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Effect of Yttrium substitution on superconductivity in Bi-2212 textured rods prepared by a LFZ technique

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Abstract

In this study, the physical and superconducting properties of the $Bi_2Sr_2Ca_{1-x}Y_xCu_2O_{8+\delta}$ with $x=0.0$, 0.05, 0.075 0.1, and 0.20 textured superconducting rods prepared by a laser floating zone technique were presented. The effects of Y^{3+} substitution for Ca^{2+} have been investigated by X-ray diffraction (XRD), scanning electron microscopy (SEM), energy dispersive X-ray spectroscopy (EDX), dc-magnetization, magnetic hysteresis and critical current density calculation by using the Bean's critical state model. The powder XRD patterns of the samples have shown the Bi-2212 phase is the major one. Along with the powder samples, the textured rod surfaces also were investigated by XRD. The grains found to be well-oriented along the longitudinal rod axis which is a typical result for superconductors prepared by laser floating zone (LFZ) method, has been observed. The best critical temperature, T_C, has been found as 92.9 K for the sample with 0.15Y substitution, under DC magnetic field of 50 Oe in ZFC mode. It has also been observed that the critical current density decreases with increasing Y-substitution. Using those values, the maximum J_C value has been determined as 2.37×10^5 A/cm^2 for the undoped sample.

Keywords: C. Magnetic properties; Bi-2212; Yttrium substitution; Critical current density J_C; Laser floating zone technique

1. Introduction

The BSCCO family can be described using the $Bi_2Sr_2Ca_{n-1}Cu_nO_{2n+4+y}$ general formula, where $n=1$, 2, and 3. The n value indicates the number of CuO_2 layers in the crystal structure, forming the Bi-2201, Bi-2212, and Bi-2223 phases with critical temperatures, T_C's, of about 20, 85, and 110 K, respectively [1,2]. Since their discovery, many experiments have been performed to understand better the structural and physical properties of these systems, and to improve their critical temperature (T_C) and critical current density (J_C) [3–21]. After these works, it is well-known that the Bi-2212 phase is the most stable and easy to prepare among the high-T_C phases. This phase was found in a wide range of compositions and processing temperatures, when compared with the Bi-2223 phase. On the other hand, T_C of Bi-2212 phase can be modified by its cationic composition and oxygen content, i.e. T_C clearly increases when the Bi and Ca contents are decreased [22].

Besides BSCCO superconductors have some advantages as high critical temperature and magnetic field carrying capacity, they also have some disadvantages as the weak-links, high anisotropy, and small coherence length. These phenomena restrict them from using in massive technological applications. Generally, a negative effect on J_C values can be observed by very small misorientation of the grains in these materials. For solving this problem, many different strategies have been tested to overcome those disadvantages and maximize the transport properties at 77 K. One of the most promising way to improve their transport properties is inducing an adequate grain orientation via texturing methods. Among these methods, it is possible to distinguish between solid state texturing, as the hot-pressing technique [23,24], and directional solidification

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from the melt, as the laser floating zone (LFZ) or the electrically assisted laser floating zone (EALFZ) [25,26]. Among these methods, the LFZ has been shown being very effective to produce a good grain orientation in Bi-2212 superconductors [3,5,6,14,27]. This method is characterized for producing very high thermal gradients in the solidification front, leading to a preferential alignment of grains with their *c*-axis perpendicular to the growth direction [28]. This process also maximizes the transport properties along the growth axis.

In this study, $Bi_2Sr_2Ca_{1-x}Y_xCu_2O_{8+\delta}$ textured ceramics with different Y-content have been prepared by the LFZ technique. The effect of Y on T_C, magnetic properties, magnetic J_C and microstructural features has been investigated.

2. Experimental

The initial $Bi_2Sr_2Ca_{1-x}Y_xCu_2O_{8+\delta}$ ($x=0.0$, 0.05, 0.075 0.1, and 0.20) polycrystalline materials used in this work were prepared using the classical solid-state route from commercial Bi_2O_3 (Panreac, 98+%), $SrCO_3$ (Panreac, 98%), $CaCO_3$ (Aldrich, $\geq$ 99%), Y_2O_3 (Sigma-Aldrich, 99.99%), and CuO (Panreac, 99%). They were weighed in the appropriate proportions and ball milled in an agate ball mill in acetone media at 300 rpm for 30 min. The slurry was then introduced in a rapid drying system equipped with infrared radiation until all the acetone has been evaporated. The resulting homogeneous mixture was then manually milled in order to break the agglomerates, leading to easier alkaline-earth carbonates decomposition in the next steps. The soft powder was subsequently calcined at 750 and 800 °C for 12 h with an intermediate manual milling. This step has been proven in previous works to be adequate to totally decompose the Sr and Ca carbonates [29]. This is due to the fact that if carbonates are present in the LFZ process, they would decompose in the molten zone, producing CO_2 bubbles and destabilizing the crystallization front [30]. As a consequence, smaller grain sizes, higher amount of secondary phases and grain misalignment would be produced in the bulk samples. Other effect of this carbonates decomposition could be the formation of porosity by trapping the bubbles in the solidification front, decreasing the effective section for electrical conduction.

