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EFFECT OF SPIN REORIENTATIONAL TRANSITION ON MAGNETORESISTIVITY OF NONCOLLINEAR FERROMAGNET U_3As_4

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Transverse magnetoresistivity ($H \parallel [001]$; and current $\parallel [110]$) of U_3As_4 has been measured in field up to 35 T. An abrupt change of the magnetoresistivity behaviour from saturated (low field) to unsaturated (high field) type was observed at the spin reorientational transition (19.1 T at 4.2 K). The transition is accompanied by a peak in the magnetoresistivity. The behaviour is ascribed to fractional spin polarization of the band electrons.

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Below $T = 198$ K $5f$ electron system U_3As_4 is ferromagnetic one with a complex noncollinear magnetic- and bcc Th_3P_4-type crystal structure [1]. The system is interesting due to moderate hybridization of uranium $5f$ electrons with band electrons, proved by optical spectroscopy [2] and dHvA [3] studies, and simultaneously existing localized magnetic moments. The dHvA results (done between 0.3 K and 0.8 K) were interpreted in terms of compensated semimetal band structure, though only one Fermi sheet (with mass of $5.3m_0$) has been found. At the same study two Fermi sheets have been found for U_3P_4 (one with mass of $8.1m_0$). Basing on the great similarity of many other properties of U_3As_4 and U_3P_4 two Fermi sheets were anticipated also for U_3As_4. The problem of the compensation became more complex since additional sheets (one with mass of $\approx 20m_0$) have been revealed for U_3P_4 by dHvA studies in mK range [4].

We present results of magnetoresistivity, $\Delta\rho/\rho_0$, that clearly show a compensated type of the band structure of U_3As_4. The results also show a spin polarization of the band electrons.

A rectangular sample (with dimensions of $3 \times 0.4 \times 0.4$ mm^3) was prepared from U_3As_4 crystal grown by chemical vapor transport method. The long sample direction was along [110] axis. The residual resistance ratio $R(300)/R(4.2)$, was equal to 170. The transverse magnetoresistivity was measured by conventional four-point dc method in magnetic field along [001] axis. The resistivity was measured in the High Magnetic Field Facility of the University of Amsterdam [5]. In the high-field installation the pulsed magnetic field can be generated up to 40 T with total pulse time of about one second. The measurements were done at different magnetic field sweep rates obtained by changing the pulse shape. The lowest rate of 15 T/s was applied at the phase transition.

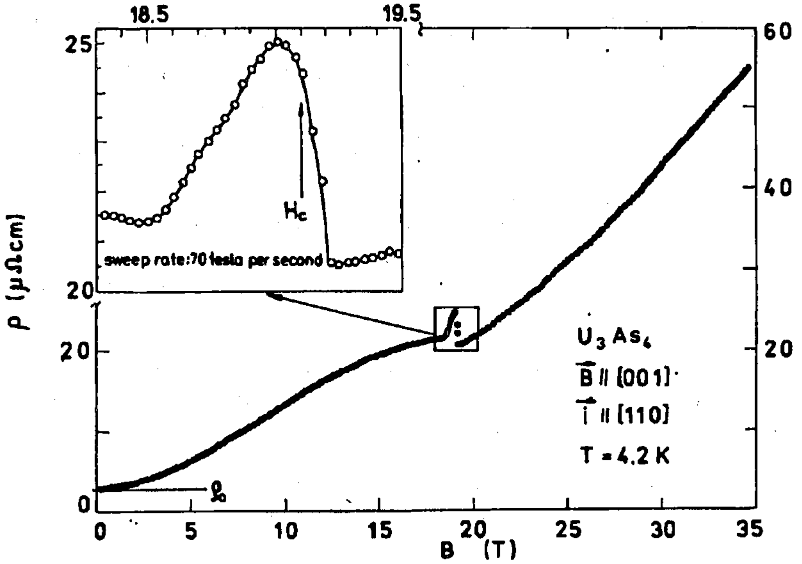

Fig. 1. Resistivity for U_3As_4 in transverse magnetic field. Inset shows the resistivity peak near by orientational phase transition. *i* denotes direction of the electric current.

The resistivity data are shown in Fig. 1.The peak of the resistivity (shown in enlarged scale in inset) is observed at the same magnetic field as discontinuous magnetization jump ($H_c = 19.1$ T) reported earlier [6, 7]. According to a more recent consideration [8], the jump is due to a spin reorientational transition from noncollinear ferromagnetic structure at low fields (⟨111⟩ easy magnetic axis) to collinear ferrimagnetic one at high fields (magnetic moments along ⟨100⟩ axis).

Our resistivity data taken in magnetic field cycled between 17 and 22 tesla with sweeping rate 15 T/s showed no hysteresis of the resistivity peak with accuracy better than 0.05 T for the value of H_c and 0.02 T for the width of the peak. We did not notice dependence of H_c on the magnetic field sweeping rate, but we observed an effect of the sweeping rate on the width of the peak. It is equal to 0.65 T and 0.45 T for the sweeping rate 70 T/s and 15 T/s, respectively. The peak is asymmetrical at both rates.

