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THE ab-ANISOTROPY OF TWINFREE $YBa_2Cu_3O_{7-\delta}$ FILMS ABOVE AND BELOW T_C

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High quality twin-free c-axis oriented $YBa_2Cu_3O_{7-\delta}$ films were grown by pulsed laser deposition on $NdGaO_3$. We find resistive anisotropies between $1 < \rho_a / \rho_b < 1.6$. The resistive anisotropy above T_c appears to be correlated to the anisotropy in the critical current below T_c. The normal state properties of the chains along **b** seem to have a significant influence on the superconducting properties of $YBa_2Cu_3O_{7-\delta}$.

1.INTRODUCTION

Scherer et al. [1] demonstrated the possibility to sputter almost twin-free $YBa_2Cu_3O_{7-\delta}$ films on (001) $NdGaO_3$ substrates. The **a** and **b** axes of these films are uniquely aligned with respect to the substrate and as a result a resistive anisotropy was found. Previously, we showed [2] that twinfree films can also be prepared by laser ablation if a substrate temperature of around 800 °C is used and the film thickness does not exceed 100 nm. Although the structural anisotropy was well established by X-Ray diffraction and Rutherford Back Scattering (RBS), we found no electrical anisotropy in our films.

Recently, however, we observed in twinfree films a normal state resistive anisotropy ρ_a / ρ_b between 1 and 1.6. Moreover, it appeared that the anisotropy in resistance is correlated with an anisotropy j_a / j_b in the critical current. We attribute the anisotropy in j_c to the anisotropy in the coherence length ξ. The correlation between ρ_a/ρ_b and ξ_a / ξ_b follows from a simple Drude model.

2.EXPERIMENTAL

Thin 80 nm c-oriented $YBa_2Cu_3O_{7-\delta}$ films were laser deposited on (001) $NdGaO_3$ using a 248 nm excimer laser provided with projection optics [3], using a substrate temperature T_s = 800 °C and an oxygen pressure of 15 Pa. The crystallinity of the films was investigated by RBS channeling using a 2 MeV He^+-beam plotting the angular dependence of the Ba-signal. The chemical composition of the films was investigated with secondary ion mass spectrometry (SIMS) using a Cameca ims4f system with a 0.3 μA current of 3keV O_2^+-primary ions. Four-point resistivity measurement were performed both on mechanically scratched 0.5x2.0 mm^2 and on small wet etched 10x100 μm^2 striplines. The anisotropy of j_c was measured from the flux penetration pattern at 4 K, by magneto-optics using a Bi-doped YIG-film with in-plane anisotropy as an indicator [4].

3.RESULTS

High quality $YBa_2Cu_3O_{7-\delta}$-films were obtained with channeling minimum yields along [001] down to χ_{Ba} = 1.3 %. The T_c of the films on $NdGaO_3$ is typically between 89 and 90 K, which is 1 degree lower than for our films on $SrTiO_3$ substrates. The resistive anisotropy ρ_a / ρ_b of the 80 nm films varies between 1 and 1.6. As shown in fig.1 the resistivity both along **a** and **b** is only slightly higher than in single crystals [5]. Moreover, we find that the anisotropy in our films remains constant with temperature, both resistivities being linear down to ~100 K. The flux penetration profiles as detected by magneto-optics at 4 K, are distinctly anisotropic only for films with an anisotropic resistivity.

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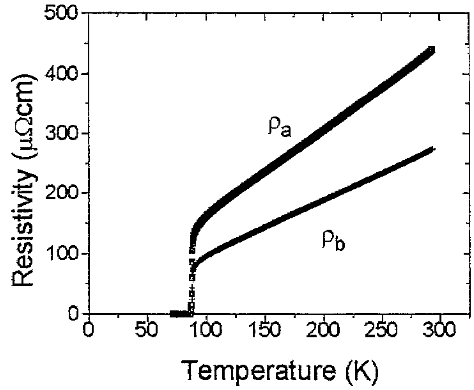

fig.1. Resistivity of a twin-free $YBa_2Cu_3O_{7-\delta}$ film as measured along the **a** and the **b** axes. (ρ_a / ρ_b) = 1.6

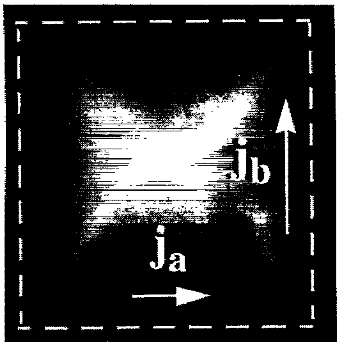

fig.2. Anisotropic flux penetration in a square of the film of fig.1, upon reducing the magnetic field from 200 to 28 mT along the hysteresis loop.

From an analysis of the flux profile shown in fig.2 we deduce the anisotropy in the critical current to be $j_a / j_b \approx 0.8$ (compare with fig.3d in [4], where $j_2 / j_1 = \text{tg}\ \alpha$). SIMS analysis of the Ga-content of the films shows no relation between the anisotropy and the purity of the film. Using a Ga-implanted $YBa_2Cu_3O_{7-\delta}$ film on $SrTiO_3$ as a reference, Ga concentrations of $\approx 10^{18}$ at/cm^3 were found. This means that in our films at most 1 in every 1000 Cu-chain atoms, is substituted by Ga.

4. DISCUSSION

While the ab-anisotropy in critical current has not been reported before, it is consistent with previously published work on the anisotropy of λ and ξ: by infrared techniques it was found that $\lambda_b / \lambda_a = 0.6$ [6], while from the anisotropic shape of the vortex core as detected by STM the ratio $\xi_a / \xi_b = 0.67$ was deduced [7]. Assuming that the pinning defect is not much larger than the vortex core, the activation energy for depinning $U_c \propto j_b\ \xi_a$. Since U_c is proportional to the condensation energy which is independent of the current direction, $j_a\ \xi_b = j_b\ \xi_a$. To relate the normal state transport properties to those in the superconducting state, we consider a simple Drude model with m_i the mass of the quasi-particles. Since $\xi_i \propto (m_i)^{-0.5}$ one expects $(\rho_a / \rho_b)^{-0.5} = (\xi_a / \xi_b)$. Using the relation between ξ_i and j_i one finds $(\rho_a / \rho_b)^{-0.5} = (j_a / j_b)$, which compares reasonably well with our experimental findings. For (ρ_a / ρ_b) = 1.6 we find $j_a / j_b = 0.8$, while for films with (ρ_a / ρ_b) = 1, also the critical current is found to be isotropic. Note, furthermore, that the observed anisotropy in ξ on single crystals ($\xi_a / \xi_b = 0.67$. [7]) is consistent with the maximum resistive anisotropy found in detwinned single crystals $\rho_a / \rho_b = 2.25$. Thus the normal state properties of the chains have a significant influence on the superconducting properties of $YBa_2Cu_3O_{7-\delta}$. Given the low Ga-content, we assume that either the oxygen content or the oxygen ordering within the CuO-chains sensitively determines the anisotropic properties of our $YBa_2Cu_3O_{7-\delta}$ films on $NdGaO_3$.

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