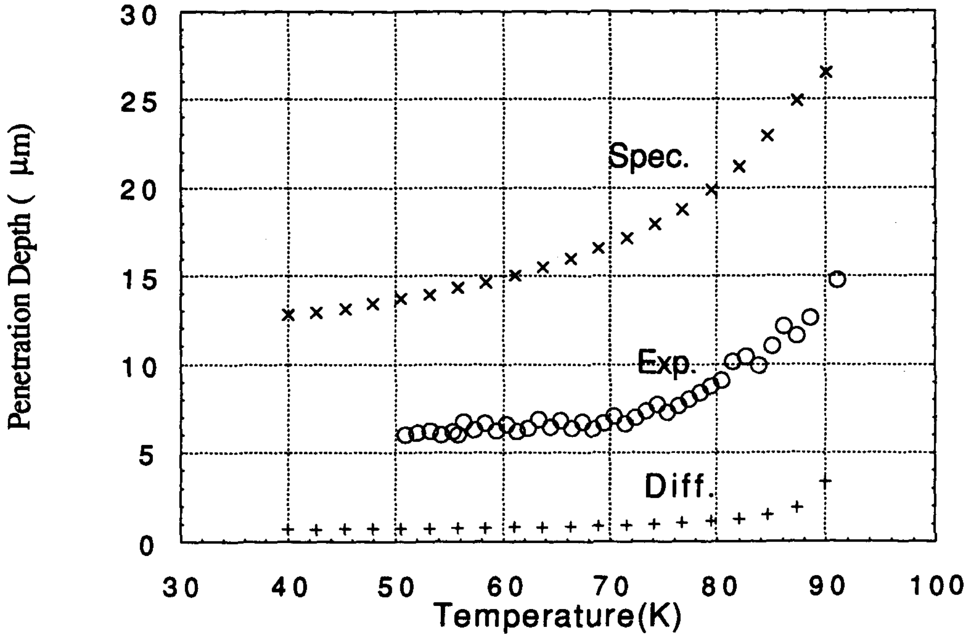

Fig.4 The penetration depth of magnetic field as the function of the temperature.
(o): the experimental results;
(x): theoretical calculation in the specular reflection regime;
(+): theoretical calculation in the diffuse reflection regime.

The magnetic field dependence of the surface resistance Rs(H) has been measured at different fixed temperature, shown in fig.5. The results were found to be well consistent with the Josephson junction model of weak links$^{(4)}$, which is widely used in high Tc superconductors and specially in polycrystalline forms. The basic point of the model supposes that the material is composed of individual grains which are coupled or weakly linked through resistive shunted Josephson junctions. The electric properties of the weak links are characterised by the junction critical current Jc, grain size and junction specific resistance. Accordingly, the rf field dependence of Rs is readily described in three regions of the magnitude of the fields. First, in the very low power level, the rf field-induced current J is much smaller than the critical current Jc in the grain boundary, the dissipation is constant, do not dependent on the field; The similar field independent behaviour happens in the other extreme limit of very high rf fields. In this case the current J induced by the field is much higher than the Jc, the grains decoupling takes place. The grain boundary behaves like pure resistor and the Rs(H) saturates

**till to normal state break-down. On the contrary, at the intermediate field, the dissipation increases with arising rf power because of the resistive property of the shunted Josephson junction.**

**The measurement of Rs (H) displayed a field independent behaviour at low rf field till to 0.1 Gauss. Then, it increased almost linearly in arising field. The high dissipation and low Q factor of the polycristalline superconducting cavity have limited the high rf field available in our measurements to about 1 Gauss. It has also been observed in fig.5 that the surface resistance Rs(H) becomes less field dependence at higher temperatures.**

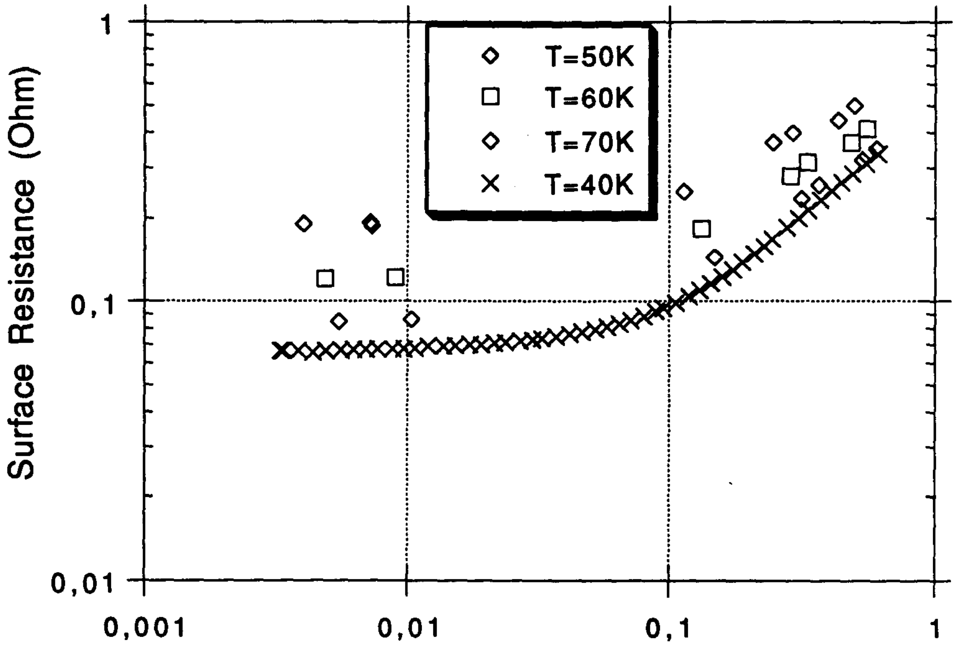

Figure 5. The surface resistance vs rf magnetic peak field.

## Reference:

1. B.Zhang, P.Fabbricatore, G.Gemme, R.Musenich,R.Parodi. Physica C 193 (1992) 1-7.
2. B.Zhang, P.Fabbricatore, G.Gemme, R.Musenich,R.Parodi.Physica C 203 (1992) 51-58.
3. P.P. Nguyen, E. Oates et al, PR. 48 (1993) 6400, and D.A.Bonn et al, PRL. 68 (1992) 2390.
4. J. Halbritter J.Appl.Phys.68(12),1990