High-field magnetotransport in strained $La_{2-x}Sr_xCuO_4$ films

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Abstract

We present the transport properties of the low-temperature normal-state for strained $La_{2-x}Sr_xCuO_4$ films achieved by suppressing superconductivity with high magnetic fields up to 50 T. Systematic measurements were performed on six MBE grown films with three different doping levels (underdope, optimumdope, and overdope) and also with either compressive or tensile epitaxial strain. The results showed that the low-temperature semiconducting upturn observed in under- or optimum-doped $La_{2-x}Sr_xCuO_4$ bulk single crystals is significantly suppressed by in-plane compressive strain.

Key words: high-T_c cuprate; high magnetic field; epitaxial strain

There has been a considerable amount of controversy on the low-temperature normal state in high-T_c cuprates: whether the ground state is metallic or insulating. This is because a low-temperature semiconducting upturn ($d\rho/dT<0$) with a resistivity minimum has frequently been observed in both of hole-doped and electron-doped high-T_c cuprates [1–3]. The semiconducting upturn seems to be universal in under-doped high-T_c cuprates although its origin has not been clarified yet. In this article, we report the low-temperature normal transport properties of strained $La_{2-x}Sr_xCuO_4$ (LSCO) films with an emphasis on the distinctly different behaviors between compressively strained films and expansively strained films.

High magnetic fields are required in order to unveil the "normal" ground state of high-T_c cuprate superconductors. In this study, high-field magnetotransport measurements were performed using a pulse magnet energized by a capacitor bank on c-axis oriented LSCO films prepared by molecular beam epitaxy. LSCO, a prototype high-T_c superconductor, has an optimum T_c of $\sim$ 37 K for bulk specimens under ambient pressure [4]. However, the T_c for LSCO films can be varied by epitaxial strain [5,6]. We performed high-field measurements on six LSCO films with three different doping levels and also with either compressive or tensile epitaxial strain. One set of films ("compressed films") grown on $LaSrAlO_4$ (LSAO) substrates, have in-plane compressive and out-of-plane tensile strain, and show a higher T_c than the bulk value. The other set of films ("expanded films") grown on $SrTiO_3$ (STO) substrates, have in-plane tensile and out-of-plane compressive strain, and show a lower T_c than the bulk value. The properties of the films used in this work are summarized in Table 1.

Doping-level(x)	$T_c(\rho=0)$	Substrate	a-axis	c-axis
0.11 (film)	30.8 K	$LaSrAlO_4$	not measured	13.22
	17.5 K	$SrTiO_3$	not measured	13.17
0.15 (film)	44.2 K	$LaSrAlO_4$	3.762	13.29
	25.9 K	$SrTiO_3$	3.837	13.18
0.19 (film)	33.2 K	$LaSrAlO_4$	not measured	13.27
	22.3 K	$SrTiO_3$	not measured	13.21
0.15 (bulk)	36.7 K	——	3.777	13.23

Table 1
T_c and lattice constants of strained LSCO films as compared to the bulk values[4].

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Figure 1 shows the temperature dependence of in-plane resistivity of LSCO films under an applied magnetic field parallel to the *c*-axis. The behaviors for the "compressed" and "expanded" LSCO films show a striking contrast. The "expanded" films of all the three doping levels show a semiconducting upturn. In contrast, the semiconducting upturns are significantly suppressed in the "compressed" films, and disappear at the optimum- and over-doping levels, leading to the metallic behavior kept down to lowest temperatures. The observed semiconducting upturn seems to have a $\log T$ dependence as most clearly seen in the underdoped films (Fig. 1(a)).

With regard to the origin of this upturn, our recent systematic magnetotransport studies on electron-doped T'-$(Ln,Ce)_2CuO_4$ films (Ln = La, Pr, and Nd), where a similar anomalous upturn was observed at low temperatures [3], have provided strong evidences pointing toward Kondo scattering due to Cu^{2+} local spins. The evidences include (1) $\log T$ dependence of the semiconducting upturn, (2) saturation of the semiconducting upturn at lower temperatures (unitarity limit of scattering), and (3) suppression of the semiconducting upturn by applying a high magnetic field (isotropic negative magnetoresistance). The present results in LSCO are essentially similar to those observed in $(Ln,Ce)_2CuO_4$ except for the following two points: (1) more robust superconductivity in LSCO than in $(Ln,Ce)_2CuO_4$ prevents us from definite observation of the unitarity-limit scattering regime, *i.e.*, undoubted saturation of the upturn, and (2) stronger Kondo interaction in LSCO than in $(Ln,Ce)_2CuO_4$ prevents us from observation of the negative magnetoresistance within our attainable fields up to 50 T. In spite of lack of these evidences, we believe that the upturns observed in hole-doped LSCO and electron-doped $(Ln,Ce)_2CuO_4$ have the same origin, namely Kondo scattering due to Cu^{2+} local spins. If this is true, our present results strongly indicate that the Kondo interaction (H_K) is regulated by epitaxial strain: weaker H_K in "compressed" films and stronger H_K in "expanded" films. This scenario may shed light on a better understanding of the strain effect on the superconducting transition temperature in high-T_c cuprates.

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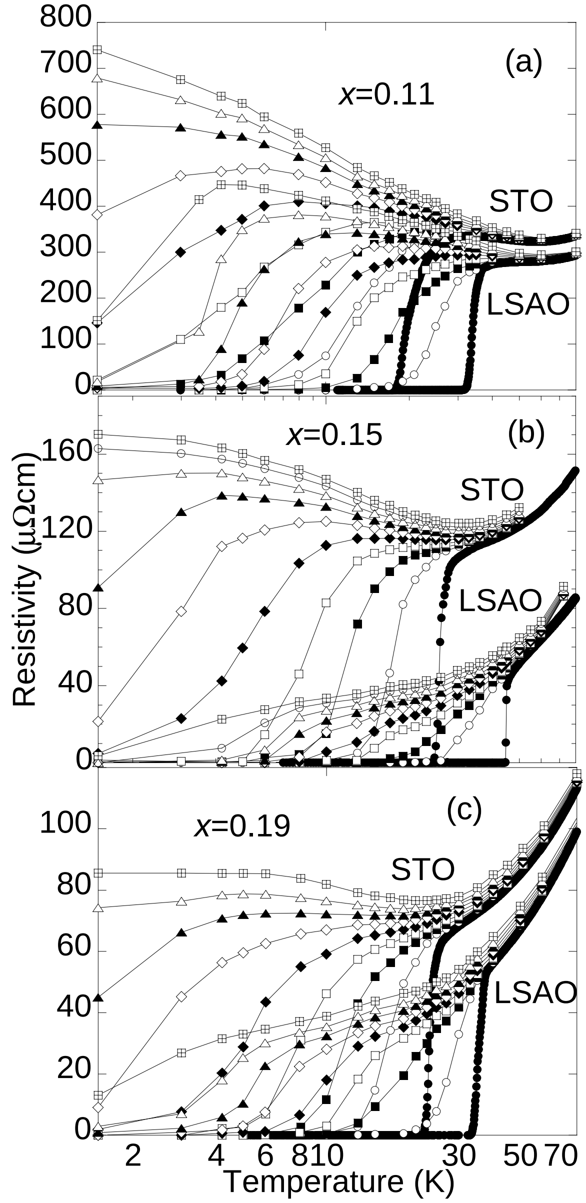

Fig. 1. ρ -vs.- $\log T$ at different magnetic fields from 0 T to 45 T (interval of 5 T) for (a) underdoped, (b) optimumdoped, and (c) overdoped LSCO films grown on LSAO and STO substrates.

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