USE OF A FABRY-PEROT RESONATOR FOR THE MEASUREMENT OF THE SURFACE RESISTANCE OF HIGH $T_c$ SUPERCONDUCTORS AT MILLIMETER WAVE FREQUENCIES

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Abstract

The use of a Fabry-Perot Resonator to measure the surface resistance of bulk and thin film samples of YBa$_2$Cu$_3$O$_{7-\delta}$ at W-band frequencies is described. The Fabry-Perot measurement technique provides a more convenient size, higher Q and is capable of determining the surface resistance more accurately than cylindrical resonators at these frequencies.

Introduction

Since a crucial frequency limit to millimeter wave circuits is ohmic loss, the announcement of superconductors with transition temperatures ($T_c$) above 90 K [1] produced much interest among microwave and millimeter wave engineers. In addition to reducing ohmic loss, a superconducting line will also have the advantage of lower dispersion [2].

Unfortunately, superconductors only have near zero resistance to dc currents. For ac currents, the surface resistance ($R_S$) of a superconductor varies as approximately $f^2$, as predicted by the London equations [3], as opposed to the surface resistance of a normal metal which varies as $f^{1/2}$ as predicted by classical theory. Hence, beyond some critical frequency ($f_c$),
normal metal, for example copper at 77 K, will have a lower \( R_s \) than the superconductor.

At the present time, bulk samples of high \( T_C \) materials have \( f_C \) values, when compared to copper at 77 K, around 10 GHz [4]. However, thin-film high \( T_C \) superconductors appear to have \( f_C \) values beyond 100 GHz [5]. All published \( R_s \) measurements at millimeter wave frequencies use a TE\(_{0nq}\) mode cylindrical resonator in determining the surface resistance from the cavity Q [5-9]. This paper is concerned with the use and evaluation of a Fabry-Perot resonator in measuring the surface resistance of bulk and thin-film superconductors above 75 GHz. The use of a Fabry-Perot resonator instead of a cylindrical resonator provides a more convenient size above 75 GHz, has higher Qs and avoids problems with degenerate modes.

Surface Resistance Measurement with a TE\(_{011}\) Mode Resonator and a Fabry-Perot Resonator

The Q of a cylindrical resonator depends on the surface resistance (\( R_s \)) of the walls of the resonator. By making one or more of the walls of the resonator a high \( T_C \) material, the surface resistance of the superconductor (\( R_{sc} \)) can be determined.

Usually a TE\(_{011}\) mode cylindrical resonator is used for \( R_s \) measurements because the Q is high, and there are no axial currents across the interface between a high \( T_C \) material used as the resonator top and the metal side walls of the cavity. The Q of the resonator is determined by measuring the magnitude of the transmitted power as a function of frequency as indicated in Figure 1.

The unloaded Q of a TE\(_{011}\) mode resonator can be expressed in the form [10]

\[
Q = \frac{\mu_0 c \left[ (r_{01})^2 + \left( \frac{\pi a}{\lambda_o} \right)^2 \right]^{3/2}}{2R_s \left[ (r_{01})^2 + \pi^2 \left( \frac{a}{\lambda_o} \right)^3 \right] + 2R_{sc} \pi^2 \left( \frac{a}{\lambda_o} \right)^3}
\]

or

\[
Q = \frac{1}{1/Q_{\text{max}} + b R_{sc}}
\]