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LETTER TO THE EDITOR

Magnetoresistance of $Fe_xNi_{80-x}Cr_{20}$ ($50 \leqslant x \leqslant 66$) and $Fe_{25}Cr_{75}$ alloys

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Abstract. We have measured longitudinal and transverse magnetoresistance (MR) of crystalline pseudo-binary alloys $Fe_xNi_{80-x}Cr_{20}$ ($50 \leqslant x \leqslant 66$) and the binary alloy $Fe_{25}Cr_{75}$. Both the alloy systems have complex magnetic phases because the alloys have compositions close to the critical composition regime for ferromagnetism. While the Fe–Ni–Cr alloys have a FCC γ-phase, the binary Fe–Cr alloy has a BCC α-phase. This gives an opportunity to compare magnetoresistances for γ-phase and α-phase Fe alloys when they lie close to the critical composition. The experiments were conducted at 4.2 K with magnetic fields up to 7 T. We observed that all the alloys show negative magnetoresistance at 4.2 K in fields up to 7 T. However, for the γ-phase alloys the typical maximum MR ($\Delta\rho/\rho$) is about 1%, while for the α-phase alloy it is 10%. In the γ-phase alloys there is a small but finite anisotropy of MR in the phases with long-range magnetic order which gradually vanishes near the critical region ($x = x_c \simeq 59$–63) when it becomes a spin glass. In the range $x \simeq x_c$, $\Delta\rho/\rho \propto M^n$ (M = magnetization) with $n \simeq 2$.

The alloys of the pseudo-binary system $Fe_xNi_{80-x}Cr_{20}$ and the binary system Fe_xCr_{100-x} undergo magnetic transformations at low temperature as x is varied. The magnetic phase diagrams of these systems have been well studied [1, 2, 3]. By varying x, Fe–Ni–Cr alloys can be transformed from long-range ordered ferromagnetic (FM) to long-range antiferromagnetic (AFM) phases through spin-glass (SG) and re-entrant spin-glass (RSG) phases. In all these phases they retain the FCC γ-phase structure. The electrical resistivities $\rho(T)$ of these alloys (Fe–Ni–Cr) at low temperatures show resistivity minima at temperatures $T_{min} \simeq 6$–11 K [4]. The low-temperature rise in $\rho(T)$ below T_{min} has a $T^{1/2}$ dependence and is believed to arise from the quantum correction to conductivity due to electron–electron interactions [4]. In contrast to Fe–Ni–Cr alloys, Fe_xCr_{100-x} alloys have a BCC α-phase and as x is varied the alloys show FM to AFM phase changes with exotic low-temperature magnetic phases (including a spin-glass phase) for $x \simeq 30$–10 [3]. We have chosen an alloy with composition $Fe_{25}Cr_{75}$ which has a $T_c \simeq 150$ K and a lower-temperature transition to a re-entrant phase at $\simeq$20 K. Electrical resistivities and magnetic properties have been studied in these alloys [1, 4–7]. However, to our knowledge there are no reports on the magnetoresistance (MR) of these alloys up to moderately high fields and down to liquid He temperatures. Recently, Nath and Majumdar [5] have reported MR studies on γ-phase Fe–Ni–Cr alloys of similar composition for $T > 10$ K and fields up to 1.8 T. In this letter we report preliminary measurements of MR in these alloys at 4.2 K with fields up to 7 T. The important feature in this report is the comparison of the MR for γ-phase and α-phase Fe alloys near the critical composition where they exhibit exotic magnetic phases.

To start with, we note that while γ-phase Fe–Ni–Cr alloys show resistivity minima, the α-phase $Fe_{25}Cr_{75}$ alloy does not show any rise in $\rho(T)$ until the lowest temperature

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measured (0.4 K) is reached [6, 7]. In this work we measured the MR for both longitudinal and transverse configurations. For longitudinal MR ($\Delta\rho_{\parallel}/\rho$), applied current and field are in the same direction, and for transverse MR ($\Delta\rho_{\perp}/\rho$), the current and field are perpendicular to each other. Details of sample preparation have been given elsewhere [4, 6]. The resistance was measured using a high-precision four-probe AC bridge (20 Hz) with a PC/XT-based automatic data acquisition programme [7]. The nominal sensitivity of the bridge is better than 40 ppm, i.e. one can measure a change to within 4 nΩ cm for a typical resistivity of $\simeq$100 $\mu\Omega$ cm using a measuring current of 1.5 mA. It may be noted that the changes in resistance are extremely small and high precision is needed to measure them. We will also see that this allows us to measure the small but finite anisotropy in the MR.

