MEASUREMENTS OF THE SURFACE RESISTANCE OF YBCO AT 500 MHz

Fang Jiaguang*, Wu Baimei**, Dieter Proch
Deutsches Elektronen-Synchrotron DESY, Notkestraße 85, 2000 Hamburg 52, West Germany
* on leave of absence from Tsinghua University, Beijing, PR China
** on leave of absence from University of Science and Technology, Hefei, Anhui, PR China

Abstract The inner conductor of a 500 MHz coaxial cavity is plated with YBCO. Painting as well as electrophoretic deposition are used as methods to cover the massive silver rod. The surface resistance is measured in the temperature range from 300 to 77 K. We present the measured data and discuss the relevant fabrication parameters.

INTRODUCTION

"Classical" superconductors like Niobium or Lead are used to build superconducting cavities for accelerator application. Operating gradients of more than 5 MV/m have been demonstrated at low loss levels. The working temperature is 4.2 K for frequencies below about 1 GHz. Lower temperatures are needed at higher frequencies because of the quadration increase of the surface resistance with frequency. Ceramic superconductor like YBCO have a transition temperature above 77 K, the temperature of liquid Nitrogen. One of the possible advantages for radio frequency application is the use of liquid Nitrogen instead of liquid Helium.
In our work we applied elsewhere published fabrication methods to coat silver which is a high conductivity metal suitable for cavity fabrication. A coaxial resonator with a coated inner conductor is used to measure the surface resistance of YBCO. At a frequency of 500 MHz this resonator is relatively small (outer length and diameter is 400 mm and 100 mm). The surface of the inner conductor is 40 cm^2 so that a coating technique suitable for large areas has to be used. Frequency dependency of the superconducting surface resistance can easily be measured because at any integer multiple of the fundamental frequency resonances with the same field pattern occur.

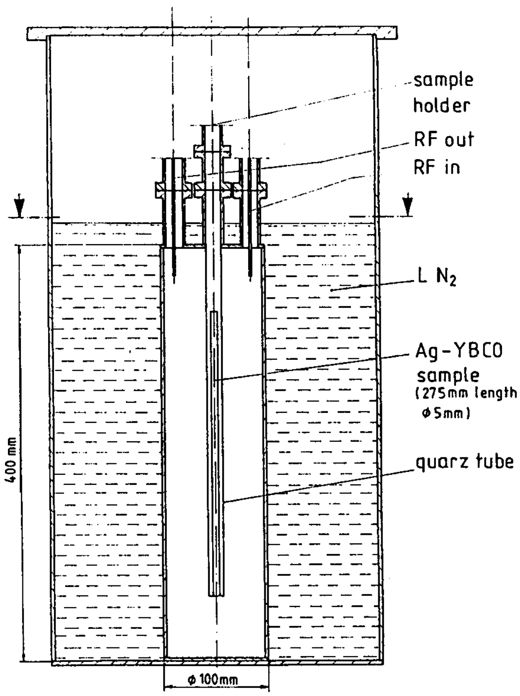

Fig. 1
Coaxial resonator for cryogenic measurements

RESONATOR DESIGN

The inner conductor of the resonator has a length of 270 mm to exite a 1/2 x λ resonance at 500 MHz (see Fig. 1). The diameter of the inner conductor should be small as compared to the outer conductor to increase the measurement sensitivity. So far we used a ratio of inner diameter to outer diameter of 5 mm to 100 mm so that 95 % of the total loss is contributed by the inner wall. The outer conductor is 130 mm longer than the inner conductor and thus effectively cancels contact losses at the top and bottom cover. To calculate the surface resistance R_s from the measured quality factor Q the geometry factor G = Q x R_s has to be known. We used the analytic expression:

$$G = \frac{\omega \sqrt{\mu_0}\, Z_0}{1/2\pi(1/a + 1/b)}$$

where: μ_0 permeability in vacuum
Z_0 characteristic impedance
a inner diameter
b outer diameter

URMEL calculations result in misleading number for G because the mesh size cannot be easily adjusted to the small inner conductor. The inner conductor is held in place by a quarz tube. The loss of this tube has been measured to be smaller than 2 %of an Cu equivalent inner conductor.

