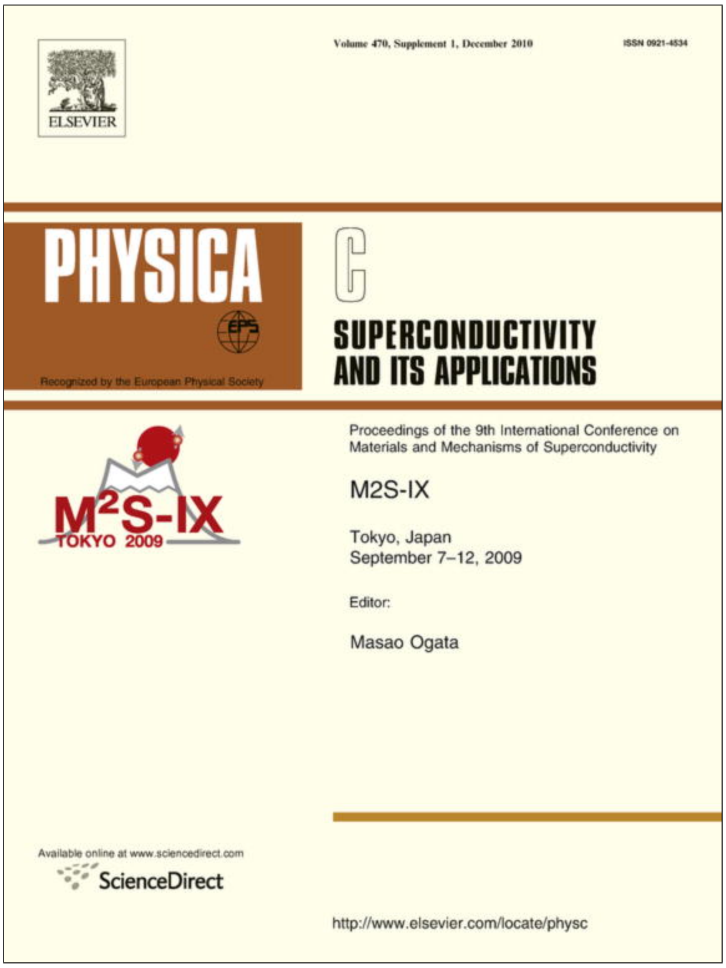
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Irreversibility line and anisotropy of $SmBa_2Cu_3O_{7-\delta}$ with varying oxygen content

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We report on magnetization and torque measurements of $SmBa_2Cu_3O_{7-\delta}$ (Sm123) single crystals with an oxygen content $7-\delta = 6.60, 6.70$ and 6.78. The anisotropy increases from 40.1 ± 0.4 to 56.4 ± 0.7 with decreasing oxygen content from 6.78 to 6.70. The crossover field, H_{cr}, where the irreversibility line changes slope, is lowered for crystal with a lower oxygen content. The H_{cr} values are higher for Sm123 than for $YBa_2Cu_3O_{7-\delta}$ (Y123) single crystals. The anisotropy dependence on the oxygen content is compared to that of Y123.

1. Introduction

It has been established that the intrinsic and extrinsic properties of high temperature superconductors strongly depend on the oxygenation level. The dependence of the thermodynamic parameters on the oxygen content was studied in detail for Y123. Upon increasing the δ value, the critical temperature, T_c, decreases until superconductivity vanishes for $\delta = 0.6$ [1].

Removal of oxygen from the conducting CuO chains increases the effective mass anisotropy, γ, from 5 to 8 for optimally doped (i.e. $\delta = 0.085$) crystals to about 40 for a crystal with $\delta = 0.5$ [2]. Such an increase is related to a reduction of the coupling strength between adjacent CuO_2 planes.

The irreversibility line shifts to lower fields in crystals with lower oxygen content [3]. A crossover between three-dimensional and two-dimensional systems (i.e. at H_{cr}), that is due to a reduction of the in-plane hole concentration, was found for Y123 [4].

A lot of attention has been paid to Sm123 recently due to its higher T_c, but mainly due to its higher critical current densities as compared with those of Y123, both at low and high magnetic fields [5].

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2. Experimental

Single crystals of Sm123 were grown by the top seeded solution growth technique that allows obtaining large crystals of good quality. The specific oxygen content, $7-\delta = 6.60, 6.70$ and 6.78, was obtained by a controlled oxygenation process, performed at various oxygen pressures below 1 bar and at temperatures around 510 °C. An XRD analysis was performed to confirm the crystal quality and to determine the lattice constants. The magnetization measurements were performed in a 7 T SQUID magnetometer (Quantum Design, MPMS). T_c was determined to be 19.6, 41.4 and 51.6 K for the crystals with an oxygen content of 6.60, 6.70 and 6.78, respectively. The irreversibility line for $H \| c$-axis was determined from magnetization hysteresis loops. The torque measurements were performed in a 9 T Quantum Design PPMS. The angular dependence of the torque proposed by Kogan et al. [6,7] with an additional term related to the anisotropic background [8] was fitted to the experimental data in order to determine the anisotropy parameter.

3. Results

The critical temperature systematically decreases in $SmBa_2Cu_3O_{7-\delta}$ single crystals with decreasing the oxygen content. The extrapolated value of $7-\delta$ at which superconductivity vanishes, is estimated to be 6.51, somewhat higher than 6.40 reported for Y123 [1].

