Microwave Measurements of Surface Impedance of High-T_c Superconductors Using Two Modes in a Dielectric Rod Resonator

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***Abstract*— A novel technique using two resonant modes in a dielectric rod resonator, the TE_{021} and TE_{012} modes, is proposed to measure the surface impedance $Z_s = R_s + jX_s$, where R_s is the surface resistance and X_s is the surface reactance of high-T_c superconductors at microwave frequency. The temperature dependence of Z_s can be obtained from only one time measurement as a function of temperature, although the conventional two-resonator method needs to repeat the measurement for temperature twice. The high precision in the R_s measurement is comparable to the conventional two-resonator method using two ceramic rod resonators. The excellent repeatability in the X_s measurement is superior to that of the two-resonator method.**

***Index Terms*— Dielectric resonators, high-temperature superconductors, microwave measurements, surface impedance.**

I. INTRODUCTION

MEASUREMENT of the surface impedance $Z_s = R_s + jX_s$, where R_s is the surface resistance and X_s is the surface reactance, of high-T_c superconductors at microwave frequency is essential for the material development and the research of superconductor physics. For the R_s measurements, many papers have been presented [1]–[7]. For the X_s measurements, however, there are few papers; one is the perturbation technique using a Pb cavity [1], [2] and the other is so-called two-resonator method; one is a TE_{011} mode dielectric rod resonator having length L_1 and the other is a TE_{01p} mode dielectric rod resonator having length $L_p = pL_1$, usually $p = 3$ [3]. However, the measurement accuracies of X_s are not sufficiently high for these methods.

In this paper another method is proposed to measure the temperature dependences of X_s as well as R_s simultaneously. In this method, we use two resonant modes in a dielectric rod resonator, the TE_{021} and TE_{012} modes, which will be called the one-resonator method [8]–[10]. For the R_s measurements, it has been verified that the high accuracy is realized because the measurements for these two modes can be performed alternately and almost simultaneously at a given temperature [9]. In the same reason, we can expect a high accuracy also for the X_s measurements.

II. MEASUREMENT PRINCIPLE

In this measurement, the TE_{012} and TE_{021} modes are used in a dielectric rod resonator having relative permittivity ε_r, loss tangent $\tan\delta$, diameter D, and length L, which is placed between two parallel conducting plates having Z_s and diameter d. The field plots of these modes are shown in Fig. 1. A mode chart calculated for $\varepsilon_r = 24$ is shown in Fig. 2 [11]. The

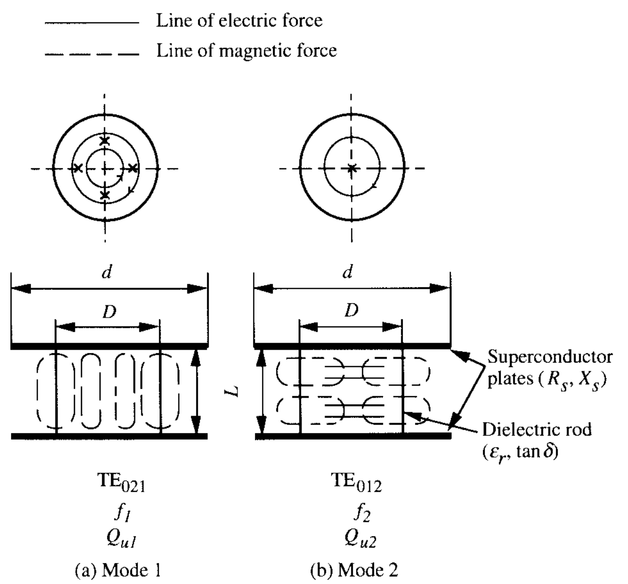

Fig. 1. Field plots of the TE_{021} and TE_{012} modes in a dielectric rod resonator placed between two parallel conducting plates.

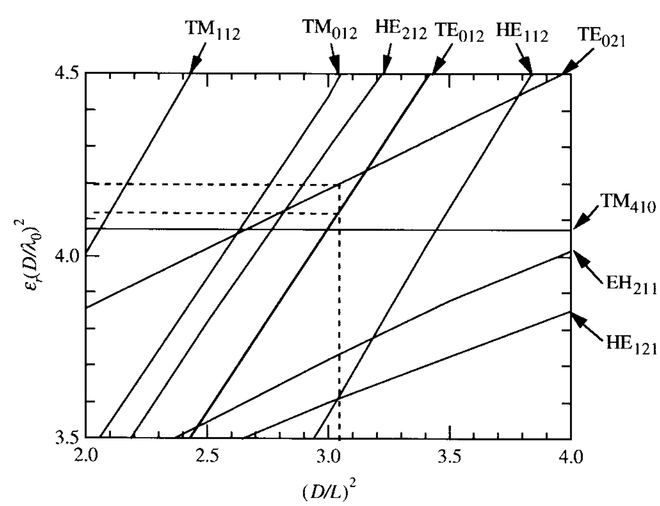

Fig. 2. A mode chart calculated for $\varepsilon_r = 24$.

