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ON THE RF SURFACE RESISTANCE OF THE PEROVSKITE SUPERCONDUCTORS AT 3 GHZ

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Abstract: We have measured the rf surface resistance of $Y_1Ba_2Cu_3O_7$ samples fabricated in different laboratories by exposing them to the rf field of a niobium cavity at 3 GHz in a temperature range from 4.2 to 300 K. The rf surface resistance of the best sample decreases sharply at the transition temperature from typically 0.2 Ω at 100 K by more than two orders of magnitude. The residual losses measured at 4.2 K in the superconducting host cavity are strongly dependent on the purity of the sample. The observed dependence of the residual losses on the rf field level is attributed to the granular structure of the superconductor. Rf magnetic fields of up to 1800 A/m have been achieved in pulsed operation. This field corresponds to a surface current density of $1.3 \cdot 10^6$ A/cm^2. The low residual losses indicate that less than one percent of the conduction electrons of the perovskite superconductors remain unpaired.

Introduction: Heinz London was the first to suggest the investigation of the conduction mechanism in superconductors by exposing them to a microwave field [1]. The then observed non vanishing Joule losses are attributed to those conduction electrons which are not condensed into Cooper pairs. The rf magnetic field penetrates into the sample by the London penetration depth, which in the new superconductors is about 1400 Å [2], and induces a time varying electric field. Because of the inertia of the Cooper pairs the induced electric field is not shunted to zero. The unpaired conduction electrons will gain energy from this rf field, transfer it to the lattice ions and thereby produce Joule heating. A niobium cavity which itself becomes superconducting at 9.2 K and has an intrinsic Q of more than 10^8 at 4.2 K is a useful "microwave laboratory" to investigate the charge transport properties of superconducting samples [3]. This contribution reports on the experimental determination of the rf surface resistance of $Y_1Ba_2Cu_3O_7$ in the normal and superconducting state at 3 GHz.

Sample preparation: Stoichiometric mixtures of high purity powders (> 99,99%) of Y_2O_3, $BaCO_3$ and CuO were ground or ball milled. After a heat treatment in air at 930°C for more than 15 hours and a final ball milling pellets with 13 mm diameter and 1,6 mm thickness were pressed with a pressure of 7 kbar. The pellets were annealed in a pure oxygen atmosphere at 930°C for at least 6 hours and then slowly cooled down. Figures 1 and 2 summarize the results of dc measurements performed on sample W9-T5.

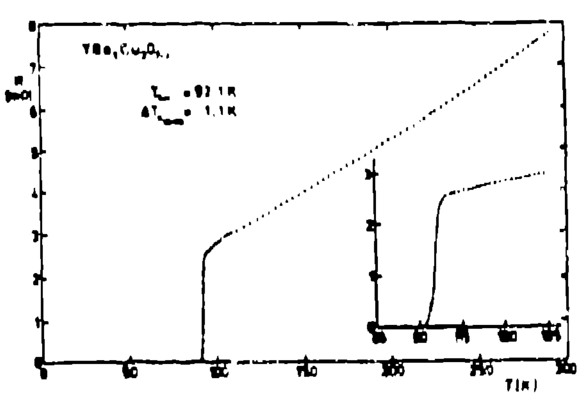

Fig. 1: temperature dependence of the dc resistance of a $Y_1Ba_2Cu_3O_7$ sample measured by four point technique with a midpoint T_{CM} = 92.1 K and a transition width (10 - 90%) of 1.1 K. The derived value of the resistivity at 300 K of the rectangularly shaped sample is 800±150 μΩcm.

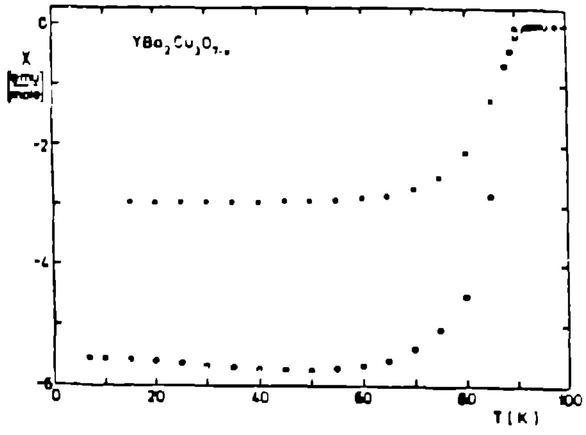

Fig. 2: Magnetic susceptibility of a $Y_1Ba_2Cu_3O_7$ sample versus temperature. Cooling with (100 Oe) and without magnetic field results in a susceptibility of 37% (full circles) respectively 68% (open circle) of the complete Meissner effect.

