Strain induced renormalization of transport properties in UPt_3 thin films

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The growth of sputter deposited UPt_3 thin films on Al_2O_3 (10$\bar{1}$2), $LaAlO_3$ (111) and $SrTiO_3$ (111) was investigated. We found strongly 0001–textured growth of UPt_3 in a small compositional range of 23 – 25% uranium content. For Al_2O_3- and $LaAlO_3$–substrates no in-plane order could be observed whereas epitaxial growth was initiated on $SrTiO_3$ (111). The growth can be identified as Vollmer–Weber like resulting in the formation of large lateral strain as a consequence of the growth mode and a lattice misfit of −4.3% between UPt_3 (0001) and $SrTiO_3$ (111). Strong deviations from the typical heavy–fermion characteristics in electronic transport properties like resistivity, magnetoresistivity and Hall–effect are attributed to changes of the hybridization between the localized 5f- and itinerant states.*

1. INTRODUCTION

Different experimental techniques, like specific heat and ultrasonic velocity measurements [1, 2], give evidence for the unconventional nature of the superconducting pair state in UPt_3. The conclusion on possible knots in the energy gap by means of tunneling experiments revealed to be rather subtle up to now [3]. This is one reason why the preparation of UPt_3 thin films can be promising since tunnel junctions can be prepared under controlled conditions. This approach has already proven to be successful in superconducting tunneling spectroscopy experiments on UPd_2Al_3 thin film samples [4]. The growth of UPt_3 on different substrate materials and substrate orientations by means of a sputter process from high purity targets (see [5] for details) revealed epitaxial growth on $SrTiO_3$ in (111) orientation whereas only textured growth could be observed on Al_2O_3 (10$\bar{1}$2) and $LaAlO_3$ (111). In all cases the film's c–axis is oriented perpendicular to the film plane. The films were deposited onto heated substrates ($T_{sub} \simeq 1000\,K$) which resulted in an island growth mode (epitaxial Vollmer–Weber mode on $SrTiO_3$ (111)). The combination of epitaxial growth despite a lattice misfit at the film–substrate interface and the coalescence of the film islands without grain–boundary formation resulted in the development of a strong lateral compressive strain. This phenomenon is well known for metal films on insulating substrates [6]. As a consequence we assume the growth mode to be responsible for a renormalized electronic structure of the UPt_3 films. This point will be further corroborated by the following resistivity and magnetoresistivity data.

2. RESULTS

The temperature dependent resistivity of UPt_3 films on Al_2O_3 and $SrTiO_3$ is shown in figure 1.

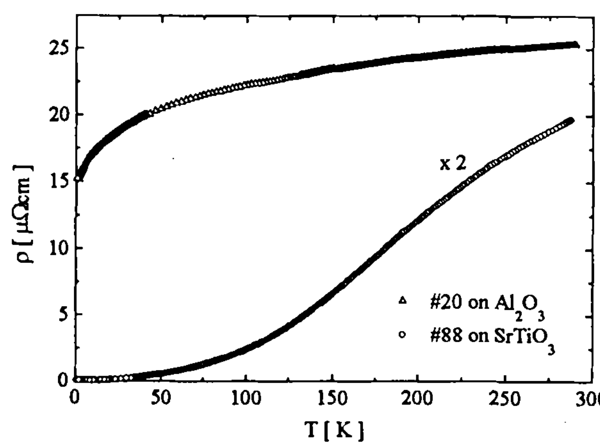

Figure 1: Temperature dependent resistivity of UPt_3–films on different substrate materials.

