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MAGNETORESISTANCE BEHAVIOR OF UNiGe

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We have measured the temperature dependences of the magnetoresistance of single-crystalline UNiGe for both parallel (i//B//*c*-axis) and perpendicular configurations (i//*a*-axis, B//*c*-axis) in magnetic fields up to 18 T. Both configurations yield similar magnetoresistance behavior, which emphasizes the strong magnetic contribution to the resistivity in all directions. Crossing magnetic-phase boundaries causes anomalies in the magnetoresistance, which allowed a completion of the previously proposed magnetic phase diagram.

1. Introduction

UNiGe is a 5*f*-moment antiferromagnet crystalizing in the orthorhombic TiNiSi structure.[1,2] Below 41.7 K, the U magnetic moments order antiferromagnetically (phase II) in a commensurate magnetic structure with $\mathbf{q} = (0,1/2,1/2)$.[1–4] The occurrence of two domains is indicated in our recent neutron-diffraction results. Between 41.7 and 50 K, there is a second incommensurate antiferromagnetic structure.[4] Application of a magnetic field along the *c* axis causes the destruction of both antiferromagnetic phases accompanied by two metamagnetic transitions, which yields first an uncompensated antiferromagnetic structure with $\mathbf{q} = (0,1/3,1/3)$ and eventually transforms to a forced-ferromagnetic alignment.[4] In the configuration i//B//*c*, drastic changes in the low-temperature electrical resistivity were found at both metamagnetic transitions (at 3 and 10 T), yielding a reduction of the electrical resistivity by 75% in the forced-ferromagnetically aligned phase.[5,6]

In the present investigation we have extended our magnetoresistance studies on UNiGe, which had been restricted to the parallel configuration (i//B//*c*-axis) at 4.2 K previously.[5,6]

2. Experimental

The experimental results were obtained on two samples, which were cut along the *a* and *c* axis,were about 5 mm in length and had cross-sectional areas of less than 1 mm^2. Contacts for the transport measurements were established by silver paint. Although the sensitivity of the measuring apparatus is much better, the absolute accuracy of the measurements may be as great as 5% due to errors in the determination of the geometrical factor and/or possible microcracks present in the samples. Both samples were oriented with the c axis parallel to the applied magnetic field in the 20 T superconducting magnet of the National High Magnetic Field Laboratory at Los Alamos. The temperature dependences of the electrical resistivity were exclusively measured during cooling from about 85 K (paramagnetic region) down to 6.5 K with a cooling rate of about 20 K/h. In this way, the effects arising from changes in the domain populations are thought to be well defined.

3. Magnetoresistance studies

First, we measured the variation of the electrical resistivity for both i//*a* and i//*c* during a field sweep up to 18 T with B//*c* at T = 6.5 K (Fig. 1). For both configurations, we observe abrupt changes in the electrical resistivity at magnetic fields around 3.7 and 9.5 T. Previous magnetization studies revealed metamagnetic transitions at the same fields reflecting subsequent changes in the magnetic structure.

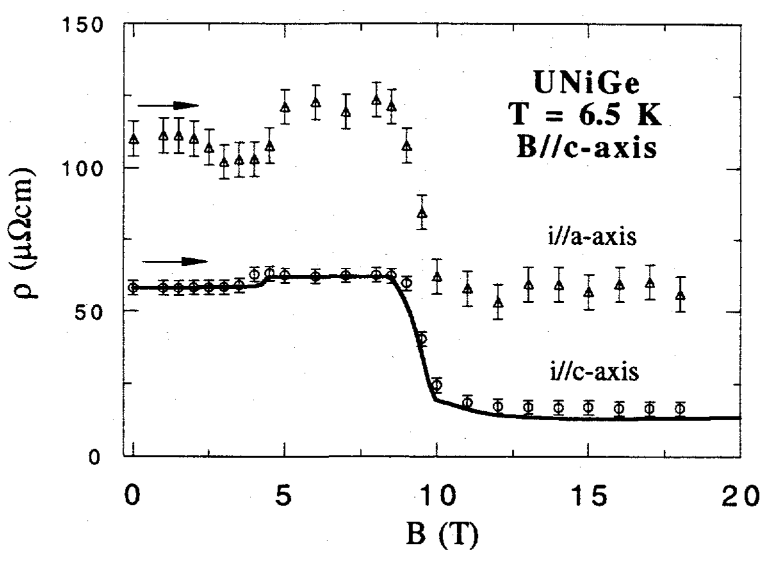

Figure 1: Field dependence of the electrical resistivity of UNiGe for B//*c*-axis and i//*a*-axis (triangles) and i//*c*-axis (circles) at 6.5 K. The solid line represents the magnetoresistance at 4.2 K for i//B//*c*-axis taken from ref. 5.

