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Role of nano and micron-sized inclusions on the oxygen controlled preform optimized infiltration growth processed YBCO superconductors

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ABSTRACT

In the present work, with the aim of improving the local flux pinning at the unit cell level in the $YBa_2Cu_3O_{7-\delta}$ (YBCO) bulk superconductors, 20 wt% of nanoscale Sm_2O_3 and micron sized (Nd, Sm, Gd)$_2BaCuO_5$ secondary phase particles were added to YBCO and processed in oxygen controlled preform optimized infiltration growth process. Nano Dispersive Sol Casting method is employed to homogeneously distribute the nano Sm_2O_3 particles of 30–50 nm without any agglomeration in the precursor powder. Microstructural investigations on doped samples show the chemical fluctuations as annuli cores in the 211 phase particles. The introduction of mixed rare earth elements at Y-site resulted in compositional fluctuations in the superconducting matrix. The associated lattice mismatch defects have provided flux pinning up to large magnetic fields. Magnetic field dependence of current density (J_c(H)) at different temperatures revealed that the dominant pinning mechanism is caused by spatial variations of critical temperatures, due to the spatial fluctuations in the matrix composition. As the number of rare earth elements increased in the YBCO, the peak field position in the scaling of the normalized pinning force density ($F_p/F_{p\ max}$) significantly gets shifted towards the higher fields. The curves of J_c(H) and $F_p/F_{p\ max}$ at different temperatures clearly indicate the LRE substitution for LRE' or Ba-sites for δT_c pinning.

1. Introduction

The bulk high-temperature superconductors (HTSC) have been generated a considerable scope for technological applications such as quasi-permanent magnets by trapping the higher magnetic fields than the best conventional magnetic materials. Compared to $LREBa_2Cu_3O_{7-\delta}$ (LREBCO or LRE-123 or 123, LRE represents light rare earth elements such as Nd, Sm, Gd, etc.) $YBa_2Cu_3O_{7-\delta}$ (YBCO or Y-123) show low irreversible fields that limit the applications. Only the LRE-123 composites exhibit a sufficiently good performance up to 90 K due to large flux pinning properties. But LREBCO superconductors cannot be processed in the air, in which large fractions of solid solutions of $LRE_{1+x}Ba_{2-x}Cu_3O_y$ (LRE/Ba -ss) type will form and deteriorate the superconducting properties [1,2]. To suppress the formation of LRE/Ba –ss in LREBCO composites, the oxygen controlled (OC) atmosphere methods have been developed to achieve high critical temperatures (T_c), which was first accomplished by Yoo et al. [3]. However, the formation of solid solutions in these materials could not be avoided completely [3].

The literature on the investigations of many binary and ternary LRE doped high-T_c LREBCO compounds has been reported including the studies on systems like (Y, Nd)BCO, (Y, Sm)BCO, (Nd, Eu, Gd)BCO, (Y, Sm, Nd)BCO, (Sm, Eu, Gd)BCO, etc, [4–15]. Most of these reports were on the compounds processed through melt growth (MG) technique [16] which results in several problems such as the inhomogeneous distribution of (Y/LRE)$_2BaCuO_5$ (Y/LRE-211 or 211) phase particles and the presence of macro defects (pores and cracks) in final composites.

To overcome the problems associated with the MG process, Chen et al. [17] proposed a method called Infiltration Growth (IG) process which allows the fabrication of near net-shaped samples with no or relatively little shrinkage. In the IG process, the liquid phases ($Ba_3Cu_5O_8$) are allowed to infiltrate into a porous 211 preform through heating above their melting points. While slow cooling, below the peritectic temperature, the peritectic reaction of 211 with liquids will form a LRE-123 matrix with left back 211 inclusions. Even though the macro defects and the sizes of 211 are controlled in IG process, there are some reports on the non-uniform distribution of 211 phase particles in the matrix that results in spatial dependent properties [18]. Modifications were made in the IG process by optimizing the preform sintering temperature and applied pressure to make the preforms and developed a method namely Preform Optimized

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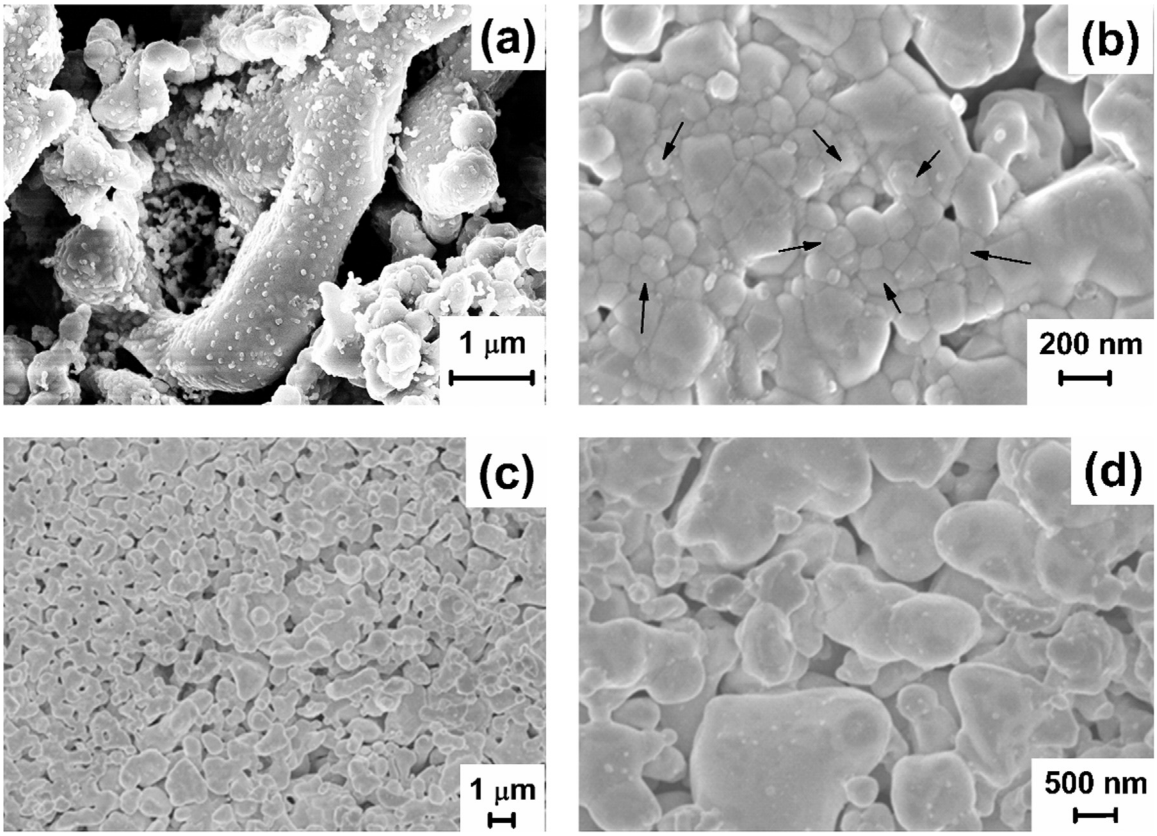

