



Comparative study of critical current density, pinning force and levitation force behavior in Yb211 doped-Sm123 bulk superconductors

K. Ozturk^{a,*}, S. Akbulut^a, S. Kutuk^a, S. Bolat^a, S. Celik^b, M. Basoglu^a

^a Department of Physics, Faculty of Arts and Sciences, Karadeniz Technical University, 61080 Trabzon, Turkey

^b Department of Physics, Faculty of Arts and Sciences, University of Rize, 53100 Rize, Turkey

ARTICLE INFO

Article history:

Received 20 June 2011

Received in revised form

30 November 2011

Accepted 8 December 2011

Available online 17 December 2011

Keywords:

High- T_c superconductor

Critical current

Compositional fluctuation

Flux pinning

ABSTRACT

The effect of Yb211 doping on the critical transition temperature (T_c), c -lattice parameter, critical current density (J_c), volume pinning force (F_p) and the vertical levitation force density properties of MPMG-processed $(\text{Sm123})_{1-x}(\text{Yb211})_x$ samples were investigated. In this study the $(\text{Sm123})_{1-x}(\text{Yb211})_x$ sample with $x=0.25$ shows the best $J_c(0)$ value which is almost five times larger than that of the undoped one at zero field and at 77 K, though in the peak effect region the best J_c performance has the sample with $x=0.05$ Yb211 doping ratio. $J_c(H)$ curves exhibits a wide plateau ranging from 0.75 to 2.75 T at 77 K with Yb211 doping ratio for $0.05 \leq x \leq 0.20$ pointing out that the $(\text{Sm123})_{1-x}(\text{Yb211})_x$ samples presented here are attractive for superconducting application especially under high magnetic fields.

© 2011 Elsevier B.V. All rights reserved.

1. Introduction

The most promising fields for potential application of the high-temperature superconductors (HTS) are large scale power applications such as superconducting magnets, superconducting bearings as an energy storage systems, power cables, and MAGLEV transportation systems [1–3]. Almost all these applications require a high current density under magnetic field flowing at acceptable low dissipation in liquid nitrogen temperature. Unfortunately, J_c is disappointing low of high-temperature superconductors based on the RE–Ba–Cu–O compounds (where RE is a rare-earth-elements, such as Dy, Gd, Nd, Sm, and Y), because of ceramic character of these materials with its granular structure and the appearance of the weak-links problem, generally occurring at grain boundaries [4–6]. Since the discovery of high temperature superconductivity, a variety of attempts have been carried out to enhance the critical current density J_c and to optimize the critical temperature T_c of the superconductor for technological applications. It is well known that achieving high J_c , irreversibility field B_{irr} and magnetic field trapping ability in high temperature superconductors requires effective flux pinning. Therefore, several preparation techniques were developed to enhance pinning properties of HTS such as melt-textured growth (MTG) [7], liquid phase process [8], powder melting process

(PMP) [9], melt powder melt growth (MPMG) [10], and top-seeded melt-growth (TSMG) [11,12] process.

In many research center, various kinds of chemical doping, including metal and nonmetal elements particles of magnetic alloys [13–16], various insulating particles such as $\text{RE}_2\text{BaCuO}_5$ (RE211) and $\text{RE}_2\text{Ba}_4\text{CuO}_5$ (RE-2411) and other nonsuperconducting particle have been used as secondary phase particles which can be act as pinning centers in bulk HTS superconductors [17–19]. It is well known that, compared to $\text{YBa}_2\text{Cu}_3\text{O}_{y-\delta}$ the $(\text{LRE})\text{Ba}_2\text{Cu}_3\text{O}_{7-\delta}$ superconductors, where LRE is a light rare earth element, such as La, Nd, Sm, Eu and Gd, attract important attention as a consequence of their higher superconducting transition temperature (T_c) and critical current density (J_c), especially in medium and strong magnetic fields. However, due to a close size difference between LRE^{3+} and Ba^{2+} ions, the light rare earth elements can easily substitute Ba, resulting in the formation of $\text{LRE}_{1+x}\text{Ba}_{2-x}\text{Cu}_3\text{O}_{7-\delta}$ solid solution. As a result, this substitution causes a reduction in T_c and a broadening of the superconducting transition interval [20]. It was reported that to overcome this drawback, the oxygen controlled melt growth (OCMG) process was developed successfully, consisting of synthesizing the LRE123 material under low partial oxygen pressure (1% or 0.1% O_2 in Ar ambient) [21]. Alternatively, to suppress the LRE/Ba substitution and to enhance T_c and the superconducting properties of the (LRE)123 bulk with the melt-texture-growth (MTG), various Ba-rich additions, such as $\text{Sm}_2\text{Ba}_4\text{Cu}_2\text{O}_9$ (Sm242) and Sm_2BaO_4 (Sm210) have been used [19,22]. It was also pointed out that mixed rare-earth compounds are more favorable than single rare-earth compounds because a better controlled growth of

* Corresponding author. Tel.: +90 462 377 41 54; fax: +90 462 377 31 95.
E-mail address: kozturk@ktu.edu.tr (K. Ozturk).

superconductor material and enhanced pinning properties through formation of local strain fields arising from the differences in ionic sizes of the rare-earth elements, such as Yb, Tm and Er [16,23,24]. It was also reported that the feature of compositional fluctuation regions, which induce pinning centers needed for higher critical current in superconductor, could be altered by differences in peritectic temperature, solubility in liquid phase, and ionic radius [25].

