MICROWAVE EXPERIMENTS ON $YBa_2Cu_3O_{9-\delta}$ THIN FILMS

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Abstract

The nonohmic behavior of classic superconductors is a well known phenomenon. Results of phase-resolved microwave harmonic mixing (PREHM) experiments show that such nonlinearities exist also in ceramic superconductors. The PREHM method seems to be well suited for sample characterization.

Introduction

The nonohmic behavior of superconductors is a microwave property due to the short characteristic time constants involved [1]. Therefore this effect might be exploited in the microwave frequency range [1] for devices such as frequency converters or parametric amplifiers. We studied this nonlinearity on $YBa_2Cu_3O_{9-\delta}$ thin films at different stages of the annealing procedure to show the influence of the sample quality on the nonohmic behavior.

Experimental

The PREHM method applied in the present study has been described in detail in [2]. In principle it consists of mixing a fundamental microwave of frequency ω, in our case 9.5 GHz, and of amplitude E_ω with its second harmonic wave of amplitude $E_{2\omega}$ in a sample located through a borehole in the waveguide parallel to the microwave field at the position of its maximum value. If the current-voltage characteristic of the sample is nonohmic then a dc mixing voltage U_{mix} develops between the ends of the filamentary sample. To discriminate spurious effects the phase ϕ between the two microwaves is varied slowly by a motor-driven phase shifter. An on-line Fast-Fourier Transformation of $U_{mix}(\phi)$ allows to determine the amplitude U_2 of the predominant $\cos(2\phi)$-dependent component which is used for sample characterization. Amorphous films were deposited by HF sputtering from a stoichiometric target on a polycristalline $SrTiO_3$ substrate. The first annealing step consisted in heating the sample during 12 hours to 820°C, holding this temperature for 10 min. and finally decreasing it in a $8^1/_2$ hour ramp to room temperature. In a second step a temperature of 550°C was reached in 2 hours, held constant for 3 hours and ramped down again in 2 hours.

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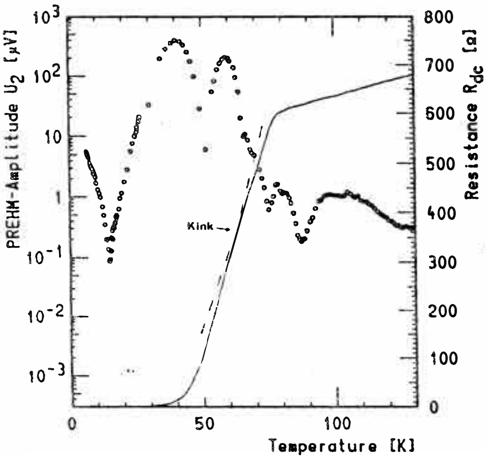
Results and discussion

The quality of the films is rather poor as one can see from the temperature dependence of the dc resistance R_{dc} shown in Fig.1. The onset temperature of the transition is around 80 K and the width of the transition approx. 40 K. There is a kink in the transition region indicative of the presence of more than one phase. The structure in $U_2(T)$ in the transition region also shown in Fig.1 is obviously related to the two different slopes in the R_{dc} curve. Notice the logarithmic scale: the maximum value of U_2 is three orders of magnitude higher than the room temperature value. This result reminds strongly of results by Leviev et al. [3] on frequency tripling in $YBa_2Cu_3O_{9-\delta}$ and in NbTi at 9.3 GHz. The authors speculate that this nonlinearity might arise from the dependence of the order parameter on the alternating magnetic field. The dependence of U_2 on the microwave field strength E_ω at a temperature of 44 K shows an abrupt change from an E_ω^3 power law to a much steeper $E_\omega^{5.36}$ dependence as can be seen in Fig.2. This might be an indication for two different mechanisms, one possibly associated with a Josephson weak link network between the grains of the ceramic and the other one associated with the intrinsic properties of the grains as was speculated by Kaiyuan et al. [4] who found two different regions of nonlinearity in the dc current-voltage



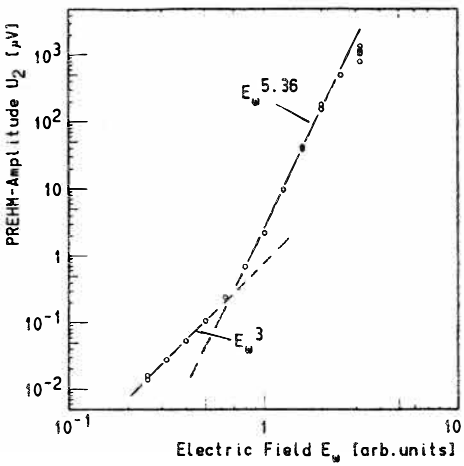


Fig.1: DC-resistance R_{dc} (right scale and full curve) and $\cos(2\phi)$-dependent component U_2 (left scale and circles) of the mixing signal vs. temperature after the final annealing step. The dashed lines stress out the kink in $R_{dc}(T)$.

Fig.2: $\cos(2\phi)$-dependent component U_2 of the mixing signal vs. microwave field strength E_ω for $E_\omega / E_{2\omega}=$ const. at a temperature of 44 K. The full lines are guide lines to the eye.

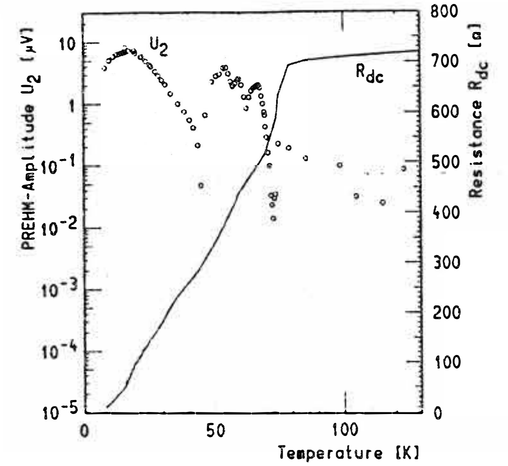


Fig.3: Same as Fig.1 but before the final annealing step.

characteristic of $YBa_2Cu_3O_{9-\delta}$ thin films. A clarification of the mechanism will require further experimental investigations. To show the influence of the sample quality on the mixing signal we measured R_{dc} and U_2 on a sample cut from the substrate adjacent to the sample discussed above, before the second annealing step was applied. As shown in Fig.3 the transition of R_{dc} is very broad and the superconducting state was not even reached at 10 K. The double bump of U_2 between 40 K and 80 K seen on the first sample can be seen with this sample too. But in addition there is another broad peak at lower temperatures related obviously to the very broad transition region in R_{dc}. This transition is due to the large amount of phases with lower T_c which are still present before the final heating step.

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