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values of D and L are designed so that the resonant frequency f_1 for the TE_{021} mode is in proximity to f_2 for the TE_{012} mode, as indicated by the broken lines in Fig. 2.

The values of ε_{rp}, where $p = 1$ is the TE_{021} mode and $p = 2$ the TE_{012} mode, are obtained from the measured values of f_p by the following formula [12]:

$$\varepsilon_{rp} = \left(\frac{c}{\pi D f_p}\right)^2 \left(u_p^2 + v_p^2\right) + 1 \tag{1}$$

where c is the light velocity and

$$v_p^2 = \left(\frac{\pi D f_p}{c}\right)^2 \left\{\left(\frac{cp}{2Lf_p}\right)^2 - 1\right\} \tag{2}$$

$$u_p \frac{J_0(u_p)}{J_1(u_p)} = -v_p \frac{K_0(v_p)}{K_1(v_p)}. \tag{3}$$

In the above, J_n is the Bessel function of the first kind, and K_n is the modified Bessel function of the second kind. It is noted that u_1 for the TE_{021} mode is the second solution of the transcendental equation (3) and u_2 for the TE_{012} mode is the first solution of (3).

The values of $\tan\ \delta_p$ are obtained from the unloaded Q, Q_{up} measured at f_p by the following formula [12]:

$$\tan\ \delta_p = \frac{A_p}{Q_{\mathrm{up}}} - B_p R_{sp} \tag{4}$$

where R_{sp} is given by (8) described below, and constants A_p and B_p are given by

$$A_p = 1 + \frac{W_p}{\varepsilon_{rp}} \quad B_p = \left(\frac{cp}{2Lf_p}\right)^3 \frac{1 + W_p}{30\pi^2 p \varepsilon_{rp}} \tag{5}$$

$$W_p = \frac{J_1^2(u_p)\{K_0(v_p)K_2(v_p) - K_1^2(v_p)\}}{K_1^2(v_p)\{J_1^2(u_p) - J_0(u_p)K_2(u_p)\}}. \tag{6}$$

We define ε_{r0}, $\tan\ \delta_0$, R_{s0}, and X_{s0} by the values of ε_r, $\tan\ \delta$, R_s, and X_s at f_0, respectively, which is given arbitrarily near f_1 and f_2, taking their frequency dependences into account. In particular, for ion crystallized material such as polycrystalline ceramics and sapphire used in this measurement, we assume that the following relations are kept in the frequency region including f_1, f_2, and f_0:

$$\varepsilon_{rp} = \varepsilon_{r0} \quad \tan\ \delta_p = \frac{f_p}{f_0} \tan\ \delta_0. \tag{7}$$

Similarly, for conducting plates we assume that the following relations are kept:

$$R_{sp} = \left(\frac{f_p}{f_0}\right)^n R_{s0} \quad X_{sp} = \left(\frac{f_p}{f_0}\right)^m X_{s0} \tag{8}$$

where $n = m = 1/2$ for a normal conductor and $n = 2$ and $m = 1$ for a superconductor, according to the two-fluid model [13]. The substitution of (7) and (8) into (4) yields

$$\frac{f_p}{f_0} \tan\ \delta_0 = \frac{A_p}{Q_{\mathrm{up}}} - B_p \left(\frac{f_p}{f_0}\right)^n R_{s0}. \tag{9}$$

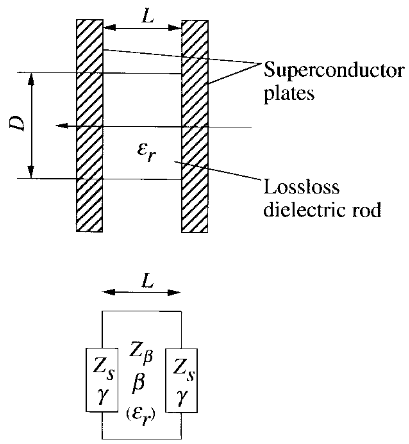

Fig. 3. Equivalent circuit of TE_{0ml} mode dielectric resonator.

Eliminating $\tan\ \delta_0$ from two equations derived from (9) for $p = 1$ and 2, we obtain

$$R_{s0} = \frac{f_0^n f_2 \dfrac{A_1}{Q_{u1}} - f_0^n f_1 \dfrac{A_2}{Q_{u2}}}{B_1 f_1^n f_2 - B_2 f_2^2 f_1}. \tag{10}$$

Similarly, eliminating R_{s0} from these two equations, we obtain

$$\tan\ \delta_0 = \frac{B_1 f_1^n f_0 \dfrac{A_2}{Q_{u2}} - B_2 f_2^n f_0 \dfrac{A_1}{Q_{u1}}}{B_1 f_1^n f_2 - B - 2 f_2^n f_1}. \tag{11}$$

