LOW TEMPERATURE VORTEX LIQUID IN SINGLE-LAYERED HIGH T_C CUPRATES

Lu Li, Yayu Wang, Joseph G. Checkelsky, N. P. Ong (Princeton Univ., Physics); S. Komiya, S. Ono, Y. Ando (CRIEPI, Tokyo)

Introduction

High resolution torque magnetometry is a unique method for measuring magnetization in intense field of high T_c cuprates. These measurements uncover diamagnetism above T_c and display unconventional T dependence of H_{c2}. H_{c2} is finite at T_c and remains almost independent of T for $T < T_c$ [1,2,3]. An interesting question is how H_{c2} evolves in the phase diagram, especially as superconductivity disappears as the doping x decreases below the critical doping $x_c = 0.055$. Lightly doped LSCO ($0.03 \leq x \leq 0.09$) single crystals are measured by using torque magnetometry down to pumped He3 temperature 0.35 K. [4]

Experimental

Detailed torque magnetometry measurements are carried out in a 33 T resistive DC magnet (cell 9) with a user provided vacuum sealed He4 probe and in the 31 T 50 mm bore magnet (cell 5) with the He3 insert at the NHMFL.

Results and Discussion

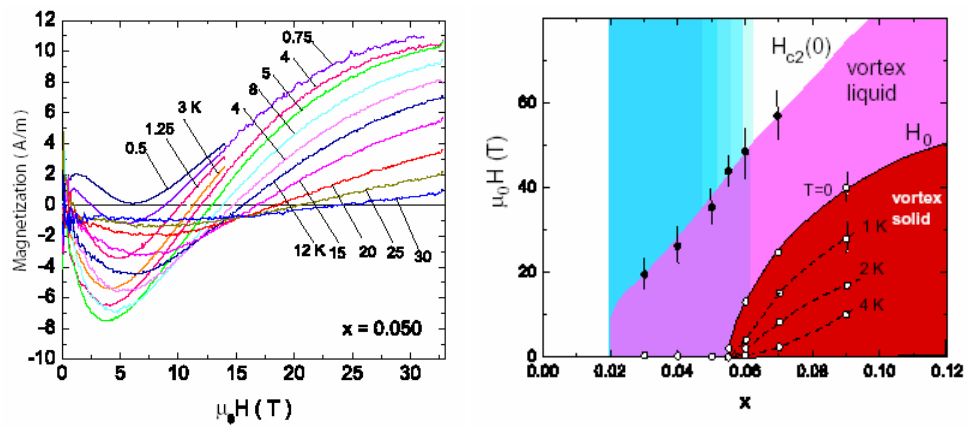

FIG 1: Left panel: Curves of magnetization M vs. field H up to 32 T in the $La_{2-x}Sr_xCuO_4$ (x = 0.050) at select T; Right panel: x-H phase diagram at low temperature showing vortex liquid and vortex solid state [4] .

The left panel above displays typical magnetization curves for the measured lightly doped LSCO. Though not superconducting, magnetization curves show a negative "dip" at low field 0 – 10 T, which suggests diamagnetism arising from the vortex liquid state. At higher fields, magnetization tends to saturate, showing the contribution of paramagnetic anisotropic spins. The net result is an interesting oscillating behavior which occurs at 0.5K and 0.75K. After separating the aforementioned paramagnetic contribution, the diamagnetic signal with characteristic "tilted-hill" feature is restored and we are able to determined H_{c2}. The phase diagram in the right panel shows H_{c2} at the lowest achievable temperature 0.35K for different dopings. H_{c2} extends smoothly across the critical doping $x_c = 0.055$. Blue shading displays the region of spin anisotropy contributing to magnetization. We also measure irreversible MH behavior and detect the field H_{irr} where this hysteresis stops. Since MH hysteresis arises from pinning in the vortex solid state, H_{irr} provides a good probe to study the melting of the vortex solid and additionally approaches the real melting field at the lowest temperatures.

Conclusions

Diamagnetic signals of vortices are observed in lightly doped LSCO, even for doping x below the critical doping $x_c = 0.055$. Doping and temperature dependence are studied with torque magnetometry for two field scales, the upper critical field H_{c2} and the melting field H_{irr}. The results suggest that below x_c, the pair condensate survives as a vortex liquid, though long range phase correlation is absent down to 0.35K.

Acknowledgements

This work is supported by a NSF grant (DMR 0213706). The authors wish to thank Dr. Scott Hannahs, Dr. Alexei Souslov and Dr. Eun Sang Choi for their generous assistance during the experiment.

References

[1] Yayu Wang, Lu Li *et al* , Phys. Rev. Lett., **95,** 247002 (2005).
[2] Lu Li, *et al.*. Europhys. Lett., **72**, 451 (2005).
[3] Yayu Wang, Lu Li, N.P.Ong , Phys. Rev. B., **73**,024510 (2005)
[4] Lu Li, et *al,* to be published.