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TEMPERATURE DEPENDENCE OF THE EXTRAORDINARY HALL EFFECT IN AMORPHOUS (FeCoNi)₇₈B₁₂Si₁₀ ALLOYS

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Abstract. – Temperature dependences of the extraordinary Hall coefficient R_s and resistivity ρ , yield $R_s \sim \rho^2$ (arising from the side-jump mechanism) for the majority of investigated FeCoNi-based alloys. The deviation from ρ^2 variation in Co-rich alloys is probably due to the temperature dependence of the magnetic anisotropy in these alloys.

One of the characteristic features of amorphous ferromagnetic alloys, as compared to the crystalline ones, is large extraordinary Hall effect. This is a direct consequence of the high resistivity ρ of these alloys. It is generally accepted [1, 2] that in strongly disordered transition metal alloys the main contribution to the extraordinary Hall effect comes from the side-jump mechanism [3] that leads to the ρ^2 dependence of the extraordinary Hall coefficient R_s . The experimental confirmation of this dependence is somewhat difficult in amorphous alloys because their resistivity, that is already large, changes only slightly with temperature, and the same holds for R_s too. Therefore very accurate determination of R_s is required in order to deduce the correlation between R_s and ρ . Here we report this correlation for amorphous Fe_xNi_{78-x}B₁₂Si₁₀, Fe_xCo_{78-x}B₁₂Si₁₀ and Co_xNi_{78-x}B₁₂Si₁₀ alloys. All our alloys are ferromagnetic with the Curie temperature T_c above 420 K except for Fe₂₃Ni₅₅B₁₂Si₁₀ and Co₃₉Ni₃₉B₁₂Si₁₀ alloys ($T_c=410$ and 390 K respectively).

The Hall resistivity ρ_H (in magnetic field up to 1 T) and electrical resistivity have been measured from 77 to 420 K. The details concerning the sample preparation and the measurement technique were reported earlier [4, 5]. The temperature variations of the resistivity were reported in reference [6]. The rather small cross section of our samples (typically 0.8×0.018 mm²) resulted in an uncertainty of about 10 % in the absolute value of ρ_H .

The initial slopes of the Hall resistivity as a function of magnetic field $R_H = (\Delta\rho_H/\Delta B)_{B=0}$ for all our alloys are of the order 10^{-8} m³ A⁻¹ s⁻¹. At the same time the normal Hall coefficient R_0 of the amorphous alloys is equal to or lower than the free electron value and is practically temperature independent. For our alloy systems R_0 is of the order 10^{-10} m³ A⁻¹ s⁻¹ and therefore we neglect its contribution to R_H . Hence R_H is practically equal to R_s ($\mu_0 \Delta M/\Delta B$)_{B=0} where M is

the magnetization of the sample. In the case of a thin Hall sample and isotropic material R_H is then equal to the extraordinary Hall coefficient R_s .

The concentration dependence of R_s for our alloys at room temperature is shown in figure 1. The data for amorphous Fe_xNi_{80-x}B₁₈Si₂ alloys from references [4, 5] are included in the same figure. We note a similar size and practically the same concentration dependence of R_s in two FeNi-based systems. The variation of R_s with x in FeCo-based alloys is also similar to that observed for homogeneous ferromagnetic FeNi-based alloys ($x \geq 15$). For ferromagnetic CoNi-based alloys we have not enough data to deduce the variation of R_s with x in this system. It would be misleading to correlate R_s and ρ values for different alloys because the differences in the band structure may influence R_s more than the resistivity does [3]. Therefore one has to investigate the temperature variations of ρ and R_s in order to deduce the actual dependence of R_s on ρ .

Fig. 1. – Concentration dependence of R_H in FeCoNi-based alloys.

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The temperature dependence of R_s in four alloys is shown in figure 2. A continuous increase of R_s with temperature was observed for all alloys. We note that the relative change of R_s in the temperature interval from 77 to 420 K is ranging from 10 to 15 % only. The behaviour of R_s in $\text{Fe}_{23}\text{Ni}_{55}\text{B}_{12}\text{Si}_{10}$ and $\text{Co}_{39}\text{Ni}_{39}\text{B}_{12}\text{Si}_{10}$ alloys as well as our previous data [4, 5] indicate that the extraordinary Hall coefficient does not change on passing through T_c . We consider that such behaviour of R_s is characteristic for FeCoNi-based amorphous alloys and possibly extends to other amorphous ferromagnets as well.

In order to obtain the correlation between R_s and ρ we plotted $\ln(R_s(T)/R_s(77\text{ K}))$ vs. $\ln(\rho(T)/\rho(77\text{ K}))$ and the results for three alloys are presented in figure 3. We note that the correlation systematically depends on the concentration of the alloys. In most of FeCoNi alloys R_s varies, through the explored temperature interval, as the square of the resistivity as predicted by theory [3]. In Co-rich alloys R_s increases with temperature significantly faster than ρ^2 and cannot be described by a single power law of ρ . However the deviation from the predicted ρ^2 dependence becomes smaller with increasing temperature and in the case of $\text{Co}_{39}\text{Ni}_{39}\text{B}_{12}\text{Si}_{12}$ alloy (Fig. 3) R_s varies almost as ρ^2 when temperature approaches T_c . The observed behaviour indicates that the assumptions of the same temperature dependence and equality between R_s and R_H may not be quite correct for Co-rich alloys. Although we have no detailed explanation for this observation we note that for magnetically anisotropic material $(\mu_0\Delta M/\Delta B)_{B=0}$ value is expected to be different from unity and temperature dependent. Even small temperature variation of $(\mu_0\Delta M/\Delta B)_{B=0}$ values can influence the determination of the actual R_s values from the ρ_H data only. In this case in order to obtain the exact correlation between R_s and ρ a detailed knowledge of the temperature and field dependences of magnetization is required.

In conclusion, an average ρ^2 dependence of R_s (consistent with the side-jump mechanism [3]) has been obtained for the majority of amorphous FeCoNi-based alloys. For Co-rich alloys R_s vs. ρ dependence cannot be described by a single power law. This behaviour is tentatively ascribed to the temperature dependence of the magnetic anisotropy which affects the determination of actual R_s values.

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Fig. 2. - Variation of R_H with temperature for four alloys.

Fig. 3. - $\ln R_H$ vs. $\ln \rho$ variation for three alloys.

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