# RESEARCH ON MICROWAVE PROPERTY OF HIGH-$T_c$ SUPERCONDUCTOR

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***Abstract***

A parallel plate resonator technique for the measurement of microwave surface resistance and penetration depth of superconductive film is discussed. The method allows the evaluation of small, flat samples over a broad range of temperature. It can accurately characterize samples with surface resistance as low as 5μΩ or as high as 1mΩ at 5GHz, and with penetration depth to the accuracy of 100 Å. In addition to high resolution, it has several other advantages.

## 1 INTRODUCTION

Much effort has been directed toward the goal of developing high-$T_c$ superconductive thin films with microwave surface loss that are appreciable lower than that of nonsuperconductive metal. Traditionally, surface resistance of superconductors has been measured by fabricating an entire resonating cavity from the material to be evaluated. When sample size and geometry are severely constrained, this approach is no longer feasible; And because of the anisotropic nature of the high-$T_c$ materials, there is no simple arrangement that allows the fabrication of an adequte, completely enclosed cavity resonator from such samples.

In practice, many groups have resorted to using cylindrical cavities fabricated from some conventional material and simply replacing one end with the sample to be evaluated. Other methods commonly in use require that the sample be patterned into a long meander line that is enclosed between distant ground planes that provide a minor contribution to the overall loss. But such methods are not entirely satisfactory because it is preferable to employ a test method that is rapid and accurate that presents the simplest possible sample preparation requirements.

In the following paragraphs we can see that parallel plate resonator technique can meet the need above.

## 2 METHOD

In the method described here, a parallel plate resonator is formed with a thin dielectric spacer placed between two flat superconducting surfaces, as shown in Fig.1, The two samples are intended to be congruent but their exact shape is not crucial, square or rectangular pieces are all convenient.

Fig.1: Illustration of parallel plate resonator

There are altogether three signifiant loss contribution that establish the $Q$ of parallel plate resonator modes, i.e., resistive loss at the superconducting surfaces, dielectric loss and the radiation loss at the edges resulting from the fringing fields which extend outside the resonator. To increase the resolution of the microwave impedance, the former two factors are to be constrained. Here we choose sapphire as the dielectric spacer for its very low dielectric loss tangent, meanwhile make its thickness as small as possible.

For open boundary conditions at the edges of rectangular parallel resonator with length $L$ and width $W$, the resonant frequency and quality factor could be expressed as

$$f^2 = \frac{c^2}{\varepsilon K}\left[\left(\frac{n}{2L}\right)^2 + \left(\frac{m}{2W}\right)^2\right] \tag{1}$$

$$\frac{1}{Q} = \frac{1}{Q_s} + \alpha s + \tan\delta \tag{2}$$

Where $n$ and $m$ are mode indices($TM_{nm}$), and $K$ is a factor involved with the change in phase velocity. The three terms in the right side of Eq.(2) represent different kinds of contributions to the quality factor respectively.

As we mentioned above, the first term represents the resistive loss at the superconducting surfaces; while the second term represents the radiation loss, here we assume that it is proportional to the thickness of dieletric; and the third term, which is the loss tangent, represents the dielectric loss.

The penetration depth λ could be acquired via the calculation of the factor *K* in Eq.(1) which resulted from the kinetic inductance of superconductor by the expressions[1]:

$$\frac{\Delta f}{f} = \mathrm{Re}[\frac{\lambda}{s}\coth(\frac{d}{\lambda})] \quad (3)$$

$$\frac{1}{Q_s} = \mathrm{Im}[\frac{\lambda}{s}\coth(\frac{d}{\lambda})] \quad (4)$$

Where $\Delta f/f$ is the fractional frequency shift and $d$ is the thickness of the sample films, combined with $Z_s=R_s+iX_s=i\omega\mu_0\lambda$, it gives the expressions: $R_s=2\pi fs/Q_s$, $X_s=2\pi s\Delta f$.

