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Tuning from Failed Superconductor to Failed Insulator with Magnetic Field

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Introduction

$La_{2-x}Ba_xCuO_4$ with x = 1/8 exhibits a mean-field transition to two-dimensional (2D) superconductivity at 40 K; however, three-dimensional (3D) superconductivity is only established below 5 K [1]. In a sense, it can be viewed as a failed superconductor. This compound is also known to exhibit charge and spin stripe order. An explanation of the 2D superconductivity with depressed 3D superconductivity has been proposed in terms of pair-density-wave superconductivity [2]. This involves strong electron pairing within charge stripes and Josephson coupling between the stripes, with the phase of the superconducting wave function shifting by π from one stripe to the next. A 90° rotation of the stripes from one CuO_2 layer to the next leads to a frustration of the interlayer Josephson coupling.

We set out to see what happens when a large magnetic field is applied perpendicular to the CuO_2 planes, with the expectation that it would suppress the Josephson coupling between stripes.

Experimental

We performed measurements of the in-plane resistivity and the Hall effect at temperatures down to 0.35 K on two similar crystals in the 35-T dc magnet in Tallahassee.

Results and Discussion

Our results are summarized in **Fig. 1**, which shows the in-plane resistivity for one sample (converted to sheet resistance R_s, equal to the resistivity divided by the interlayer separation) as a function of temperature (on a logarithmic scale) and c-axis magnetic field [3]. The units of R_s are the quantum of resistance for pairs, $R_Q = h/(2e)^2$. In zero field, we see R_s go to zero at ~ 16 K due to the onset of 2D superconducting order, which we know, from previous work [1], changes to 3D order below ~ 5 K. At low temperature, the zero-resistance superconducting state survives for fields up to H_{3D} ~ 10 T. At higher fields, we find reentrant 2D superconductivity centered at H_{2D} ~ 20 T, beyond which R_s rises rapidly, shooting through $R_s = R_Q$. One might expect this to indicate a transition to an insulating state, but the sample fails to go insulating. Instead we find evidence for an ultra-quantum metal state in which R_s saturates at ~ $2R_Q$, a very large value, but just half the quantum of resistance for single electrons. This state onsets at H_{UQM}.

The Hall constant below 16 K is consistent with zero, and, within uncertainty, remains at the level up to 35 T.

Conclusions

We conclude that the ultra-quantum metal state at high field is due to electron pairs hopping incoherently between charge stripes, behaving like an exotic Bose metal phase.

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References

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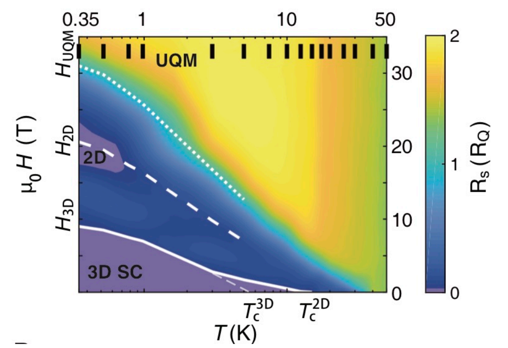

Fig.1 Interpolated color contour plot of the sheet resistance R_s as a function of temperature and magnetic field. Black vertical marks indicate measurement temperatures. The regimes of 3D and 2D superconductivity with zero electrical resistance are labeled; the ultra-quantum metal phase occurs at fields above the dotted line. Characteristic fields H_{3D}, H_{2D}, and H_{UQM}