It is also well known that the microstructure characteristics of bulk RE123 superconductor composites control their physical properties. Therefore, the understanding and control of the microstructure are attractive challenges to enhance the superconducting properties of MPMG-processed Sm123 sample. Our previous studies indicated that the doping of Yb211 ($\text{Yb}_2\text{BaCuO}_5$) into the Sm123 superconductor sample increases the value of the vertical magnetic levitation force [26]. The main objective of this study is to determine the relations between critical current density, volume magnetic pinning force, magnetic levitation force (in zero field cooling regime) and pinning mechanism of the bulk superconductor samples with nominal composition of $(\text{Sm123})_{1-x}(\text{Yb211})_x$ depending on non-superconducting Yb211 doping ratio x , varying from 0.00 to 0.35. The second aim is to investigate the influence of the fabrication temperature of $(\text{Sm123})_{1-x}(\text{Yb211})_x$ samples on levitation force and pinning properties. Therefore, in this study the measurements of field-dependent magnetization, resistivity ρ , volume magnetic pinning force, magnetic levitation force, pinning mechanism and microstructural analysis were performed to further understand the effect of Yb211 doping on the superconducting properties of the nominal $(\text{Sm123})_{1-x}(\text{Yb211})_x$ samples.

2. Experimental

Firstly, high purity commercial Sm_2O_3 , BaCO_3 , CuO and Yb_2O_3 powder are weighed to have a nominal composition of $\text{SmBa}_2\text{Cu}_3\text{O}_{7-\delta}$ and $\text{Yb}_2\text{BaCuO}_5$, which are denoted as Sm123 and Yb211 thereafter, respectively. The polycrystalline Sm123 sample is prepared by the MPMG method, while Yb211 powder to dope into Sm123 superconductor is prepared by the solid-state reaction technique (SSR). After the stoichiometric mixture of Sm_2O_3 , BaCO_3 and CuO is thoroughly ground for half an hour the powder in the Pt-crucible is placed into a furnace for 5 min at a temperature of 1460°C . Then, the sample is immediately cooled down to the room temperature. After the quenched samples are ground and mixed well the Yb211 powder is added to the Sm123 powder to have nominal composition of $(\text{Sm123})_{1-x}(\text{Yb211})_x$ structure for $x = 0.00, 0.05, 0.10, 0.15, 0.20, 0.25$ and 0.35 and this powder is mixed well again. Following this procedure, Yb211-doped and undoped powders are pressed into a pellet form with 13 mm in diameter under 400 MPa pressure. Then, to understand whether the reheating temperature and cooling speeds have an effect on superconducting levitation force or not $(\text{Sm123})_{1-x}(\text{Yb211})_x$ samples are heated to 1170°C (reheating temperature) which is different than our earlier produced Sm123 samples [26]. After that, the samples were held at this temperature for 15 min and cooled down to 980°C at the speed of $1.7^\circ\text{C}/\text{min}$. This process was followed by slow cooling with a rate of $0.02^\circ\text{C}/\text{min}$ down to 880°C and finally the samples were cooled to room temperature at the rate of $2^\circ\text{C}/\text{min}$. At the final stage of the cooling, the samples are subjected to oxygenation at 500°C for four hours, then cooled down to 300°C at the rate of $2^\circ\text{C}/\text{min}$ under oxygen flow, and finally, the cooling process was continued to room temperature at the rate of $5^\circ\text{C}/\text{min}$.

Magnetization hysteresis loops (M-H) were measured using a vibrating sample magnetometer (VSM) of the Quantum Design PPMS system at temperatures such as 5, 50 and 77 K with the magnetic field applied perpendicular to the sample surface. The measurements were performed by the sweep rate of 5 mT s^{-1} . All resistance measurements in PPMS system after ZFC regime were carried out at constant magnetic field, varying the temperature from 50 to 100 K in steps of 0.25 K with a heating rate of 3 K min^{-1} . All samples were rectangular and typical dimensions were $1.1\text{ mm} \times 2.1\text{ mm} \times 9.0\text{ mm}$ and $0.5\text{ mm} \times 3.2\text{ mm} \times 2.6\text{ mm}$ for electrical resistivity and magnetization studies respectively.

