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ENHANCEMENT OF T_c OF HEAVY-FERMION SUPERCONDUCTOR UPt_3 BY ALLOYING WITH B

T. VORENKAMP, K. KADOWAKI, A. de VISSER *, P. HAEN *, V.J.M. MEULENBROEK, M. van SPRANG and J.J.M. FRANSE

Natuurkundig Laboratorium der Universiteit van Amsterdam, Valckenierstraat 65, 1018 XE, Amsterdam, The Netherlands
* *Centre de Recherches sur les Très Basses Températures, BP 166X, 38042, Grenoble-Cédex, France*

The influence of boron on the superconductivity of the heavy-fermion superconductor UPt_3 has been studied by resistivity measurements. In the annealed samples, a shift of the T_c value is observed from 530 mK in pure UPt_3 up to 600 mK in the boron added samples. This is the first experimental evidence that the T_c of UPt_3 can be increased by adding impurities.

Over the recent years there has been a great deal of interest in the heavy fermion intermetallic compound UPt_3 in which the coexistence of strong spin fluctuations and superconductivity [1,2] is indicative of the possibility of unconventional superconductivity. The superconducting transition temperature T_c of UPt_3 seems to be sample dependent and values in literature vary between 290 and 530 mK for bulk single-crystalline samples [2,3]. The highest T_c value reported so far is 547 mK, observed for a whisker [3]. A remarkable aspect of the superconductivity in UPt_3 is the sensitivity to small concentrations of impurities. Substitution of 0.5 at% palladium for platinum reduces T_c to below 40 mK [4], and similarly substitution of only 0.55 at% thorium for uranium reduces T_c at least to below 0.3 K [5]. We have investigated the effect of additional impurities. One of the interesting systems is UPt_3B_x in which the boron is believed to occupy the interstitial sites in the hexagonal $MgCd_3$ structure of UPt_3. In this paper we present results of resistivity measurements on UPt_3B_x with $0.0 \leqslant x \leqslant 0.3$.

Conventional four point ac-resistivity measurements were performed on polycrystalline samples which were prepared by arc-melting. The phase diagram of UPt_3–B is not known yet in detail. However, X-ray diffraction indicates the presence of a second phase in the 30 at% B sample. From the transport properties which are more sensitive to the presence of a second phase we expect it to appear at roughly 17 at% concentration of B. Therefore, spatial inhomogeneities in the samples with concentrations $\geqslant 17$ at% B cannot be excluded. The samples were annealed in vacuum at 900 °C for one week. Before annealing, measurements were performed down to 0.3 K in a ^{3}He-cryostat and with a typical current density of 0.11 A/cm^2. After annealing the samples were placed inside the mixing chamber of a dilution refrigerator and a typical current density of 25 mA/cm^2 was used.

In fig. 1, we present three curves of the resistivity before annealing. In the 11 at% B sample the superconductivity is suppressed at least down to 390 mK, whereas the 3 at% B and the 5 at% B samples have already completed their transition at this temperature. The residual resistivity is largely enhanced with boron concentration, but surprisingly enough the 5% alloy with the large ρ_0 value of 14.6 μΩcm still becomes superconducting at 410 mK. This fact is in clear contrast to UPt_3 substituted with palladium in which system a value for ρ_0 of 5–10 μΩcm leads to complete suppression of the superconductivity [6]. In fig. 1, the effect of annealing on the resistivity of the 5 at% B sample is also shown. The annealing not only causes an increase in transition temperature, but also an enormous drop in residual resistivity of roughly 13 μΩcm.

The superconducting transitions after annealing are presented in fig. 2 and characteristic parameters are given in table 1. Although there is some variation in the T_c and ρ_0 values, there is a general tendency for boron doped samples to have a higher T_c and a lower ρ_0 compared to UPt_3. The pure UPt_3 has a transition temperature of 530 mK as determined by the midpoint of the transition. The 5 at% B sample has a broader transition and a T_c value which is only a few mK higher than that of the pure UPt_3, but all other concentrations have T_c values exceeding 560 mK. The 11 at% B sample reveals a transition temperature of 600 mK.