The irreversibility field, H_{irr}, at $T = 0.5T_c$ shifts from 1.8 to 0.55 T while lowering of the oxygen content from 6.78 to 6.60. In the tem-

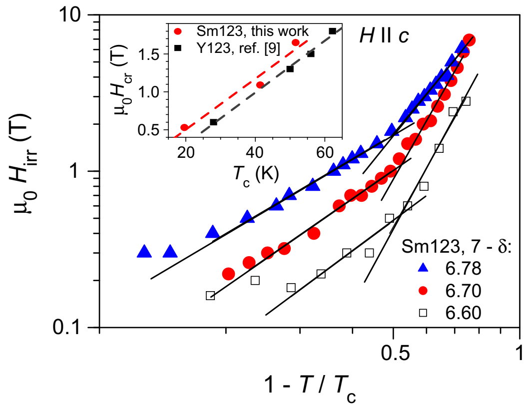

Fig. 1. Irreversibility line for $H||c$ in Sm123 with an oxygen content of 6.60, 6.70 and 6.78. Insert: crossover field dependence on the transition temperature for Sm123 (this work) and Y123 (Ref. [9]), both with linear fits.

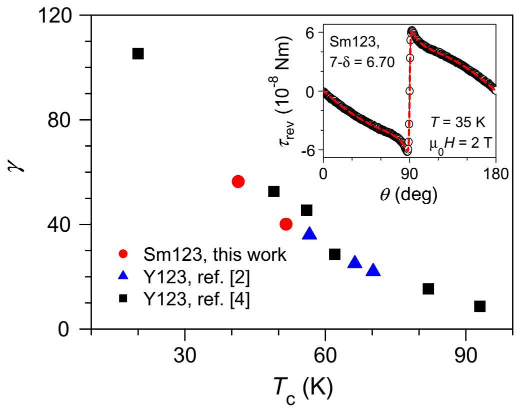

Fig. 2. Dependence of the anisotropy parameter on the critical temperature for Sm123 (this work, circles) and Y123 (from Refs. [2,4], triangles and squares, respectively). Insert: reversible angular torque dependence of Sm123 with an oxygen content of 6.70 at $T = 35$ K and $\mu_0 H = 2$ T.

perature dependence of H_{irr}, two slopes are visible (Fig. 1). The crossover field H_{cr} shifts from 1.65 to 0.53 T while lowering the oxygen content from 6.78 to 6.60. These values are systematically higher than those found in Y123 single crystals, see the insert of Fig. 1. At $H = H_{cr}$, a change from a power law dependence $H_{irr} = \beta(1 - T/T_c)^{\alpha}$, with α around 1.5 (as in Y123 [3]), to a more rapid temperature dependence at higher fields, $\alpha = 3.2 - 4.8$, was observed.

This increase of the exponent α for higher fields may be interpreted as an indication of increasing two-dimensionality of the system at lower temperatures. In the fields lower than H_{cr}, pancakes couple into vortices and form a three-dimensional system. According to Blatter et al. [10] a vortex system with weak pinning crosses over from 2D to 3D behavior at a field $\mu_0 H_{cr} = \Phi_0/(s^2\gamma^2)$, where Φ_0 is the flux quantum and s is the spacing between the sets of CuO_2 sheets. Hence, observed shift of H_{cr} for Sm123 with respect to the crossover fields for Y123 may indicate that γ values for Sm123 are lower than for Y123. However, since the assumption of weak pinning is not justified in the case of studied crystals and strong pinning centers may cause shift of H_{cr} to higher fields value [3] we have performed direct studies of γ by torque magnetometry.

The magnetic torque, τ, was recorded at increasing and decreasing angles θ between the c-axis of the sample and the applied magnetic field in the angular range of 180° with the step of 0.5 degree. The mean (reversible) torque $\tau_{rev} = [\tau(\theta^+) + \tau(\theta^-)]/2$ was calculated from measurements under counterclockwise and clockwise rotation of the sample in the magnetic field for minimizing pinning effects. The angular dependence of both, Kogan and the background, contributions was fitted to the experimental data. The effective mass anisotropy was derived after subtracting the anisotropic paramagnetic background [6–8], see the insert of Fig. 2. The contribution to the torque due to an anisotropic paramagnetic susceptibility, of sinusoidal angular dependence, can be treated as a background contribution to the superconducting torque [8].

At $T = 0.82T_c$ and $\mu_0 H = 2$ T we find an anisotropy of 56.4 ± 0.7 and 40.1 ± 0.4 for Sm123 crystals with an oxygen content of 6.70 and 6.78, respectively. The result for Sm123 with an oxygen content of 6.60 is not shown due to its wide superconducting-to-normal state transition which could lead to an artificially lowered anisotropy. As reported for Y123, the anisotropy in Sm123 crystals strongly depends on the oxygen stoichiometry $7 - \delta$. A comparison of the anisotropy in Sm123 and Y123 is presented in Fig. 2. Note that the anisotropy dependence on T_c is very similar for both rare-earth superconductors.

In summary, irreversibility lines, crossover fields, and anisotropy parameters for Sm123 with varying oxygen content were assessed and compared with those of Y123 single crystals. Despite the very similar anisotropy Sm123 shows higher crossover fields, which are related to better vortex pinning in this compound.

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