EXPERIMENTAL TECHNIQUE

For cool down the resonator is inmersed in LN_2. The inner conductor is gas cooled by dry He-gas inside the resonator and the quarz tube. The temperatures of the the inner conductor cannot be measured simultaneously during cool down because sensor

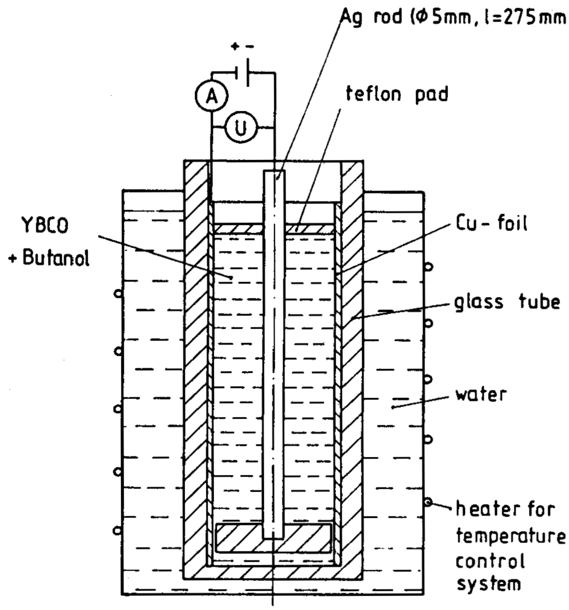

Fig. 2 Set up for electrophorese deposition technique

leads would disturb the RF fields. We calibrated the temperature decrease by cool down time and also used the frequency change caused by temperature shrinkage to determine the temperatures of the inner conductor during cool down. The temperature errors of ± 10 K can be tolerated to interprete the cool down curve. The transition temperature, however, is measured (with DC current or inductively) at equally prepared samples. The change of the surface resistance during cool down is measured continously by recording the coupled through power. In addition the bandwidth is measured at 300 K and 77 K.

PRODUCTION OF YBCO FILMS

The powder YBCO is prepared in the standard way (for example see [1]. For painting the powder is dissolved in Butanol. A soft brush is used to paint the silver rod. After drying at 80 ^{0}C the film is sintered at 920 ^{0}C under flowing oxygen for 24 hours. This procedure is repeated three or four times to reach a film of about 50 µm (measured by weight increase). Smaller probes (1 cm^2) on silver substrate were measured by the four point DC method and showed transition temperatures of 89 K.
The electrophorese deposition technique is described in [2]. Fig. 2 shows our apparatus. The silver rod is placed vertical in the centre and a cylindric copper foil is arranged as anode. The suspension consists of 30 g fine sintered YBCO powder dissolved in 300 ml Butanol. The fall out of larger particles at the bottom is substracted so that a concentration of about 10 g YBCO per 1 liter is reached. With the applied voltage of 100 Volt a field strength of 200 V/cm and a current density of 30 $\mu A/cm^2$ is established. After a deposition time of two minutes the film is dryed for several minutes at 100 ^{0}C and sintered for 10 minutes at 910 ^{0}C with oxygen flow. This procedure is repeated several times to reach a film of 50 µm.

