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Physica B 359–361 (2005) 398–400
PHYSICA B
www.elsevier.com/locate/physb

Studies of electrical resistivity under pressure on superconducting Sn-doped $CeCoIn_5$

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Abstract

Experiments of electrical resistivity as a function of hydrostatic pressure for single crystals of Sn-doped $CeCoIn_5$ are reported. Due to the subtle Sn-doping, T_c is strongly suppressed from $T_c = 2.3\,K$ of undoped $CeCoIn_5$ to $T_c \sim 0.7\,K$ for the reported concentration ($x \sim 0.12$). As for pure $CeCoIn_5$, superconductivity (SC) seems to evolve out of a non-Fermi liquid (NFL) normal state just above T_c. A temperature–pressure phase diagram is constructed from our results and compared with the properties of pure $CeCoIn_5$ under pressure. Effects of chemical pressure and/or hybridization tuning associated with Sn-doping are discussed.

PACS: 75.30.Mb; 74.20.Mn; 75.20.En

Keywords: Heavy fermion superconductivity; Quantum critical point; Phase diagrams

The system $CeCoIn_5$ is a recently discovered heavy fermion superconductor [1] which has the highest $T_c = 2.3\,K$ for this class of materials. The $CeCoIn_5$ superconducting state emerges from an NFL normal state characterized by a $C/T = -\ln T$ divergent specific heat coefficient and a power-law T-dependence of the electrical resistivity ($\rho \sim T^n$ with $n \sim 1$). This intriguing NFL state can be achieved, for instance, by tuning the magnetic field slightly above the upper critical H_{c2}. The observed scaling properties of the specific heat as function of temperature for $H > H_{c2}$ lead to the conclusion that this NFL behavior is due to

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[1]Work supported by CNPq, FAPERJ, FAPESP and US-DOE.

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doi:10.1016/j.physb.2005.01.076

an incipient antiferromagnetic (AF) order in $CeCoIn_5$ [2]. When hydrostatic pressure is applied to $CeCoIn_5$, T_c initially increases and reaches a maximum $T_c = 2.6$ K at $P^* \approx 16$ kbar, where a crossover in the transport properties is also observed [3]. The temperature–pressure (TP) phase diagram constructed from these data also suggests that $CeCoIn_5$ is close to an AF quantum critical point (QCP) located at slightly negative pressures [3]. Based on the above, experimentally tuning this compound towards its AF QCP have become a topic of great interest. In this work we report electrical resistivity as a function of hydrostatic pressure for single crystals of Sn-doped $CeCoIn_5$. Because Sn is larger than In, the In–Sn substitution is expected to expand the lattice and act as negative pressure. We have found that the Sn-doping strongly suppressed T_c from $T_c = 2.3$ K of undoped $CeCoIn_5$ to $T_c \sim 0.7$ K for the reported concentration. In contrast to pure $CeCoIn_5$, T_c decreases with applied pressure and extrapolates to zero at the critical pressure $P_c \approx 8$ kbar. The temperature where the resistivity reaches its maximum $T_m \approx 50$ K at ambient pressure increases as a function of pressure at a rate of ~ 3.5 K/kbar for $CeCoIn_{5-x}Sn_x$ ($x \approx 0.12$). A TP phase diagram is constructed from our results and compared with the properties of pure $CeCoIn_5$ under pressure.

Fig. 1 presents low-T $R(T)$ for various applied pressures and the specific heat divided by temperature for $CeCoIn_{5-x}Sn_x$ ($x \approx 0.12$) while a TP phase diagram constructed from our data is shown in Fig. 2.

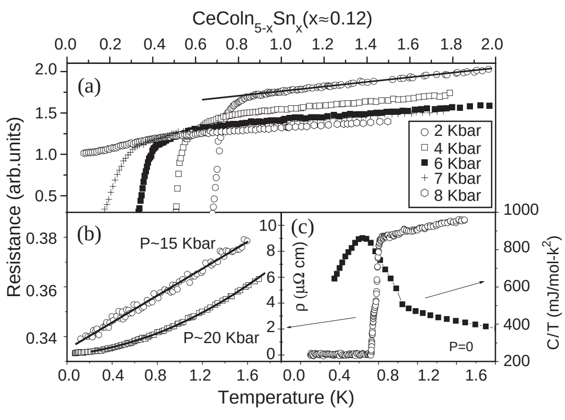

Fig. 1. (a) $R(T)$ for several applied pressures, (b) $R \propto T$ and $R \propto T^2$ behaviors shown in detail and (c) ambient pressure properties for $CeCoIn_{5-x}Sn_x$ ($x \approx 0.12$).

