Magnetotransport study of in situ magnetic field textured Dy$_1$Ba$_2$Cu$_3$O$_7-\delta$ superconductors

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Abstract. The electrical resistivity, thermoelectric power and the Nernst effect have been studied as a function of temperature and magnetic field for a typical superconductor DyBa$_2$Cu$_3$O$_7-\delta$ magnetically textured in situ at 1035°C. The three transport coefficients show hybrid microscopic features. In particular, we show the anisotropy with respect to the field direction (H//a, H//c) in all transport coefficients. We verify that Tinkham’s law is obeyed for the broadening of the resistive transition in a magnetic field. Similarly we obtain anisotropic broadening exponents for each integrated excess property. From Arrhenius plots we obtain orders of magnitude for the activation energies characterizing each property. They are markedly different from each other.

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I. Introduction

Polycrystalline ceramic materials rather than single crystals will be the main components of superconducting devices excluding the use of thin films. The most important properties of interest are those pertaining to the class of “dynamic properties”. Thus, physical effects in an electrical gradient, like the electrical resitivity and Peltier effect, or in an external temperature gradient, like the Seebeck effect and thermal conductivity, are of fundamental interest. Furthermore these materials will be used in applied external fields. It is thus necessary to characterize these “dynamic responses” in presence of a magnetic fields. One peculiar effect of interest leads to the Nernst coefficient which is the analog of the Hall effect but results from an external thermal gradient rather than an external electric current. There has been already much work on such effects and to quote the whole set of references would be unreasonable. Pertinent references can be found in our previous papers reporting such coefficients in polycrystalline (Bi/Pb)$_2$Sr$_2$Ca$_2$Cu$_3$O$_y$ [1], polycrystalline but textured and lead-free Bi$_2$Sr$_2$Ca$_2$Cu$_3$O$_y$ [2] and thin film of Y$_{0.3}$Ba$_{0.6}$Na$_{0.1}$Cu$_3$O$_{y-\delta}$ [3]. In particular, we have found apparently universal power laws relating the temperature integrated area under the “coefficient of interest” and the applied magnetic field [4]. The exponents depend on the characteristic dimensionality of the system.

Some of these high temperature superconducting ceramics (HTSC) could be improved. First, the chemical and physical homogeneities could be better controlled together with the inescapable defects, like in the melt texture growth technique [see Ref. 5 for a review]. A second possibility is to use the magnetic anisotropy inherent to the crystal structure [6] in order to improve the crystal growth itself, and to obtain “magnetically textured grown” (MagTG) systems [7–19]. These samples in fact look like single crystals. This magnetic texturing can be done by sintering grains in situ. In such a case the field must be chosen together with the geometry according to whether the Y and Ba sites are occupied by a magnetic or not ion. One should note that such an idea has been implemented in the case of thick film growth as well [14].

The so called mixed state properties are well seen in transport coefficients. In polycrystalline samples, the situation is difficult to disentangle because of important granular effects, and competition between weak link and intragrain pinning. Single crystals are of fundamental necessity for obtaining specific parameters. However, single crystals are not made for realistic situations. Therefore, it is of interest to examine textured systems. An interesting situation occurs when replacing Y by a rare earth ion, like Dy [15–19]. We have previously reported about microscopic features of such samples [15–19]. We recall (Fig. 1) that the texturing is very pronounced.

After recalling the synthesis procedure in Sect. II and characterizing the microstructure is Sect. III we briefly present the measuring methods in Sect. IV. Data are presented in Sect. V. Section VI serves as a discussion. Tinkham’s law for the resistive transition broadening is well obeyed. In the same framework the characteristic exponent of the field broadening for the so called “excess” integrated thermoelectric power and Nernst effect.
exponents is shown to depend on the field direction. Moreover, they differ from coefficient to coefficient. This means that field dependent coefficient amplitude and the broadening temperature range are distinct problems. Finally, we plot the coefficients in order to determine whether they follow an Arrhenius law. It is seen that an activation energy is specific to the transport coefficient. This indicates that the notion of activation energy must be scattering mechanism dependent. Brief conclusions are given in Sect. VII.

II. Sample preparation

We have sintered a Dy$_3$Ba$_2$Cu$_3$O$_{7-\delta}$ compound (Dy123) at 1035°C, just below the peritectic temperature, in a permanent magnetic field. Synthesis details and fine characterization have been reported in several publications [15–19] using X-ray, scanning electron microscopy, and high resolution optically polarized microscopy. Let us quickly recall that we start from (RE)$_2$O$_3$, BaCO$_3$, and CuCO$_3$, Cu(OH)$_2$ first pretreated at 920°C during 48 h including two intermediary grindings. We maintain the high temperature during at least 2 h. The cooling part is first slow: 2°C/h till 940°C, and is followed by (30°C/h) cooling. The sintering time complete run varies rapid between 1 and 3 days. The system is later on reoxygenated following classical treatments.

The presence of the Dy ion and the intrinsic anisotropic magnetic susceptibility allows us to grow the ceramics with the a-b plane perpendicular to the imposed (0.6 T) magnetic field. This sintering technique leads to “large” microcrystals (4 mm wide) which are optically seen to be well oriented [19]. The main impurities beside 211 particles are CuO and Ba-cuprates. Cracks are also seen more or less parallel to the ab-planes. They sometimes cut across 211 particles.

III. Sample characterization

Microstructural observations have been made on a Hitachi S2500 scanning electron microscope. All the samples present the same microstructural features independent of their geometry (Fig. 2): 211 particles and BaCu$_2$O$_4$ phases are precipitated and seen on optical micrographs (Fig. 2) (see also [19]). The size of the 211 particles is approximately centered on $15 \times 10^{-6}$ m, in agreement with previous work [20].

However the quantity of such particles and precipitates is so small (10%) and the texturing so good that only the (003) (005) (006) and (007) peaks are seen in a X-ray diagram (Fig. 1) for the diffraction angle span from 20° to 70° [21]. The c lattice parameter calculated from the (0,0,1) reflections is equal to 11.64 Å and is very close to 11.668 Å reported by Datta et al. and by Tarascon et al. [22]. This in turn, corresponds to an oxygen content between 6.92 and 7.12 [23]. A large number of cracks (Fig. 2) is seen though, and are explained by a gap formation mechanism in the ac plane [21, 24].

It is well known that the rare earth ions having the relatively larger radius easily substitute Ba instead of Y [25]. This in turn leads to a reduction of the transition temperature. The nonreduced transition temperature observed for the Dy123 superconductors studied here (see below) gives an indirect evidence that the Dy atoms do not substitute the Ba sites to a noticeable extent in our cases.

IV. Measuring methods

Samples used for the electrical resistivity, thermoelectric power and Nernst effect measurements had the approximate $6 \times 5 \times 3$ mm$^3$ dimensions. Due to the sample geometry the transport measurements were made in the ab-plane applying the external magnetic field in the ab-plane or along the c-axis. All measurements were performed inside a closed cycle refrigerator CTI M22 filled.