Pressure effect on superconductivity in CeCoIn$_{5-x}$Sn$_x$ studied by thermal expansion

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Abstract

We present low-temperature thermal expansion measurements on the Sn-substituted heavy fermion superconductor CeCoIn$_{5-x}$Sn$_x$ for $0 \leq x \leq 0.12$ in which $T_c$ is rapidly suppressed from 2.3 ($x = 0$) to 0.7 K ($x = 0.12$). The analysis of the superconducting transition anomalies reveals a drastic change of the uniaxial pressure dependences of $T_c$ with Sn substitution. The hydrostatic pressure dependence of $T_c$ is positive for Sn concentrations $x \leq 0.06$ and changes sign at larger $x$. A first-order superconducting transition, caused by Pauli limiting in magnetic fields that suppress $T_c$ to below 0.7 K, is visible at $x \leq 0.06$.

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The tetragonal heavy fermion (HF) system CeCoIn$_5$ has attracted much interest because of its unusual normal and superconducting (SC) properties. An unconventional SC state below $T_c = 2.3$ K is indicated by power-law behavior in specific heat and thermal conductivity [1]. Its nodal structure obtained by thermal conductivity indicates most likely a d-wave nature [2]. Strong Pauli limiting leads to a first-order transition when superconductivity is suppressed by magnetic fields to temperatures below 0.7 K [3]. Furthermore, evidence for the formation of an inhomogeneous SC (FFLO) state has been found very close to $H_{c2} = 5$ T ($B||c$) and 11.5 T ($B \perp c$) [3,4].

Remarkably, $H_{QCP}$ and $H_{c2}$ cannot be separated from each other by suppressing superconductivity with Sn substitution in CeCoIn$_{5-x}$Sn$_x$ [7]. We use thermal expansion measurements to study the SC properties of CeCoIn$_{5-x}$Sn$_x$. Since the Sn atoms preferentially occupy the in-plane In(1)-site [8], this allows to investigate the evolution of the anisotropy in this system in a controlled way. The measurements on the same single crystals studied in Ref. [7] have been performed with the aid of a high-resolution capacitive dilatometer adapted to a dilution refrigerator.

Previous specific heat measurements have shown that the Sn-substitution leads to a drastic suppression of the SC transition with a rate $dT_c/dx = -0.6$ K/at% Sn [7]. Fig. 1 displays the linear thermal expansion measured along and perpendicular to the c-axis for different Sn concentrations. For measurements along the c-direction, the positive jump anomaly $\Delta x > 0$ at $T_c$, observed for $x = 0$, becomes suppressed with increasing Sn concentration, resulting in a pronounced negative anomaly at $x = 0.12$. This resembles the evolution of the c-axis expansion behavior in undoped CeCoIn$_5$ under magnetic fields [9]. For a quantitative analysis, the jump anomalies $\Delta x_{\perp}$ are
concentrations of CeCoIn5

The uniaxial pressure dependences of estimated as usual by equal-areas construction. The

Fig. 1. Temperature dependence of the linear thermal expansion coefficient along (left) and perpendicular (right) to the c-axis for various concentrations of CeCoIn5-xSnx.

electrical resistivity [11]. Our data indicate a strong decrease in the hydrostatic pressure dependence with Sn substitution. \( \partial T_c/\partial P \) becomes negative for \( x \geq 0.06 \). This indicates that the system is driven towards the right side of the SC dome in accordance with measurements of the electrical resistivity of CeCoIn4.94Sn0.06 under hydrostatic pressure [12]. Most interestingly, it is the c-axis uniaxial pressure dependence which is most drastically changed in CeCoIn5-xSnx, although the Sn atoms preferentially occupy the in-plane In(1) site. This supports our previous conclusion that the HF properties in CeCoIn5 are most sensitive to c-axis strain, counterintuitive to viewing this system as a 2D HF system [9].

Finally, we discuss the effect of Sn substitution to the first-order SC transition in magnetic fields close to \( H_c2 \) which is caused by strong Pauli limiting [3]. As shown for CeCoIn4.94Sn0.06 in Fig. 2, with increasing magnetic field, the SC transition anomaly changes from a step-like decrease at low fields to a sharp, almost divergent behavior indicative of a first-order transition for fields near \( H_c2 \). A similar observation has been made in CeCoIn5 [9]. For larger Sn concentration, the first-order transition is suppressed by disorder. We also note that specific heat experiments on CeCoIn4.94Sn0.06 show no first-order transition [13].

To summarize, the substitution of In by Sn in CeCoIn5-xSnx leads to a drastic change in the pressure dependence of the SC transition in this system. Although the Sn atoms preferentially occupy the in-plane In(1) site, they most effectively increase the f-conduction electron hybridization along the c-axis. The detailed analysis of the normal state thermal expansion behavior of CeCoIn5-xSnx will be published elsewhere [14].

References