DIELECTRIC RESONATOR USED AS A PROBE FOR HIGH Tc SUPERCONDUCTOR MEASUREMENTS

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ABSTRACT

A novel probe for high Tc superconductor measurements based on the post dielectric resonator is described. Advantages of the device and the method of measurements include high sensitivity, simplicity, ability to measure small superconductor samples and nondestructive measurements of selected areas of larger samples including thin film superconductors. The technique and selected results are presented.

INTRODUCTION

The newly developed high temperature superconductors offer exciting possibilities for microwave and millimeter wave components and subsystems. Reduced surface resistance of the superconductor at microwave frequencies as compared to traditional metals is expected to significantly improve performance of these components. For this reason, proper microwave characterization of high Tc superconductors is crucial. Different characterization techniques for microwave surface resistance are described in [1].

The techniques include use of a cylindrical cavity operating in the TE011 mode (shown in Figure 1), disk resonator, stripline and coaxial resonators, and finally, a cavity perturbation technique. However, all these techniques have certain drawbacks. A method utilizing the TE011 cavity requires relatively large samples of superconductor material (greater than 5 cm^2 for frequencies below 20 GHz) if measurements need to be performed at lower microwave frequencies. Also, the cavity is only partially superconducting and losses in the metal side wall dominate Q value, reducing sensitivity and accuracy of measurements.

The TE011 mode dielectric filled high Tc superconductor cavity described in [2] is difficult to make from bulk material, air gaps are a problem, and at the present time it is impossible to realize such a cavity with thin film superconductor. The disk resonator method is very promising, however, large samples of superconductor are also required. Stripline or coaxial resonator methods can be used to measure over a wide range of frequencies, however, test resonators must be manufactured from supercondutive samples (thin film or bulk material). The perturbation method requires very small samples of the material, and in the case of high Tc superconductors, the best results were obtained using superconductive niobium (low Tc) for the test cavity.

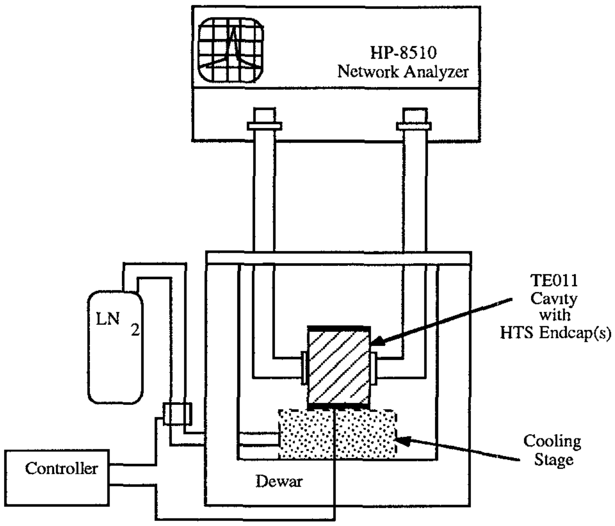

Figure 1 Cavity Q Measurement Technique

In this short paper, a novel method based on a post dielectric resonator is proposed for high Tc superconductor resistivity measurements. A basic principle of the method is well known and widely used for dielectric constant and loss tangent measurements of materials for dielectric resonators (Hakki-Coleman method [3] with numerous modifications [4-6]). In all these methods, significant effort was devoted to calibrate out surface resistance of conductive walls. In our case, these methods will be evaluated and modified to obtain surface resistance and calibrate out loss tangent of the dielectric material. Advantages of the proposed method and fixture for measurements (probe) include the ability to measure small samples of superconductor at lower microwave frequencies, the possibility of probing different areas on a sample such as a large superconductive thin film, simplicity, and accuracy. Since end walls of the post resonator are the main contributors to Q factor, and side walls are absent, the method is much more sensitive then the TE011 mode cavity method. An additional advantage is related to the fact that the method is nondestructive and many different samples can be measured using the proposed fixture (probe) and later used to manufacture an actual device such as a resonator.

DIELECTRIC PROBE STRUCTURE AND MEASURING TECHNIQUE

The basic configuration of the proposed dielectric resonator probe is shown in Figure 2. A circular dielectric resonator is attached on one side to a copper plate, which also serves as a support for input and output coupling probes (the resonator is weakly coupled). The bottom plate serves as a calibration surface and also can be used as a support for the high Tc superconductor sample- typically in the form of a disk or plate. The TE011 mode is used for measurements in a fashion similar to that described by e.g. Kobayashi [6]. The field configuration of this particular mode is shown in Figure 3. The TE011 mode is easily identified, relatively insensitive to small gaps between dielectric and conductive plates, and due to its field configuration, has no axial currents across any possible joints in conductive plates (similar to the TE011 mode in circular metal cavity). Typical resonant modes of the structure are shown in Figure 4.

