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Electrical transport in amorphous Fe-Mn-Zr alloys

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The magnetic and electrical transport properties of amorphous Fe-Zr based alloys with compositions near 10 at. % Zr with various elements substituted for Fe are of particular interest. In the case of Mn substitutions the Curie temperature and the average magnetic moment decrease monotonically with increasing Mn content and the temperature dependence of the magnetization is significantly modified. The electrical transport properties of amorphous $Fe_{90-x}Mn_xZr_{10}$ (for $x=0$, 4, 8, and 12) over the temperature range of 4.2–300 K and the magnetoresistance for fields up to 4.0 T at 4.2 K are reported in the present work. A broad minimum in the resistivity is observed at around 255, 235, 200, and 180 K for the four compositions, respectively. In the case of the $x=8$ sample a second minimum occurs at around 50 K. The magnetoresistance of all samples shows a sharp increase for small fields and a linear field relationship for fields above about 0.1 T.

I. INTRODUCTION

The amorphous FeZr (a-FeZr) alloys with compositions near 10 at. % Zr form an interesting disordered magnetic phase. A variety of unusual properties, e.g., small Fe moment, low Curie temperature (T_C), a large high field susceptibility, etc., have been observed in these materials. The replacement of Fe with other $3d$-transition metals (TM) can introduce significant changes in the magnetic properties. In particular Mn substitutions[1] have the following effects on a-FeZr: (1) a monotonic decrease in T_c with increasing Mn content, (2) a large high field susceptibility for alloys with up to at least 10 at. % Mn, and (3) re-entrant behavior of the initial susceptibility for samples with Mn content up to at least 10 at. %.

As the Mn substituted alloys show re-entrant magnetic behavior over a wide range of compositions, i.e., 0–10 at. % Mn, these samples are a suitable means for investigating the details of the magnetic transitions in amorphous ferromagnets.[2,3] Few magnetic and electronic transport studies have been reported for Mn substituted a-FeZr alloys and these do not allow for well-defined conclusions concerning the inter-relationship of magnetism and electronic properties. In the present work we report the results of a detailed investigation of resistivity and magnetoresistance of a-$Fe_{90-x}Mn_xZr_{10}$ alloys over the temperature range of 4.2–300 K. Particular emphasis is placed on the regions near magnetic phase transitions with the idea of improving our understanding of the effects of magnetic interactions on electron scattering mechanisms.

II. EXPERIMENTAL METHODS

Amorphous alloys of the composition $Fe_{90-x}Mn_xZr_{10}$ with $x=0$, 4, 8, and 12 were prepared by arc melting high purity elemental components followed by quenching from the melt on to a single Cu roller in an argon atmosphere. X-ray diffraction patterns obtained using Cu $K\alpha$ radiation confirmed the amorphous nature of all as-prepared ribbons. The magnetic properties of the alloys were characterized by standard ac susceptibility measurements and will be presented in detail elsewhere.[4] Four-point resistivity and magnetoresistance measurements were carried out over the temperature range of 4.2–300 K in applied magnetic field from 0 to 4.5 T using standard dc techniques.

III. RESULTS AND DISCUSSION

The temperature dependence of the reduced electrical resistivity, $\rho(T)/\rho(300\ K)$ for the a-$Fe_{90-x}Mn_xZr_{10}$ samples is illustrated in Fig. 1. The magnetic data (observed T_C) and the resistivity data (T_{min}) of this series of alloys is shown in Fig. 2. It is clear from the figures that

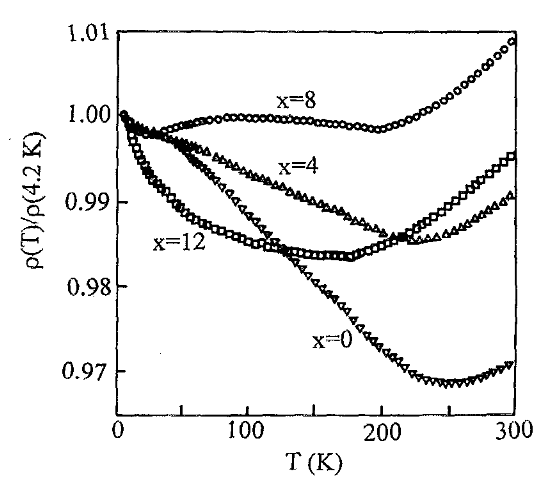

FIG. 1. $\rho(T)/[\rho(4.2\ K)]$ as a function of temperature for a-$Fe_{90-x}Mn_xZr_{10}$ with $x=0$, 4, 8, and 12.

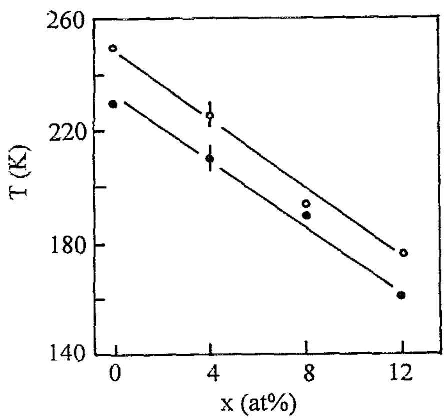

FIG. 2. T_{min} (○) and T_C (●) as a function of Mn concentration (x) for a-$Fe_{90-x}Mn_xZr_{10}$.

(1) all samples show a resistivity minimum at a temperature (T_{min}) near T_C,
(2) both T_C and T_{min} decrease by about 30% as x increases to 12 at. %,
(3) in the case of $x=0$ and $x=4$ a small anomaly in the resistivity at low temperatures (~20 K) is observed,
(4) a second minimum is observed at low temperatures for 8 at. % of Mn and a broad minimum is observed in the case of 12 at. % of Mn alloy.

