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PROPERTIES OF LIFT-OFF STRUCTURED HIGH T_c MICROBRIDGES

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Abstract

Microbridges and dc-SQUIDs were fabricated in lift-off technique from rf sputtered YBaCuO films on MgO single crystal substrates. Microwave measurements at 9GHz on microbridges and the magnetic field dependence of their critical current reveal wide bridge behavior up to temperatures near the maximum operating temperature of the bridge. Mostly a linear dependence of the critical current on the temperature is found, which is connected to high intrinsic 1/f-noise if the bridge is constant current biased slightly above the critical current. In some bridges and dc-SQUIDs regimes with a temperature dependence proportional to $(1-T/T_c)^{1.5}$ are found. In this case the 1/f noise level is much smaller and SQUID modulation can be followed to about 65K.

1. Introduction

Probably the most promising applications of the new high-T_c superconductors lie in the field of classical and superconducting electronics. Among other reasons this is due to the relatively high critical current densities which were already accomplished in films prepared,e.g. by coevaporation[1] and sputtering[2], and which are strongly connected to the two-dimensional nature of c-axis oriented high-T_c thin films with their large anisotropy. For electronic applications film structuring to small linewidth while preserving the high-T_c is of essential importance. In addition a good surface quality is mandatory for multilayer applications.

A special challenge is the fabrication of active superconducting components, e.g. tunneljunctions and microbridges, from these oxyd materials: tunneljunctions suffer from degradation of superconducting properties near the surface and microbridges from the demand for dimensions only few times the tiny coherence length of high-T_c superconductors, if a clean Josephsoneffect should be observed. Wide bridges structured from granular material - even though reasonably small in their critical current - show large intrinsic noise and no clean Josephson-like behavior as will be shown in Sec.3.

2. Film Preparation and Structuring

For the fabrication of integrated superconducting devices (e.g. dc-SQUIDs[3,4]) from high-T_c materials, e.g. YBaCuO, thin film techniques have to be used which yield films with sufficiently high T_c and with properties that should not degrade during the lithographic process, e.g. by etching or ion bombardment as well as exposure to aqueous solutions like resist developers. Lift-off technique is a feasible solution although it limits the deposition temperature to the maximum temperature the photo resist can tolerate, so that deposition on ambient temperature substrates with annealing in oxygen after lift-off has to be used. In addition this technique yields better film stability since all surfaces of the structured geometry are exposed to oxygen during the annealing.

As film preparation methods[5] we apply rf and dc magnetron sputtering from a ceramic YBaCuO target (1-2-3-composition)[1,2] in a turbo-pumped vacuum chamber. The background pressure before sputtering is better than 10^{-3}Pa. The target[4] was prepared from oxides by sintering and annealing in oxygen and cut into strips of about 5 mm width in order to prevent it from breaking during sputtering. This allows easy film-composition adjustment by replacing individual strips with different Y:Ba:Cu-ratios. The target is glued to a thin copper plate with silver conductive adhesive (Johnson Matthey A 500) to obtain a good thermal contact between target and the copper mounting-plate. To further increase the thermal contact between target and magnetron cathode an intermediate layer of indium is used.

The actual deposition technique for the films used in this investigation was rf-magnetron sputtering in a pure argon atmosphere : the deposition was performed at a generator power of 50-150W (corresponding to a cathode self-bias voltage of 60-140V) and a frequency of 13.5MHz, the argon pressure is 2-8Pa and the resulting deposition rate 1,5Å/sec. The argon pressure as well as the target-substrate distance was varied in order to yield the 1:2:3 stoichiomertry[4].

As substrates, we use (100)-oriented MgO single crystals. Due to the well cooled sputtering target and the sufficiently large target-substrate distance of 50mm, the surface of the substrate can be kept at ambient temperature during the deposition. Thus lift-off in acetone can easily be applied to structure the deposited films, e.g. single microbridges or microbridge-dc-SQUIDs with brigdewidths of 10..20µm and coupling holes up to 600µm² were structured with standard photoresist (Shipley AZ 1450).

Finally, the films were annealed in a pure oxygen atmosphere using the following recipe: room temperature to 920°C with a temperature rise of 10°C/min, 1h at 920°C, to 700°C with 5°C/min and then back to room temperature with 2°C/min.