Fig. 1. FESEM images of sintered (Y, Sm)-211 preform powder and pellet are shown in (a) and (b) respectively. Nano Sm_2O_3 particles are marked by arrows. Similar images of YNSG preform are shown in (c) and (d) respectively. The preform pellets were fabricated in a die at a pressure of 460 MPa and sintered at 950 °C for 4 h.

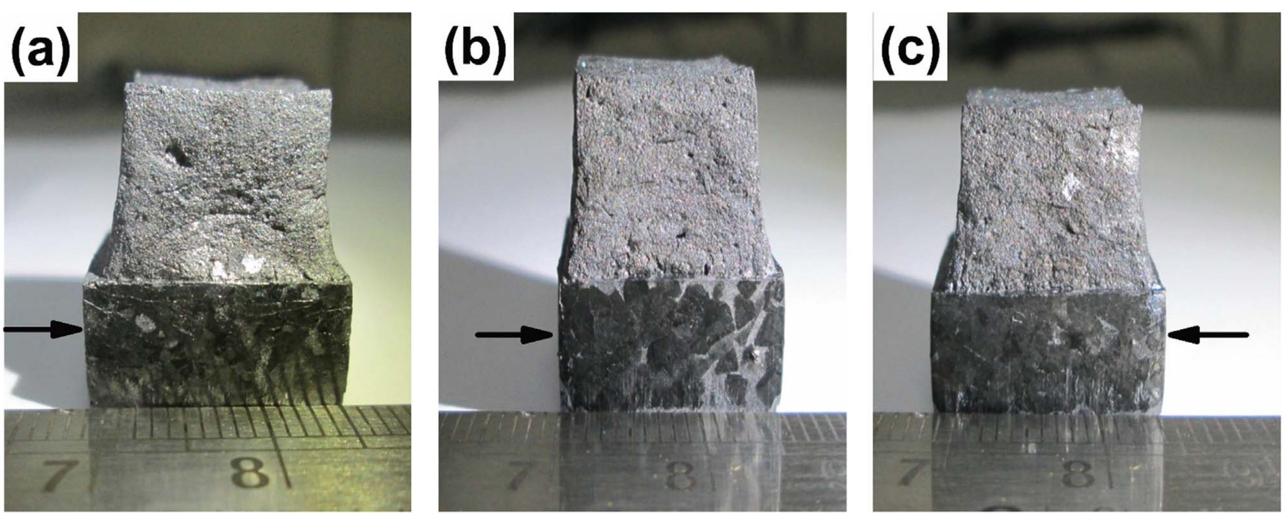

Fig. 2. Photographs of the POIG processed samples: (a) YBCO-Ar, (b) (Y, Sm)BCO and (c) YNSG. The arrow marks indicate the POIG processed (Y, LRE)BCO composites.

Infiltration Growth (POIG) process [19]. Compared to various reports on YBCO samples made using MG and IG processes, POIG process begets fine and homogenously distributed non-superconducting secondary phases (Y-211) in superconducting 123 matrix [20–23]. Eventually, the POIG process emerged as a technique that offers high J_c up to higher fields in the YBCO due to homogenously distributed Y-211 phase particles with negligible unwanted macro-defects.

The atomic scale defects or fluctuations act as effective flux pinning centers since the HTSC composites possess a very short coherence lengths. Doping with different LRE elements can enhance the flux pinning properties due to the formation of chemical fluctuations at the local unit cell level. Many researchers have investigated the flux pinning behavior of MG processed LREBCO superconducting materials through the addition of different LRE elements. Murakami et al. [24] have proposed that nano-sized LRE/Ba –ss clusters of lower T_c act as field-induced pinning centers, and show peak effect at higher fields in the LREBCO materials. Recent studies of mixing three different LRE elements (NEG-123) showed the occurrence of peak effect in $J_c(H)$ curves, at higher fields, and are attributed to the presence of a different chemical ratio of LRE elements in the matrix phase [25,26]. Compositional fluctuations or clusters in mixed LREBCO, arising from a distinct range of the rare earth chemical ratio have strongly affected the pinning properties at high fields (ΔT_c pinning). Melt processed YBCO doping with binary rare earth elements yielded high $J_c(0)$, but