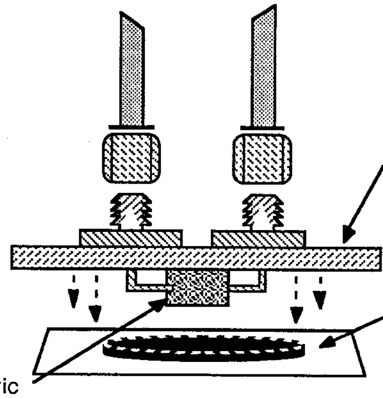

Figure 2 Dielectric Resonator Probe Assembly

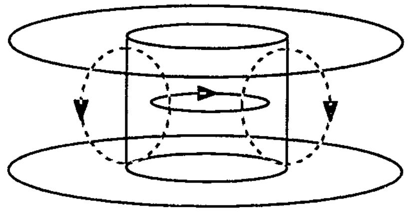

Figure 3 Field Configuration for the TE011 Resonant Mode

To determine microwave surface resistance of the plates (or one plate), the Q factor of the structure must be measured. Relative measurements of the resistance can be accomplished quite easily by simple determination of the Q factor ratio for copper and the sample under test, for example a high Tc superconductor plate. For measurements of absolute values of resistance we should note, that for this particular structure

$$1/Q_{total} = 1/Q_d + 1/Q_{top1} + 1/Q_{top2} + 1/Q_{bottom1} + 1/Q_{bottom2} + 1/Q_r$$

where : $Q_d = 1/\tan\delta$ - the dielectric quality factor
Q_r - the radiation quality factor- which in this case can be omitted
$Q_{top1}/Q_{bottom1}$ - the quality factor corresponding to losses in conductive plates directly under the high dielectric - top/bottom respectively
$Q_{top2}/Q_{bottom2}$ - the quality factor corresponding to losses in conductive plates outside the dielectric - top/bottom respectively.

It can be shown that for high dielectric constant materials (typically ranging from 80 for lower frequency resonators to 25 for higher frequency resonators), 90-95 % of losses occur in the plates directly under the high dielectric constant material. In addition, typical dielectric materials used are very low loss especially at cryogenic temperatures, which gives the method high sensitivity. The effect of loss tangent can be also calibrated out using the method described in [6], utilizing two dielectric resonators manufactured from the same lot of material; one operating in the TE011 mode, the second in a higher, for example TE012, mode.

The formulas for resistance calculations from measured Q factor values are given below. Since the fixture (probe) can be characterized for tanδ (dielectric resonator) and surface resistance (copper) at any given temperature, the only unknown will be the surface resistance of the sample (superconductor) under test. Therefore we have:

$$Rsmeas = (A/Qtotal - \tan\delta) / B - R_{sfixt}$$

where [6];

$$A = 1 + W/\varepsilon \qquad B = (\lambda_o / 2L)^3 * (1+W)/(60\pi^2\varepsilon)$$

$$W = \frac{J1^2(\xi)\,[K0(\zeta)K2(\zeta) - K1^2(\zeta)]}{K1^2(\zeta)\,\,[J1^2(\xi) - J0(\xi)J2(\xi)]}$$

and,
Rsmeas - surface resistance of the sample
Rsfixt - surface resistance of the fixture
L - length of the dielectric resonator
ε - dielectric constant
λ_o - wavelength
J0, J1, J2, K0, K1, K2 - regular and modified Bessel functions

$$\xi^2 = (2\pi / \lambda_o)^2 - (\pi / L)^2$$

$$\zeta^2 = (\pi / L)^2 - (2\pi / \lambda_o)^2$$

EXPERIMENTAL RESULTS

The developed dielectric resonator probe, shown in Figure 5, was used to determine microwave surface resistance of bulk high Tc superconductors such as Y-Ba-Cu-O and Bi-Sr-Ca-Cu-O. The results are listed in Figure 6. At the present time, additional samples of thin film superconductors are undergoing similar evaluation. We should note that due to the high dielectric constant of dielectric resonator materials, the surface area of the samples needed for measurements is quite small, for example less than 0.2 cm^2 at 10 GHz. This would enable us to probe larger samples of materials, when available, and locate areas with the best microwave properties.