These observations suggest that the resistivity minimum around T_C is closely correlated to the magnetic behavior. This is in agreement with the results of studies of pressure effects on T_C and T_{min} in similar alloys.[5]

Magnetoresistance data provide information about the microscopic magnetization and can aid in the understanding of the relationship between magnetic interactions and electron scattering mechanisms. Spin disorder scattering and the Kondo effect (in the case of dilute magnetic alloys) can account for the differences between the zero field and the infield resistivity. This scattering is expected to be sensitive to magnetic ordering on a distance scale comparable to the electron mean free path in the alloys. On the other hand, the coherent-exchange scattering (CES) model, which is well suited to magnetic systems, takes into account the contribution to resistivity from coherent exchange scattering by neighboring ions and predicts that the change in resistivity due to magnetic ordering is either positive or negative depending on whether the interference between the scattered waves is constructive or destructive.

In order to determine the effects of an applied magnetic field on the resistivity minimum, we have carried out temperature dependent resistivity measurements in external fields of 0.7 and 4.0 T. Figure 3 illustrates that there is a shift in T_{min} as the applied field is increased. It is also evident that the external field suppresses the minimum. Transverse and longitudinal magnetoresistance measurements were carried out in a field of 4.5 T at 4.2 K and the results for samples with $x=0$, 4, 8, and 12 are shown in Fig. 4. The magnetoresistance increases monotonically with applied field and the slope is observed to be positive for both geometries. It is also

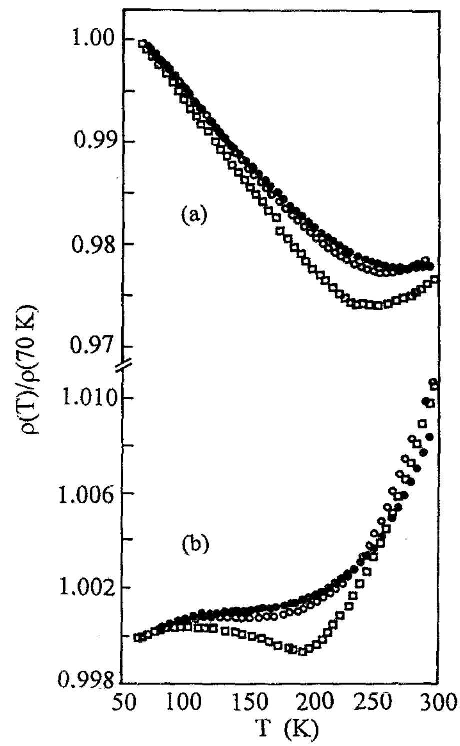

FIG. 3. Normalized resistivity, $\rho(T)/[\rho(70\text{ K})]$, as a function of temperature for a-$Fe_{90-x}Mn_xZr_{10}$ with (a) $x=0$ and (b) $x=8$ for different values of the applied magnetic field: 0 T (■); 0.7 T (○); and 4.0 T (●).

seen that the magnitude of the spontaneous resistive anisotropy decreases with increasing Mn concentration. The technical saturation is achieved at lower applied field values in the longitudinal mode than in the transverse case and this is an indication that the domain rotation process occurs at lower fields for the longitudinal geometry.

The present materials are concentrated magnetic alloys and variations in the exchange interaction between localized

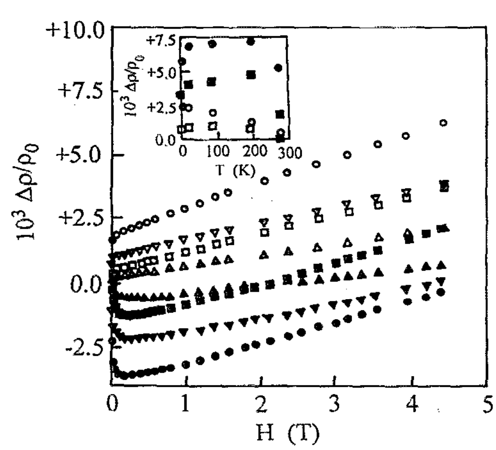

FIG. 4. $\Delta\rho/\rho_0=[\rho(H,T)-\rho(0,T)]/[\rho(0,T)]$ as a function of applied magnetic field for $x=0$ (●,○); $x=4$ (▼,▽); $x=8$ (■,□); and $x=12$ (▲,△). Closed symbols represent the transverse mode and open symbols represent the longitudinal mode. Inset: magnetoresistance as a function of temperature for $x=0$ (closed symbols) and $x=8$ (open symbols) in an applied field of 0.7 T (□,■) and 4.0 T (○,●).

moments at the first nearest-neighbor distance will result in the formation of regions of short range ferromagnetic and antiferromagnetic order. The large values of high field susceptibility which have been observed for the present series[1] have been interpreted in terms of weakly coupled antiferromagnetic spins and are a prerequisite for the existence of a Kondo anomaly. However, the longitudinal magnetoresistance as measured in the present work is positive at all temperatures (see insert in Fig. 4 for $x=0$ and 8) and this is inconsistent with the assumption that T_{min} is due to Kondo behavior. It is also seen that the magnetoresistance shows a maximum at a temperature near T_C. Similar behavior has also been observed in rare earth-transition metal alloys[6] and has been attributed to the effects of coherent exchange scattering. The present results are, therefore, consistent with the CES model and it is suggested that the magnetic and electronic transport behavior observed for the series of a-$Fe_{90-x}Mn_xZr_{10}$ alloys can be explained on the basis of this model.

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