As compared to typical results on bulk samples the room temperature specific resistivity is strongly reduced by about a factor of 8 to 15. Especially for the film on $SrTiO_3$ the whole course of the resistivity

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has no resemblance to the typical bulk behaviour. The residual resistivity is as low as 13 nΩcm with a residual resistance ratio $RRR = \rho(300\,\mathrm{K})/\rho_0 = 612$ (sample # 88). The low temperature resistivity shows no increased value of the coefficient of the typical T^2–behaviour in the Fermi–liquid regime. Superconductivity was found in a comparable sample at 128 mK (midpoint) with a strongly reduced upper critical field $B_{c2}(0) \simeq 0.1\,\mathrm{T}$. Due to the high purity of the samples the low temperature magnetoresistivity (transveral geometry) showed quantum oscillations as function of the applied field. In figure 2 the oscillatory part of the resistivity, $R_{osc}(B) = R(B) - R(B, T = 1.3\,\mathrm{K})$, is shown for different temperatures (sample # 94, $RRR = 451$).

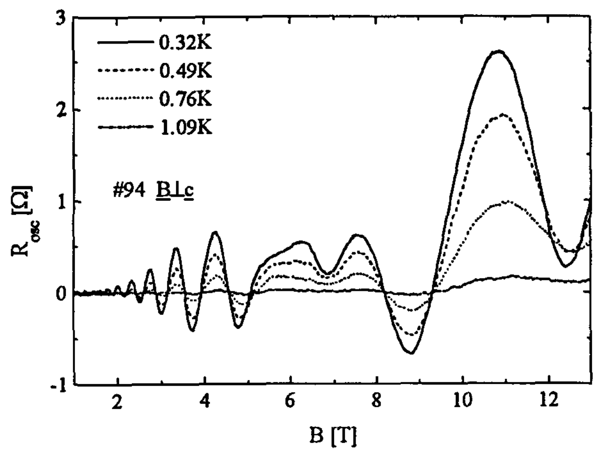

Figure 2: Oscillatory part of magnetoresistivity as a function of the magnetic field.

A spectral analysis of the magnetoresistivity for different temperatures and field orientations parallel and perpendicular to the film's c–axis was performed in order to determine the effective masses m^* of the observed main branches by means of the temperature dependent damping part of the Lifshitz–Kosevich formula [7]:

$$\frac{A_1(T)}{A_1(0)} = \kappa T \frac{m^*}{m_0} \cdot \frac{1}{\sinh(\kappa T m^*/m_0)}$$

($\kappa = 2\pi^2 k_B m_0/\hbar e B$).
In this analysis the influence of the collision broadening of the Landau levels was neglected. As can be seen in figure 3 the fits on the experimental data are quite satisfactory.

3. DISCUSSION

Within the observable mass regime $m^* < 35 m_0$ ($T > 0.3\,\mathrm{K}$, $B < 13.2\,\mathrm{T}$) the analysis yielded $10.2\,m_0$

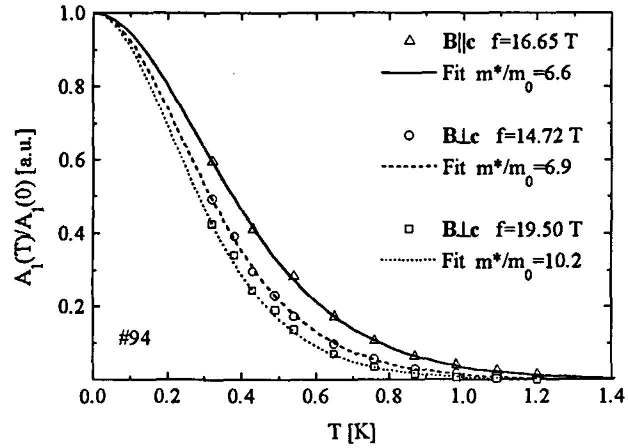

Figure 3: Temperature dependent main spectral components of the magnetoresistivity (see text for details).

for the largest effective mass. These only slightly increased effective masses are compatible with the assumption of a strongly altered electronic structure in the films due to lateral compressive strain. Nevertheless the mass enhancement is clearly more pronounced than in pure platinum [8] giving further evidence that the observed properties are not due to pure platinum as an impurity phase. We propose rather a strongly renormalized effective hybridization of the itinerant states with the 5f–states to cause a significantly changed Kondo energy scale. Further work on the influence of lateral expansion by deposition on a different substrate material (MgO_3 (111)) and expansion experiments are in progress.

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