Both configurations exhibit an initial increase of the resistance values by about 6–9% of the zero-field value at the first transition, which is followed by a drastic reduction of the resistivity beyond the second transition. For *i*//*c*, we find a huge magnetoresistance yielding 70% smaller values in the ferromagnetic-aligned phase, which is somewhat below the values observed previously at 4.2 K (solid line in Fig.1). The magnetoresistance effect is found to be reduced for *i*//*a*, but remains considerable (i.e. 50 % reduction).
Next, we measured the temperature dependence of the electrical resistivity for both configurations at various fixed fields. Again, we find very similar effects of the applied magnetic field for both configurations (Fig. 2), which emphasizes the strong magnetic contribution to the electrical resistivity in all directions.

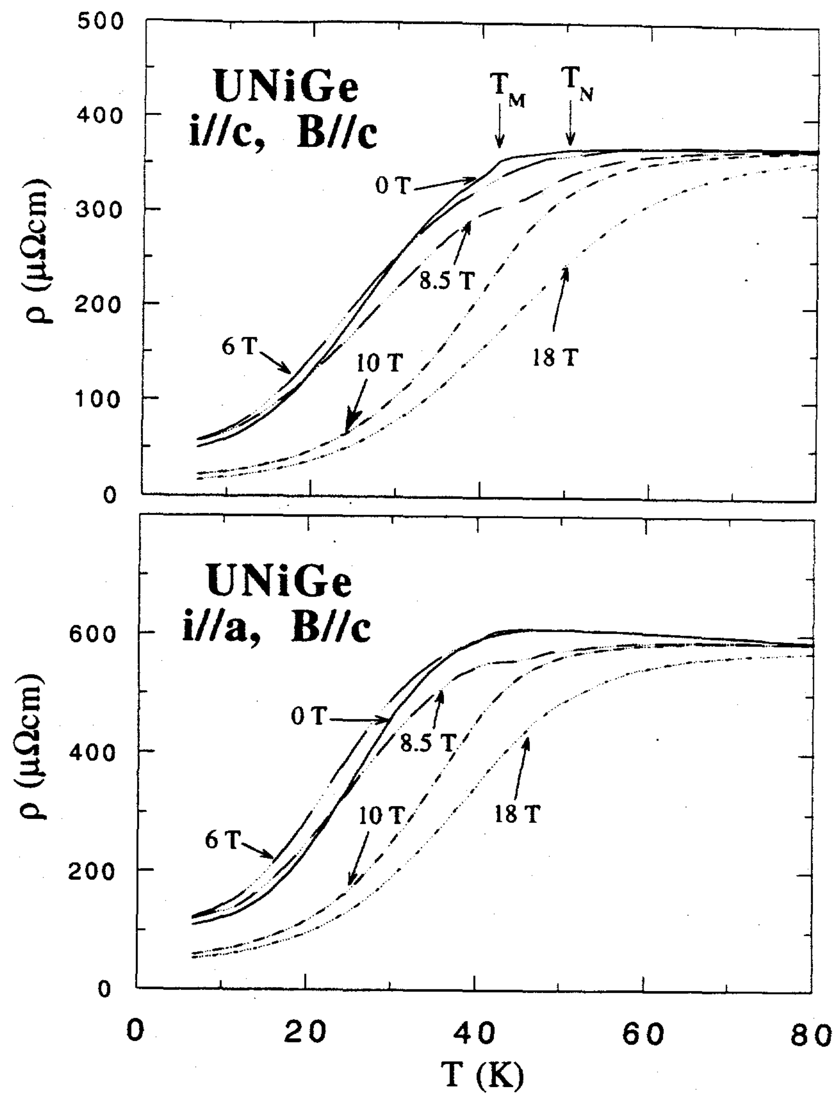

Figure 2: Temperature dependence of the electrical resistivity of UNiGe for i//B//*c*-axis (upper plot) and i//*a*-axis, B//*c*-axis (lower plot) in various applied magnetic fields. In the upper plot, the two magnetic transition temperatures are indicated.

