Resonant Ultrasound Spectroscopy (RUS) Measurements on Ultra-high Quality YBCO Single Crystal Cuprates

Arkady Shekhter, Brad Ramshaw, Jon B. Betts, Albert Migliori (LANL, NHMFL); Ruixing Liang, Walter Hardy, Doug Bonn (Physics, UBC, Canada)

Introduction

Recent polarized neutron diffraction measurements in underdoped cuprates of several families (YBCO,Hg1201,LSCO) reveal that the pseudogap phase, originally identified by anomalies in the Fermi surface structure and transport properties, is characterized by a distinct magnetic order. Resonant ultrasound spectroscopy is a natural tool to map and characterize the (doping-temperature-magnetic field) phase diagram in cuprates. One of the experimental challenges (specific to RUS probes) is the small size (sub-milligram range) of ultrahigh quality single crystal samples available today.

Experimental

At this stage the work has been a focused on a development of the RUS probe that works with crystals of very small size. There are several design goals, (i) achieving the free mechanical resonator conditions for these crystals, (ii) reducing the ultrasonic power to achieve linear elastic response, (iii) collect larger data set to increase accuracy of the determination of resonance frequency and width (iv) speeding up the measurement without compromising the quality of the data to achieve finer temperature steps in the obtained temperature evolution of elastic properties of the crystal. These goals has been met with the probe design that uses balsa wood as mechanical isolation effective in the broad temperature range and precision made pivot system to reduce load on a crystal during the measurement. Furthermore, to address goals (ii -- iv) the software side of the measurement apparatus has been rethought from ground up. In particular, (i) the peak analysis software now uses full (in-phase and quadrature) information to determine resonance frequency and width and is much more robust against the noise. This yields high quality data in a low power scans. Furthermore the frequency scans over a large number of resonances has been sped up by about a factor of hundred without compromising the ring-up time by implementing a nonuniform in frequency scan across a set of peaks that adaptively follow the resonances as they move with temperature.

Results and Discussion

These measurements provide the first observation of the jump in the elastic moduli across the superconducting transition in cuprates. Such jump is required by thermodynamics of conventional superconductors. The resonance frequency has a sharp break in slope its temperature dependence across the pseudogap phase boundary -- a standard thermodynamic signature for a phase transition. The width of the resonance (attenuation) reveals a complex dynamics associated with the physics of the pseudogap.
These measurements provide an evidence for a phase transition at the pseudogap phase boundary. Furthermore, observation of the psudogap transition below superconducting temperature in overdoped YBCO suggests that the pseudogap phase boundary has a termination point at zero temperature inside the superconducting dome.

Conclusions

The sophisticated resonance probe of elastic properties of the material has been demonstarted as a new and essential tool in studying the fascinating physical phenomena in modern condensed matter systems.

References

Shekhter *et al.*, “Ultrasonic signatures at the superconducting and pseudogap phase boundaries in YBCO cuprates”, submitted to journal.