Then, a measurement principle of X_s will be described below. Fig. 3 shows an equivalent circuit used in this analysis on the assumption of $d = \infty$ and $\tan\ \delta = 0$. The values ε_{r1} and ε_{r2} measured by (1), which is derived under the condition $R_s = X_s = 0$, have values different from each other because of different effects of X_s depending on the modes. Therefore, an intrinsic relative permittivity of the dielectric rod ε_i can be calculated by

$$\varepsilon_i = \varepsilon_{r1} - \Delta\varepsilon_{r1} = \varepsilon_{r2} - \Delta\varepsilon_{r2} \tag{12}$$

where $\Delta\varepsilon_{r1}$ and $\Delta\varepsilon_{r2}$ are correction terms due to X_{s1} for the TE_{021} mode and due to X_{s2} for the TE_{012} mode, respectively, which will be calculated by the perturbation technique [3] (see the Appendix); that is,

$$\Delta\varepsilon_{rp} = 4(1 + W_p)\left(\frac{\beta_p}{k_p}\right)^2 \frac{X_{sp}}{\omega_p \mu L} \tag{13}$$

where

$$k_p = \frac{\omega_p}{c} \quad \beta_p = \frac{\pi p}{L}. \tag{14}$$

The relationships among (8), (12), and (13) yields

$$X_{s0} = \frac{\varepsilon_{r2} - \varepsilon_{r1}}{(C_2 - C_1)} \tag{15}$$

where

$$C_p = 4(1 + W_p)\left(\frac{\beta_p}{k_p}\right)^2 \frac{1}{\omega_p \mu L}\left(\frac{f_p}{f_0}\right)^m. \tag{16}$$

As a result, the value of X_{s0} can be obtained from the measured values ε_{r1} and ε_{r2} by using (15).

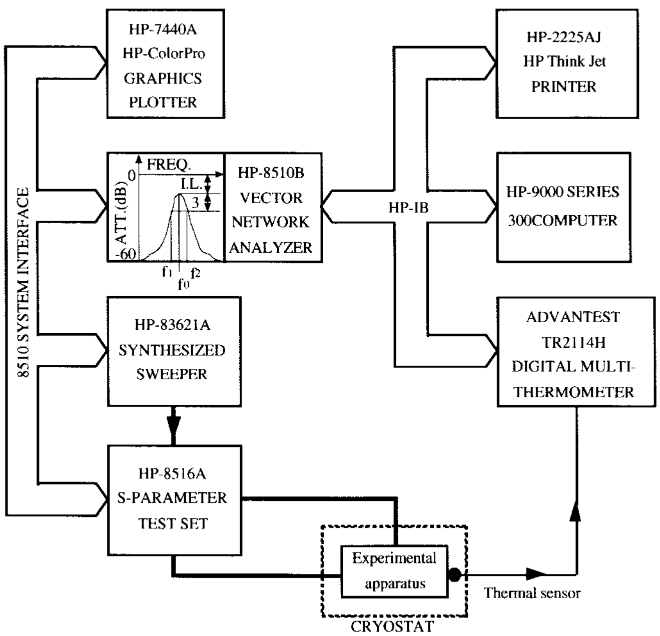

Fig. 4. Automatic measurements system.

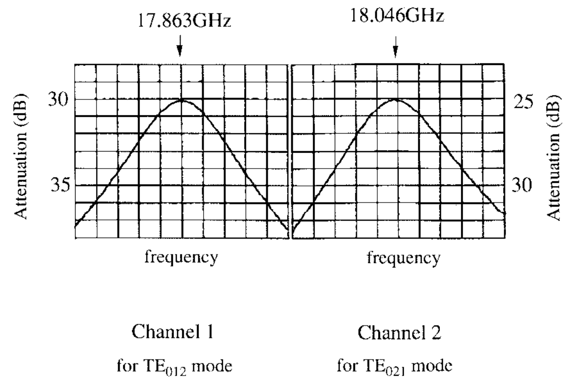

Fig. 5. Two resonance curves observed on network analyzer.

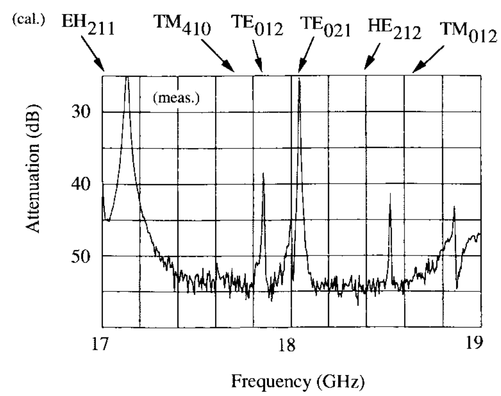

Fig. 6. The frequency response for a dielectric resonator placed between two copper plates and the resonance modes calculated from the mode chart.

Furthermore, on the basis of the two-fluid model [12], the complex conductivity σ can be obtained from measured Z_s value by

$$\sigma = \sigma_1 - j\sigma_2 = \frac{j\omega\mu_0}{Z_s^2} \tag{17}$$

and the skin depth δ and the penetration length λ are given by

$$\delta = \sqrt{\frac{2}{\omega\mu_0\sigma_1}} \quad \lambda = \sqrt{\frac{1}{\omega\mu_0\sigma_2}}. \tag{18}$$

Finally, it is assumed that the temperature dependences of D and L are given by

$$L = L_0[1+\tau_\alpha(T-T_0)] \quad D = D_0[1+\tau_\alpha(T-T_0)] \tag{19}$$

where D_0 and L_0 are the values at the reference temperature T_0, and τ_α is the linear thermal expansion coefficient of the dielectric rod.

