Magnetoresistance of Hydrogen-Doped Zr_2Ni Metallic Glass

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(Received 18 November 1986)

We report the results of magnetoresistance measurements on amorphous hydrogen-doped Zr_2Ni samples and compare them with the current theoretical concepts based on weak localization in three-dimensional systems in the presence of strong spin-orbit interaction. We find that the hydrogen dopant strongly suppresses the spin-orbit and the Maki-Thompson contributions to magnetoresistance.

PACS numbers: 72.15.Gd, 71.55.Jv

In the last few years numerous experiments have demonstrated anomalous magnetoresistance in quasi two-dimensional films[1-6]; a few measurements are also available on three-dimensional systems, particularly amorphous ones.[7-9] The results are reasonably well understood in terms of weak localization[10,11] and electron-electron interactions.[11] In this paper we report the results of anomalous magnetoresistance measurements on a number of hydrogen-doped samples of Zr_2Ni metallic glass.

The samples were prepared by the conventional single-wheel melt-spinning technique and were doped with hydrogen in different concentrations by means of an electrolytic method.[2] The dopant concentrations were verified by the use of a previously established relationship between the gain in resistance and the volumetrically determined hydrogen absorption.[12] Magnetoresistance measurements were carried out with the use of a superconducting magnet with samples mounted on an orientable holder contained in a separate He bath. The temperature range covered was from 1.7 to 4.2 K in magnetic fields up to 6 T. The results are shown in Figs. 1 and 2. We observe a decrease of anomalous magnetoresistance with increasing temperature, in accordance with earlier experiments on similar systems,[8] and its independence of sample orientation as expected. The magnetoresistance slopes are lowered by the dopant and the

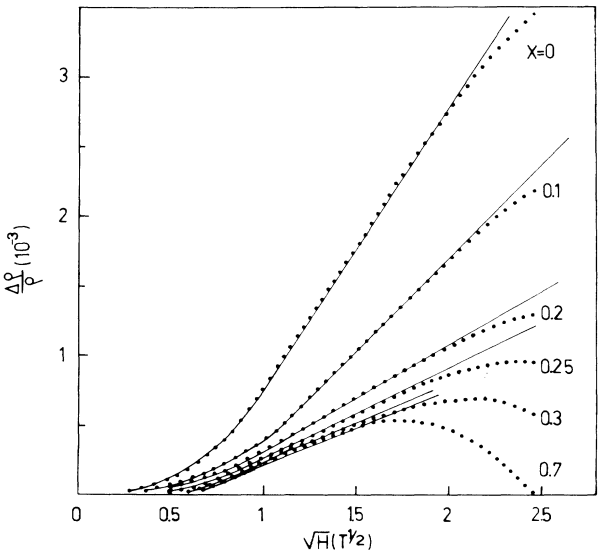

FIG. 1. Anomalous magnetoresistance of hydrogen-doped Zr_2NiH_x glasses at 4.2 K. Curves fitted to the data are calculated by use of relation (1).

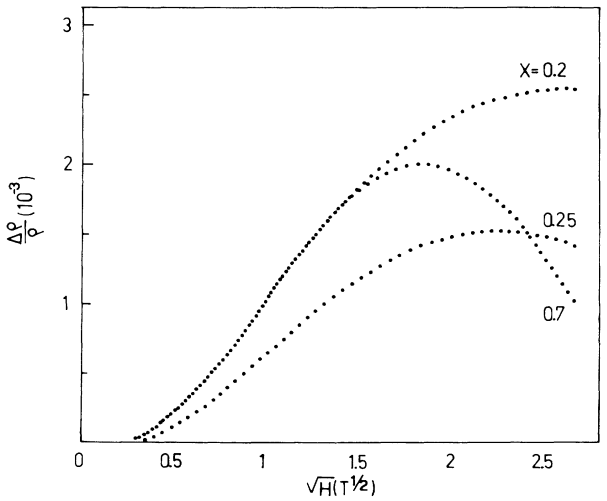

FIG. 2. Magnetoresistance data taken with the same samples as in Fig. 1 but at 1.7 K.

saturation is shifted to lower fields.

We have analyzed our data semiquantitatively using the theoretical model of Altshuler *et al.*[13] The contribution of quantum interference to the anomalous magnetoresistance pertaining to a three-dimensional system[13,14] in the presence of spin-orbit scattering and superconducting fluctuations can be expressed as

$$\Delta\sigma(H)=(e^2/2\pi^2\hbar)(eH/\hbar c)^{1/2}[\tfrac{3}{2}f_3(4DeH\tau'/\hbar c) - (\tfrac{1}{2}+\beta)f_3(4DeH\tau_\phi/\hbar c)], \quad (1)$$

where $1/\tau'=1/\tau_\phi+2/\tau_{s.o.}$ and $D=\frac{1}{3}v_F^2\tau$. Here we denote by τ and $\tau_{s.o.}$ the electron relaxation times for elastic and spin-orbit scattering, respectively, and by τ_ϕ the electron phase-coherence time. The function $f_3(x)$ is defined in Ref. 13. The factor β in (1) is related to the suppression of superconducting fluctuations and in its asymptotic form is given[13] (for small fields, $H/T \ll \pi k_B/2De$) as

$$\beta(T)=\begin{cases} -\frac{1}{4}\pi^2 g(T) & \text{for } -g(T)\gg 1, \\ \frac{1}{6}\pi^2 g^2(T) & \text{for } |g(T)|\ll 1, \end{cases} \quad (2)$$

where $g(T)$ is the interaction constant for the Maki-Thompson correction.[13] In its field-independent form it is given as $g^{-1}=-\ln(T/T_c)$.

