Pressure Study of Pure and Rh-doped $RuSr_2GdCu_2O_8$ 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 $RuSr_2GdCu_2O_8$ 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 $RuSr_2GdCu_2O_8$ 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.
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INTRODUCTION

The coexistence of superconductivity (SC) with weak ferromagnetism (FM) in the rutheno-cuprates with general composition $RuSr_2LnCu_2O_8$ (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 $RuSr_2GdCu_2O_8$, and the onset of SC doesn't affect the ordered state noticeably.[2]

The resistivity (ρ) 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 $T_{c,inter}$, $T_{c,intra}$, 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 $RuSr_2GdCu_2O_8$. 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 ρ 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 $T_{c,inter}$, and $T_{c,intra}$, as shown in Fig. 1b. The value of T_m = 123.7K is also raised with pressure at the rate of about 6.1 K/GPa (data not shown). The ρ vs T curves for the best undoped materials did not show noticeable anomalies at T_m, or $T_{c,inter}$, and a reliable determination of their values could not be made from these curves.

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 ρ/ρ_{300K} (T) for the unpressured, and pressured materials (with P_{max} = 1.1

GPa, and 1.2 GPa, respectively) are shown in Fig. 2. Since the behavior of ρ(T,H) does not depend strongly on P, only the isofield data for the samples pressurized with P_{max} are shown in Fig. 2. The magnetic field induces noticeable changes in the shape of ρ(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.

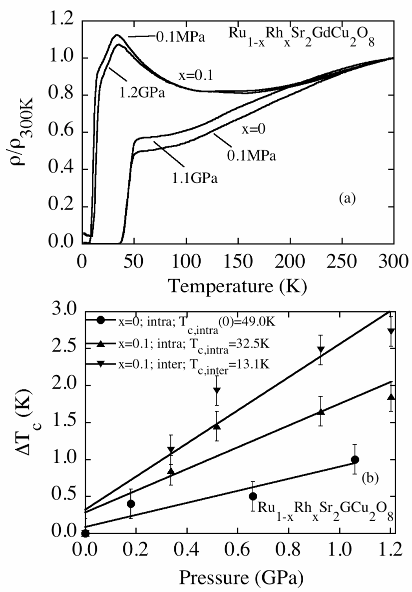

FIGURE 1. (a) Normalized electrical resistance ρ/ρ_{300K} versus T, in pure and Rh-doped $RuSr_2GdCu_2O_8$, in ambient P, and P_{max}; (b) pressure dependence of $T_{c,inter}$, $T_{c,intra}$, and T_m. The solid lines in (b) are guides to the eye.

In light of the broad and step-like transitions to the SC state, it is not trivial to determine the upper critical field H_{c2} 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 $H_{c2}(T)$ can be determined, as shown in Fig.3.[6] The magnitude of dH_{c2}/dT increases with H, reflecting the narrowing of the SC transition in higher fields. The positive curvature of $H_{c2}(T)$ is reminiscent of other high-T_c cuprates. The extrapolated value of $H_{c2}(T=0)$ can be estimated by using the WHH expression $H_{c2}(0) = -0.7(dH_{c2}/dT)T_c$. Assuming that for the pure material at ambient P $T_c = 44.3$ K, and using the $dH_{c2}/dT = -0.75$ T/K value extracted from the high H portion of Fig. 3, the yielded value for $H_{c2}(0)$ is ≈ 23.3 T. This value clearly increases with pressure.

In summary, our magnetoresistance measurements in $Ru_{1-x}Rh_xSr_2GdCu_2O_8$ under pressure show that 1) $T_{c,inter}$, $T_{c,intra}$, and T_m all increase with P; and 2) the $H_{c2}(T)$ curves are shifted to higher T with P.

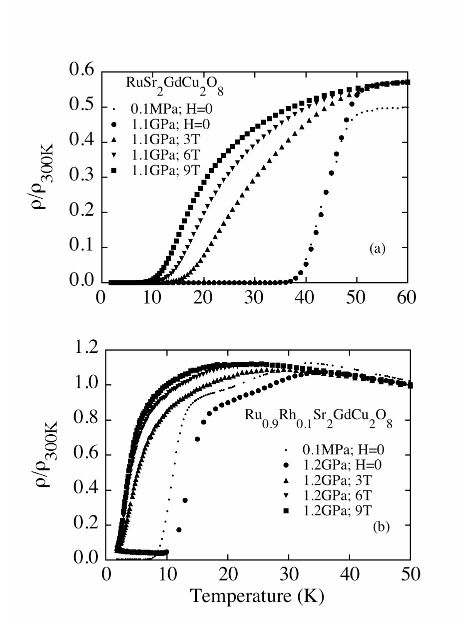

FIGURE 2. Normalized electrical resistance ρ/ρ_{300K} versus T, in (a) $RuSr_2GdCu_2O_8$; and (b) $Ru_{0.9}Rh_{0.1}Sr_2GdCu_2O_8$; for H = 0, 3, 6, and 9 T, at P_{max} = 1.1, and 1.2 GPa, respectively. ρ/ρ_{300K} (T, H=0, P=1atm) curves are shown for reference.

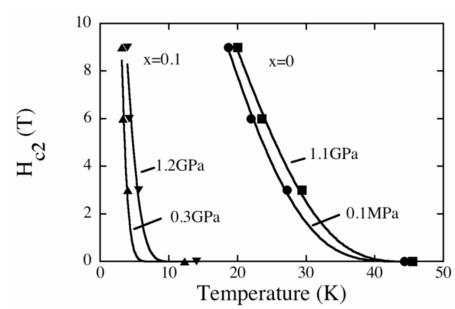

FIGURE 3. Curves of H_{c2} vs T for $Ru_{1-x}Rh_xSr_2GdCu_2O_8$. The solid lines correspond to fits to the phenomenological expression $H_{c2}(T) = H_{c2}(0)[1-(T/T_c)^2]^{\alpha}$.

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