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Melt-processed YBCO with Pt or Ce additions: comparison of pinning behavior

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Abstract

The critical current density and magnetic relaxation as a function of temperature and magnetic field are compared for the melt-processed YBCO with Ce or Pt additions. The pinning parameters estimated show an enhancement of current density, and consequently pinning force in the presence of Ce. The difference in pinning capabilities between the Ce- and Pt-added melt-processed YBCO samples is attributed to inherent differences in microstructure. It was observed that in the Ce-added sample the size of the 211 particles can be reduced to 200–500 nm, while in the melt-processed sample with Pt additions the size of the 211 precipitates is usually greater. The obtained results suggest that the benefits of melt-processed YBCO with Ce additions come from the increase of the effective pinning area of the refined 211 precipitates.

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Keywords: Melt processed YBCO; Critical currents; Magnetic relaxation

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1. Introduction

Melt-processed YBCO is the promising material for bulk engineering applications such as flywheels for energy storage, rotors of electric motors, levitation devices, etc. High critical current densities in superconductors depend closely on the microstructure of the material. Therefore, control of the size and morphology of defect structure is essential for the fabrication of the superconducting material with high pinning efficiency. In spite melt-processed YBCO possess structural defects of different kinds such as 211 precipitates, oxygen vacancies, twin boundaries, dislocations, microcracks etc., the majority of these defects have size greater than the coherence length (~4 nm for

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YBCO at 77 K) and cannot be considered as effective pinning centers. A high current density requires nanoscale disorder with the areal number density of the defects of the order of $(H/2) \times 10^{11}\ \text{cm}^{-2}$, where H is the applied magnetic field in Tesla [1,2]. Various material-processing methods have been employed to enhance pinning in melt-processed YBCO. Chemical doping with small amounts of Zn^{2+} or Li^{1+}, substituting at CuO_2 plane sites has been shown to be very beneficial to enhance the superconducting properties of melt-processed material [3–5]. An alternative way of introducing nanoparticles of secondary phases has been explored in Ref. [6]. Another approach for flux pinning enhancement is a further refinement of the existing structural defects, for example, 211 inclusions. Since the residual 211 particles (~1 μm) are much greater than the coherence length in YBCO, the particles themselves are not effective in flux pinning. However, at the interface of $Y_2BaCuO_5/YBa_2Cu_3O_{7-\delta}$ modified microstructure pins magnetic flux effectively [7]. Experimentally, it was found that the additions of $BaSnO_3$, Pt or Ce are effective in reducing the particle size of 211. Ce, for example, is suggested to increase the viscosity of the melt and to act as an inhibitor for growth of the 211 particles [8–10]. Others, like Pt are assumed to refine 211 by altering the 211/liquid interfacial energy and/or Y diffusivity [11]. Some of the chemical additions, such as $BaSnO_3$ promote 211 dissolution, resulting in finer 211 [11]. In this paper we use Ce and Pt, which are two of the most effective second phase additions in the point of view of enhancing the critical current density [12–14]. Although intensive research of microstructure of the melt-processed YBCO with above mentioned additions has been done. The experimental data of the influence of these additions on pinning behavior, for example, their effectiveness in the reduction of decay of the magnetic decay, are still missing. We report on a significantly different pinning behavior in YBCO with Ce in comparison to YBCO with Pt. An influence of Ce on the critical current is demonstrated by the magnetization and by the flux-creep measurements. These studies, conducted on the melt-processed samples over wide temperature range at various magnetic fields, show the higher pinning efficiency of the material having Ce additions. We believe that this difference in pinning properties is a consequence of the microstructure of these samples.

2. Experimental

The samples were prepared using the modified melt-crystallization process [12]. In this study we use the Pt-added standard YBCO sample, described in Ref. [5]. To prepare the Ce-added samples, commercial Y123, Y_2O_3, CeO_2 each of at least 99.99% purity have been used as precursors. The powders were mixed in a molar ration of $Y123 + 0.3Y_2O_3$. Up to 2 wt.% Ce were added with the aim of refining the secondary phase. The powders were ball milled and pressed in 30 mm diameter pellets after grinding. A $SmBa_2Cu_3O_7$ seed crystal was mounted on their top so that the *a–b* plane of the seed was parallel to face of the pellet. After melt-processing the samples were annealed in flowing oxygen at 380 °C for 300 h. The single domain samples with a square dimension of $18 \times 18\ \text{mm}^2$ were obtained.

The microstructure of the samples was studied by scanning electron microscopy (SEM), transmission electron microscopy (TEM) and polarized light microscopy. For TEM investigations the samples were ion-milled in argon atmosphere. Identification of the chemical composition was performed with a Philips XL 30 using back-scattering scanning electron image and energy dispersion analysis of X-rays (EDAX) calibrated by the Y123 single-crystal standard.

To perform magnetic measurements small samples with cylindrical shape (3 mm in diameter) were cut from various areas of the larger YBCO discs using an ultrasonic drilling machine. The superconducting transition temperatures were measured by a Lake Shore ac-susceptometer. The magnetization measurements were performed using a vibrating sample magnetometer in the temperature range 65–77 K in magnetic fields up to 8 T at a constant sweep rate of 160 mT/s. The magnetic field was applied parallel to the *c*-axis. The critical current densities were calculated from magnetization loops according to the Bean critical state model.