Using the equations shown above, by performing a quadratic least-square fit to the data, the surface resistance $R_s$, the penetration depth λ as well as the dielectric loss tangent tanδ and the radiation loss factor α are all available.[2]

## 3 MEASUREMENT CONFIGURATION[3]

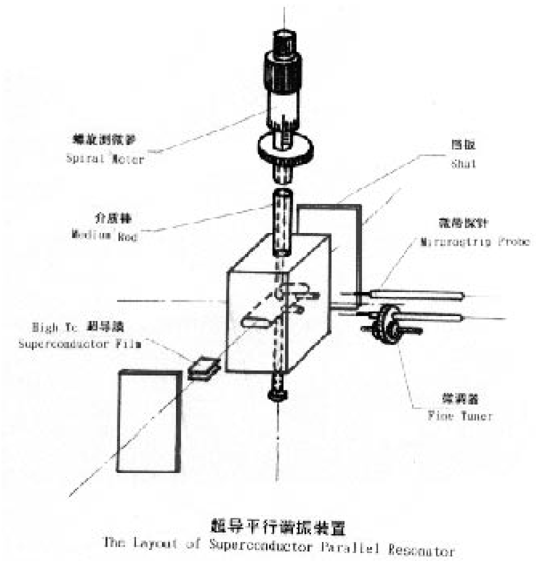


Fig. 2: Expand view of the measurement configration

The overall test arrangement is shown in Fig. 2, where the samples are pressed together using dielectric posts, one of which is spring loaded from outside. They are positioned approximately in the center of the test chamber, but the precise location is not critical. The chamber is made of copper with both open sides covered to minimize the radiation loss. The whole test chamber include the resonant system is soaked into a liquid nitrogen Dewar.

Coupling to the test resonator is obtained by positioning a pair of 50-Ω microstip probes, which are soldered to the ends of a coaxial line, near the two corners of the resonator. The probes are oriented to be coplanar with the test resonator and the positions of the open ends are separately adjusted to provide sufficient coupling.

For convenience, the coupling probes are positioned such that the coupling is so weak that the loaded and unloaded Q become indistinguishable. This condition is obtained when the probe tips are within a few tenths of a millimeter from the edge of the parallel resonator.

The measurement are performed with the aid of HP8757D scalar network analyzer, HP8350B sweep oscillator, HP34401A multimeter and HP9000 controller. All the microwave measurement are programmed.

## 4 RESULT

Table 1 shows the resonant frequency *f* and quality factor *Q* of a certain parallel $YBa_2Cu_3O_7$ resonator according to different thickness of sapphire, all these data are obtained under the temperature 77K. Substitution into the equations above, using a quadratic least-square fit, gives: $\tan\delta=2.55\times10^{-6}$, $\alpha=6.63\times10^{-5}$, and $R_s=695\mu\Omega$(77K).

| | | | | | | |
|---|---|---|---|---|---|---|
| S(μm) | 158 | 273 | 315 | 425 | 483 | 515 |
| F(GHz) | 5.288 | 5.137 | 5.262 | 5.283 | 5.257 | 5.276 |
| Q | 2134 | 2597 | 2744 | 2957 | 3042 | 3106 |

Table 1: Variance of *f* and *Q* with dielectric thickness

We also studied the temperature dependence of the resonant frequency *f* and quality factor *Q*, acquring the temperature lower than 77 K by lowering the pressure of nitrogen in Dewar. The measurement result of *f* and *Q* are shown in Fig. 3 and Fig. 4 respectively($T_c$=86.0K), with the temperature range 55K-90K. The two curves in Fig. 3 and Fig. 4 are composed by over 2400 points. With these data we can easily the variance of surface resistance with temperature.