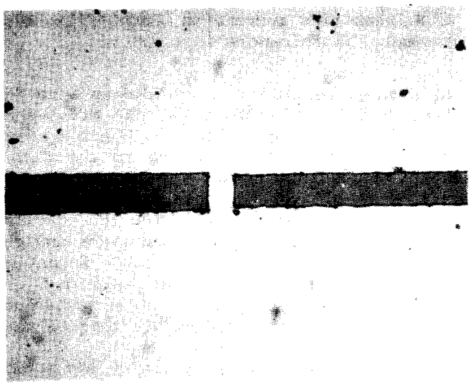

Fig. 1 : YBaCuO microbridge fabricated in lift-off technique. The width of the bridge is 15µm.

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3. Film and Microbridge Properties

Depending on the detailed fabrication process either thin films with nearly exclusive c-axis orientation and high surface quality (shiny surfaces) or textured granular films with a grain diameter of some micrometers were obtained. Details on surface composition and film-substrate interdiffusion are given in Ref. 6. The critical temperature of the films, the IV-characteristics of the microbridges and SQUIDs and their modulation behavior are measured in a helium cryostat with variable temperature insert. The temperature is determined with an accuracy of about 0.5K by a calibrated platinum resistor. For the microwave experiments the microbridges are mounted at the end of a stainless steel X-band waveguide, which feeds microwaves with a frequency of about 9GHz to the junctions.

All measurements are performed using a four-terminal measuring technique and a precision low noise amplifier and current source. The external field for the SQUID-modulation measurements is generated by a long cylinder coil.

The films, which were not yet optimized for optimum stoichiometry and thus maximum T_c, show an onset at 88K and a quite broad transition to the zero resistance state at temperatures $T_{c,end}$ up to 74.5K (Fig. 2).

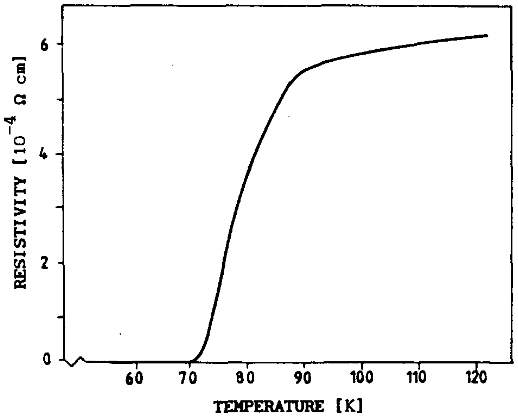

Fig. 2 : Transition curve of a YBaCuO-film on polycrystalline MgO. Filmthickness is 1.8µm.

As already mentioned, microbridges were fabricated from YBaCuO-films using standard lift-off technique and post annealing in oxygen (Fig. 1). Their T_c was reduced to values of 40K to 50K compared to the film's T_c of above 70K. A possible reason for the decrease of T_c is a remaining thin layer of photoresist in the bridge region prior to the sputtering of the YBaCuO-film. Such a layer could change the growth conditions and cause a Ba deficiency in the bridge due to $BaCO_3$ formation during the film annealing and thus a decrease in T_c. A cleaning of the substrate surface by argon bombardment prior to the film deposition could reduce this effect.

In this investigation especially the applicability of wide constant thickness microbridges (10..20µm) as Josephson junctions was tested[7]. In order to achieve, nevertheless, low critical currents and possibly Josephson-like operation, the bridges were prepared from granular films with small coupling between the grains. Typical for such bridges are current densities of less than $100 A/cm^2$ at 4.2K. The temperature dependence of the critical current (see Fig. 3) is linear over a quite a wide temperature range and only steeply increasing below 12K. Such a temperature dependence of microbridges as well as the small value of their critical current is well suited to their application in dc-SQUIDs[8], where the product $L \cdot I_c$ should be small enough for optimum SQUID performance. L is the inductance of the SQUID.

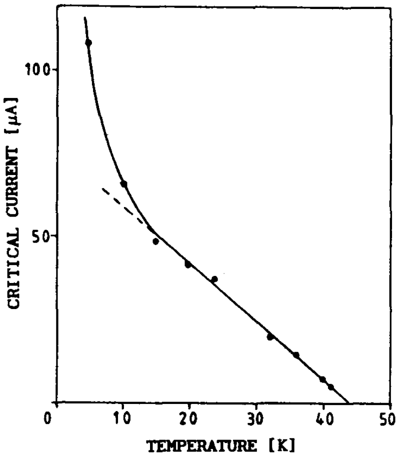

Fig. 3 : Temperature dependence of the critical current of a microbridge fabricated from a granular YBaCuO-film. The bridge width is 15µm, the film thickness 1.8µm.

