Pressure Study of Pure and Rh-doped RuSr$_2$GdCu$_2$O$_8$
Magnetic Superconductors

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Abstract. We carried out an investigation of the effect of quasi-hydrostatic pressures up to 1.2 GPa in pure and Rh-doped RuSr$_2$GdCu$_2$O$_8$ compounds, by means of measurements of electrical resistivity in magnetic fields up to 9 T. The onset temperatures for superconductivity, and for magnetic order in the undoped RuSr$_2$GdCu$_2$O$_8$ compound are $T_c \approx 50$ K, and $T_m \approx 133$ K, respectively. The partial substitution of Rh for Ru lowers both these transitions temperatures. However, the effect of pressure for all compositions studied, up to 10% substitution, was to increase both $T_c$ and $T_m$. The effect of pressure on the upper critical magnetic field of the pure, and Rh-doped compounds is discussed.

Keywords: pressure; magnetic superconductors; critical field.

PACS: 74.25.Ha; 74.25.Op; 74.62.-c; 74.62.Fj.

INTRODUCTION

The coexistence of superconductivity (SC) with weak ferromagnetism (FM) in the rutheno-cuprates with general composition RuSr$_2$LnCu$_2$O$_8$ ($Ln = Eu$, Sm, and Gd) is quite remarkable.[1] For example, SC with onset at $T_c \approx 50$ K coexists with magnetic order ($T_m \approx 133$ K) in RuSr$_2$GdCu$_2$O$_8$, and the onset of SC doesn't affect the ordered state noticeably.[2]

The resistivity ($\rho$) transition to the SC state spans a quite broad T-range of 15 K or higher in these materials. These broad transitions have been attributed to cation disorder, self-induced vortices,[3] and granularity.[4] Lorentz et al. extracted the onset of the intra- and inter-granular SC, as well as of FM from the $d\rho/dT$ data, and they determined that $T_{c,\text{inter}}$, $T_{c,\text{intra}}$, and $T_m$ all increased with pressure (P) up to about 2 GPa.[4]

In order to probe the SC, magnetic, and granular behavior of these materials, we studied the effect of pressure and magnetic field (H) in pure and Rh-doped RuSr$_2$GdCu$_2$O$_8$. The polycrystalline specimens for this study were synthesized by reacting CuO with Sr$_2$(Ru,Rh)GdO$_6$ precursors.[5] These measurements were performed in a Quantum Design 9-T measurement station (PPMS-9), using a 1.5 GPa self-clamping quasi-hydrostatic cell from EasyLab.

RESULTS AND DISCUSSION

The partial substitution of Rh for Ru up to about 25% can be accomplished while retaining phase purity. The substitution of Rh reduces $T_c$ and $T_m$, while driving the SC behavior towards granularity. As shown in Fig. 1a, the SC transition evolves from a linear drop in $\rho$ vs $T$ for the pure compound to a 2-step drop in the 10% Rh-substituted material. The first and second drops represent the onset of intra- and inter-granular SC, respectively. The effect of the high pressure in the Rh-doped material is to raise the values of $T_{c,\text{inter}}$, $T_{c,\text{intra}}$, and $T_m$ all increased with pressure (P) up to about 2 GPa.[4]

In order to determine the effect of the magnetic field on the SC state of the pressurized materials, we carried out measurements of magnetoresistivity in fields up to 9 T. The values of $\rho/\rho_{300K}$ (T) for the unpressured, and pressured materials (with $P_{\text{max}} = 1.1$
GPa, and 1.2 GPa, respectively) are shown in Fig. 2. Since the behavior of \( \rho(T,H) \) does not depend strongly on \( P \), only the isofield data for the samples pressurized with \( P_{\text{max}} \) are shown in Fig. 2. The magnetic field induces noticeable changes in the shape of \( \rho(T) \). As the \( H \) increases, the SC transition becomes much broader near the onset of SC, and it sharpens up again near the zero-resistance state.

In light of the broad and step-like transitions to the SC state, it is not trivial to determine the upper critical field \( H_c^2 \) vs \( T \) phase diagram. However, assuming the same \( T \) onset for SC in all fields, and taking the midpoint of the SC transitions as \( T_c \), the upper limit for \( H_c^2(T) \) can be determined, as shown in Fig.3.[6] The magnitude of \( dH_c^2/dT \) increases with \( H \), reflecting the narrowing of the SC transition in higher fields. The positive curvature of \( H_c^2(T) \) is reminiscent of other high-\( T_c \) cuprates. The extrapolated value of \( H_c^2(T=0) \) can be estimated by using the WHH expression \( H_c^2(0) = -0.7(dH_c^2/dT)T_c \). Assuming that for the pure material at ambient \( P \) \( T_c = 44.3 \) K, and using the \( dH_c^2/dT = -0.75 \) T/K value extracted from the high \( H \) portion of Fig. 3, the yielded value for \( H_c^2(0) \) is \( \approx 23.3 \) T. This value clearly increases with pressure.

In summary, our magnetoresistance measurements in \( \text{Ru}_{1-x}\text{Rh}_x\text{Sr}_2\text{GdCu}_2\text{O}_8 \) under pressure show that 1) \( T_{\text{c,inter}}, T_{\text{c,intras}} \) and \( T_m \) all increase with \( P \); and 2) the \( H_c^2(T) \) curves are shifted to higher \( T \) with \( P \).

**ACKNOWLEDGMENTS**

The support from NSF Grant No. DMR-0306165 (MST, MS, LH, and DB), Fapesp-Brazil Grant No. 99/10798-0 (RFJ), and CNPq-Brazil Grant No. 303272/04-0 (RFJ) are gratefully acknowledged.

**REFERENCES**