Highly Tunable, Rare Earth Tantalate Pyrochlore Nanoparticles for Superior Flux Pinning in YBCO Films

Sophie Harrington[1] and John H. Durrell[1] and Boris Maiorov[2], Haiyan Wang[3], Stuart C. Wimbush[1], A. Kursumovic[1], J. H. Lee[3], J. L. MacManus-Driscoll[1]

[1]*Department of Materials Science and Metallurgy, University of Cambridge, Pembroke Street, Cambridge CB2 3QZ, UK*

[2]*Superconductivity Technology Centre, Los Alamos National Laboratory, Los Alamos, New Mexico 87545, USA*

[3]*Department of Electrical and Computer Engineering, Texas A&M University, College Station, Texas 77843, USA*

sah59@cam.ac.uk

Practical flux pinning in the high temperature superconductor, $YBa_2Cu_3O_{7-\delta}$ (YBCO), was first demonstrated around five years ago. Since that time, significant progress has been made in materials optimisation and the various candidate pinning additives show several factors higher current carrying performance in magnetic field than standard YBCO. Despite the major advances, there has been little basic understanding about what is the optimum additive and how to achieve the 'perfect' pinning microstructure. Here, through a simple understanding of the kinetic and thermodynamic factors at play, combined with a knowledge of the materials chemistry of candidate pinning phases, we propose a new pinning additive, RE_3TaO_7 (where RE is rare earth). We demonstrate a very fine pinning nanostructure from the phase as well as exemplary flux pinning. The nanoparticle self-assembly is readily tunable, allowing for both strong random and correlated pinning. State-of the art or better pulsed laser deposition current densities of 1.2 MA.cm^{-2} at 1 T, 0.55 MA.cm^{-2} at 3 T, and 0.2 MA.cm^{-2} at 5 T, were achieved in the first films grown.

Introduction

Improvement of flux pinning, and thus the critical current, J_c, in YBCO is crucial for achieving widespread applications of this technologically important material. Practical pinning enhancement methods developed within the last 5; years such as incorporating nano-inclusions in the films [1-4], or on the substrate surface [5,6], disorder effects from rare-earth (RE) modifications [7], and microstructural modification have all been successful in specific field and temperature regimes [8-14]. However, often the superconducting transition temperature T_c is reduced by the additions due to disordering or poisoning. Also there is a strong sensitivity of performance to processing conditions, mainly because of lack of control of the sizes and distributions of nanoparticles.

Further improvement and reproducibility of properties will only come about through careful understanding of nanopartilce nucleation and growth, as well as an understanding of materials chemistry for the choice and design of the second phase addition.

Method

Mixed PLD targets containing RE_3TaO_7 were pressed and sintered in flowing oxygen at 985°C for 24hrs. Films 0.5-1μm thick were deposited on single crystal (001) STO using a Lamda Physik KrF excimer laser (λ=248nm) in 30 Pa flowing oxygen at 755-805°C.

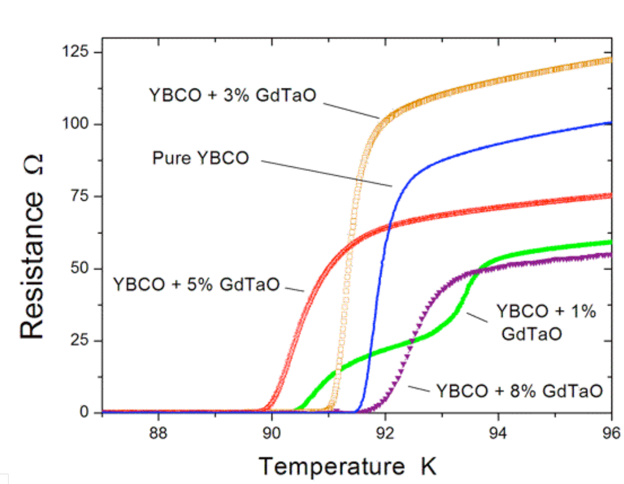

Figure 1. Resistance vs. temperature measurements for thin films with GdTaO 1-8 mol % that show the phase included does not lower T_c.

