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# Microwave Microstrip Resonator Measurements of $Y_1 Ba_2 Cu_3 O_{7-x}$ and $Bi_2 Sr_2 Ca_1 Cu_2 O_{8-y}$ Thin Films

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## ABSTRACT

Radio frequency (RF) surface resistance measurement experiments on high-$T_c$ thin films were performed between July and November 1988. The method uses a microstrip resonator comprising a top gold conductor strip, an alumina dielectric layer, and a separate superconducting ground plane. The surface resistance of the superconducting ground plane can be determined, with reference to a gold calibration standard, from the measured quality factor of the half-wave resonator. Initial results near 7 GHz over the temperature range from 25 to 300 K are presented for $Y_1\,Ba_2\,Cu_3\,O_{7-x}$ and $Bi_2\,Sr_2\,Ca_1\,Cu_2\,O_{8-y}$ thin film samples deposited by an electron beam flash evaporation process. The RF surface resistance at 25 K for both materials in these samples was found to be near 25 milliohms.

High-$T_c$ superconducting thin films have potential applications in analog signal processing circuits with bandwidths of tens of terahertz.[1] Characterizing the microwave surface resistance of these thin films is vital to assessing and predicting their performance in microwave devices. Several methods have now been employed to measure microwave surface resistance. Low-$T_c$ material cavities have produced some of the most sensitive and widest dynamic range measurements of ceramic, thin film, and single crystal high-$T_c$ samples.[2] Another powerful method uses electro-optical techniques to determine attenuation and distortion of sub-picosecond pulses on coplanar transmission lines.[1] Loaded-waveguide methods have also been used with some success.[3] The use of a superconducting stripline (tri-plate) resonator has been successfully used in the microwave band.[4] A low impedance microstrip resonator, excited by an impedance mismatch method has also been used.[5] Finally, a disk resonator structure has been used for measuring thin films and bulk material.[6]

In this work, a simple open-ended, gap-coupled microstrip resonator method[7,8] adapted for determining the RF surface resistance of a material is discussed. The method does not require dc electrical contact or patterning and is insensitive to the film supporting substrate material. This technique applies a frequently used microwave circuit element, i.e., a half-wave resonator.[7] Preliminary measurements of the RF surface resistance of $Y_1Ba_2Cu_3O_{7-x}$ (YBCO) and $Bi_2Sr_2Ca_1Cu_2O_{8-y}$ (BSCCO) thin films are presented.

The cryogenic and microwave test equipment was specially assembled for these experiments. A commercially available two-stage, closed-cycle helium cryopump was modified for cooling the test resonator package. Vacuum system flanges and electrical feedthroughs were added onto the basic cryopump vacuum shroud. This allowed us to connect heater wires and stainless steel microwave coaxial cables to the test fixture. Base temperatures of approximately 16 K were possible. The microwave response (magnitude of $S_{21}$) was measured using an HP8510A automatic vector network analyzer and the $S_{21}$ data were used to calculate the quality factor of each resonance.

Figure 1 illustrates the microstrip resonator test configuration. During measurements, high-$T_c$ film is used as a ground plane. A reference or known material, such as gold, is used for the top strip of the resonator. A known material ground plane is used in place of the high-$T_c$ film during calibration measurements. Excitation of the resonator arises by capacitive gap coupling from open-ended coaxial connectors in proximity to the resonator ends. The weakly coupled condition (insertion loss greater than 30 decibels) is achieved by empirically adjusting the spacing between the center conductor end and the resonator end. Radiation loss from the resonating microstrip is controlled by choosing an appropriately small resonator geometry.[9] Dielectric loss effects are avoided through the use of low microwave loss dielectrics such as alumina or sapphire.

The high-$T_c$ films reported here were deposited by a novel electron beam flash evaporation technique which reliably produces YBCO and BSCCO films whose dc zero resistance temperatures were typically 75 and 80 K, respectively.[10] This process is unique in that the starting material is high purity superconducting powder. The films were deposited on heated, 0.5 by 0.5 by 0.02 inch MgO single crystal (100) substrates. The films were approximately 0.5 micrometer thick. The YBCO and BSCCO films required a post-deposition annealing at 875° and 860° C, respectively, followed by a slow, 6-hour cooling to room temperature in flowing oxygen. No special treatment of the film surface was performed to reduce RF losses. The BSCCO films were highly oriented with the c-axis perpendicular to plane of the substrate. The YBCO films were not preferentially oriented.

