Freezing of stripes in lightly-doped $La_{2-x}Sr_xCuO_4$ as manifested in magnetic and transport properties of untwinned single crystals

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Abstract

Resistivity and magnetization measurements are used for studying the *transverse* sliding of AF domain boundaries in lightly doped $La_{2-x}Sr_xCuO_4$. We discuss that it is the freezing of the transverse boundary motion that is responsible for the appearance of "spin-glass" features at low temperatures.

Key words: stripes; antiferromagnetic state; high-T_c cuprates

In high-T_c cuprates, charges and spins in the CuO_2 planes tend to self-organize in a peculiar striped manner, where the doped holes form quasi-1D "charged stripes" separating antiferromagnetic (AF) domains [1–5]. Manifestations of the unidirectional AF domain (stripe) structure in lightly doped $La_{2-x}Sr_xCuO_4$ (LSCO) have been found in neutron scattering [1] and in such macroscopic properties as magnetic susceptibility [3] and resistivity [4,5]; in particular, remarkable in-plane resistivity anisotropy [5] has shown that the charge motion is actually facilitated along the stripe direction. Here we report that the resistivity and magnetization can also be used for studying the *transverse* sliding of the AF domain boundaries, and show that the stripe freezing in lightly doped LSCO coincides with the transition into the "spin-glass" state.

The details of LSCO crystal growth and detwinning (the crystals were detwinned to avoid the stripe pinning by crystallographic twin boundaries) along with details of measurements are described in Refs. [3–5].

Owing to the spin canting induced by the Dzyaloshinskii-Moriya interaction, the AF order in LSCO is always accompanied with a weak *ferromagnetic* component [6]. At zero magnetic field, the weak ferromagnetism is hidden: the direction of canted moments depends on the local *phase* of the AF order, and is

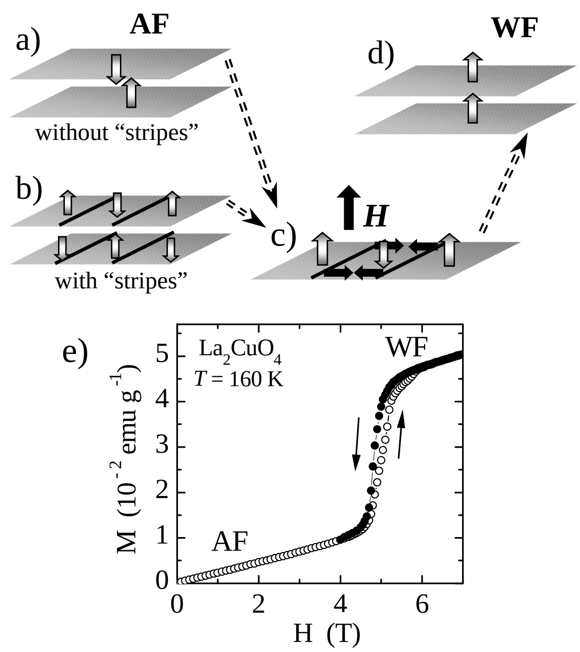

Fig. 1. (a-d) Motion of AF domain boundaries in LSCO upon the weak-ferromagnetic transition; gray arrows indicate the direction of canted moments, which is uniquely linked with the *phase* of the AF order. (e) Magnetization behavior ($H \parallel c$) of La_2CuO_4 illustrating the transition into the WF state.