III. Measured Results

Based on the formulas derived in the above section, a program was developed to realize an automatic measurement system for the one-resonator method. The block diagram is shown in Fig. 4. Two resonance curves observed on a network analyzer are shown in Fig. 5. Channel 1 is set for the TE_{012} mode, and channel 2 is for the TE_{021} mode. The f_o and Q_u for these modes are measured at a given T, alternately with a high speed switching between these two channels. The dielectric resonator is set up in the cryostat and is cooled from the room temperature to the lowest temperature. We take data of f_o and Q_u for the TE_{012} and TE_{021} modes with the natural increase of each 1 K after turning off the electric power of the cryostat. The values of ε_r, $\tan\,\delta$, R_s, and X_s are calculated as a function of T from these data.

A. Copper Plates

At first, a BMT ceramic rod ($\varepsilon_r = 24, \tau_\alpha = 6.3$ ppm/K, Murata Mfg. Co.) having $D = 6.994 \pm 0.001$ mm and $L = 4.003 \pm 0.001$ mm [9] was placed between two copper plates of $d = 35$ mm, which is greater than the 20-mm diameter required to satisfy 10% in precision for the measured value $R_s = 0.1$ mΩ under the condition of 1% in precision in the Q measurements [14]. The measured frequency response is shown in Fig. 6, together with the resonance modes calculated from the mode chart in Fig. 2. The resonant frequencies measured for the TM, EH, and HE modes are about 2% higher than the calculated ones because of air-gap effects between the dielectric rod and the plates. The values of f_1, Q_{u1}, f_2, and Q_{u2} measured as a function of T are shown in Fig. 7(a)–(c), respectively. The reason why the values of f_1 and f_2 have minimum around $T = 130$ K is due to a characteristic of BMT ceramics itself. The values of ε_r, $\tan\,\delta$, X_s, and R_s calculated from these measured values are shown in Fig. 7(d)–(f). In these calculations, $L_0 = 4.0035$ mm at 293 K was used so that two values of ε_{r1} and ε_{r2} take the same values. Furthermore, the actual length of the rod was decided to be $L_0 = 4.0033$ mm by taking the skin depth of two copper plates $\delta = 2R_s/\omega\mu_0 \fallingdotseq 0.2$ μm into account. In this case, the X_s measurements of Cu plates are not sufficiently precise because the X_s values of Cu are ten times less than those of YBCO bulk plates.

