SQUID based AC Susceptibility of $RuSr_2GdCu_2O_8$ under 10 kbar of Pressure

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Introduction

Three independent transitions occur on each sub-lattice: weakly ferro-magnetic order on ruthenate chain site, superconductivity in the cuprate plane site and antiferromagnetic order on gadolinium plane spacer site.

External pressure can decrease the unit cell parameters and significantly alter the sample characteristics. These magnetic transition are well suited for analysis using AC Susceptibility and in particular the frequency dependence. The metallic casing of the pressure cell precludes sensitive measurements above 10 Hertz drive frequency. Only SQUID based AC can achieve the low frequencies required.

This specific Mcell by easyLab is on the seventh pressure campaign and prepared by filling the Teflon container with transmitting fluid, inserting tin wire as the internal pressure standard, then assembling as directed. The second analysis uses a small piece of the epoxy plus Dy_2O_3 standard sample provided by Quantum Design. The third analysis inserts a 21.4 milligram bar shaped sample of $RuSr_2GdCu_2O_8$.

Single-phase sintered bulk compound is prepared using the Sr_2GdRuO_6 precursor and CuO phases with a final annealing at 1060 C in oxygen. The tetragonal lattice parameters are a=3.838 Å and c/3 = 3.844 Å.

For analysis of the $RuSr_2GdCu_2O_8$ sample, the pressure is applied up to the maximum rating of 10.6 kbar. The value is determined from the superconducting transition of tin using **ZERO** DC field and low frequency AC. Pressure is stable over 10 thermal cycles and weeks of measurements.

VSM M(H) loop for blank cell

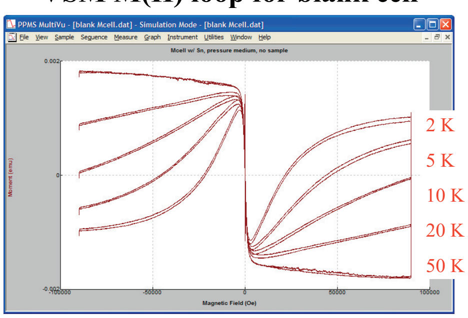


Figure 1. The cell is assembled without a sample and pressurized. The magnetization versus field up to 9 Tesla at various temperatures are collected using a PPMS with the VSM, large bore coil-set option. Use 1 hour wait for thermal equilibrium. At 50 K, the response appears to be an inverted ferromagnetic signal which saturates with field around 0.5 Tesla. At the colder temperatures, a paramagnetic contribution increases in magnitude of moment and exhibits a saturating field. At the higher temperatures, a more subtle influence from synchronous noise is expected as the long, now more flexible carbon fiber rod reacts to large weight that hangs from the end.

MPMS® Family of SQUID based magnetometers

Dy_2O_3 Paramagnetic Standard

AC Response Amplitude

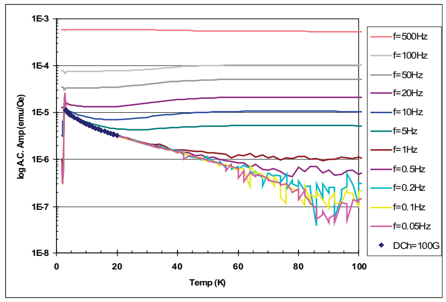


Figure 2. The cell is loaded with paramagnetic Dy_2O_3 sample and minimal pressure is applied. In 100 Oersted of DC bias field, temperature is stabilized on warming. The DC magnetization and full range AC Susceptibility measurements are made. The graph plots the unaltered logarithmic AC response amplitude versus temperature for a range of AC drive frequencies. Essentially the noise floor of this cell at each frequency is shown. The drop in amplitude below 3 K results from the equal signals of the in-phase paramagnet and out-of-phase tin.

