Physica C 153–155 (1988) 1329–1330
North-Holland, Amsterdam

ELECTRICAL RESISTIVITY OF $YBa_2Cu_3O_{7-\delta}$ SINGLE CRYSTALS AS A FUNCTION OF TEMPERATURE AND MAGNETIC FIELD

Rinke J. WIJNGAARDEN, K. HEECK and R. GRIESSEN

Natuurkundig Laboratorium, Vrije Universiteit, Amsterdam, The Netherlands

A.A. MENOVSKY and M.J.V. MENKEN

Natuurkundig Laboratorium, Universiteit van Amsterdam, The Netherlands

Using ultrasonic bonding we developed a technique to make contacts between gold wires and the unprepared surface of single crystals of $YBa_2Cu_3O_{7-\delta}$. The surface resistance of the contacts proved to be $\lesssim 10^{-4}\ \Omega\ cm^2$. The anisotropic dependence of the resistivity upon magnetic field was studied up to 5 T. It is postulated that the broadening of the transition with magnetic field is due to disorder in the (a,b) plane.

1. INTRODUCTION

Since the discovery of high T_c superconductivity and the study of the sintered material by a vast number of groups it has become clear to a number of them that one way to a better understanding of this exciting system is the study of single crystals (1,2). The mere smallness of these crystals asks for a small contact area in resistivity measurements. Using ultrasonic bonding we were able to make small contacts enabling a large portion of the crystal to contribute to our four point resistivity measurement.

Susceptibility measurements on crystals from the same batch are reported elsewhere (3).

2. CRYSTAL PREPARATION

Single crystals of $YBa_2Cu_3O_{7-\delta}$ were grown from the stochiometric composition (Y:Ba:Cu = 1:4:8.5) by partial melting followed by slowly cooling of the uncompacted components (4). Typical crystal dimensions were approximately 1x1x0.1 mm^3. The crystals turned out to be superconducting without additional oxygen annealing. We established that the single crystals had their c-axis perpendicular to the largest face of the samples. The experiments described herein were done on a single crystal of dimensions 0.57x0.42x0.18 mm^3 (0.18 mm in the c-axis direction).

3. BONDING TECHNIQUE

Various techniques have been described to make electrical contacts on $YBa_2Cu_3O_{7-\delta}$ samples. Except for the forced contacts method, which is not appropriate for the relatively fragile single crystals, all methods lead to rather large contact surfaces.

We used a TU-907 Ultrasonic Wedge Bonder with a 10 G Controller, both from Mech.el. Industries. No pre-treatment of the crystal was necessary for bonding with the 25 μm diameter gold wires (5). A typical contact resistance was ~ 3 Ω at 77 K. The surface resistance of the contacts is smaller than $10^{-4}\ \Omega\ cm^2$.

4. EXPERIMENTAL PROCEDURE

The resistance of the sample was measured with a 4 probe d.c. technique. All 4 contacts were located on the same (001) face of the crystal. The direction of the current was always parallel to the largest dimension of the crystal. The temperature was measured with a standard platinum resistor, calibrated in magnetic fields up to 5 T. In a typical experiment we kept the orientation of the crystal fixed and the magnetic field constant. The temperature was varied slowly (~ 0.1 K/min) and the voltage was plotted directly versus temperature. The curves shown in Fig. 1 and 2 are not a fit to measured points, but are the original measurements.

5. RESULTS

In figure 1 and 2 the resistivity of our sample is shown with the magnetic field $\vec{B}$ perpendicular ($\vec{B} \perp \vec{c}$), respectively parallel ($\vec{B} \parallel \vec{c}$) to the $\vec{c}$-axis of the crystal. Note that T_c=90.7 and the transition width of less than 1 K in zero field which is significantly sharper than reported in the litterature (1). We believe this is an indication of the good quality of the crystal.

For $\vec{B} \perp \vec{c}$ (in fact B was parallel to the 0.42 mm edge of the sample) the width of the transition increases only slightly with increasing magnetic field (fig. 1).

0921–4534/88/$03.50

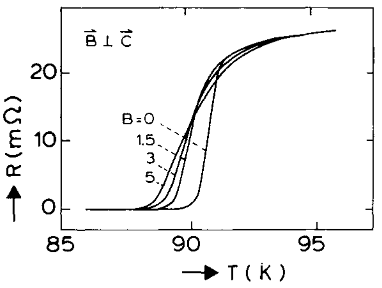

FIGURE 1
Resistivity of $YBa_2Cu_3O_{7-\delta}$ as a function of temperature. Values for magnetic fields of 0, 1.5, 3 and 5 Tesla are given. The magnetic field is perpendicular to the c-axis of the crystal.