The microstructure of the samples was investigated by an optical microscope and a scanning electron microscope (SEM, Zeiss Evo LS10) equipped with an EDX analyzer. The X-ray diffraction (XRD) data were collected using a Rigaku D/Max-IIIC diffractometer with $\text{Cu K}\alpha$ radiation over the range $20\text{--}60^\circ$ with a step 0.02° and a scan speed 2° min^{-1} at room temperature. The orthorhombic lattice parameters (a – c) were calculated from (006), (020), (200), (013), (103) and (116) peaks using least square methods.

The levitation force measurements of the samples at liquid nitrogen temperature were performed using a self-made device. Details were reported elsewhere [27]. Vertical forces between the bulk HTSs and cylindrical NdFeB Permanent

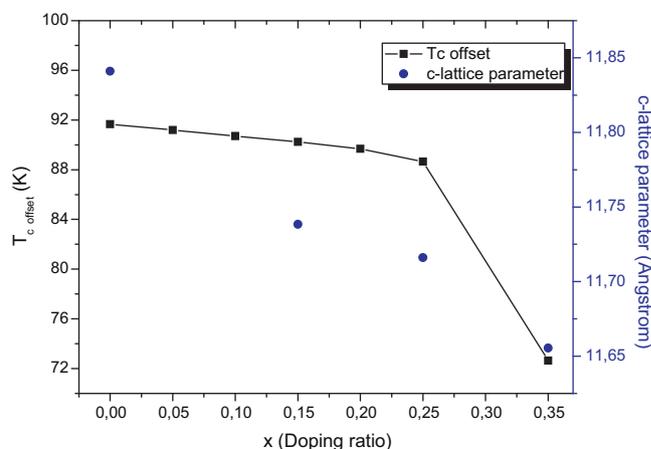


Fig. 1. The variation of the transition temperature $T_{c\text{ offset}}$ and c -lattice constant of nominal $(\text{Sm123})_{1-x}(\text{Yb211})_x$ bulk samples depending on Yb211 doping ratio x .

magnet (PM) were measured for zero field cooling (ZFC) regime at 77 K. The cylindrical PM, which is used in the measurement of vertical force vs. vertical distance, has a diameter of 13 mm, a thickness of 6 mm and a magnetic field of 0.5 T in the center of the top surface of the PM. The levitation force experiment is performed by first placing the bulk sample at the same cooling height and approximately over the center of top surface of the PM. The magnet is moved toward to or away from the superconductor sample by a servo motor. The vertical distance and vertical force are measured by using a displacement sensor and load cells, respectively. The vertical forces vs. vertical distance of the bulk samples are measured continuously, controlled by PC and the movement rate of the PM for force measurement is fixed to be 2 mm/s.

3. Results and discussion

In order to obtain a better understanding of the effects of Yb211 doping on the formation of Sm123 superconductor compound with increasing doping level x , XRD measurements were performed on the nominal $(\text{Sm123})_{1-x}(\text{Yb211})_x$ samples. The Yb211 doping ratio dependence of the $T_{c\text{ offset}}$ and the c -lattice constant of nominal $(\text{Sm123})_{1-x}(\text{Yb211})_x$ bulk samples (reheating temperature 1170°C) with $x = 0.00, 0.05, 0.10, 0.15, 0.20, 0.25$ and 0.35 are shown in Fig. 1. It is found that although the crystal structure of the samples kept their orthorhombic form, the value of c -lattice constant reduces with increasing x similar as reported in a former study, in which the reheating temperature was 1100°C [27]. In our study, the decrease of the c -lattice constants with increasing Yb211 doping ratio shows that Yb^{3+} ions with small ionic size partly substitute for Sm^{3+} ions with relatively large ionic size [16,28]. In addition, a combination of $(\text{Sm,Yb})123$, Yb123 and Sm123 superconducting phases form in the main superconductor matrix (in literature values of c -lattice constants of 11.65 and 11.76 \AA were reported for Yb123 and Sm123 bulk superconductors respectively [28,29]). It is also known that the peritectic temperature of Yb123 is lower than that of Sm123 and therefore, Yb123 and $(\text{Sm,Yb})123$ are formed during the Sm123 growth. It was found that superconducting transition width broadens with increasing of Yb211 doping ratio. This broadening indicates that the Yb211 doping induces a fluctuation of the T_c in the Sm123 sample. It is also seen from Fig. 1 that the value of $T_{c\text{ offset}}$ decreases gradually up to the value of $x = 0.25$ and after that decreases rapidly with increasing of x doping ratio. The rapid decrease of $T_{c\text{ offset}}$ for $x = 0.35$ can be explained by the excess of the non-superconducting phases amount in superconductor sample [22,29].

To illuminate the origin of the pinning force, the critical current and the levitation force improvement, we observed the microstructure and performed a quantitative analysis by SEM-EDX. It was seen in both former and current SEM images that the average grain size of $(\text{Sm123})_{1-x}(\text{Yb211})_x$ samples were about 15–45 μm and that the

Download English Version:

<https://daneshyari.com/en/article/1616587>

Download Persian Version:

<https://daneshyari.com/article/1616587>

[Daneshyari.com](https://daneshyari.com)