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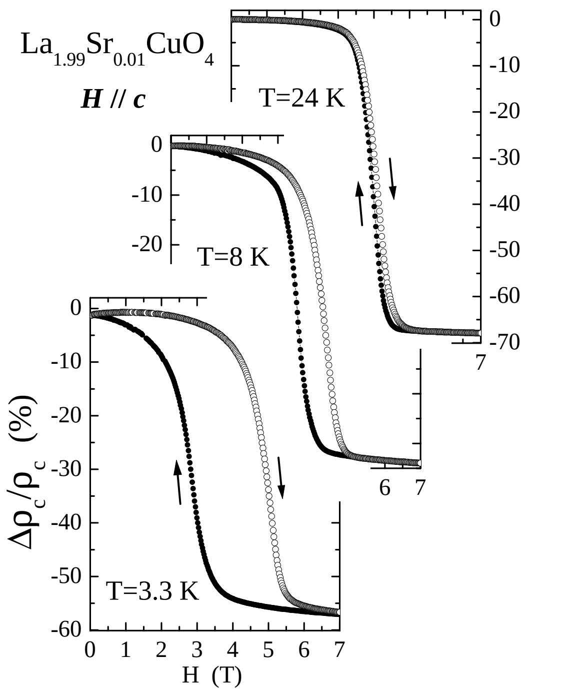

Fig. 2. The c-axis MR measured in a $La_{1.99}Sr_{0.01}CuO_4$ crystal upon increasing (○) and decreasing (●) magnetic field at a rate of 0.4 T/min.

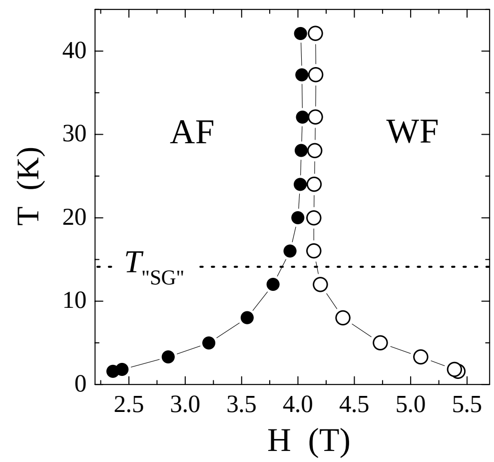

Fig. 3. Magnetic phase diagram of $La_{1.99}Sr_{0.01}CuO_4$ obtained from the MR data in Fig.2. The dashed line indicates the "spin-glass" transition temperature.

opposite in neighboring CuO_2 planes (Fig. 1a). Apparently, if CuO_2 planes themselves contain AF domains with opposite phases, the canted moments form a similar pattern in the in-plane direction, changing their sign upon crossing the antiphase AF-domain boundaries (Fig. 1b). A magnetic field applied along the c-axis couples with the canted moments and eventually causes a transition into the weak-ferromagnetic (WF) state [6], where the phase of the AF order is unified and all the canted moments are aligned along the field direction (Fig. 1d); the corresponding step-like increase in the magnetization is illustrated in Fig. 1e. Whatever the initial magnetic state is – a homogeneous AF order (Fig. 1a) or a striped domain structure (Fig. 1b) – the transition into the WF state should involve the transverse motion of the antiphase domain boundaries as shown in Fig. 1c. This opens an intriguing possibility of studying the kinetics of the transverse domain-boundary (stripe) sliding.

A large change in the resistivity at the WF transition [6] points to the magnetoresistance (MR) as the most convenient probe to watch the transition kinetics. Figure 2 illustrates the MR behavior in a $La_{1.99}Sr_{0.01}CuO_4$ crystal upon increasing and decreasing the magnetic field. While the WF transition is virtually reversible at high temperatures, a significant hysteresis develops upon cooling, as the pinning of the AF domain boundaries gains strength (Fig. 2). Using the transition fields obtained from the MR data, we have sketched the magnetic phase diagram (Fig. 3) which clearly shows that the transition region between the AF and WF states broadens abruptly upon cooling below ≈ 14 K – exactly the temperature where spin-glass features appear in weak-field magnetization data [3]. Apparently, at low temperatures the mobility of the AF domain boundaries becomes inhibited so that the equilibrium state cannot be reached over the experimental time scale.

The following physical picture can be drawn from the obtained results: At high temperatures, the AF domain boundaries are mobile and fluctuating in the transverse direction; however, at low temperatures their pinning quickly gains strength, bringing about the freezing of the AF domain structure, and corresponding memory features in transport and magnetic properties.

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