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Interaction of AC magnetic field with the vortex system in highly anisotropic Bi-2223 superconductor; intercalation effects. Comparison with Bi-2212

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Abstract

The microwave dissipation induced by the interaction of AC magnetic field with the vortex system is reported for the first time in a Bi-2223 compound. It is the third high anisotropy compound, in addition to Bi-2212 and the organic superconductor $\kappa(ET_2)Cu(NCS)_{2+}$, where similar microwave dissipations were observed. It confirms that intrinsic Josephson coupling is necessary to induce this interaction. Intercalation of less than 2% of Bi-2212 and Bi-2202 phases in this single crystal results in the formation of different regions in the crystal with T_c's ranging from 110 K to 80 K, where only a very small part could be assigned to stoichiometric Bi-2223. Comparison of the results with a high quality optimally-doped Bi-2212 compound shows that the presence of the different regions in the Bi-2223 single crystal, affects the distribution of the PV and JV.

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1. Introduction

Great efforts have been made recently to grow high quality triple layer $Bi_2Sr_2Ca_2Cu_3O_{10+\delta}$ (Bi-2223) single crystals, $T_c = 110$ K, in order to study their intrinsic properties and compare them with those of the double layer $Bi_2Sr_2CaCu_2O_{8+\delta}$ (Bi-2212), $T_c = 90$ K, and the mono layer $Bi_2Sr_2CuO_{6+\delta}$ (Bi-2201), $T_c = 10$ K. The best available single crystals were grown using the travelling solvent zone technique, with a steep temperature gradient along the melting zone, using a very slow grow rate and long annealing time [1,2]. Large single crystals were obtained that show an onset $T_c = 110$ K. However the transition width was much larger than in Bi-2212. Intergrowth phases (<2%) of Bi-2212 and Bi-2201 were observed that can explain the larger transition width in this compound. Several properties of the Bi-2223 such as the pseudo-gap temperature and resistivity anisotropy were investigated as a function of oxygen doping in these crystals [1–3].

The effect of an ac magnetic field on the vortex system in high-T_c superconductors has been demonstrated by the so called "shaking effect" which showed that the application of an ac magnetic field parallel to the *a–b* plane in the high-T_c superconductors thermalizes the vortex system [4,5].

The interaction of the AC field with the vortex system was studied in high anisotropy superconductors such as Bi-2212 by the "Induced Microwave Dissipation by the AC Magnetic field" (IMDACMF) technique [6,7]. In Bi-2212 the AC magnetic field induces two different signals that result from either *changes in the microwave dissipation* due to changes in the thermally activated flux flow (TAFF) resistivity induced by the AC magnetic field [8,9], or from *microwave dissipation* induced by the interaction of the AC field with the vortex system [6]. The IMDACMF is a contact-less technique, very sensitive and simple to operate. It can measure the superconducting transition in any material either in powders or solids. In single crystals it can investigate the magnetic anisotropy of this transition. Its unique advantage is the investigation of dynamic effects of the interaction of AC magnetic fields with PV and JV in highly anisotropic superconductors where non linear effects were observed [6,7].

As the anisotropic unit cell structure of the tri-layer Bi-2223 is larger than the bi-layer Bi-2212 structure, the effect of the increase of the distance between the conducting layers on the AC interaction with the vortex system can be studied from the changes of the response of the AC field on the microwave absorption, where it is expected that the general behaviour will be similar. Indeed strong signals as strong as in Bi-2212 were observed. However it was found that the intergrowth layers affect the crystal homogeneity and that only a small portion of the crystal shows superconducting properties related to Bi-2223 with a T_c of 110 K. The major part of the crystal exhibits superimposed transitions of superconducting material whose T_c's range from 100 K to 80 K. Nevertheless the results enabled the study of the interaction of the AC field with its vortex system and the effect of the intergrowth layers on its superconducting properties. For the measurements we used a Bruker ELEXSYS spectrometer working at X-band frequency (9.36 GHz). The microwave response of the sample is detected by a lock-in amplifier at the modulation frequency of 100 kHz. A He-continuous flow cryostat ESR 900 (Oxford Instruments) allowed for temperature regulation of the sample in the temperature range $4.2 < T < 300$ K.

2. Experimental and results

The Bi-2223 single crystals used in this experiment were grown using an improved travelling solvent floating-zone technique described in Ref. [1] and were characterized by various methods. The crystals used in the present experiment were small platelets of about $1 \times 1 \times 0.2$ mm^3 whose large facet was a (001) crystallographic plane, determined by Laue X-ray back-reflection method. The microwave experimental technique is described elsewhere [6]. Note that the sample is exposed to a collinear DC and 100 kHz AC magnetic field. The crystal could be rotated around an axis within the *a–b* plane that allowed the orientation of the magnetic fields parallel or perpendicular to the