An asymmetrical peak of resistivity due to magnetic disorder at the reorientation phase transition was predicted by theory [9]. However, spin independent scattering by magnetic disorder should reduce magnetoresistivity caused by cyclotron motion of electrons ($\Delta\rho/\rho_0 > 1$).

The Kohler plot of data from Fig. 1 is presented in Fig. 2. The data from the

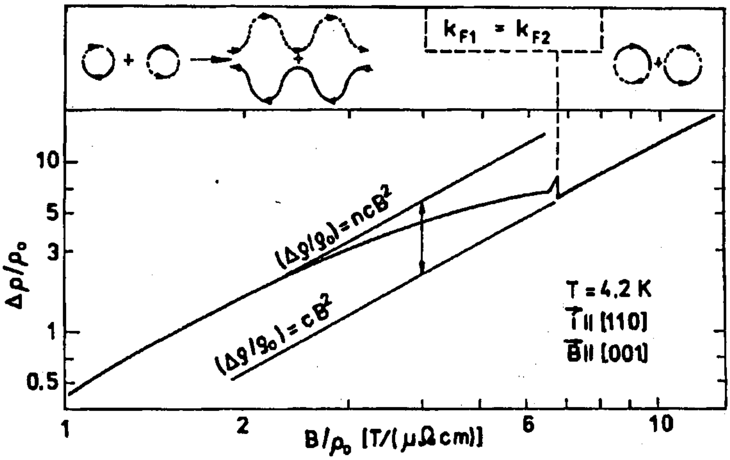

Fig. 2. Log–log plot of transverse magnetoresistivity vs. reduced induction (bold line) for U_3As_4. $\vec{i}$ denotes direction of the electric current. Upper part of the figure presents models of electron orbits (described in text) corresponding to the observed behaviour of the magnetoresistivity.

ferrimagnetic range determine the $\Delta\rho/\rho_0 = cB^2$ dependence. The $\Delta\rho/\rho_0 \sim B^2$ dependence can be also found (though with lower accuracy) in the ferromagnetic phase at low fields. However, the coefficient is here higher by factor of $n = 2.8$. An increase in the field towards H_c leads the magnetoresistivity to saturation.

The determined behaviour can be understood consistently in terms of the Cabrera and Falicov (CF) theory of galvanomagnetic properties of ferromagnetic metal [10]. In this model the conduction electron band is split into majority- and minority-spin states. Any perturbation is distributed uniformly over each spin Fermi surface by spin-independent scattering in relatively short time τ. Spin–orbit coupling, although weak, is present and allows collisions with spin-flip. These spin-dependent collisions are responsible for the equilibrium reached by the up and down spin distributions over, relatively long, relaxation time τ_s. CF have determined magnetoresistivity behaviour for various models of electron orbits and showed reduction of the transverse magnetoresistivity with increase of $\tau/\tau_{\rm eff}$ ratio for most of them; $(\tau_{\rm eff})^{-1} = (\tau)^{-1} - (\tau_s)^{-1}$. It is worth noticing that this model is consistent with results of the Kerr-effect examination [11] which showed negative spin polarization of the charge carriers.

The magnetoresistivity versus temperature dependence observed for U_3As_4 is consistent with that obtained by CF for models shown in upper part of Fig. 2. There are one-electron and one-hole orbits of hybridized majority (full line) and minority spin (dotted line). It is so-called compensated case; the electron and hole orbits, denoted by k_{F1} and k_{F2}, respectively, are the same. For ferromagnetic phase of U_3As_4 there is a transition from a compensated free-electron–hole-like orbit at low magnetic fields to an open orbit at the higher fields. Therefore the magnetoresistivity which increases linearly with B^2 at low magnetic field goes to the saturation as B approaches H_c. The inclusion of the extra (spin-dependent) relaxation mechanism by CF yields no new qualitative effects upon the behaviour of the magnetoresistivity. The major expected changes are reductions both in the saturation value and in the coefficient at B^2.

The field induced transition to the ferrimagnetic state removes the magnetic breakdown presumably due to change of the spin polarization of the band electrons. This change obviously does not remove the compensation but causes a reduction of the coefficient at B^2 by the n factor as shown in Fig. 2. According to the CF theory this reduction is due to the increase in τ/τ_{eff} ratio possibly due to a decrease in τ_s. Consistently, the maximum of the resistivity at H_c may result from a decrease in τ/τ_{eff} due to a field induced transition.

In conclusion: the presented results show that magnetoresistivity of U_3As_4 behaves as it can be predicted for a compensated ferromagnetic metal with spin polarization of the band electrons depending on magnetic structure. This effect should be accounted for with the interpretation of the results of the recent dHvA study of U_3P_4 [4]. The discovered additional sheets of the Fermi surface may be the Fermi sheets of different spins.

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