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Electric transport phenomena in amorphous \( \text{(Hf, Ta)} \text{Fe}_2 \) alloys

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**Abstract**

Electrical resistivity and high-field magnetoresistivity of vapor-quenched itinerant-electron ferromagnetic amorphous \( \text{Hf}_{1-x}\text{Ta}_x\text{Fe}_2 \) 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 \( \mu_B \), particularly at low Ta concentrations.

Vapor-quenched amorphous \( \text{(a-)} \text{Hf}_{1-x}\text{Ta}_x\text{Fe}_2 \) alloys show itinerant-electron ferromagnetic behavior with a systematic decrease of the Curie temperature \( T_C \) and the static ferromagnetic Fe moment \( p_F \) 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 \( p_S \) 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 \( \mu \text{m} \) has been reported previously [1,4]. For the electrical resistivity measurements we prepared rectangular samples with a typical size of 15 \( \times \) 1.5 mm\(^2\) 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

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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 
\( c_p/2(p_s/2 + 1) \) with both Ta concentration \( x \) and field 
\( B \) as implicit parameters. Here, \( c \) is the Fe concentration 
and shows the small correction to \( \frac{2}{3}p_s \) 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 we can see in this 
figure, all the data scale with \( c_p/2(p_s/2 + 1) \), 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 
orher 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

\[ \Delta_c R(4.2)/R \]

\[ \Delta R(B)/R \]

\[ \frac{c_p}{2}(p_s/2 + 1) \]

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

\[ \Delta_c R(4.2)/R + \Delta R(B)/R \]

\[ T = 4.2K \]

\[ c_p/2(p_s/2 + 1) \]

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

\[ \Delta_c R(T)/R \]

\[ \frac{c_p}{2}(p_s/2 + 1) \]

\[ T = 4.2K \]

\[ c_p/2(p_s/2 + 1) \]

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