The measurement technique involves first measuring a reference gold metal resonator, then replacing the gold reference ground plane with the high-$T_c$ thin film to be tested. Using standard analytical relations for a microstrip transmission line model, an RF surface resistance can be assigned to the high-$T_c$ thin film sample.[7,8,11] The total $Q$ of the resonator can be expressed by the equation

$$1/Q = 1/Q_c + 1/Q_d + 1/Q_r + 1/Q_e + \cdots$$

where $Q_c$, $Q_d$, $Q_r$, and $Q_e$ are the quality factors corresponding to the conductor, the dielectric, radiation, and external losses, respectively. Other terms may be added to this equation. However, in this work additional terms were not considered because of their negligible influence on the measured $Q$.

In transmission line theory, the total conductor loss is a function of the surface resistances of the top strip line and ground plane. By measuring $Q$ for a resonator in which both conductors are gold, one can solve for the surface resistance of gold under the assumption that the top gold strip and the ground plane have equal surface resistance. Replacing the gold ground plane by the high-$T_c$ ground plane to be tested, then performing again the $Q$ versus temperature measurements, one can then calculate the microwave surface resistance of the high-$T_c$ ground plane.

In its present form this technique can be used for measuring thin films whose resistance is of the same order or higher than the reference metal. Raw microwave data are available from approximately 5 to 26.5 GHz; however, only the data from approximately 5 to 7 GHz are presently used due to cabling and connector interfering reflections which become worse at higher frequencies. Methods are available to improve the test fixture and to extend the useful measurement frequency range.

Figure 2 demonstrates typical frequency response as viewed on the network analyzer around the fundamental microstrip resonance for a BSCCO thin film ground plane. One can notice an increasingly sharper peak with lowering temperature which indicates lessening surface resistance.

Figure 3 shows the dependence of $Q$ and the calculated microwave resistance on temperature for a high-$T_c$ ground plane. For gold the $Q$ value increases smoothly to approximately twice the room temperature value at 25 K. However, the $Q$ value of the high-$T_c$ films increases typically by orders of magnitude in the same range of temperature and shows the characteristic rapid increase below $T_c$. A dramatic drop in RF resistance below the critical temperature is similar to the dc resistance, but unlike the dc resistance the RF surface resistance in these samples is not negligible below the critical temperature. Surface resistance values around 25 milliohms were encountered in our samples at 25 K. The YBCO and BSCCO samples here showed, by coincidence, similar RF surface resistance values.

A microstrip resonator method useful for determining the rf surface resistance of high-$T_c$ samples was described. Some initial results were presented. We believe this test method is attractive because it is simple to apply and should be especially useful for quickly characterizing high-$T_c$ samples for their RF losses. Improvements to our method might include using a very low-loss superconductive top strip and reducing the microstrip dielectric height further. These improvements should increase the sensitivity of measurement.

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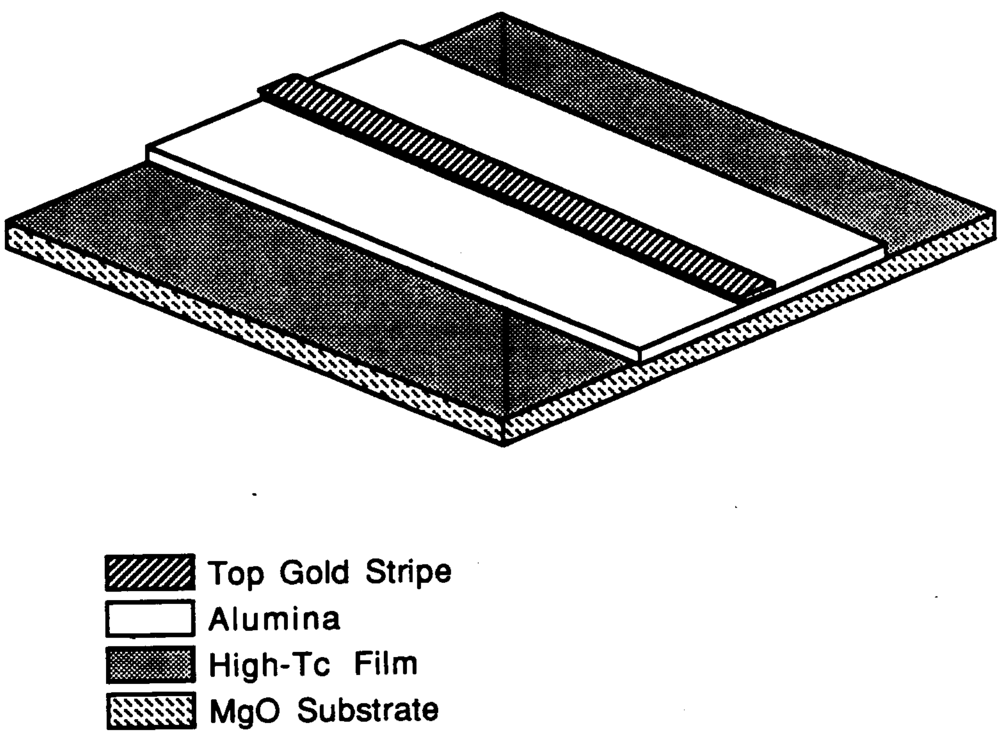