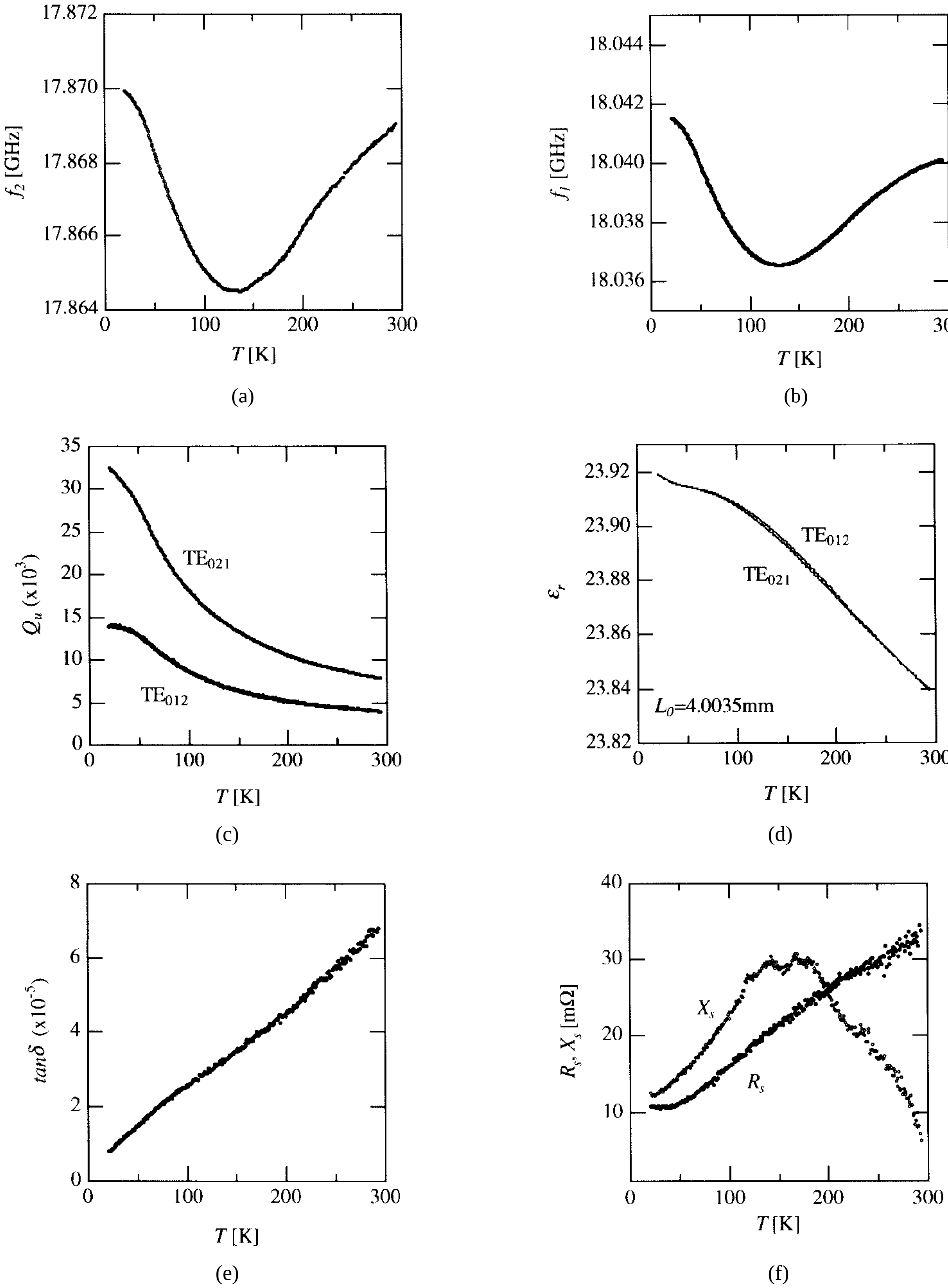

Fig. 7. Measured results for ε_r and $\tan\ \delta$ of a BMT ceramic rod and R_s of Cu plates by one-resonator method. (a) $f_2 - T$ for TE_{012} mode. (b) $f_1 - T$ for TE_{021} mode. (c) $Q_u - T$. (d) $\varepsilon_r - T$. (e) $\tan\ \delta - T$. (f) $R_s, X_s - T$.

B. YBCO Bulk Plates

Second, the two copper plates were changed into two melt-textured YBCO bulk plates (Imura Material R&D Co.) of $d = 33$ mm [9]. The measurements were repeated two times. The f_1 and f_2 for the Cu and YBCO plates are shown in Fig. 8(a) and (b) where the Nos. 1 and 2 indicated in the curves are for the first and second measurements, respectively. The measured values of Q_{u1} and Q_{u2} are shown in Fig. 8(c). The ε_{r1} and ε_{r2} values calculated from these f_1 and f_2 values are shown in Fig. 8(d), together with the ε_i values calculated from these values using (12), (13), and (15), and similar results for Cu to be compared with these ε_i values. The $\tan\ \delta$ and R_s values calculated from the Q_{u1} and Q_{u2} values are shown in Fig. 8(e) and (f), respectively. The X_s values calculated from the ε_{r1} and ε_{r2} values are shown in Fig. 8(f). The reproducibility of these measured results is excellent. Fig. 9 shows the error of X_s calculated from a small change of the length of dielectric rod. Particularly, the X_s measurements by the one-resonator method were 53% superior in precision to 95% in precision for the conventional two-resonator method [3].

C. $\sigma = \sigma_1 - j\sigma_2, \delta$, and λ

The σ_1 and σ_2 values were calculated from the measured Z_s values. These results are shown in Fig. 10(a). Furthermore, λ and δ values calculated from the σ_1 and σ_2 values are