I-V characteristics were measured at 77K on photolithographically patterned bridges, using a conventional four point measurement geometry. The characteristic structure and orientation of the films were studied using high-resolution X-ray diffraction and transmission electron microscopy.

Results

As shown in Fig. 1 the T_cs of the films were 91 ±1K all within the normal window for pure YBCO. This proves the lack of substitutional poisoning by Ta and lack of perturbation and disordering of the YBCO lattice by the additive phase.

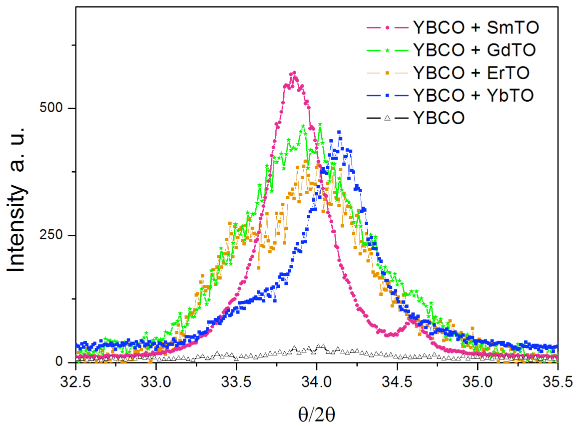

Figure 2. X-ray θ/2θ scans showing the shift of the (004) peak for RE_3TaO_7 with RE = Sm, Gd, Er and Yb.

Fig. 2 shows the (004) peak of the RE_3TaO_7 phase that was observed from X-ray measurements in the standard Bragg-Brentano geometry. A shift in peak position that corresponds to the change in size of the RE ion incorporated.

Fig.3 shows significant enhancement of J_c for fields parallel to the *c*-axis for the RTO samples of 1.5 and 5 mol.% level compared to pure YBCO. At higher fields, the J_c for the 5 mol.% samples are higher than the 1.5 mol. % one, indicative of a higher density of nanorods that is expected for the higher level of addition.

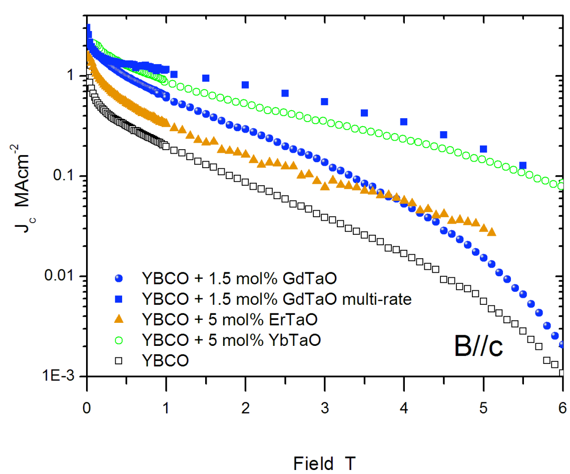

Figure 3. Critical current density at 77K, θ = 0 (H ǁ c) is enhanced for all fields in 0.5μm thick films.

Conclusion

In conclusion, a new strain-selected, non-poisoning pinning additive, RTO, was explored in the high temperature superconductor, YBCO. These rare earth tantalates form a very stable secondary phase which readily assembles into narrow (~ 5nm), straight, *c*-axis correlated nanorods with 10-20 nm pitch. Strong flux pinning is observed with RTO additives, giving J_c's up to 1.2 $MAcm^{-2}$ at 1T, and 0.55 $MAcm^{-2}$ at 3T with no reduction in T_c.

Acknowledgment

The work was supported by the European Commission (Marie Curie Excellence Grant “NanoFen”, MEXT-CT-2004-014156), EPSRC of the U.K, and the Los Alamos National Laboratory Directed Research and Development Project under the United States Department of Energy. We also wish to acknowledge the use of the EPSRC's Chemical Database Service at Daresbury.

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