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The superconducting phase diagram of $U(Pt_{1-x}Pd_x)_3$

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Abstract

We report on the superconducting phase diagram of $U(Pt_{1-x}Pd_x)_3$ with $x = 0.001$ and 0.002. Resistivity experiments in field were carried out on high-quality single-crystalline samples in order to determine the upper-critical field, $B_{c2}(T)$. The phase diagrams for the Pd-doped compounds have the same characteristics as for pure UPt_3. For $B \perp c$ a pronounced kink is observed in $B_{c2}(T)$ at $T_{cr} = 0.309(8)$ K and $B_{cr} = 0.461(8)$ T for $x = 0.001$ and at $T_{cr} = 0.225(8)$ K and $B_{cr} = 0.490(8)$ T for $x = 0.002$. For $B \| c$ the kink is less pronounced.

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The pseudobinary $U(Pt,Pd)_3$ system presents a case study for the investigation of the interplay of magnetism and superconductivity in heavy-fermion systems [1]. Pure UPt_3 is an unconventional superconductor with a multicomponent phase diagram. In zero magnetic field two superconducting phases are present, the A phase below $T_c^+ = 0.50$ K and the B phase below $T_c^- = 0.44$ K, while a third phase, labelled C phase, is induced by magnetic field. The three phases meet in a tetracritical point. Within the Ginzburg–Landau formalism the double superconducting transition in zero field, $\Delta T_c = T_c^+ - T_c^- \sim 0.055$ K, is explained by a coupling of the superconducting vector order parameter to a symmetry breaking field (SBF), where $\Delta T_c \propto$ SBF [2]. A study of UPt_3 doped with small amounts of Pd may serve to test the SBF model [3]. Specific-heat experiments carried out on poly [4,5] and single-crystalline [3] samples showed that by substituting small amounts of Pt by Pd, ΔT_c increases at a rate of 0.3 K/at% Pd. Furthermore, neutron-diffraction experiments [6] demonstrate that the minute antiferromagnetically ordered moment ($m = 0.02\mu_B$/U-atom, $T_N = 6$ K for pure UPt_3), which is the most plausible candidate for the SBF, increases with Pd content. This close relation of ΔT_c and m lends further support for the Ginzburg–Landau scenario with the small-moment magnetism as the SBF.

We here report on upper-critical field $B_{c2}(T)$ measurements of single-crystalline $U(Pt_{1-x}Pd_x)_3$ ($x = 0.001$ and 0.002) in order to investigate the multicomponent superconducting phase diagram. The experiments are carried out on parts of the single-crystalline samples that were used for the specific-heat [3] and neutron-diffraction [6] experiments. The samples were annealed at 950°C for 5 days followed by cooling to room temperature in 3 days. B_{c2} was determined by resistivity experiments in a transverse constant magnetic field. The values for T_c^+ were determined by the 50% resistivity criterion. The results for $B \perp c$ and $B \| c$ are shown in Fig. 1, where we have also plotted the resistively determined $B_{c2}(T)$ data of pure UPt_3 [7,8] for comparison.

For $B \perp c$ clear kinks in $B_{c2}(T)$ are observed. The kink indicates that in the Pd-doped samples the C phase is present, as for pure UPt_3. The tetracritical point shifts towards lower temperatures and higher fields upon Pd doping, which indicates that the A phase becomes more stable. For $x = 0.001$ $T_{cr} = 0.309(8)$ K and $B_{cr} = 0.461(8)$ T, while for $x = 0.002$ $T_{cr} = 0.225(8)$ K and $B_{cr} = 0.490(8)$ ($B \perp c$). We conclude that for $B \perp c$ the

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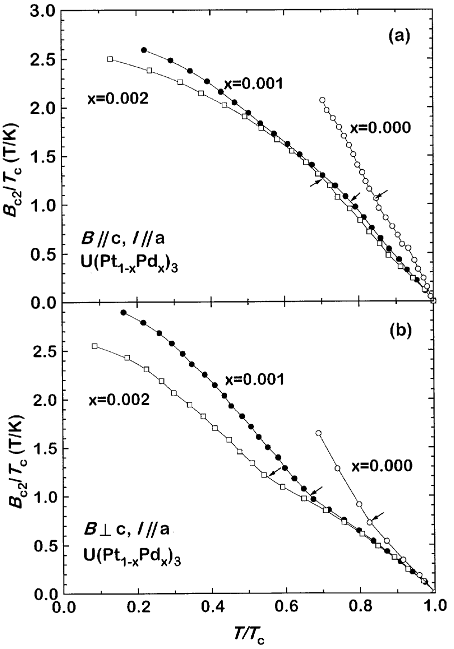

Fig. 1. The upper critical field of $U(Pt_{1-x}Pd_x)_3$ as function of temperature in a plot of B_{c2}/T_c versus T/T_c for (a) $B||c$ and (b) $B\perp c$, determined by resistivity in constant applied fields. For all data I||a and also $B\perp I$. T_c amounts to 0.547(5) K, 0.466(5) K and 0.420(5) K for $x = 0.000$, 0.001 and 0.002, respectively. Arrows indicate the position of the tetracritical points. The data for pure UPt_3 are taken from Refs. [7,8].

phase diagrams for $U(Pt_{1-x}Pd_x)_3$ ($x \leqslant 0.002$) have the same topology. The kink in $B_{c2}(T)$ is also reflected in the width ΔT_c^+ of the superconducting transition (defined using the 10–90% resistivity criterion). At B_{cr} a large drop of the order of 50% in ΔT_c^+ is observed. After correcting ΔT_c^+ for the different values for dB_{c2}/dT in the A and C phase, a smooth variation of ΔT_c^+ through the tetracritical point results.

For pure UPt_3 an upward kink in $B_{c2}(T)$ was reported [7,8] for $B||c$ at lowering the temperature, yielding evidence for a tetracritical point at $T_{cr} = 0.45(2)$ K and $B_{cr} = 0.60(2)$ T. In the case of the Pd doped samples the presence of a tetracritical point is not unambiguous. A weak change (20%) in the slope dB_{c2}/dT is observed near $T_{cr} = 0.36(1)$ K and $B_{cr} = 0.47(2)$ T for $x = 0.001$ and near $T_{cr} = 0.29(1)$ K and $B_{cr} = 0.52(2)$ T for $x = 0.002$. In contrast to the data for pure UPt_3 the kink is downwards: $|dB_{c2}/dT|$ for the C phase is lower than for the A phase. We have verified that this is not in conflict with the thermodynamic constraints on the phase diagram [9], with the restriction that the BC phase line is (weakly) first order.

In summary, we have determined $B_{c2}(T)$ for UPt_3 doped with 0.1 and 0.2 at% Pd. The results show that the multicomponent superconducting phase diagram is robust upon doping, with the A phase gaining stability with respect to the B phase.

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