The solid curves fitted to the experimental data in Fig. 1 are derived on the basis of relation (1). We have assumed that corrections due to the electron-electron interactions in the diffusive channel are small for the temperature region explored, as has been observed by others.[8] The values of $\beta(T)$ as determined experimentally by fitting expression (1) to the data are plotted as a function of the dopant concentration in Fig. 3. The lowering of the value of $\beta(T)$ is in agreement with observed lowering of the superconducting transition temperature by the dopant.[12]

The dependence of β on temperature has been calculated on the basis of superconducting transition temperatures obtained in earlier measurements and from the results of Mizutani, Ohta, and Matsuda[15] by our using a procedure outlined in Ref. 13 and also in a paper by Larkin.[16] These results, pertaining to the low-field limit, are given in Fig. 4, together with our experimental points obtained from the best-fit curves shown in Fig. 1.

The influence of the hydrogen dopant can be explained by recalling earlier results on the resistivity.[12] The increase in the temperature coefficient of resistivity shows that hydrogen enhances localization by providing additional centers of quasielastic scattering, thus reducing the effective electron diffusion constant. The results of the present experiment affirm this even more explicitly; the best-fit curves in Fig. 1 give values of D and τ_ϕ which decrease with rising hydrogen concentration. Soft-x-ray spectroscopy measurements[17] show that hydrogen locates in Zr-rich sites and hybridizes with the Zr d band. It reduces the d-band density of states at the Fermi level. Since most of the spin-orbit scattering occurs at Zr sites, the hydrogen reduces the effective spin-orbit contribution to the magnetoresistance.

We also notice in Figs. 1 and 2 that at 1.7 K the curve pertaining to the highest hydrogen concentration ($x=0.7$) rises much faster in relation to the other two curves ($x=0.2$ and $x=0.25$). This significantly different behavior of the $x=0.7$ curve can be accounted for by the fact that the hydrogen first occupies Zr-rich sites before moving to Zr-poor ones, which begins to happen at $x\gtrsim 0.4$.[18,19] At this point a two-level system may form whose states "freeze" at low temperatures. (A dip in the specific-heat curves of similar alloys at high hydrogen concentration[15] may be taken as further evidence for the existence of a two-level system.) This reduces inelastic scattering and enhances the electron localization. An alternative explanation of the behavior of the $x=0.7$ data in terms of a higher Maki-Thompson contribution must be discarded since the factor $\beta(T)$ tends to level out at high values of x (Fig. 3).

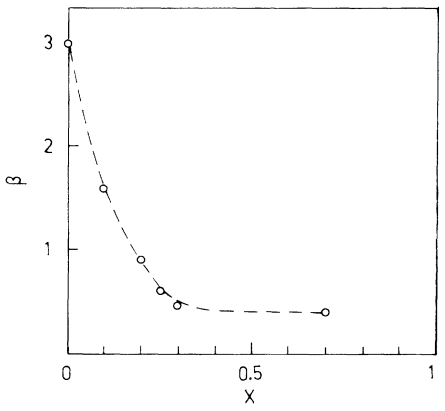

FIG. 3. Parameter $\beta(T)$ plotted as a function of hydrogen concentration x.

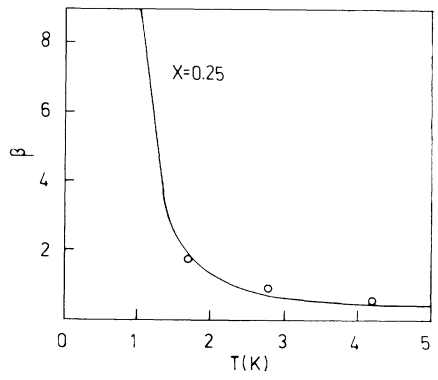

FIG. 4. Parameter $\beta(T)$ plotted as a function of temperature T (in kelvins).

In order to study the character of two-level systems in highly doped samples we plan to obtain very accurate low-field data at temperatures lower than those used in the present experiment.

We conclude by affirming that hydrogen is a good atomic probe to study quantum interference at defects in highly disordered systems in which specific features of topology are revealed by preferential location of the dopant atoms.

We are indebted to Dr. J. Cooper and Dr. A. Hamzić for generous help with the apparatus in the initial stages of the experiment. The experimental project was supported in part by the U.S. National Bureau of Standards through funds made available to the U.S.–Yugoslav Joint Board on Scientific and Technological Cooperation.

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