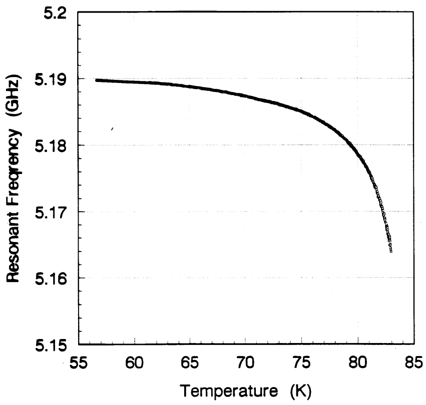


Fig. 3: Measured $f$ as a fuction of temperature

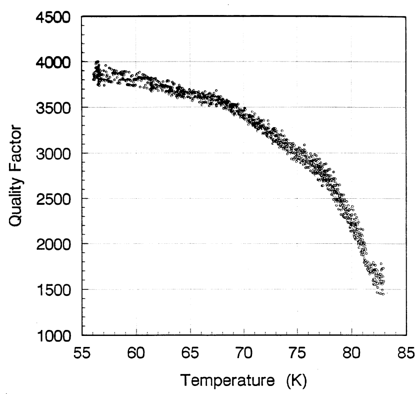


Fig. 4: Measured $Q$ as a fuction of temperature

Combined with the result of surface resistance under 77K, the temperature dependence of $R_s$ is shown in Fig. 5.

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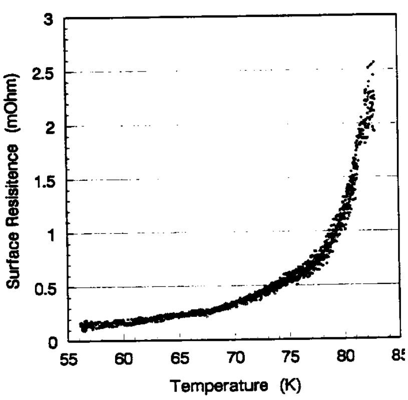


Fig. 5: $R_s$ of $YBa_2Cu_3O_7$ as a fuction of temperature

According to Fig. 3, together with the equations given previously, we got the penetration depth of the $YBa_2Cu_3O_7$ sample, which is 2900 Å(77K) as the result of least-square fit to data in Fig. 6.

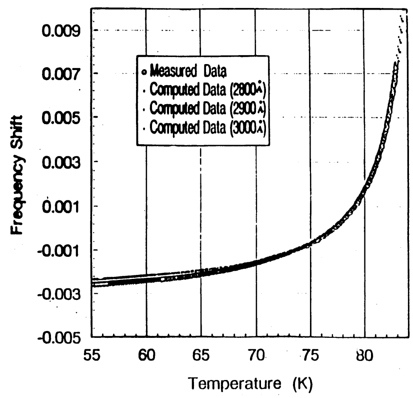


Fig. 6: Penetration depth(λ) of $YBa_2Cu_3O_7$ films acquired by least-square fit of measured data

## 5 CONCLUSION

According to our experiment, the technique of parallel plate resonator can be appreciated in several aspects, i.e., the measuring resolutions is quite high, sample requirements are minimal; the current distribution within the sample under test is relatively uniform and can be accurately calculated; no other superconducting or normal conducting material is required for the resonator, thus no additional corrections for such materials are needed; and the whole procedure is comparatively rapid.

## 6 ACKNOWLEDGMENTS


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## 7 REFERENCE


[1] A.Ya.Basovich et al.: "Parallel-Plate Resonator of Variable Spacer Thickness for Accurate Measurement of Surface Impedence of High-$T_c$ Superconductive Films", Journal of Superconductivity, Vol.5, No.6, 1992.

[2] R.C.Taber et al.: "A Method for the Accurate Measurement of the Complex Conductivity of High-$T_c$ Superconductive Thin Films", Journal of Superconductivity, Vol.5, No.4, 1992.

[3] Zhitao Yang et al.: "Research on Microwave Property of High-$T_c$ Superconductor", Proceedings of the 4th Chinese Laser Conference, 1997.