Evidence for Charge Glasslike Behavior in Lightly Doped $La_{2-x}Sr_xCuO_4$ at Low Temperatures

I. Raičević, J. Jaroszyński, D. Popović (NHMFL); C. Panagopoulos (Cavendish Laboratory, University of Cambridge and Department of Physics, University of Crete and FORTH, Greece); T. Sasagawa (Materials and Structures Laboratory, Tokyo Institute of Technology)

Introduction

In hole-doped cuprates, various experimental techniques have firmly established the existence of charge and other types of heterogeneities, suggesting [1] that glassiness of both spins and charges emerges in the ground state with the first added holes. While spin glass (SG) behavior is well established at low temperatures $T < T_{sg}$, the evidence for glassy freezing of charges or dynamical heterogeneities is not conclusive. We employ a combination of transport and resistance noise spectroscopy, a powerful probe of glassiness, to explore charge dynamics in $La_{1.97}Sr_{0.03}CuO_4$.

Experimental

The *c*-axis resistance *R* was measured on a single crystal of $La_{1.97}Sr_{0.03}CuO_4$ with T_{sg} ~ 7-8 K. A 5-probe bridge technique was used to measure *R* noise in magnetic fields $B \parallel c$ of up to 9 T. Surprisingly, we find several clear signatures of glassiness in transport [2], such as the difference between zero-field cooled and field-cooled $R(B=0)$ at low *T*, and hysteresis and memory in the magnetoresistance (MR) at $T < 1$ K. The MR data suggest the existence of interacting magnetic domains (clusters) with holes confined within the domain walls. However, it is important to establish whether the observed glassiness reflects simply the dynamics of glassy spins or it is a signature of glassy ordering of holes due to Coulomb interactions. The noise data in *B* provide evidence in favor of the latter scenario.

Results and Discussion

The noise, i.e. the time series of the relative changes in resistance $\Delta R(t)/\langle R\rangle$ ($\langle R\rangle$ – the time-averaged *R*), provides evidence for the existence of some switching units as well as other random, slow fluctuations on different time scales [Fig. 1(a)]. The noise power spectra obey $S_R \propto 1/f^{\alpha}$ (*f* – frequency), where α increases from ~1 to ~1.6 as *T* is reduced from 0.3 K to 0.1 K [Fig. 1(c)], but it does not depend on *B*. The noise magnitude, on the other hand, does not depend on either *T* or *B* [Fig. 1(b)]. The analysis of the second spectra, a measure of correlations, also shows a dependence on *T* but not on *B* [2]. Moreover, all the noise characteristics are independent of the magnetic history.

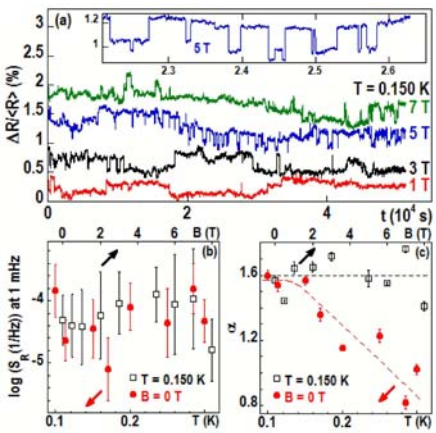

Fig. 1 (a) Relative fluctuations of *R* vs. time at *T*=0.150 K for several $B \parallel c$. All traces are shifted for clarity. Inset: a section of the noise at 5 T. (b) The noise power S_R (f = 1 mHz) and (c) the exponent α vs. *T* (•) and *B* (□).

Conclusions

The noise study indicates that, at low *T*, the system wanders collectively between many metastable states. In contrast to conventional spin glasses, here the noise statistics is insensitive to *B* and to the magnetic history, and the onset of glassiness in both transport and noise occurs at $T \ll T_{sg}$. Therefore, the data strongly suggest [2] that, deep inside the SG phase, the doped holes form a cluster glass state as a result of Coulomb interactions. The experimental technique may be extended to other strongly correlated systems to explore possible dynamical heterogeneities.

Acknowledgements

We thank G. Jelbert for technical help, V. Dobrosavljević and M. B. Weissman for discussions, NSF No. DMR-0403491, NHMFL, The Royal Society, the EURYI scheme, and MEXT-CT-2006-039047 for support.

References

[1] Panagopoulos, C., *et al.*, Phys. Rev. B **72,** 014536 (2005), and references therein.
[2] Raičević, I., *et al.*, Phys. Rev. Lett. **101**, 177004 (2008).