In order to investigate, if these microbridges behave like wide bridges or Josephson-like we measured the dependence of the critical current on the amplitude of microwave radiation illuminating the bridge. For wide bridges one expects a linear dependence[9], for Josephson-like behavior a dependence determined by the Besselfunction J_0.[10] Even a crossover[11] between these two behaviors at a certain temperature could be expected since with rising temperature, more and more percolation paths within the bridge exceed their T_c, so that the coupling across the bridge becomes weaker and

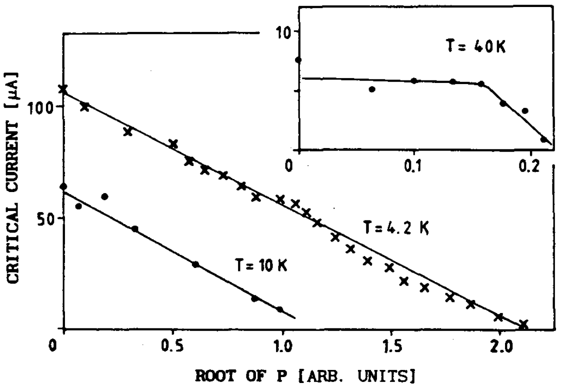

Fig. 4 : Dependence of the critical current I_c of a microbridge on the microwave amplitude for different temperatures. The microwave frequency is 9GHz.

more Josephson-like. Typical results of these measurements are depicted in Fig. 4. At low temperatures always a linear dependence was found, whereas at higher temperatures a more Bessel-like behavior was observed without ever showing reentrance of the critical current. At low microwave power level and temperatures near T_c of the bridge Shapiro steps could be observed. These steps were not well developed and very noisy.

In accordance with the microwave measurements no Fraunhofer diffraction pattern was observed, when a magnetic field was applied perpendicular to the bridge (see Fig. 5). Instead, two overlapping linear curves with different critical field H_c and different temperature dependencies were observed. This again indicates wide-bridge-behavior with at least two major current paths of different strength within the bridge.

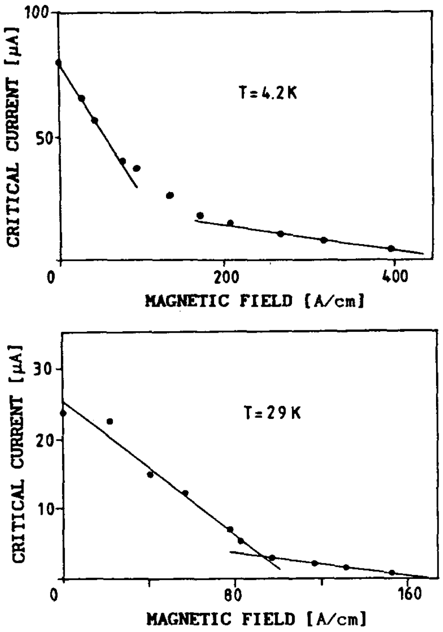

Fig. 5 : Magnetic field dependence of the critical current of a microbridge for two different temperatures.

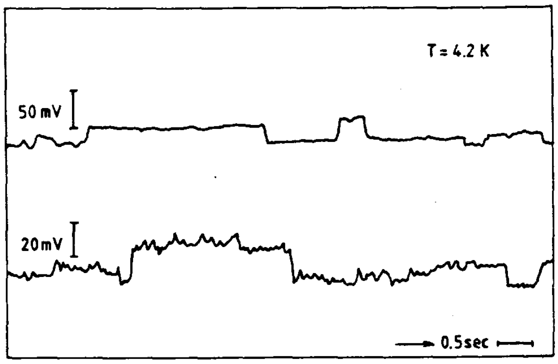

Fig. 6 : Timedependent voltage across a wide microbridge, constant-current biased slightly above the critical current, demonstrating the quite high 1/f noise.

A very striking property of these wide bridges is the large intrinsic low frequency noise. The IV-characteristics obviously switch between different semistable curves (see Fig. 6), and thus - for constant current bias above the critical current - between different semistable voltage levels. We attribute this to the random switching between different percolation paths with differing normal resistance. This gives rise to a large 1/f-noise contribution and limits the use of such bridges significantly.

