First publ. in: Physica / B [Condensed Matter], 284-288 (2000), Part 2, pp. 1858-1859

Universal conductance fluctuations in Cu : Mn nanocontacts

H. v. Löhneysen[a,b,*], C. Paschke[a], H.B. Weber[a,b], E. Scheer[a]

[a] *Physikalisches Institut, Universität Karlsruhe, D-76128 Karlsruhe, Germany*
[b] *Forschungszentrum Karlsruhe, Institut für Nanotechnologie, D-76021 Karlsruhe, Germany*

Abstract

Universal conductance fluctuations in Cu : Mn nano-contacts of different Mn concentrations c yield the phase coherence length L_φ which exhibits a minimum at $c \approx 100$ ppm. Above this concentration which marks the onset of a spin-glass state below 0.2 K, L_φ depends on the magnetic field range, rising to nearly the $c = 0$ value for $B \in [9.5,\ 12.5\ \mathrm{T}]$ and leveling-off at a much lower value for $B \in [0,\ 3\ \mathrm{T}]$. These results demonstrate the recovery of phase coherence due to spin-glass correlations and a strong magnetic field.

Keywords: Mesoscopics; Phase coherent transport; Spin-glasses; Spin scattering

Universal conductance fluctuations (UCF) arising from quantum interferences between different electron paths [1] can be used to probe the complex frozen magnetic order in metallic spin-glasses [2,3]. Here we report on UCF in Cu : Mn nanocontacts with a Mn concentration c between 31 and 920 ppm, encompassing the transition from the single-impurity regime to the spin-glass state. We estimate the spin-glass temperature for our thin samples $T_f = 0.06$, 0.43 and 1.08 K for 31, 315 and 920 ppm Mn, respectively [4].

The samples were fabricated by electron-beam lithography followed by flash-evaporation and lift-off in a two-lead geometry. The contact width w varies between 60 and 480 nm, and the length L between 100 and 2000 nm. The Cu : Mn films (thickness 10–20 nm) were mounted within the mixing chamber of a ^{3}He–^{4}He dilution refrigerator with a base temperature of $T \approx 0.05$ K.

A typical $R(B)$ curve is shown in Fig. 1a. The sample with $c = 920$ ppm exhibits a resistance (R) maximum at $B = 0$. The negative magnetoresistance (MR) arises from the suppression of spin–flip scattering by the magnetic field B. The resistance fluctuations δR obtained from the $R(B)$ data by subtracting the negative MR using a spline fit, yield the conductance fluctuations $\delta G = -\delta R / R_{\mathrm{meso}}^2$, where R_{meso} is the resistance of the nanobridge, i.e. the contribution of the contact leads subtracted from R ($R_{\mathrm{meso}} = 17.7\ \Omega$ for the sample of Fig. 1). Fig. 1b shows δG whose amplitude increases with the magnetic field. $\delta G(B)$ fluctuates on a magnetic-field scale B_c which is determined by the magnetic flux $\phi_0 = B_c A_\varphi$ through a phase-coherent region A_φ where $\phi_0 = h/e$. A_φ is bounded by the width w of the sample and the phase coherence length L_φ if $w < L_\varphi < L$ [1]. Therefore, L_φ may be estimated from the correlation field $B_c = \phi_0 / w L_\varphi$ which corresponds to the HWHM of the autocorrelation function of $\delta G(B)$ [1]. This simple relation has been verified for Au and Ag nanowires of widths between 45 and 340 nm [5]. Combining the results of B_c for samples with the same c but different w, a linear fit B_c versus w^{-1} gives an estimate for L_φ.

We calculated a low-field ($B \leqslant 3$ T) and a high-field ($B \geqslant 9.5$ T) B_c for the different samples, yielding L_φ (cf. Fig. 2). The large error in L_φ is caused by the small number of samples (2–4) for each c as well as an uncertainty in the data analysis due to the restricted field range. Furthermore, the simple relation $B_c \sim L_\varphi^{-1}$ may be violated by up to 20% in the case of spin–orbit scattering [6].

Two regimes in Mn concentration can be distinguished: $c \lesssim 84$ ppm and $c \gtrsim 315$ ppm. $L_\varphi \approx 750$ nm for the nominally pure Cu sample is in good agreement with previous results for Au and Ag [5]. A small amount of magnetic impurities reduces L_φ by a factor of two:

* Corresponding author. Physikalisches Institut, Universität Karlsruhe, D-76128 Karlsruhe, Germany

E-mail address: H.vL@phys.uni-karlsruhe.de (H. v. Löhneysen)

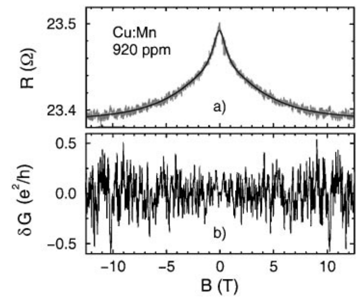

Fig. 1. (a) Magnetoresistance $R(B)$ of a Cu : Mn sample with width $w = 150$ nm and length $L = 1730$ nm at a temperature of $T = 0.05$ K. The solid line is a spline fit to the data to determine the background $R(B)$. (b) Conductance fluctuations δG as defined in the text.

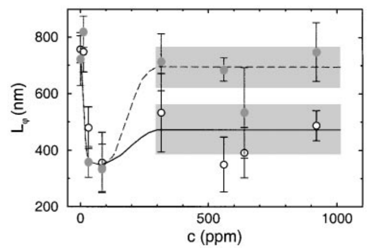

Fig. 2. Phase-coherence length L_φ as a function of Mn concentration c. L_φ was calculated for $B \leqslant 3$ T (open symbols) and for $B \geqslant 9.5$ T (closed symbols). The shaded areas mark the 2σ width of the average L_φ calculated for $c > 315$ ppm.

$L_\varphi \approx 350$ nm for $c = 31$ ppm and 84 ppm. We interpret this result as a signature of an enhanced spin-scattering rate resulting in additional dephasing of the electrons. Even at high magnetic fields spin fluctuations can occur, therefore no increase of L_φ with B is observed. If c exceeds ~ 315 ppm, L_φ exhibits a significant B dependence. Averaging L_φ over the four different Mn concentrations $c \geqslant 315$ ppm yields $\bar{L}_\varphi \approx 470$ nm ($B \leqslant 3$ T, solid line) and ≈ 700 nm ($B \geqslant 9.5$ T, dashed line). The latter value is close to L_φ for the undoped Cu sample suggesting the complete suppression of spin-scattering in high magnetic field. A similar B dependence of L_φ was observed previously in Cu : Mn rings with $c = 1000$ ppm [3].

The qualitative picture emerging from our measurements, i.e. the recovery of L_φ in a high field *and* at high Mn concentrations while neither B nor c alone leads to a strongly enhanced L_φ with respect to the minimum around 100 ppm, needs to be investigated in more detail both theoretically and experimentally. Measurements with four-lead geometry to test the time-reversal behavior are in progress.

Acknowledgements

This work was performed within the research program of SFB 195 supported by the DFG.

References

[1] P.A. Lee et al., Phys. Rev. B 35 (1987) 1039.
[2] S. Feng et al., Phys. Rev. B 36 (1987) 5624.
[3] P.G.N. de Vegvar et al., Phys. Rev. Lett. 66 (1991) 2380.
[4] G.G. Kenning et al., Phys. Rev. B 42 (1990) 2393.
[5] E. Scheer et al., Physica B 218 (1996) 85.
[6] V. Chandrasekhar et al., Phys. Rev. B 42 (1990) 6823.