High pressure, high magnetic field Fermiology studies of YBCO6.50

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Keywords: high pressure, high magnetic fields, Fermi surface measurements.

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The pnictide, cuprate and molecular conductor families exhibit similar phase diagrams, leading to a great deal of interest in a common mechanism for a “universal phase diagram”. The typical ingredients for such phase diagrams include an antiferromagnetic phase, a superconducting dome, and possibly one, or several quantum critical points (QCP). Chemical doping is one traditional way to look at such materials, however thermodynamic variables such as magnetic field or hydrostatic pressure have proven to be powerful tools to explore this phase diagram, with very strong magnetic fields being used to suppress the superconducting dome, allowing one to investigate the QCP.

YBCO’s temperature-oxygen doping phase diagram exhibits a small antiferromagnetic region at lowest doping and charge and spin orders around p=0.1 that compete with or induce superconductivity, as well as a pseudogap region and a QCP under the SC dome [1]. Over this range of doping, the Fermi surface changes from small pockets to arcs and finally a large pocket beyond the superconducting dome. Both the QCP and this change in FS are critical to our understanding of the cuprates and the universal phase diagram. Ramshaw, et al. [2] have found a divergence of the effective mass in the region of the CDW that hints at a QCP around p=0.19. Ideally, strong fields could also be used to suppress Hc2, allowing for the observation of quantum oscillations (QOs) in the region around the QCP, but this would require fields of approximately 150 T, well above the 100 T limit currently available. Instead doping has been used to suppress the dome to about 30 K [3], but doping at this level precludes the observation of QOs.

Our group performed high pressure SdH studies of YBCO6.5 (p=0.1) at He-3 temperatures in pulsed fields to 70 T and 7 GPa at HLD and dc fields of 45 T and pressures of 25 GPa at NHMFL using plastic and metal diamond anvil cells (DACs), respectively, that are coupled with an LC tank circuit based on a tunnel diode oscillator. The small coil that makes up the inductor of this LC circuit and resides in the high pressure volume of the DAC senses changes in sample resistivity due to variations in temperature, pressure or magnetic field.

Our high pressure studies show an enhancement of the superconducting critical field from 24 to 42T between ambient pressure and 6 GPa, which limits the observation of QO to 5 GPa in the 45T Hybrid. Our Fermiology studies clearly show a strongly diverging effective mass at 4.5 GPa along with a local maximum in frequency and superconducting critical temperature, attributed to the effect of various charge orders present in this material. For pressures greater than 15 GPa we are able to measure a critical field of the order of 30T and to measure again QOs. We find that the orbital frequency has increased from 550 T at ambient pressure to 690 T at 15 GP and above. Assuming that the samples are driven by pressure to the overdoped state, those results do not match the reported frequency of 18kT observed for the overdoped analog Tl-2201. This indicates that pressure and doping are not playing an equivalent role on the CDWs and the superconducting state as also pointed in other studies [5][6], and shows that pressure is a new axis in the YBCO phase diagram which can help understand the interplay between CDWs and superconductivity in this material.

Acknowledgments: *The National High Magnetic Field Laboratory is supported by National Science Foundation through NSF/DMR-1157490* and *DMR-1644779 and the State of Florida. We acknowledge the support of the HLD-member of the European Magnetic Field Laboratory (EMFL).*

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