In contrast to the marked change of ρ_0 with

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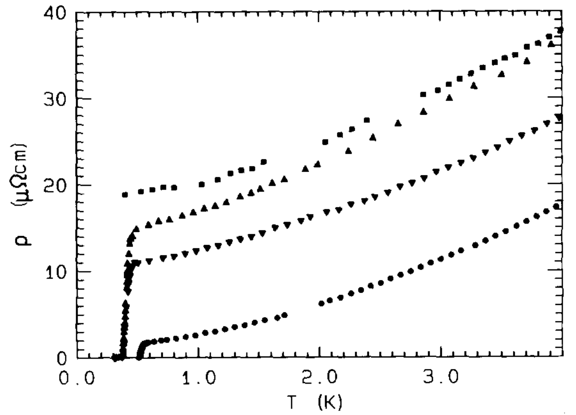

Fig. 1. Resistivity of the UPt_3B_x compounds, with $x = 0.03$ (▼), $x = 0.05$ (▲) and $x = 0.011$ (■) before annealing and $x = 0.05$ (●) after annealing.

annealing, the A coefficient of the T^2 term of the resistivity does not change noticeably [7]. Moreover, the different boron concentrations do not influence it's value which remains (1.40 ± 0.25) $\mu\Omega cm/K^2$. This is different from the case of the palladium substitutions, where for the A coefficient, an increase with concentration is reported, leading to a value of 4.40 $\mu\Omega cm/K^2$ for the 5 at% substitution [4].

It must be noted that by plotting T_c against ρ_0 a correlation between the two parameters is observed, which points to a ρ_0-sensitive nature of the superconductivity in UPt_3.

In conclusion we can state that the effect of boron addition in UPt_3 is significantly different from the case of Pd and Th substitution. The role of the boron is not yet clear. It cannot be exluded that the boron binds oxides and that volatile products are created. In this way the combination of boron addition and annealing could lead to a removal of shortcomings in the crystal structure, as is suggested in ref. [8]. However, the broadening of the transitions of the boron doped samples is in contradiction with this tendency to perfection of crystal structure. Another possibility one may think of is a subtle change of the electronic state caused by the increase of lattice parameters due to boron addition. As presented in ref. [9] external pressure on the lattice results in reduction of T_c. Further analyses from these points of view are in progress.

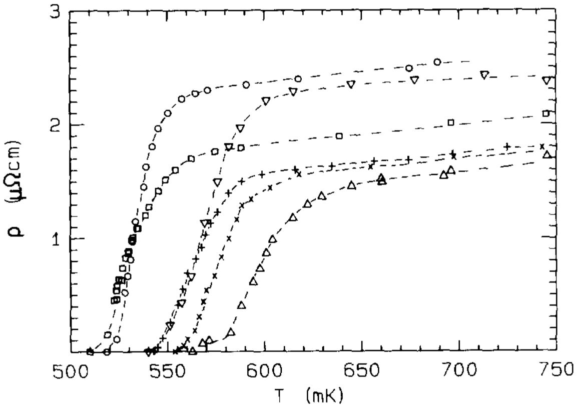

Fig. 2. The superconducting transitions of the UPt_3B_x compounds, with $x = 0.00$ (○), $x = 0.05$ (□), $x = 0.11$ (△), $x = 0.17$ (▽), $x = 0.20$ (+), $x = 0.30$ (×) after annealing.

Table 1
Several physical parameters of UPt_3B_x after annealing as determined by the resistivity measurements. T_c is determined from the midpoint of the resistive transition. ΔT is the width of the transition as determined from the 10% and 90% value of the resistive transition. The error in the absolute value of both ρ_0 and A is less than 10%

x	T_c (mK)	ΔT (mK)	ρ_0 ($\mu\Omega$cm)	ρ(294 K) ($\mu\Omega$cm)	A ($\mu\Omega cm/K^2$)
0.00	530	22	1.85	234	1.42
0.05	532	30	1.37	228	1.30
0.11	600	40	0.79	236	1.63
0.17	570	40	1.81	239	1.25
0.20	565	32	1.17	199	1.15
0.30	577	30	1.04	201	1.37

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