ENHANCEMENT OF \( T_c \) OF HEAVY-FERMION SUPERCONDUCTOR UPt\(_3\) BY ALLOYING WITH B

T. VORENKAMP, K. KADOWAKI, A. de VISSE*, 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\(_3\)B\(_x\) 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\(_3\)B\(_x\) with 0.0 \( \leq \) x \( \leq \) 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 \( \geq 17 \) 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 \( \rho_0 \) value of 14.6 \( \mu \)\Omega cm still becomes superconducting at 410 mK. This fact is in clear contrast to UPt\(_3\) substituted with palladium in which system a value for \( \rho_0 \) of 5–10 \( \mu \)\Omega cm 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 \( \mu \)\Omega cm.

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 \( \rho_0 \) values, there is a general tendency for boron doped samples to have a higher \( T_c \) and a lower \( \rho_0 \) 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 \( \rho_0 \) with

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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 its value which remains $(1.40 \pm 0.25) \ \mu \Omega \text{cm/K}^2$. 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 $4.40 \ \mu \Omega \text{cm/K}^2$ for the 5 at% substitution [4].

It must be noted that by plotting $T_c$ against $\rho_0$, a correlation between the two parameters is observed, which points to a $\rho_0$-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 excluded 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.

### Table 1

Several physical parameters of UPt$_3$B$_x$ after annealing as determined by the resistivity measurements. $T_c$ is determined from the midpoint of the resistive transition. $\Delta T$ 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 $\rho_0$ and $A$ is less than 10%.

<table>
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<th>$x$</th>
<th>$T_c$ (mK)</th>
<th>$\Delta T$ (mK)</th>
<th>$\rho_0$ ($\mu \Omega \text{cm}$)</th>
<th>$\rho(294 \text{K})$ ($\mu \Omega \text{cm}$)</th>
<th>$A$ ($\mu \Omega \text{cm/K}^2$)</th>
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### References