Prokeš et al.[5] have shown that the low-temperature part of the zero-field electrical resistivity of UNiGe can be very well described using the formula:

$$\rho = \rho_0 + AT^2 + ET(1+2T/\Delta)\exp(-\Delta/T), \qquad (1)$$

in which the last term accounts for the scattering of electrons by magnons with a gap Δ in their dispersion relation around $\mathbf{k} = 0$, the quadratic term involves effects like electron scattering on spin fluctuations and ρ_0 is the residual (impurity) resistivity. Tentatively, we have analyzed the low-temperature parts of the electrical resistivity in fixed field using Eq. (1) and we obtained the parameters displayed in Fig. 3.

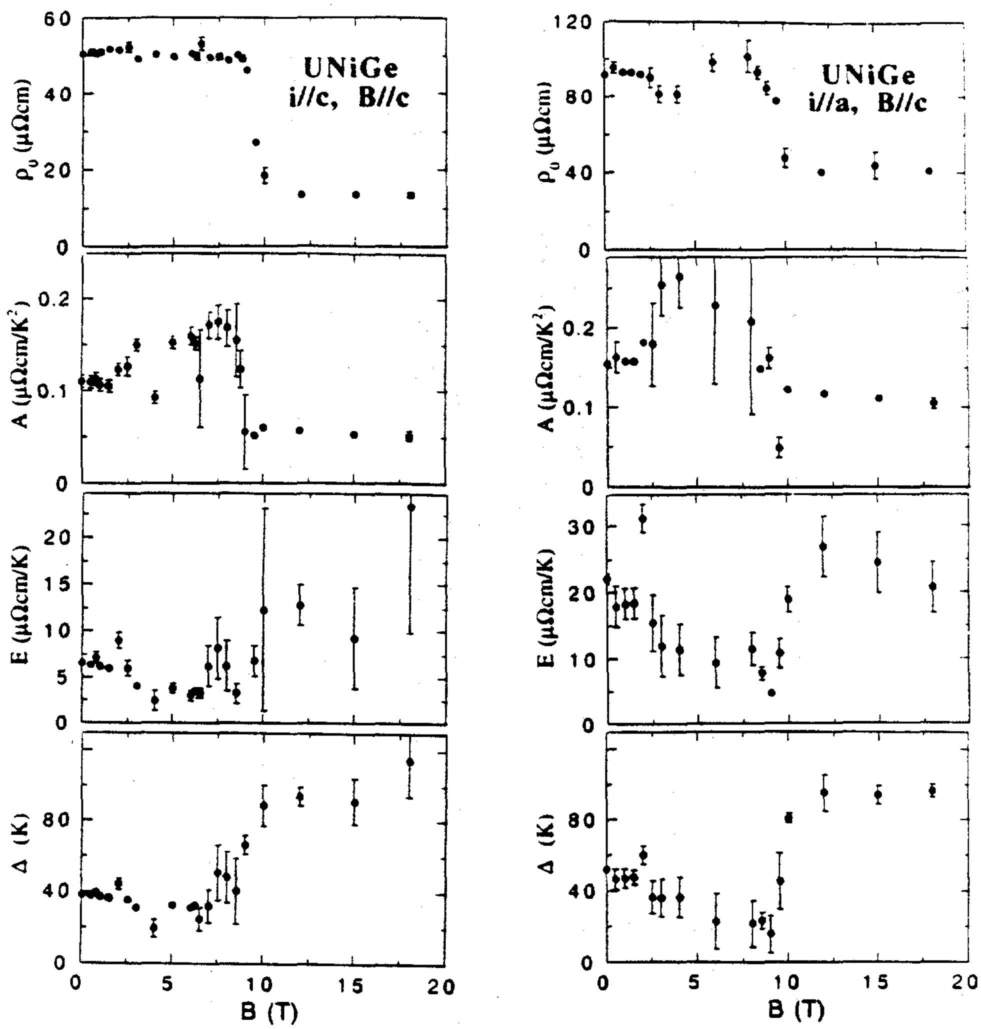

Figure 3: Fitting parameters to Eq. (1) for i//B//*c*-axis (left) and i//*a*-axis, B//*c*-axis (right).

