High Field Studies of Electron-Doped Cuprate Thin Films

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Introduction

The high transition temperatures and critical fields of the hole-doped cuprate superconductors continue to challenge our basic understanding of superconductivity and promise important technological advances. The electron-doped (n-type) counterparts of the hole-doped cuprates have an advantage in that the magnetic field needed to quench superconductivity is much lower, on the order 10 T at optimal doping. This makes it feasible to study the doping dependence of the normal state transport properties across the superconducting dome. The mechanism of the high temperature superconductivity and the normal state strange metal behavior is not understood yet. One theory suggests that these are associated with the quantum fluctuations of a quantum phase transition, i.e. a transition between two phases at T=0, that often manifests itself as a Fermi surface reconstruction. To better understand this, we are studying the resistivity of the electron doped superconductor $La_{2-x}Ce_xCuO_4$ (LCCO) as a function of temperature and field. The aim of this project is to measure the magnetoresistance (MR) at low and high fields to understand its relation to the low temperature T-linear resistivity found earlier (1) in films for doping at the QCP (quantum critical point) and above. The scattering mechanism that causes the T-linear resistivity is unknown and represents a major unsolved problem for cuprate physics.

Experimental

Thin films of LCCO are grown by pulsed laser deposition. .In our low field (14 T) and recent high field magnet experiments, we have measured the MR for doping x=0.12, x=0.13 and x=0.15 at temperatures from 700 mK to 60 K for field up to 31 T. The measurement was performed in pulsed field, cell-4 with He3 and He4.

Results and Discussion

Fig. 1 shows the *ab* plane magnetoresistance (MR) for a doping just below the FSR (x<0.14) [. In Fig. 2, we show ab plane magnetoresistance (MR) at temperatures between 700 mK and 50 K for c-axis dc field up to 65 T for doping x=0.15. In electron doped cuprates the AFM order (long range or short range) vanishes at a critical doping x_c, where the low temperature normal state resistivity upturn also ends (x=0.14 in LCCO). In this study we find that the resistivity minimum is associated with negative transverse magnetoresistance as shown in Fig-1. Most importantly, we find a linear-in-H behavior above Fermi surface reconstruction (FSR) at x=0.14, a distinctly different response than for quasiparticles in conventional metals, where one expects a MR ~H^2 for fields where $w_c t$ <<1. This work supports the finding of low field magnetoresistance study done at UMD-college park. Combining all these work, we find that the magnitude of the linear-in-H resistivity mirrors the magnitude and doping evolution of the linear-in-T resistivity, with both going to zero at the end of the superconducting dome and these results suggest that there is a strong correlation between the quantum critical excitations of the QCP and the high-T_c superconductivity (2). For more details see reference 2.

Conclusions

We have found an unexpected unconventional, linear-in-field magnetoresistance at low temperature in the electron doped cuprate LCCO above the FSR. This behavior is found over an extended doping regime above the purported quantum critical point. Its magnitude scales with Tc, which suggested a link between the cause of this anomalous magnetoresistance and the superconductivity.

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References

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[2] T. Sarkar et al., arXiv:1810.03499 (2018).
[3] T. Sarkar, et al., Phys. Rev. B 96, 155449 (2017).

Figure 1: Magnetoresistivity vs Temperature: (a) and (b) ab-plane resistivity vs magnetic field measured up to 65 T (pulsed field) temperature down to 700 mK.

Figure 2: High field magnetoresistance of x=0.15: resistance vs magnetic field up to 65T for x=0.15 as a function of temperature (color solid line) with a fit (red solid line), R (H)=R(0) + a (μ_0H) at the lowest temperature 600 mK.