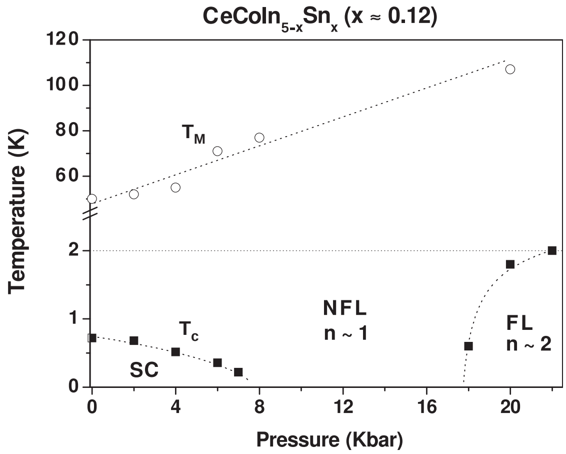

Fig. 2. A TP phase diagram for $CeCoIn_{5-x}Sn_x$ ($x \approx 0.12$).

Again, when pressure is applied to pure $CeCoIn_5$, T_c shifts to higher T until reaching a maximum for $P \approx 16$ kbar and then starts to decrease at a rate of ~ 0.1 K/kbar [3]. Based solely on this result it is expected that subtle negative chemical pressure would reduce T_c of $CeCoIn_5$ towards the AF QCP.

In fact, we have found that Sn-doping decreases T_c but the observed suppression of the SC is much more dramatic than expected by the measured initial slope $dT_c/dP \approx 0.03$ K/kbar of $CeCoIn_5$ [3]. According to this slope, a shift of $\sim$1.6 K would require a negative pressure $P \approx 50$ kbar, which is unlikely to be present in the studied crystals since no appreciable changes in the lattice of parameters were observed for these crystals. Another effect associated with the In–Sn that could produce pair breaking is disorder. In this regard, we have found no evidence for *gross* disorder in the our X-ray diffraction or $\rho(T)$ data although we have observed some crystal-to-crystal Sn-content variation.

Regarding the pressure dependence of T_c, in contrast to what was found for $CeCoIn_5$, for $CeCoIn_{5-x}Sn_x$ ($x \approx 0.12$) T_c is immediately reduced by pressure at a rate of ~ 0.1 K/kbar and SC is completely suppressed at $P_c \approx 8$ kbar. Naively, this result suggests that the Sn-doping can be acting as positive pressure, and the studied crystals are placed at the high-pressure part of pure $CeCoIn_5$ phase diagram [3]. As mentioned above, the Sn-doping introduces no measurable volume changes for the studied crystals. However, as pressure usually increases the 4f electrons hybridization strength with the conduction electrons, if Sn-doping causes the same, it could mimic positive pressure. On the other hand, the enhancement of hybridization should also lead to Fermi liquid behavior such as observed for pure $CeCoIn_5$ (see Fig. 2 and Ref. [3]).

Therefore, if the studied samples were simply located in the high pressure part of the $CeCoIn_5$ phase diagram where T_c decreases as a function of pressure, a FL behavior ($\rho \sim T^n$ with $n = 2$) should have been observed in our data in the normal state for small values of pressures. In contrast, we have found NFL behavior up to ≈ 18 kbar where a FL behavior starts to appear such as for $CeCoIn_5$ (see Fig. 2). Based on this, we speculate that for the studied crystals the Sn-doping produces no effective chemical pressure. However it introduces a subtle level of local disorder in the $CeIn_3$ blocks producing pair breaking and this effect can be somehow enhanced by applied pressure. As a result, SC is rapidly suppressed with Sn-doping and pressure exposing a wider pressure range of NFL behavior until the FL is achieved for higher pressures.

In conclusion, we have found that a subtle Sn-doping strongly suppressed T_c from $T_c = 2.3$ K of undoped $CeCoIn_5$ to $T_c \sim 0.7$ K for $CeCoIn_{5-x}Sn_x$ ($x \approx 0.12$). Under pressure T_c decreases and extrapolates to zero at $P_c \approx 8$ kbar. As for pure $CeCoIn_5$, the $\rho(T)$ in the normal state display NFL behavior up to ≈ 18 kbar. Further experiments on Sn-doping $CeCoIn_5$ for different Sn concentration are in progress to understand in detail the reported qualitative phase diagram. At the moment, our results indicate that the Sn-doping may not be the best choice for a control parameter to tune $CeCoIn_5$ to AF order.

References

[1] C. Petrovic, et al., J. Phys.: Condens. Matter 13 (2001) L337.
[2] A. Bianchi, et al., Phys. Rev. Lett. 91 (25) (2003) 257001; J.P. Paglione, et al., Phys. Rev. Lett. 91 (2003) 246405.
[3] V.A. Sidorov, et al., Phys. Rev. Lett. 89 (2002) 157004.