Figure 1.- Microstrip resonator configuration.

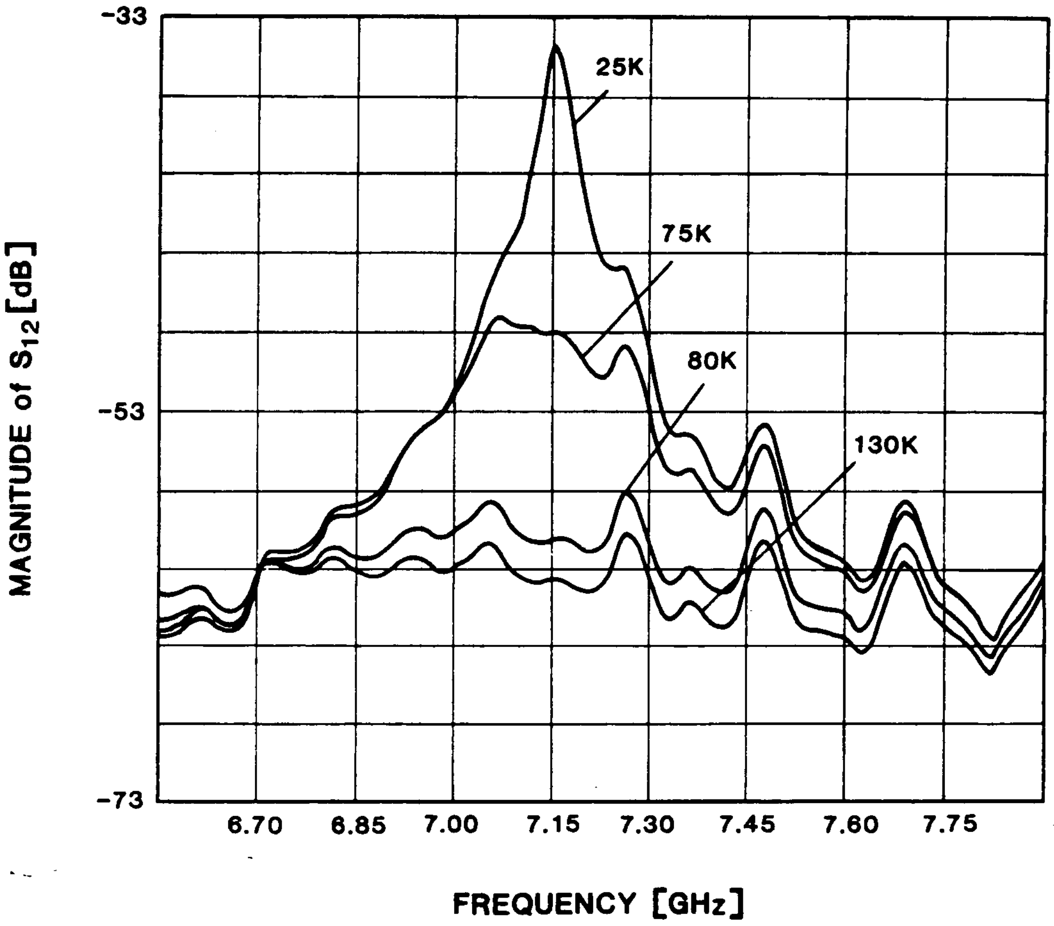


Figure 2.- Typical frequency response around the fundamental microstrip resonance for a BSCCO thin film ground plane sample.