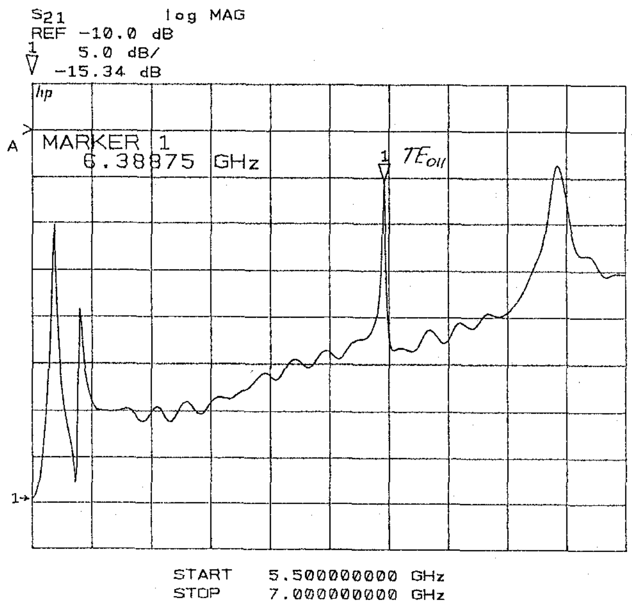

Figure 4 Typical Resonant Modes of the Dielectric Resonator Probe

CONCLUSIONS

A modification of a well established method for dielectric materials measurements was shown to have excellent potential as a production type, nondestructive test method for high Tc superconductors in bulk and thin film forms. A proposed test fixture configuration can serve as a dielectric resonator probe for large superconductor samples. At the same time, relatively small samples can be measured at lower microwave frequencies where accuracy of measurements is highest. The fixtures are easy to make and use. Analytical solutions to the electromagnetic field problem of the structure are available, and necessary computer programs were written. This facilitates discussion of error estimation of measured values, calibration and resistance calculations.

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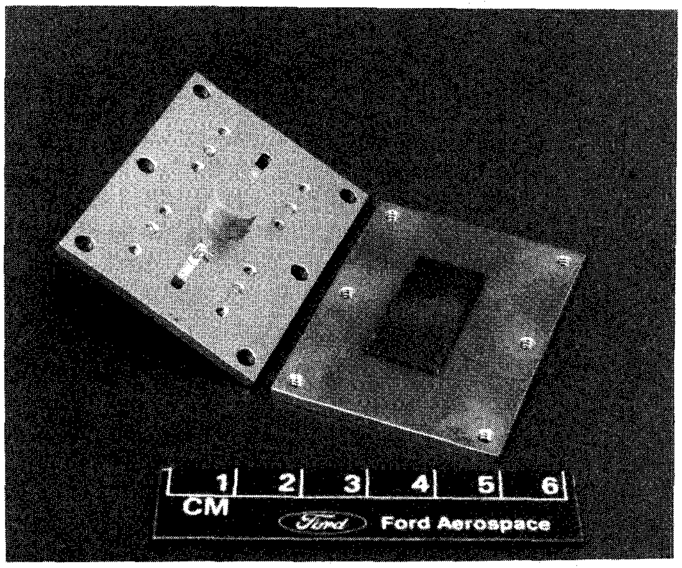

Figure 5 Dielectric Resonator Probe for 6.5 GHz Measurements

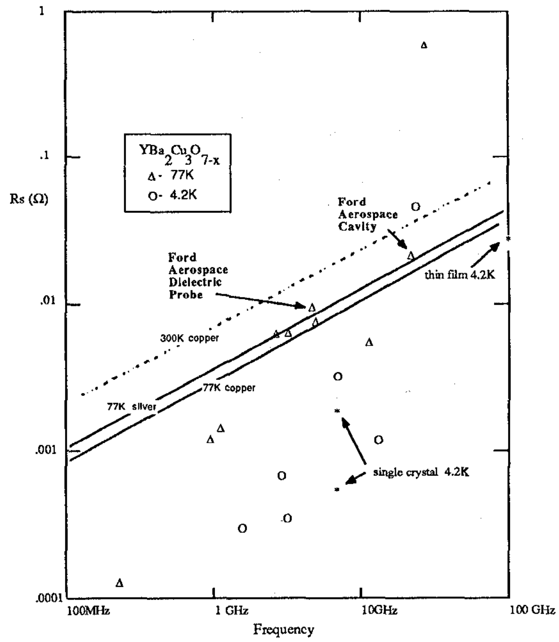

Figure 6 Microwave Surface Resistance of High Tc Superconductors
(Modification of graph presented at 1988 IEEE Symposium workshop on Superconductivity and Microwaves)