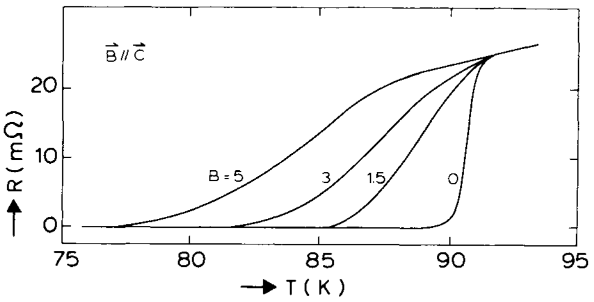

FIGURE 2
Resistivity of $YBa_2Cu_3O_{7-\delta}$ as a function of temperature. Values for magnetic fields of 0, 1.5, 3 and 5 Tesla are given. The magnetic field is parallel to the c-axis of the crystal.

For $\vec{B} \parallel \vec{c}$ however there is a dramatic broadening of the transition (fig. 2). Previously the broadening of this transition in polycrystalline samples was attributed to the random orientation of the crystallites (6). However we observe a width of the same order as that measured on polycrystals (e.g. ref. 7). To explain the width of the superconducting transition in polycrystals Welch et al. (6) postulated an anisotropy ratio $(\partial B_{2c}\perp/\partial T)/(\partial B_{2c}\parallel/\partial T)$ of 25 to 50. Because the transition is so broad we have complied to their convention to take for B_{c2} the temperature where the resistivity is half the extrapolated normal state resistivity.

We find $\partial B_{c2}\perp/\partial T = -6.0\pm2.0$ T/K and $\partial B_{c2}\parallel/\partial T = -0.7\pm0.1$ T/K and thus a ratio of ~ 10. In comparing these results with the litterature we point out that poorer quality samples are likely to have a smaller value for the difference $(\partial B_{c2}\perp/\partial T)-(\partial TB_{c2}\parallel/\partial T)$.

Due to twinning (which is present in our crystal) a randomness of crystal orientation with respect to the a and b axes is present. Since $\vec{B}$ is perpendicular to the (a,b) plane we see from symmetry that, if the crystallites were independent of each other, this randomness cannot lead to a broadening of the transition. However a behaviour, similar to that observed by us has been predicted by Morgenstern et al. (8) for a square lattice of superconducting clusters with disorder. A cluster is a region of coherent phase and does not necessarily coincide with physical (sub) grain boundaries. The postulated 2-dimensional spin-glass hamiltonian is:

$$H = -\sum_{i,j} K_{ij} \cos(\varphi_i - \varphi_j - A_{ij}) \qquad (1)$$

Here A_{ij} is proportional to the magnetic field and the disorder of the cluster-site configuration. This cluster-site disorder plays an essential role. It leads to an increase in the width of the transition with increasing magnetic field, as is observed.

6. CONCLUSION

Using ultrasonic bonding it is possible to do sensitive and accurate 4 point resistivity measurements on very small (single) crystals. The broadening of the superconduction transtion with magnetic field for $\vec{B} \parallel \vec{c}$ seems to be in agreement with a model of disordered superconducting clusters.

REFERENCES

(1) K. Murata, K. Hayashi, Y. Honda, M. Tokumoto, H. Ihara, M. Hirabayashi, N. Terada and Y. Kimura, to be published
(2) S.W. Tozer, A.W. Kleinsasser, T. Penney, D. Kaiser and F. Holtzberg. Phys. Rev. Lett. 59 (1987) 1768
(3) J. van den Berg, C.J. van der Beek, P.H. Kes, J.A. Mydosh, A.A. Menovsky and M.J.V. Menken, this conference
(4) A.A. Menovsky and M.J.V. Menken, to be published
(5) R.J. Wijngaarden, K. Heeck, R. Griessen A.A. Menovsky and M.J.V. Menken, to be published
(6) D.O. Welch, M. Suenaga and T. Asano, Phys. Rev. B36 (1987) 2390
(7) O. Laborde, J.L. Tholence, P. Lejay, A. Sulpice, R. Tournier, J.J. Capponi, C. Michel and J. Provost, Sol. St. Comm. 63 (1987) 877
(8) I. Morgenstern, K.A. Müller and J.G. Bednorz, Z. Phys. B. 69 (1987) 33