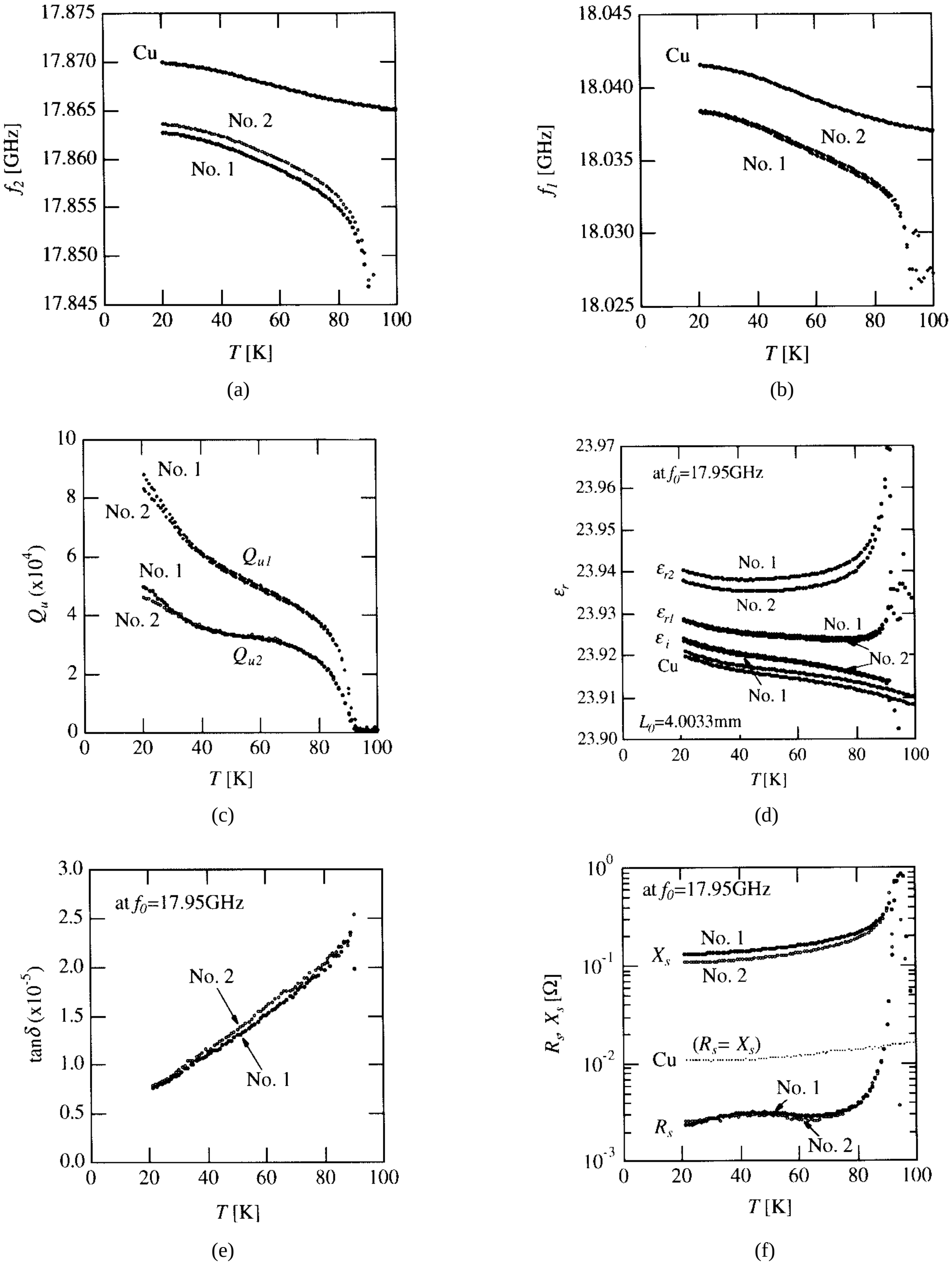

Fig. 8. Measured results for ε_r and $\tan\ \delta$ of a BMT ceramic rod and Z_s of melt-textured YBCO bulk plates by one-resonator method. (Nos. 1 and 2 are for the first and second measurements, respectively.) (a) $f_2 - T$ for TE_{012} mode. (b) $f_1 - T$ for TE_{021} mode. (c) $Q_u - T$. (d) $\varepsilon_r - T$. (e) $\tan\ \delta - T$. (f) $R_s, X_s - T$.

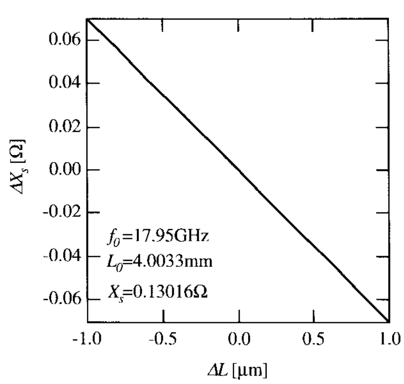

Fig. 9. The error of X_s calculated from a small change of the length of dielectric rod.

shown in Fig. 10(b). Considerably good reproducibility also was obtained for these measured results. The measured value of the melt-textured YBCO bulk plates is $\lambda \fallingdotseq 0.8$ μm which is between $\lambda \fallingdotseq 0.2$ μm for YBCO film [3] and $\lambda \fallingdotseq 2$ μm for YBCO bulk [2].

D. Comparison with the Two Resonator-Method

Finally, similar measurements of R_s for the same YBCO bulk plates were performed by using the two-resonator method, to be compared with one for the one-resonator method. For four sapphire rods ($\varepsilon_r = 9.3, \tau_\alpha = 5.3$ ppm/K, Kyocera Co.), which are two TE_{011} mode resonators having $D = 10.000 \pm 0.001$ mm and $L = 5.000 \pm 0.001$ mm and two TE_{013} mode resonators having $D = 10.000 \pm 0.001$ mm and

