Ferromagnetism and spin-glass properties of *Pd*FeMn

D. W. Carnegie, Jr. and H. Claus
University of Illinois at Chicago Circle, Chicago, Illinois 60680
(Received 24 October 1978)

Low-field dc magnetization measurements on the ternary alloy $(Pd_{0.9965}Fe_{0.0035})_{0.95}Mn_{0.05}$ show that the decrease of the ac susceptibility below 3 K which previously had been attributed to a transition from the ferromagnetic to a spin-glass state is due simply to the onset of hysteresis in the magnetization. It is shown that the alloy remains ferromagnetic down to at least 1.8 K.

In a recent paper[1] it was reported that weakly ferromagnetic *Pd*FeMn alloys undergo a transition into a spin-glass state several degrees below the Curie temperature. Similar behavior has been reported for *Au*Fe alloys just above the ferromagnetic percolation limit.[2]

We report low-field dc magnetization measurements which clearly indicate that the structure in the magnetization previously thought to signal the transition from ferromagnetic to spin-glass state[1,2] is a normal behavior of a hysteretic ferromagnet. For the one alloy investigated, we show that the ferromagnetic state prevails down to the lowest temperature measured.

Initially, to reproduce earlier results,[1] we measured the ac susceptibility of a 1-mm diameter sphere of $(Pd_{0.9965}Fe_{0.0035})_{0.95}Mn_{0.05}$.[3] We used an induction method at 37 Hz with a driving field of 0.1 Oe peak to peak. The results shown in Fig. 1(b) (open circles) agree well with the earlier measurements.[1] The ac susceptibility χ_{ac} reaches the demagnetization limit of $1/N$ at about 8 K, typical of a ferromagnetic transition. The decrease in χ_{ac} below 3 K [Fig. 1(b)] has been interpreted as evidence for a transition into a spin-glass state.[1]

dc magnetization measurements at very low fields (0–50 Oe) were then performed, using a Foner-type vibrating sample magnetometer.

Figure 1(a) shows magnetization measurements at a constant field of 0.1 Oe with increasing (open circles) and decreasing (full circles) temperature. The first one, being very similar in shape to χ_{ac}, was measured after cooling the sample initially in zero field to the lowest temperature (the earth's magnetic field was compensated throughout the measurements with a pair of Helmholtz coils).

To characterize better the magnetic state of the alloy, we measured complete hysteresis loops at various temperatures. A schematic loop is shown in the inset of Fig. 1. The maximum slope of each loop $(d\sigma/dH_a)_{max}$ and the coercive force H_C are displayed in Fig. 1(b).

The loops open up gradually as T is lowered below $T_C = 8$ K, i.e., the coercive force [open squares in Fig. 1(b)] increases initially slowly with decreasing temperatures. Below about 3 K, however, there is a dramatic increase in the coercive force. The maximum slope $(d\sigma/dH_a)_{max}$ on the other hand remains temperature independent and equal to $1/N$ (N = demagnetization factor), indicating that the alloy remains ferromagnetic down to the lowest temperatures.[4]

The ac susceptibility which essentially measures the initial slope of the virginal magnetization curve (see