Once the powders were thermally treated, they were isostatically pressed in form of long cylinders (between 2 and 3 mm diameter and 100 mm length) at 200 MPa. These cylinders were then used as feed in a directional solidification process performed in a LFZ installation described elsewhere [31]. The textured cylindrical bulk samples were obtained using a continuous power Nd:YAG laser ($\lambda=1.064$ μm), under air atmosphere, at a growth rate of 30 mm/h. Moreover, the seed has been clockwise rotated at 3 rpm to maintain the cylindrical geometry while the feed has been rotated in the opposite direction at 15 rpm to homogenize the molten zone, as reported in previous works [32]. After the melt-grown processes, long and geometrically very homogeneous bars were obtained (120 mm length and 2 mm diameter). On the other hand, as it is well-known, Bi-2212 ceramic presents incongruent melting producing different secondary phases [33]. As a consequence, a thermal treatment is necessary to obtain the superconducting phase after the directional solidification process. This annealing process was performed under air atmosphere and consisted in two steps: 860 °C for 60 h in order to form the Bi-2212 phase, followed by 800 °C for 12 h to adjust the oxygen content and, finally, quenched in air to room temperature [34].

Structural studies of textured ceramic samples were performed by using a Rigaku D/max-B X-ray powder diffractometer (CuKα radiation) with 2θ ranging between 3° and 80°. The uncertainty of the crystal lattice parameters calculation remained in the ± 0.00001 range. Microstructural features were determined on polished longitudinal cross-sections of samples, in a field emission scanning electron microscope (FESEM, Zeiss Merlin) equipped with an energy dispersive spectroscopy (EDX) system. The magnetic hysteresis measurements of samples were performed at temperature of 10 K and an applied field of ± 1 T, and *M(T)* measurement obtained under applied field of 50 Oe in ZFC mode with a 7304 model Lake Shore VSM.

3. Results and discussion

Fig. 1 shows the powder XRD patterns obtained from the textured rod samples. It can clearly be seen in the graph that major phase is the superconducting Bi-2212 phase (peaks labeled by +). Moreover, small amounts of unreacted Y_2O_3 (ICSD Card no: 01-074-1828) were detected in the samples. The unit-cell parameters of Bi-2212 phase were calculated by least square fitting and the results are given in Table 1. The crystal symmetries of all samples are obtained as pseudo-tetragonal structure with a parameter of $a-b=5.40$ Å. The *c*-parameters of all samples are found in the vicinity of 30.8 Å, which is in good agreement with the reported for Bi-2212 single crystals [35]. In addition, while *c* parameter slightly decreases with increasing Y-substitution, *a* and *b* remain almost unchanged. The crystal sizes of all samples are calculated by using the Debye–Scherrer formula [36], and listed in Table 1. It can be seen that the average grain size first increases with increase of Y concentration upto 0.075, then it

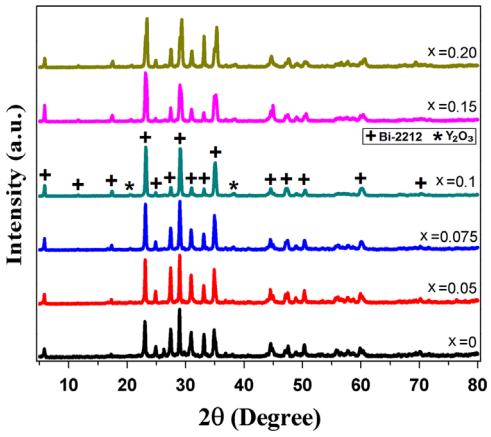

Fig. 1. Powder XRD patterns of all the samples. Peaks corresponding to the Bi-2212 and Y_2O_3. phases are indicated by + and * respectively.