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Electrical transport phenomena in amorphous (Hf, Ta)Fe₂ alloys

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Abstract

Electrical resistivity and high-field magnetoresistivity of vapor-quenched itinerant-electron ferromagnetic amorphous Hf_{1-x}Ta_xFe₂ alloys have been measured from 4.2 to 300 K and in fields up to 35 T at 4.2 K. The fractional change in resistivity at 4.2 K due to both Ta concentration and magnetic field has a linear dependence on $p_s/2(p_s/2 + 1)$, where p_s is the ferromagnetic moment in μ_B , particularly at low Ta concentrations.

Vapor-quenched amorphous (a-) Hf_{1-x}Ta_xFe₂ alloys show itinerant-electron ferromagnetic behavior with a systematic decrease of the Curie temperature T_C and the static ferromagnetic Fe moment p_s from a moderate spin amplitude for $x = 0$ to the weak limit for $x = 1$ in agreement with the Rhodes–Wohlfarth curve [1]. Recent thermal expansion measurements [2] show existence of the spontaneous volume magnetostriction induced by the ferromagnetic moment, suggesting another itinerant-magnetic character. Previously, we reported the electrical resistivity of this amorphous system and found that the fractional change in resistivity is almost proportional to p_s^2 at 0 K [3]. In order to establish the validity of this proportionality further, we present a systematic study of the refined electrical resistivity on this system for Ta concentration $x = 0, 0.3, 0.5, 0.7, 0.9$ and 1 in the temperature range 4 K < T < 300 K and the high-field magnetoresistance at 4.2 K in transverse fields up to 35 T.

Detailed sample preparation for vapor-quenched amorphous films with thickness of about 150 μm has been reported previously [1,4]. For the electrical resistivity measurements we prepared rectangular samples with a typical size of 15×1.5 mm² using a water-cooled carbon cutter. The refined resistivity was measured by using a standard four-probe ac method with lock-in detection. High-field magnetoresistivity measurements have been carried out at 4.2 K in semicontinuous transverse fields up to 35 T in the high magnetic field installation at the University of Amsterdam.

We have measured the temperature dependence of the resistivity $R(T)$ from 4.2 to 300 K for each Ta concentration using the ac method with an accuracy better than that of the previous data using a dc method [3]. However, the present reduced resistivity, $R(T)/R(300)$, data give intrinsically the same information as before and hence these data are not shown here.

Fig. 1 shows the reduced magnetoresistivity $\Delta R(B)/R$ at 4.2 K as a function of the applied field B for various Ta concentrations, where $\Delta R(B) = R(B, 4.2) - R(0, 4.2)$. An initial negative abrupt change in the magnetoresistivity has been clearly observed for $x \leq 0.7$. Its magnitude decreases with the Ta concentration and almost disappears for $x \geq 0.9$. We found from other magnetoresistivity measurements using a conventional magnet that the sharp negative change occurs just below T_C in a field of even less than 0.1 T. Above 0.3 T the magnetoresistivity becomes always

Fig. 1. Reduced magnetoresistivity $\Delta R(B)/R$ vs. applied magnetic field B at 4.2 K of amorphous Hf_{1-x}Ta_xFe₂ for various Ta concentrations.

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positive. Therefore, the negative resistivity change can be an effect of the disappearance of multi-magnetic-domain scattering of the conduction electrons due to the domain alignment by the small applied field.

In order to discuss the magnetic contribution, we subtract the resistivity of a-TaFe₂, which is paramagnetic down to 10 K, from the data for each Ta concentration, as $\Delta R(T)/R = R(T, x)/R(300, x) - R(T, x=1)/R(300, x=1)$. Then, we define the change in the reduced resistivity below T_C : $\Delta_C R(T)/R = \Delta R(T)/R - \Delta R(T_C)/R$, as we have done previously [3]. We tried to summarize all data of $\Delta_C R(4.2)/R$ and the reduced magnetoresistivity $\Delta R(B)/R$ at 4.2 K on the basis of the magnetization regarded as the sole dependent variable. The resulting resistivity change $\Delta_C R(4.2)/R + \Delta R(B)/R$ in various fields for each alloy is plotted in Fig. 2 as a function of $cp_s/2(p_s/2+1)$ with both Ta concentration x and field B as implicit parameters. Here, c is the Fe concentration and shows the small correction to 2 [1] for each alloy. p_s is the ferromagnetic moment of the Fe atom in the low-temperature limit [1] and that in the applied field obtained from the high-field magnetization measurements at 4.2 K at the University of Amsterdam [5]. As one can see in this figure, all the data scale with $cp_s/2(p_s/2+1)$, particularly in the region of low Ta concentration. This result suggests that the temperature dependence of the resistivity consists of two main contributions: one is the effect of the conduction-electron scattering by the non-magnetic amorphous structure, which is common to all the present alloys and almost independent of Ta concentration and field. The other is due to the magnetic scattering at the Fe site where the scattering potential is proportional to the static Fe moment p_s at 4.2 K, which is dependent on x and B . Such a scattering mechanism due to the disordered local moment has been proposed as an explanation of the resistivity of rare-earth-based amorphous alloys [6,7]. This model basically gives a good description for the present

Fig. 2. Change in the reduced resistivity at 4.2 K as a function of $cp_s/2(p_s/2+1)$ with Ta concentration and magnetic field as implicit parameters.

Fig. 3. Change in the reduced resistivity in zero field below T_C as a function of $cp_s/2(p_s/2+1)$ with Ta concentration and temperature as implicit parameters.

system except in the weak ferromagnetic limit as for $x=0.9$ and 1.

Fig. 3 shows the change in zero-field resistivity below T_C , $\Delta_C R(T)/R$, plotted as a function of $cp_s/2(p_s/2+1)$ with Ta concentration and temperature as implicit parameters. It is noticed that the data do not scale with $p_s/2(p_s/2+1)$. One of the explanations for this may be an effect of the evolution of the multi domain scattering above mentioned. In any way, the static local moment is not sufficient to describe the magnetic scattering in the present system either at finite temperature or in the weak magnetic limit. In these cases the disordered spin correlation should be carefully taken into account as has been done in finite-temperature itinerant-magnetic theories of amorphous alloys [8,9].

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