Surprising with these bridges is the fact, that even though their current density is very small, they behave like wide bulk microbridges, both, in the magnetic field and the microwave experiments, but on the other hand show pronounced current path switching.

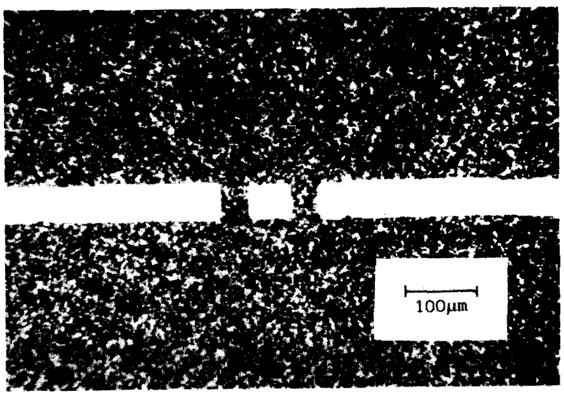

Fig. 7 : Microscopic picture of a YBaCuO dc-SQUID fabricated in lift-off technique.

4. Dc-SQUID Properties

Using the same technique as for the microbridges thin film high-T_c dc-SQUIDs with a geometric SQUID area of $4200 \mu m^2$ were prepared[2] (see Fig. 7). The temperature dependence of the critical current of such a dc-SQUID is plotted in Fig.8 in conjunction with the voltage modulation resulting from an external magnetic field. As long as the temperature dependence of the critical current is linear, the modulation pattern is a very complicated superposition of individual sinusiodal curves with different periods. Above 45K in the regime of $I_c \propto (1-T/T_c)^{1.5}$ the modulation reduces to a nearly sinusiodal pattern with only one period. The modulation period is in good agreement with the one calculated from the geometrical SQUID area if we take into account a temperature dependent field compression factor of 1.44 at 39K and 1.1 at 62K.

Especially in the linear region of the temperature dependence of the critical current, large 1/f noise was observed. Switching between different semistable current paths, as described above for single microbridges (see Fig. 6), occurred too for dc-SQUIDs. This makes the wide bridge approach on granular YBaCuO-films not applicable for low noise dc-SQUID applications. In contrast microbridges from classical superconductors like Nb_3Ge with very small width w ($\xi \leq 20 \cdot w$) exhibit only very low noise, since a very strong interaction between vortices leads to synchronous vortex motion and suppresses random velocity fluctuations due to pinning. This has especially been demonstrated for Nb_3Ge-microbridges with width of less than 100nm. For YBaCuO dc-SQUIDs this may be a promising line for future developments.

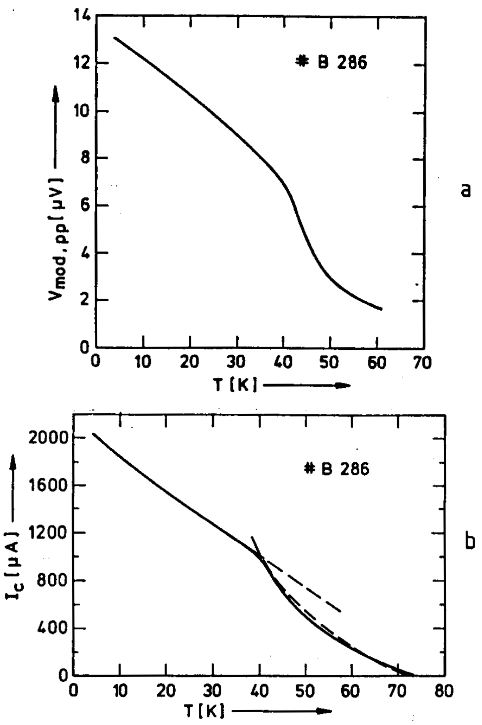

Fig. 8 : a) Temperature dependence of the voltage modulation of the same SQUID. b) Temperature dependence of the critical current of a YBaCuO dc-SQUID.

Finally a superconducting YBaCuO flux transformer was fabricated by lift-off on a second substrate and placed onto the SQUID top down. First tests showed the principle feasibility of such an approach, nevertheless fluxcreep and noise problems have still to be solved.

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