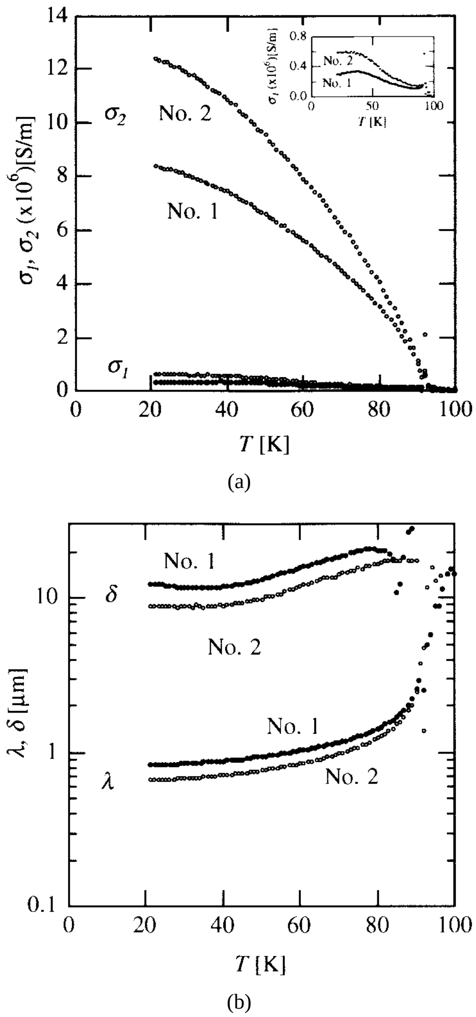

Fig. 10. Measured results for σ, λ, and δ of melt-textured YBCO bulk plates by one-resonator method. (Nos. 1 and 2 are for the first and second measurements, respectively.) (a) $\sigma - T$. (b) $\lambda, \delta - T$.

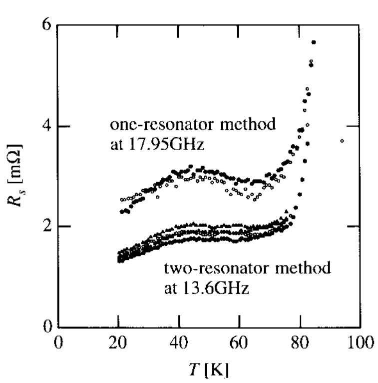

Fig. 11. Measured results of R_s of melt-textured YBCO bulk plates by one-resonator method using BMT ceramic rod and by two-resonator method using four sapphire rods.

$L = 15.000 \pm 0.001$ mm, the measurements were performed separately four times. The values of R_s for four sets of the TE_{011} and TE_{013} mode resonators were calculated from these measured values by using formulas for the two-resonator method [3]. These results are shown in Fig. 11, together with the measured R_s results taken from Fig. 7(f). The amount of scatter of these R_s values is due to the different $\tan\,\delta$ values of the each sapphire rods. As a result, for the one-resonator method using the BMT ceramic rod, the R_s measurements obtained are 4.7% in precision, which is comparable to 5.7% in precision by the conventional two-resonator method.

IV. Conclusion

It was verified that the one-resonator method is useful to measure the T dependence of Z_s, because they can be obtained from only one measurement for these two modes. For the R_s measurements, excellent reproducibility can be obtained, which is comparable to the conventional two-resonator method using sapphire rods. For the X_s measurements, one can be obtained, which is superior to the conventional two-resonator method.

Appendix
The Derivation of (13)

1) The relation between small changes $\Delta\varepsilon_r$ and Δf is derived from (1) and (2) and is given by [12]

$$\Delta\varepsilon_r = -2(\varepsilon_r + W)\,\frac{\Delta f}{f} \tag{A1}$$

where $W = du^2/dv^2$ is given in (6).

2) The characteristic equation for the equivalent circuit shown in Fig. 3 is given by

$$\begin{aligned} Z_L &= Z_\beta\,\frac{Z_s + jZ_\beta \beta L}{Z_\beta + jZ_s\,\tan\,\beta_L} \\ Z_\beta &= \frac{\omega\mu}{\beta} \quad Z_R = Z_s = \frac{j\omega\mu}{\gamma} \end{aligned} \tag{A2}$$

where Z_L is impedance seen to left side and Z_R is impedance seen to right side. From the resonance condition $Z_L + Z_R = 0$ and (A2) the following relation is obtained:

$$\tan\,\frac{\beta L}{2} = j\,\frac{Z_\beta}{Z_s}. \tag{A3}$$

Putting $X = \beta L/2$, (A3) is rewritten as

$$Z_s = \frac{j\omega\mu}{\gamma} = \frac{j\omega\mu L \cot X}{2X} \tag{A4}$$

when we define $X_0 = \beta_0 L/2 = \pi/2$ for $Z_s = 0, X$ due to the finite Z_s value is expressed by

$$X = X_0 + \Delta X = \frac{\beta L}{2} = (\beta_0 + \Delta\beta)\,\frac{L}{2}. \tag{A5}$$

Substitution of (A5) into (A4) yields

$$Z_s = \frac{j\omega\mu L \cot(X_0 + \Delta X)}{2X} \approx -\frac{j\omega\mu L}{2}\,\frac{\Delta\beta}{\beta}. \tag{A6}$$

3) From the equations

$$u^2 + v^2 = (\varepsilon_r - 1)(k_0 R)^2 \tag{A7}$$

$$v = R\sqrt{\beta^2 - k_0^2} \tag{A8}$$

given by (1) and (2), we derive

$$\frac{\Delta v}{v} = \frac{\varepsilon_r - 1}{1 + W}\left(\frac{R}{v}\right)^2 k_0^2\,\frac{\Delta\dot{\omega}}{\omega} \tag{A9}$$

$$\frac{\Delta v}{v} = \left(\frac{R}{v}\right)^2 \left\{\beta^2\,\frac{\Delta\beta}{\beta} - \left(\frac{\omega}{c}\right)^2 \frac{\Delta\dot{\omega}}{\omega}\right\} \tag{A10}$$

respectively [3], where a perturbational quantity of complex angular frequency $\Delta\omega/\omega$ [3] is given by

$$\frac{\Delta\dot{\omega}}{\omega} = \frac{\Delta f}{f} + j\,\frac{1}{2Q_s} \quad \Delta f = f - f_0 \tag{A11}$$

where f_0 is the resonant frequency when $Z_s = 0$, and f and Q_s are the resonant frequency and Q due to ohmic loss in the superconductor when $Z_s \neq 0$, respectively.

