

SQUID based DC Magnetometry and AC Susceptibility of $\text{RuSr}_2\text{GdCu}_2\text{O}_8$ 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.

The magnetic coupling of the Ru sub-lattice should be influenced by changes in the a-axis lattice parameter.

For superconductivity, the ratio of the c-axis to a-axis, in particular the exact positioning of the apical oxygen, which determines the hole content on the copper oxide planes.

The lattice parameters of grain boundaries should decrease to closer to bulk value, resulting in sharper transitions.

Single-phase sintered bulk compound is prepared using the $\text{Sr}_2\text{GdRuO}_6$ 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.

The pressure cell is prepared by inserting tin wire as the internal pressure standard. The transmitting fluid fills the cylindrical Teflon container, then the 21.4 milligram bar shaped sample is inserted and the cap is put into place.

The ambient pressure (orange data) magnetometer analysis is performed before and after pressurization (purple data). Pressure is applied up to the maximum rating of 10.6 kbar.

The pressure remains stable over 10 thermal cycles and weeks of measurements.

Tin internal pressure standard

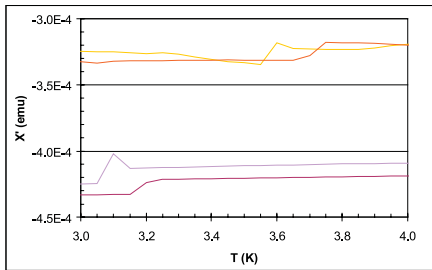
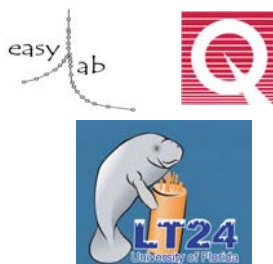
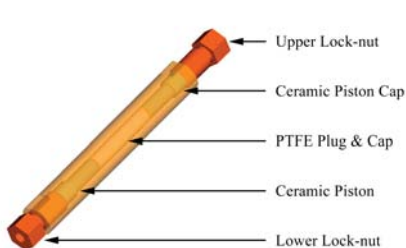


Figure 1. The lowest temperature transitions observed are the tin internal pressure reference standard. The AC susceptibility experiment uses a frequency of 0.2 Hz and a drive amplitude of 1 Oe.

In a bias field of 10 Oe, the critical transition temperature decreases from 3.66 K to 3.14 K under pressure. This change in T_c of tin corresponds to a pressure of 10.6 kBar. With zero DC biased field, significantly higher values of the tin transition temperatures are obtained. The difference still confirms the pressure of 10.6 kBar. Interestingly, in the 10 Oe bias field, a peak in the X'' (data not shown) is observed, but not in zero field data. The source is a broader transition even in small DC fields.



DC Magnetization

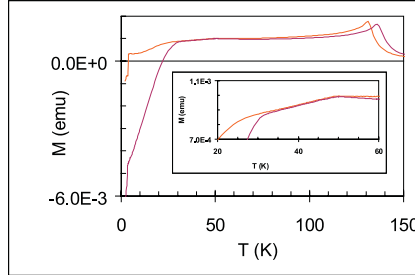


Figure 3. The sample is zero field ($H < 0.01$ Oe) cooled to 2 K, then a field of 10 Oe is applied and the magnetization versus temperature is obtained. With increasing pressure, there is an increase in the bulk superconducting volume fraction and extends up to the intra-granular T_c near 50 K. High T_c ceramics are known for the sensitivity of grain boundary junctions and pressure clearly enhances the inter-granular contact, improving the shielding currents for the ZFC state.

DC only versus DC + AC

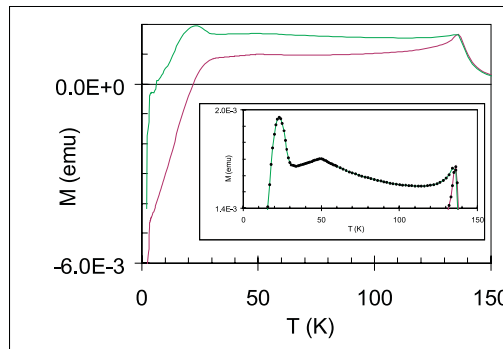


Figure 6. After zero field ($H < 0.01$ Oe) cooled to 2 K, a field of 10 Oe is applied and the magnetization versus temperature is obtained. The purple data is identical to figure 3. The green data is for simultaneous accumulation of AC susceptibility data. The peak in DC magnetization below the bulk T_c is common for this analysis technique as the AC drive forces flux dynamics to occur. The combination of DC and AC measurements essentially mimics subjecting the sample to an inhomogeneous field (10% of the applied field) during measurement transport.

AC Susceptibility

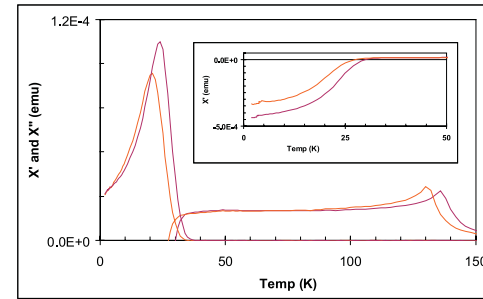


Figure 2 shows both the real (X') and imaginary (X'') AC response for 0.2 Hz and 1.0 Oe AC drive amplitude. There is an increase in peak temperature for the X'' component from 21 K to 24 K, higher superconducting bulk transition temperature and magnetic ordering defined as a peak in X' increased from 130 K to 136 K under increasing pressure.

Inverse Magnetization for T_c

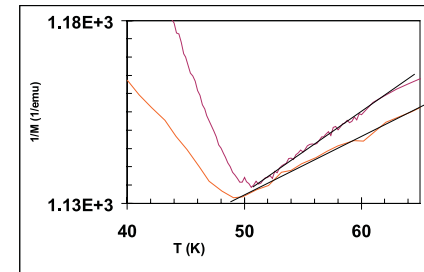


Figure 4. The inverse magnetization versus temperature determines the onset of bulk superconductivity. Above the critical temperature, Curie-Weiss behavior for the paramagnetic Gd^{3+} ion is expected to dominate until the region of the Ru ordering is approached.

Magnetization squared for T_M

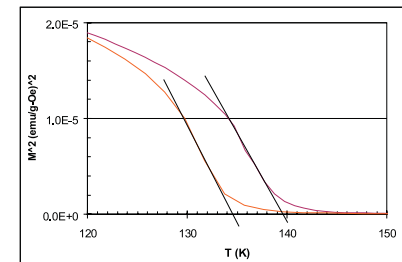


Figure 5. The weakly ferro-magnetic ordering temperature of the Ru lattice is determined from the moment squared versus temperature. The slope is extrapolated to zero and shifts from 133 K to 139 K with increase in pressure.

Conclusions

The tin complicates the search for the anti-ferromagnetic transition of the Gd ions around 3 K. An increase in the magnetic ordering temperature of the ruthenium lattice with higher pressure likely corresponds to a substantial decrease in the a-axis lattice parameter.

The increase for onset of superconductivity suggests decreases in both the c-axis and a-axis result in net holes being created and transferred to the plane as pressure is applied.

The increase in bulk superconducting properties with increasing pressure is a more mechanical solution to the issue of short coherence length, poor granular contact in ceramic materials.

Future research suggests finding the synthesis conditions for the smaller rare earth element substitution for Gd, like Dy or Er to increase the magnetic ordering temperature and possibly the superconducting temperature as well.

All data was collected on MPMS XL-5AC SQUID based magnetometer at Quantum Design.

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