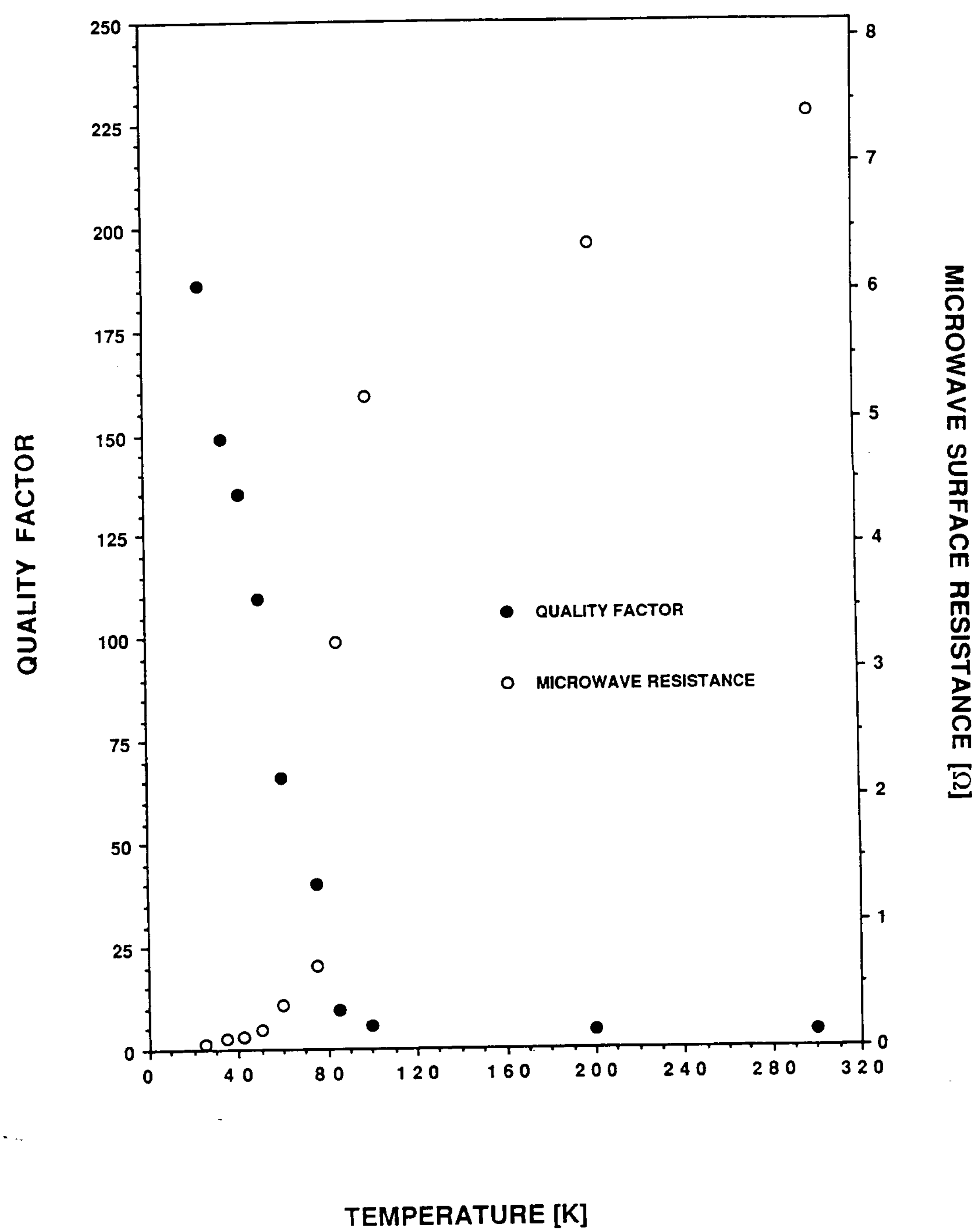


Figure 3.- Quality factor Q and RF surface resistance versus temperature at 7 GHz for a BSCCO thin film determined by the microstrip resonator technique.

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16. Abstract

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