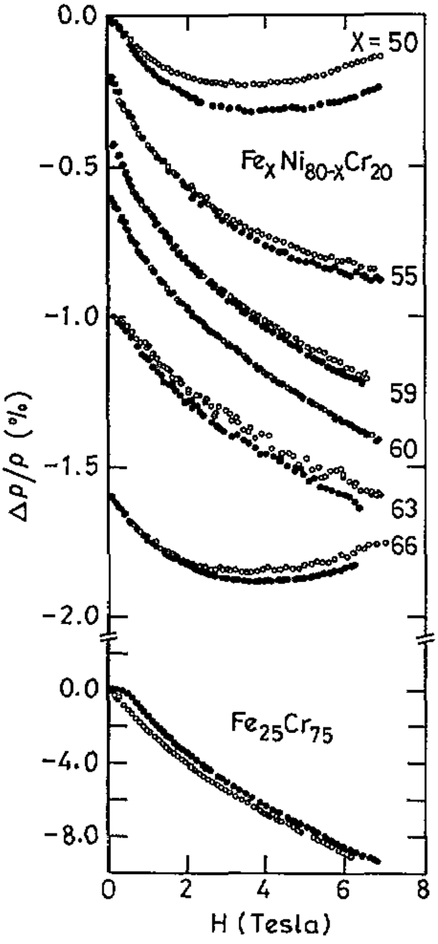

Figure 1. Longitudinal (○) and transverse (●) magnetoresistance as a function of magnetic field for six representative compositions of $Fe_xNi_{80-x}Cr_{20}$ and $Fe_{25}Cr_{75}$ at 4.2 K. (Note that data have been shifted for clarity, and also note the different scale for the $Fe_{25}Cr_{75}$ alloy.)

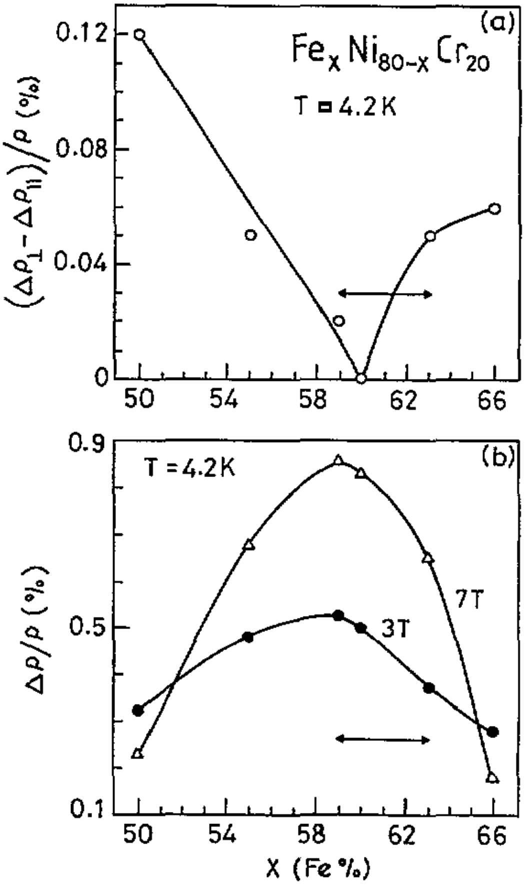

Figure 2. (*a*) Anisotropy $(\Delta\rho_{\perp} - \Delta\rho_{\parallel})/\rho$ versus Fe concentration (x) for $Fe_xNi_{80-x}Cr_{20}$ at 4.2 K. (*b*) Dependence of transverse magnetoresistance $\Delta\rho_{\perp}/\rho$ at 3 T (●) and 7 T (△) versus Fe concentration (x) for $Fe_xNi_{80-x}Cr_{20}$ at 4.2 K. In both figures the arrows indicate the critical region.

In figure 1 we have shown longitudinal and transverse MR ($\Delta\rho/\rho = (\rho(H)-\rho(0))/\rho(0)$)

for all the alloys. All the samples of the Fe–Ni–Cr series show negative MR at 4.2 K for both longitudinal and transverse modes. Interestingly, a small but finite anisotropy is noted in the alloy ($x = 50$) which has a FM phase. This anisotropy vanishes as we move progressively closer to the composition where FM vanishes ($x = x_c \simeq 59$–63). The anisotropies $(\Delta\rho_\perp - \Delta\rho_\parallel)/\rho(0)$ versus Fe concentration for the Fe–Ni–Cr series at 7 T and 4.2 K are shown in figure 2(*a*). The alloys with $x \simeq x_c$ show isotropic MR within the resolution of our experiment. A typical MR for this series is within 1%.