Dy_2O_3 Paramagnetic Standard

AC Response Phase

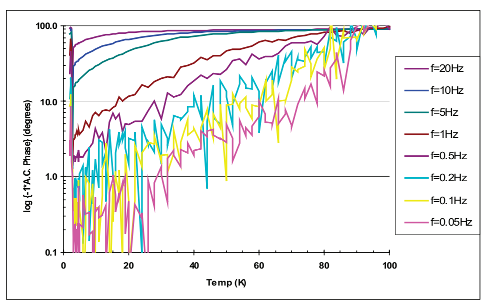
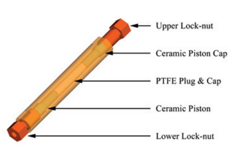


Figure 3. All reported phase values in this experiment are "negative" if not essentially zero. For comparison, the graph plots the log of the negative (-1) value of the phase versus temperature for various AC drive frequency. At a low (0.1 Hz) frequency, the phase specification of the option is obtained for amplitudes larger than $3x10^{-6}$ emu. At the lower signals or greater frequencies, the phase value is essentially 90 degrees.



easyLab
science under pressure

M2S-HTSC VIII

Dresden, Germany July 2006

→ Increase Bulk Transitions T_S and T_M

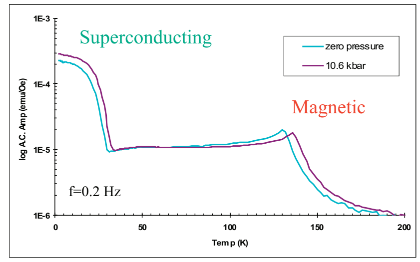


Figure 4 shows logarithmic scale for the AC response amplitude versus temperature for the $RuSr_2GdCu_2O_8$ sample. Using a 1.0 Oe AC drive amplitude, only the 0.2 Hertz frequency data is presented. There is clearly an increase in T_S and T_M transition temperatures with applied pressure. The ruthenium lattice magnetic ordering temperature increases from 135 K to 140 K. The onset of the copper oxide superconducting bulk transition increases from 30 K to 33 K.

Grain Superconducting Transition

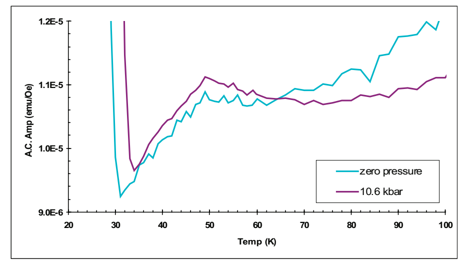


Figure 5. The AC response amplitude shows the onset of granular superconductivity at 51 K. Above the critical temperature, Curie-Weiss behavior for the paramagnetic Gd^{3+} ion is observed until the region of the Ru ordering is approached.

$RuSr_2GdCu_2O_8$ @ 10 kbar

Frequency Dependence of Real (χ') and Imaginary (χ'')

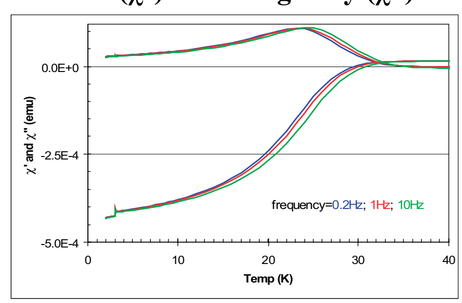


Figure 6. The real (χ') and imaginary (χ'') susceptibility using 1.0 Oe AC drive amplitude in zero DC field. The peak for the χ'' component increases from 23 K to 25 K. Because of these large signals, the 10 Hz data require significant adjustments to the phase only above 30 K.

Conclusions

Changes in transition temperatures with pressure demonstrates the ability to modify the structure.

Suggest running DC/AC measurements on paramagnets in 0.5 Tesla DC field which shows minimal slope in VSM M(H) and easily suppress the tin transition to below 1.7 Kelvin.

Low frequency AC is especially sensitive to vibrations with larger DC fields present. Isolate the system from environmental noise, only 1 measurement to average per sequence command.

The AC response amplitude is lowered with presence of 2 matched signals of opposing phase.

In $RuSr_2GdCu_2O_8$ between 30 K and 50 K, the granular superconductor matches the Gd^{3+} ion.

In Dy_2O_3 below 3 Kelvin, the paramagnetic signal is balanced with the smallest tin wire sample.

In Dy_2O_3 above 80 K for 0.05 Hz, the balance is with the out-of-phase background of the Mcell.

Future research involves the raw data from the response function of scaled SQUID voltage versus phase after 2-point measurement. The predictable contribution of components allows point by point correction. Fitting the new array will yield more accurate details of the transitions.

All data was collected on MPMS XL-5AC SQUID based magnetometer or PPMS 9T-ULF.

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