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Size-dependent resistivity in a micro-processed $YBa_2Cu_3O_{7-\delta}$ superconducting whisker

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Abstract
We report the results of a detailed geometrical and electrical study which has been performed on a $YBa_2Cu_3O_{7-\delta}$ superconducting whisker. This sample has undergone three subsequent steps of micro-machining by means of a focused ion beam (FIB) instrument, in order to progressively decrease its cross-sectional area from ∼77 to ∼4 μm^2, over a length of about 150 μm. A simple analytical model based on the exact shape both of the electrical contacts and of the micro-machined material has been proposed for the voltage drop; besides, an accurate geometrical characterization of all of the sample details has been performed by means of SEM microscopy. This enabled us to extract accurate electrical resistivity curves from the resistance versus temperature characteristics for each of the fabrication steps of the whisker, showing an increase of the sheet resistivity with decreasing cross-sectional area. Among the possible physical reasons for such behaviour, inelastic electron scattering at the sample surfaces has been ruled out because of the very short mean free path of carriers in YBCO. On the other hand, oxygen out-diffusion and Ga ion implantation due to the FIB processing are most likely to be responsible for the observed resistivity trend.

(Some figures in this article are in colour only in the electronic version)

1. Introduction

Since the discovery of high temperature superconductors (HTSC) in 1986 [1], a lot of research has been carried out in order to clarify the microscopic mechanisms underlying their unconventional properties, but, so far, a comprehensive and fully self-consistent picture of them has not been achieved yet. Among the open questions, the role of the thermodynamic fluctuations from the equilibrium state and their influence on the unusual normal-state properties above T_c, the so-called pseudogap state, is currently unclear [2]. A possible way to study these effects is represented by the measurement of the paraconductivity, which is the excess conductivity induced above T_c by metastable Cooper pairs. The whisker-like crystals are nearly ideal systems for this kind of study: their very large aspect ratio (≈100) between their length and thickness has been reported to result in an enhancement of the fluctuation phenomena; besides, this kind of sample shows a considerably lower density of defects in comparison with bulk ones [3, 4].

In the past, conductivity and paraconductivity properties of HTSC compounds have been proved to depend on the cross-sectional area of the crystals [5, 6] in a counter-intuitive way, so that both of them increased with decreasing the cross-section area. However, these experiments have been carried out by comparing different crystals, and no microscopic interpretation has been given for such a phenomenon. Therefore, the use