Experimental procedure and results: We have measured the rf surface resistance of $Y_1Ba_2Cu_3O_7$ samples fabricated at different laboratories by exposing them to the rf field of a niobium cavity at 3 GHz in a temperature range from 4.2 to 300 K. The pellet is located in the high magnetic field region of a cavity (Fig. 3) which is cooled in liquid helium. At 4.2 K this host cavity is superconducting and the rf residual losses of the pellet can be measured. A sufficient cooling of the pellet is provided by a helium gas pressure of 20 mbar inside the cavity. During the slow warming up the difference between the lower and the upper resistor thermometers was less than 2 K.

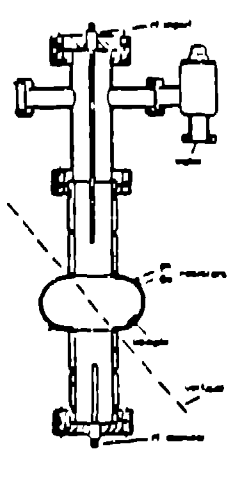

Fig. 3: Experimental setup for measuring the rf losses of a $Y_1Ba_2Cu_3O_7$ sample.

The surface resistance R_s = G/Q_o of the $Y_1Ba_2Cu_3O_7$ sample has been derived from the difference of the inverse Q-values with and without a sample (Fig.4a). The geometry factor G of 6900 Ω ± 10% was determined by calibration measurements with samples of well known resistivity. Fig. 4b shows the obtained rf surface resistance R_s and its temperature dependence.

The residual surface resistance of the sample was measured at 4.2 K (dashed line) in the superconducting host cavity at the minimum possible field level. The metallic behaviour of the sample is well demonstrated by the surface resistance above 100 K. Using the normal skin effect formula R_s (300 K) corresponds to a resistivity ρ (300 K) of 400 μΩcm. This value agrees well with the 800 ± 150 μΩcm found in the dc measurements, especially if one takes the porosity of about 25% of the sample into account.

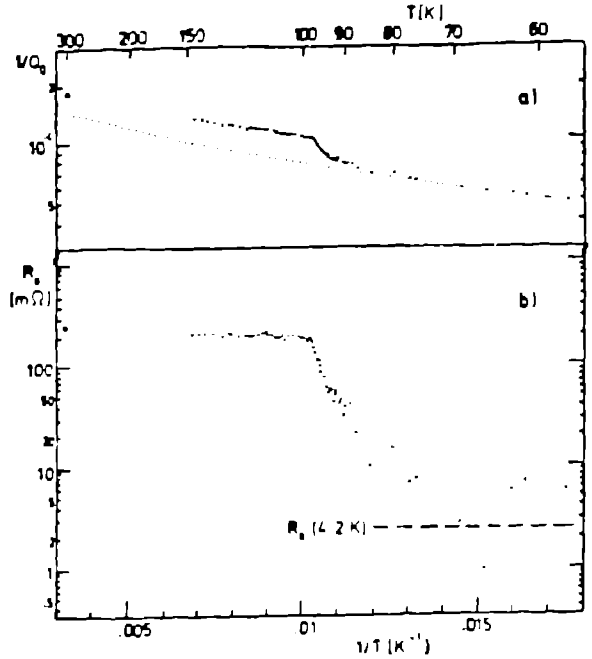

Fig. 4: a) Temperature dependence of the inverse unloaded quality factor measured with sample W7-T6. The decrease of the rf-losses ($\sim Q_0^{-1}$) at about 90 K shows rf-superconductivity of $Y_1Ba_2Cu_3O_7$. At lower temperatures the Joule losses of the normal conducting niobium (dotted line) dominate.
b) Surface resistance R_s derived from Fig. 4a)