In the high-field limit, a strong decrease of ρ_0 is observed for *i//c* and *i//a*, while the quadratic coefficient A initially increases with field and reaches a maximum around the upper critical field. This can be understood as a population of spin fluctuations in a situation where the free energies of the ferro- and antiferromagnetic states are approximately equal. The increase of Δ in the high-field state can be conceived as due to adding up field and anisotropy effects supporting the same configuration of magnetic moments. However, we find that the present analysis is very sensitive to the fitting range which is also restricted due to the lack of data below 6.5 K. Although the similar behavior seen for both configurations seems to confirm the above picture at least qualitatively, measurements to much lower temperatures where the different contributions to the electrical resistivity can be unambiguously disentangled would be helpful. Such experiments will be performed in the near future.

4. Magnetic phase diagram

Usually, magnetic transitions also cause anomalies in transport properties. However, such anomalies may be weak as in the case of UNiGe at $T_N = 50$ K (which is only barely visible as a change of the slope in the derivative), while the second transition in UNiGe appears as a nice kink at 41.7 K (see Fig. 2) at the transition from the incommensurate (phase I) and the commensurate phase (phase II). This kink shifts to lower temperatures upon increasing field and vanishes above 3.5 T, which indicates the phase boundary of phase I. The slight change in the slope around 50 K, however, is much less affected by field, eventually splits

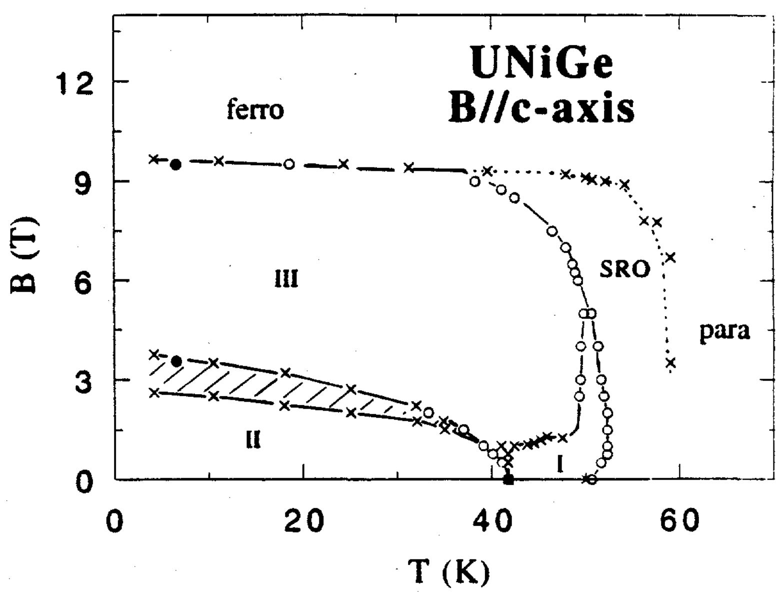

Figure 4: Magnetic phase diagram of UNiGe for B//*c*-axis. The crosses are data taken from ref. 6, the circles are obtained in this work. Open circles denote points gained in temperature scans, full circles arise from field scans. Magnetic phases are denoted by I, II and III (see text), SRO denotes the region where short-range order is expected. The hatched area between phase II and III indicates hysteresis behavior.

up into two anomalies above 2.5 T and finally a pronounced minimum in the derivative develops between 6 and 9 T. This behavior may indicate that in higher fields UNiGe enters the uncompensated AF structure (phase III) without passing through the incommensurate phase. Taking the anomalies visible in our measurements we have completed results of previous magnetization measurements[6] in the magnetic phase diagram shown in Fig. 4. We attribute thereby the observation in ref. 6 of metamagnetic transitions far above the ordering temperature to effects of short-range order. Although some neutron-diffraction work has been done already,[4] it remains indispensable to confirm the exact location of the phase boundaries using neutrons.

5. Conclusions

We have presented our recent magnetoresistance study of UNiGe in magnetic fields up to 18 T. The temperature dependences were found to be well described involving an additional exponential term arising from electron-magnon interaction. Our data indicate that in the high-field limit the changes in the magnetoresistance reflect drastic changes in the gap of the magnon excitation spectrum, while in lower fields changes are predominantly due to field effects on spin fluctuations.

Furthermore, we have determined anomalies in the magnetoresistance curves, which have been taken for a completion of the magnetic phase diagram of UNiGe for B//*c*-axis.

Acknowledgements

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