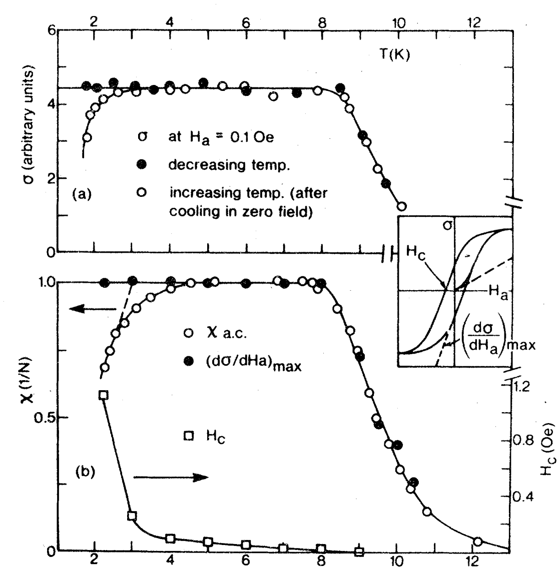

FIG. 1. Magnetic properties of $(Pd_{0.9965}Fe_{0.0035})_{0.95}Mn_{0.05}$. Upper part (a), magnetization at constant field vs temperature (increasing temperature after cooling in zero field). Lower part (b), ac susceptibilty χ_{ac}, $(d\sigma/dH_a)_{max}$, and coercive force vs temperature. Inset, schematic hysteresis loop defining $(d\sigma/dH_a)_{max}$ and coercive force, H_C.

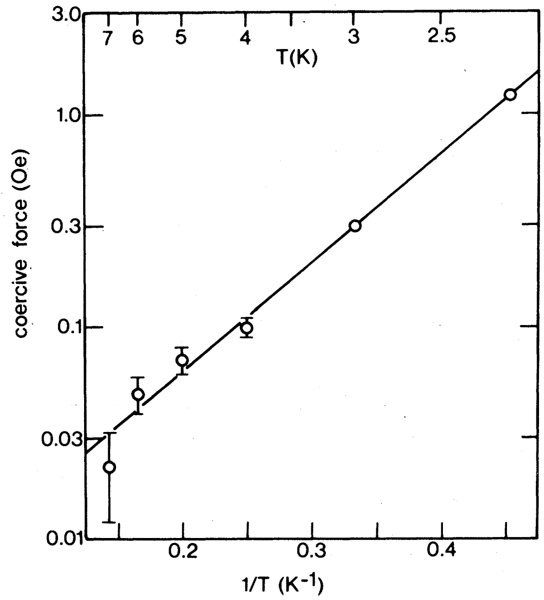

FIG. 2. Semilogarithmic plot of the coercive force vs reciprocal temperature $1/T$.

inset, Fig. 1) is expected to decrease as soon as the coercive force becomes significantly larger than the driving field of 0.1 Oe peak to peak, i.e., at about 3 K [see Fig. 1(b)]. The sudden increase in the coercive force below 3 K does not indicate any qualitative change in the magnetic state of the alloy. This is demonstrated in Fig. 2 where the logarithm of the coercive force H_C is plotted vs $1/T$. The straight-line behavior indicates that H_C simply follows an exponential law of the form $H_C \sim e^{T_0/T}$ ($T_0 = 5.1$ K) typical of any activation process.

In conclusion we have demonstrated that measurements of the ac susceptibility and/or of the magnetization at constant field are not sufficient to characterize the magnetic state of the alloy, instead, full magnetization curves should be measured. We have shown that the alloy $(Pd_{0.9965}Fe_{0.0035})_{0.95}Mn_{0.05}$ remains ferromagnetic down to our lowest temperatures without any indication of a transition into a spin-glass state as reported earlier.[1] Consequently, the proposed magnetic phase diagram of *Pd*FeMn[1] has to be corrected. Similar comments may apply to the *Au*Fe phase diagram.

ACKNOWLEDGMENTS

We are grateful to Professor J. A. Mydosh for the loan of the sample used and for many helpful discussions. This work was supported by the NSF under Grant No. DMR 76-22125.

[1]B. H. Verbeek, G. J. Nieuwenhuys, H. Stocker and J. A. Mydosh, Phys. Rev. Lett. 40, 586 (1978).

[2]See B. H. Verbeek and J. A. Mydosh, J. Phys. F 8, L109 (1978) and references therein.

[3]The alloy was kindly furnished by Professor J. A. Mydosh, see Ref. 1.

[4]A similar behavior of χ_{ac} and $(d\sigma/dH_a)_{max}$ was found for V-Fe alloys, H. Claus, Phys. Rev. Lett. 34, 26 (1975) and for Ni-Cu alloys, C. J. Tranchita and H. Claus, Solid State Commun. 27, 583 (1978).