The high field performance of sample W7-T6 was measured in pulsed operation (duty cycle: 10^{-3}) and is shown in Fig. 5. The strong decrease of the quality factor Q_0 at 4.2 K with growing surface magnetic field H_s is attributed to the granular structure of the superconductor. The rf losses in single grains with poor thermal contact to the bulk should heat them up above T_c and a rapidly growing part of the sample will turn normalconducting for increasing field level or pulse length. Neglecting the field perturbation caused by the sample a maximum H_s of 1800 A/m was achieved, at which a large part of the sample must be still superconducting. For an assumed penetration depth of 1400 Å this field corresponds to a surface current density of $1.3 \cdot 10^6$ A/cm^2.

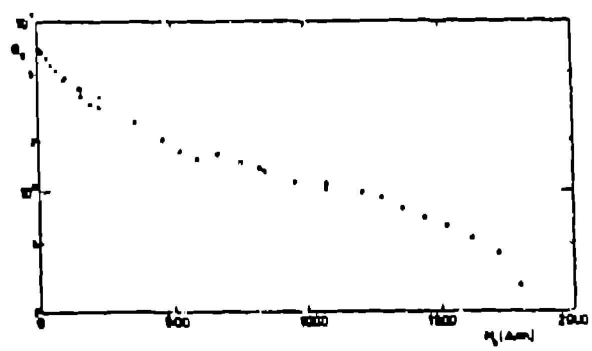

Fig. 5: Q_0 degradation of the superconducting niobium cavity due to the Joule losses in a $Y_1Ba_2Cu_3O_7$ sample (W7-T6) as a function of the magnetic field at the surface of the sample.

A total of six samples have been tested according to the procedure described above. The results of these measurements are summarized in table 1.

Table 1: Comparison of characteristic rf superconductivity parameters at 3GHz of different samples with nominal composition $Y_1Ba_2Cu_3O_7$ and in one case (sample K3-T1) $Eu_1Ba_2Cu_3O_7$.

Sample No	T_{cM} (K)	ΔT_c 10–90% (K)	R_s in mΩ 300 K	R_s in mΩ 77 K	R_s in mΩ 4.2 K	H_s^{max} (4.2 K) (A/m)
L1-T1	90.7	2.6	800	—	7.5	—
W3-T2	90.0	5.5	450	< 10	3.0	340
K3-T1	93.7	2.7	420	< 29	2.9	> 200
S1-T1	-	-	410	22	0.9	800
W7-T6	92.0	3.3	250	31	< 1.1	1800
W9-T5	92.1	1.2	210	< 16	0.4	440

From the experimental data in table 1 one can conclude that a high T_c and a small transition width ΔT_c are good indicators of the quality of a sample. It appears nevertheless that the rf surface resistance R_s at 300 K, the residual resistance at 4.2 K and the improvement factor $\eta = R_s$ (300 K)/R_s(4.2 K) together with the maximum obtainable su ce magnetic field H_s^{max} (4.2 K) are even more sensitive indicators of the phase purity and compactness of a s.c. perovskite sample. The improvement η of sample W9-T5 is close to 500. This indicates that less than 1% of all the conduction electrons remain unpaired. Our working assumption for the continuation of our experiments is that practically all the conduction electrons will be condensed to Cooper pairs as the temperature approaches zero. We attribute the residual resistance which is as yet larger or equal to 0.4 mΩ at 3 GHz to the imperfect contact regimes between grains. Improvement of this contact is also likely to increase the maximum surface field.

Conclusions: Rf - superconductivity measurements provide useful information on the charge transport properties of perovskite superconductors. A minimum surface resistance of 0.4 mΩ has been achieved for a $Y_1Ba_2Cu_3O_7$ sample at 4.2K and low field level. This is about a factor of five below the surface resistance of high purity copper at the same temperature. The improvement factor R_s(300 K)/R_s(4.2 K) which is close to 500 in the best sample indicates that less than one percent of the conduction electrons remain unpaired. At a surface magnetic field of 1800 A/m parts of one sample are still superconducting. This field corresponds to a surface current density of $1.3 \cdot 10^6$ A/cm^2.

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