In contrast to the Fe–Ni–Cr system, $Fe_{25}Cr_{75}$ shows strong negative MR of 10%. This is greater than that of γ-Fe systems by one order of magnitude. Two points are worth noting in the data for these alloys. First, there is a small positive rise in the transverse MR near zero field which is reproducible. Second, there is a small anisotropy, but $|\Delta\rho_\perp| < |\Delta\rho_\parallel|$, unlike in the Fe–Ni–Cr alloys where $|\Delta\rho_\perp| > |\Delta\rho_\parallel|$.

In figure 2(*b*) the values of $\Delta\rho_\perp/\rho$ at 3 T and 7 T are plotted against Fe concentration for the Fe–Ni–Cr system. We observe maximum fractional change $(\Delta\rho_\perp/\rho)$ in the spin-glass region ($x \simeq x_c$). We note that though the MR in γ-Fe alloys is small and (nearly) isotropic, there is a definite trend with composition and/or magnetic ordering as one traverses the critical region.

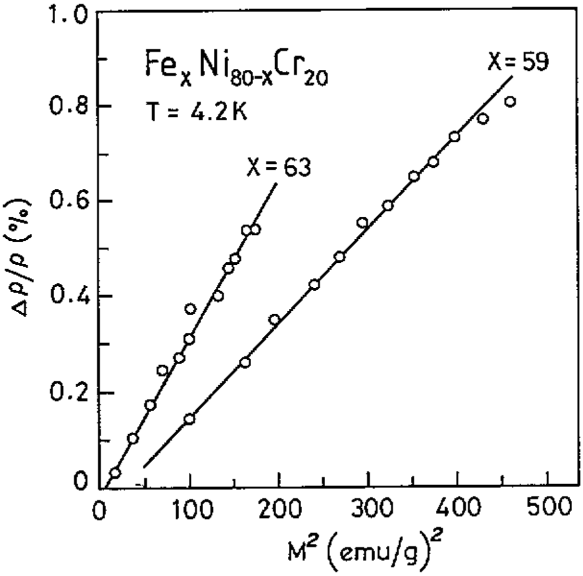

Figure 3. Transverse magnetoresistance $\Delta\rho_\perp/\rho$ versus M^2 for $x = 59$ and $x = 63$ for $Fe_xNi_{80-x}Cr_{20}$ at 4.2 K.

We now make brief comments on the magnetization (M) dependence of the MR in these alloys. We use the available magnetization data at 4.2 K for these alloys [1] which were obtained from the same samples down to a field of 6 T. We note that for Fe–Ni–Cr alloys with $x \simeq x_c$, the MR $\Delta\rho/\rho \propto M^n$ where $n \simeq 2$. This is shown in figure 3 where we show $\Delta\rho_\perp/\rho$ plotted against M^2. However, for FM and AFM phases, and also for the alloys with re-entrant spin-glass phases such dependence on M is not observed. This is a very important observation, because it shows that the MR of the re-entrant phases are more similar to that of the FM phase than to that of the spin-glass phase. For canonical spin-glass alloys (like AuFe) it is known that $\Delta\rho/\rho \propto M^2$ with $n = 2$ [8,9]. Our observation shows that the alloys lying at the critical region ($x \simeq x_c$) have a low-temperature phase quite similar to a canonical spin-glass phase. Similar observations have been made by Nath and Majumdar [5]. (Note: at high temperatures ($T > 100$ K), alloys with $x = 57$ show a positive MR [5].)

We find that for alloys having long-range order ($x = 50$ and 66) there is a positive contribution to MR which makes a dominant contribution at high field. It can be seen that the MR for these alloys show minima as a function of the field. In contrast, the MR of the Fe–Cr system has no such contribution. It is interesting to note that the MR of $Fe_{25}Cr_{75}$ (polycrystalline alloy) shows similar behaviour to that of Fe–Cr multilayers with antiferromagnetic interlayer coupling [10]. This large MR (often referred to as giant MR) has also been observed in granular metallic Fe–Ag [11] and Co–Ag [12] systems.

In conclusion, we observe that near the critical region ($x \simeq x_c$) there is no anisotropy in magnetoresistance and $\Delta\rho/\rho$ is roughly proportional to M^2 for γ-Fe alloys. An upturn in the negative MR as a function of the field for γ-Fe alloys occurs in the long-range ordered phases (both FM and AFM) and also the anisotropy is maximum in these phases. The α-Fe alloy exhibits strong negative MR which is an order of magnitude greater than that of γ-Fe alloys. A thorough study of MR at higher fields and of its temperature dependence is in progress.

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