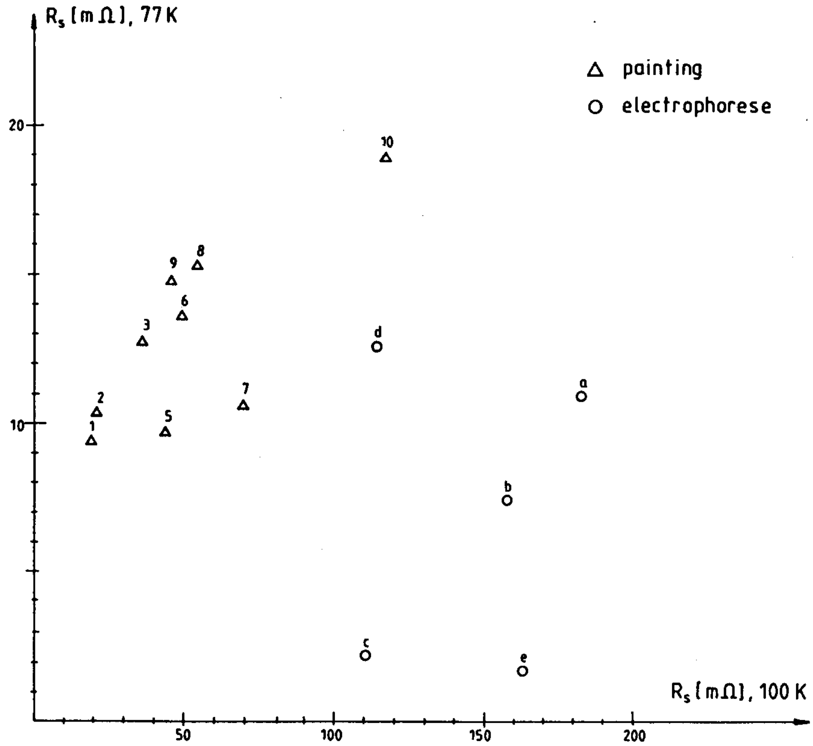

Fig. 3 Measured surface resistance above (100 K) and below (77 K) the transition temperature. The 270 mm long Ag rods were plated by painting (△) or by electrophorese (O). Data a, b, c: increasing sintering time (24 h to 90 h); d, e: see text.

MEASURED RESULTS

Fig. 3 summarizes the measured values of the surface resistances just above (100 K) and below (77 K) the transition temperature. The painted rods (triangles) show high surface resistance around 13 mΩ at 77 K. Furthermore the cool down curves indicate semiconductor behaviour. DC measurements of small samples, however, show metalic behaviour and a sharp transition at 89 K. We contribute the bad results of the painted rods to the fact, that our first furnace produced an unsufficient temperature profile of ± 15 K along the 270 mm long rod. The later rods (all covered by electrophorese) were sintered in a modified furnace with an improved temperature homogenity (± 8 K). These rods reached values around 1.5 mΩ especially after increasing the sintering time from 24 h to 90 h (circle c, e). Measurement d is an example of our experience that a good sample (measurement c) is deteriorated by a post treatment with O_2 at 450 ^{0}C. The original good performance can be restored by a short sintering (10 h) at 915 ^{0}C (measurement e). This rod has been measured also at higher frequencies (see Fig. 4). The data are consistant with a quadratic frequency dependancy (dashed line) of the surface resistance at 77 K.

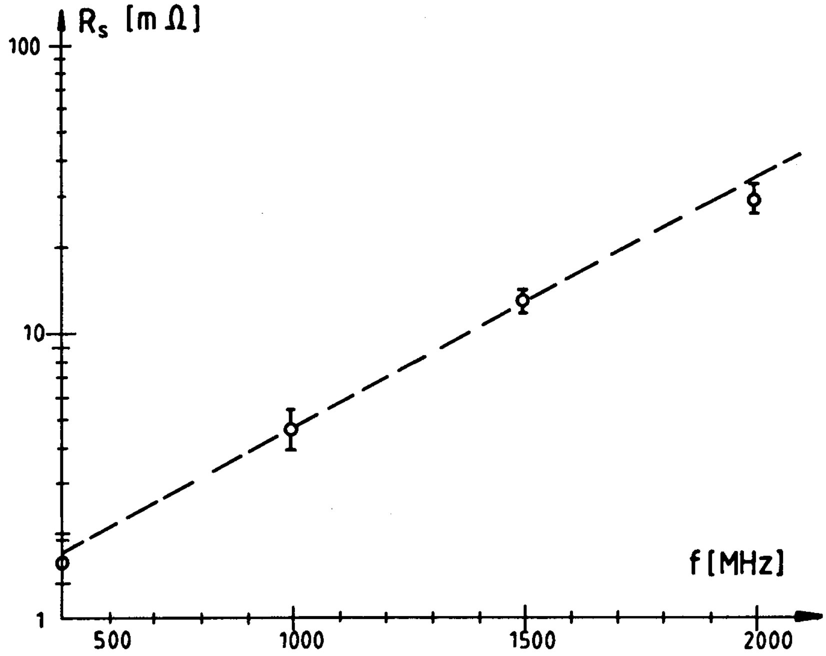

Fig. 4 Frequency dependency of the superconducting surface resistance at 77 K

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