From (A9) and (A10), we obtain

$$\frac{\Delta\beta}{\beta} = \frac{\varepsilon_r - 1}{1 + W}\left(\frac{k_0}{\beta}\right)^2 \frac{\Delta\dot{\omega}}{\omega}. \tag{A12}$$

4) Substitution of (A12) into (A6) yields

$$R_s = \frac{\omega\mu L}{2}\,\frac{\varepsilon_r - 1}{1 + W}\left(\frac{k_0}{\beta}\right)^2 \frac{1}{2Q_s} \tag{A13}$$

$$X_s = -\frac{\omega\mu L}{2}\,\frac{\varepsilon_r - 1}{1 + W}\left(\frac{k_0}{\beta}\right)^2 \frac{\Delta f}{f}. \tag{A14}$$

Finally, eliminating $\Delta f/f$ from (A1) and (A14), we obtain (13).

REFERENCES

[1] S. Sridhar, "Microwave response of thin-film superconductor," *J. Appl. Phys.*, vol. 63, no. 1, pp. 159–166, Jan. 1988.

[2] H. Kitano, T. Shibauchi, K. Uchinokura, A Maeda, H. Asaoka, and H. Takei, "C-axis microwave conductivity of YBa2Cu3O7-d in the superconducting state," *Phys. Rev. B*, vol. 51, no. 2, pp. 1401–1404, Jan. 1995.

[3] Y. Kobayashi, T. Imai, and H. Kayano, "Microwave measurement of current dependence of surface impedance for high-T_c superconductor," *IEEE Trans. Microwave Theory Tech.*, vol. 39, pp. 1530–1538, Sept. 1991.

[4] Z.-Y. Shen, C. Wilker, P. Pang, W. L. Holstein, D. W. Fance, and D. J. Kountz, "High-T_c superconductor-sapphire resonator with extremely high Q-values up to 90 K," *IEEE Trans. Microwave Theory Tech.*, vol. 40, pp. 2424–2432, Sept. 1992.

[5] J. Krupka, M. Klinger, M. Kuhn, A. Baranyak, M. Stiller, J. Hinken, and J. Modelski, "Surface resistance measurements of HTS films by means of sapphire dielectric resonators," *IEEE Trans. Appl. Superconduct.*, vol. 3, pp. 3043–3048. Sept. 1993.

[6] N. Tellmann, N. Klein, U. Dahne, A. Scholen, H. Schulz, and H. Chaloupka, "High-Q $LaAlO_3$ dielectric resonator shielded by YBCO-films," *IEEE Trans. Appl. Superconduct.*, vol. 4, pp. 143–148, Sept. 1994.

[7] J. Mazierska, "Sapphire and rutile dielectric resonators for measurements of surface resistance of superconducting thin films," in *1997 Asia Pacific Microwave Conf. Proc.*, Dec. 1997, pp. 125–128.

[8] D.-M. Xu and Z.-N. Li, "A novel method for characterizing the surface resistance of two conducting plates shorted at both ends of a dielectric resonator," in *15th European Microwave Conf. Proc.*, Sept. 1985, pp. 912–916.

[9] Y. Kobayashi and H. Yoshikawa, "Automatic measurements of surface resistance of superconductors using two modes in a dielectric rod resonator," in *27th European Microwave Conf. Proc.*, Sept. 1997, pp. 703–708.

[10] ——, "A two-modes dielectric rod resonator method for surface impedance of high-T_c superconductors," in *IEEE MTT-S Int. Microwave Symp.*, WEIF-63, June 1998.

[11] Y. Kobayashi and S. Tanaka, "Resonant modes of a dielectric rod resonator short-circuited at both ends by parallel conducting plates," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-28, pp. 1077–1085, Oct. 1980.

[12] Y. Kobayashi and M. Katoh, "Microwave measurement of dielectric properties of low-loss materials by the dielectric rod resonator method," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-33, pp. 586–592, July 1985.

[13] T. Van Duzer and C. W. Turner, *Principle of Superconductive Device and Circuits*. Amsterdam, The Netherlands: Elsevier North Holland, 1981, ch. 3.

[14] Y. Kobayashi, S. Okajima, and H. Yoshikawa, "Measurement precision in dielectric resonator methods for surface resistance measurement of high-T_c superconductors," *IEEE Trans. Appl. Superconduct.*, to be published.

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