HALL EFFECT IN FERRITES NEAR THE CURIE POINT

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The Hall emf was measured in nickel-zinc and manganese ferrites (both in polycrystalline and single-crystal specimens) in the vicinity of the Curie temperature. A new method for the determination of the ordinary Hall constant is proposed. The calculated values of the carrier density and mobility in the investigated ferrites conform in order of magnitude with the values obtained for nonferromagnetic semiconductors. The Hall emf is one order of magnitude greater in a single-crystal specimen of manganese ferrite than in a polycrystalline specimen.

1. INTRODUCTION

UNTIL now there have been very few works devoted to the study of the Hall effect in ferrites.[1,2] Yet, analysis of this effect is of great interest from the point of view of disclosing the nature of conductivity of ferrites and the interdependence of their magnetic and electric properties.

We have chosen to investigate the Hall effect near the Curie point because it is here that the spontaneous magnetization varies very abruptly, and consequently it is here that the influence of this change on the electric phenomena in ferrites should be most clearly pronounced. We have measured the temperature dependence of the Hall emf, of the electric resistance and of the spontaneous magnetization in nickel-zinc and manganese ferrites (in polycrystalline and single crystals specimens) within a temperature range close to the Curie point.

The electric resistance of the ferrites under study was not very high at these temperatures, and this allowed a dc measurement of the Hall emf by means of a PPTV-1 potentiometer. In order to obtain the exact value of the Hall current density, the sample was prepared by the Vol'kenshteĭn and Fedorov method:[3] a ferrite bar was cut in three (cf. Fig. 1). Thin mica wafers were placed between the parts and all three pieces were then glued together. Magnetization was measured using differential ballistic coils. The specimen was placed in a bifilar winding and inserted together with the winding inside the solenoid.

The primary Hall current was made to flow in the z direction through the whole shaded surface by means of contacts 1-1. The Hall emf was measured along the y axis (contacts 2-2). The contacts were in the form of silver layers deposited on the surface of the ferrite by firing-on a silver paste. The Hall current of 10 ma was within the range where Ohm's law was obeyed by the ferrites under study. Electromotive forces clearly dependent on the magnetic field were compensated by means of an additional difference of potentials. The measurements were taken with the specimen under vacuum. Under these conditions, the hysteresis of the specimen's electrical properties during the course of heating and cooling was negligible.

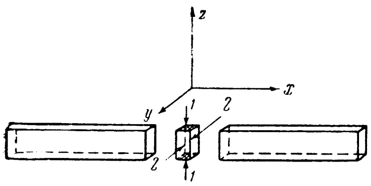

FIG. 1

2. NICKEL-ZINC FERRITE (37.5% NiO, 12.5% ZnO, 50% Fe_2O_3)

Figures 2 and 3 show the dependence of the Hall emf and of the magnetization on the magnetic field at different temperatures (Curie point ~ 40°C). The spontaneous magnetization I_s and the spontaneous Hall emf E_s in the vicinity of the Curie point were determined by the method of thermodynamic coefficients described previously.[4,5] The spontaneous (or ferromagnetic) Hall constant R_s, defined by the relation $E_s = R_s I_s$, decreased with increasing temperature and approached some constant value at the Curie temperature (cf. Fig. 4). Figure 5 shows the dependence of the constant R_s

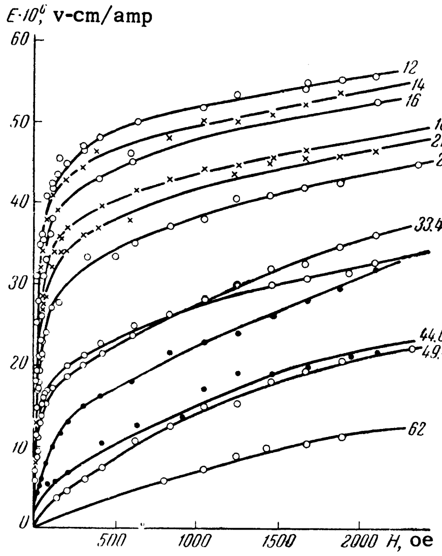

FIG. 2. Dependence of the Hall emf on the magnetic field in polycrystalline nickel-zinc ferrite at different temperatures (the numbers adjacent to the curves indicate °C).

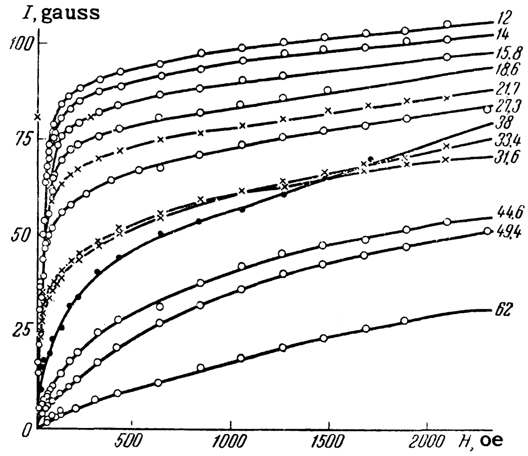

FIG. 3. Magnetization isotherms for nickel-zinc ferrite (the numbers adjacent to the curves indicate °C).

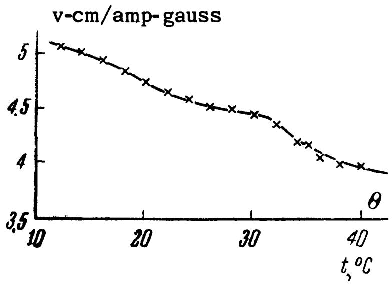

FIG. 4. Temperature dependence of the spontaneous Hall constant ($10^7 \cdot R_s$) for the nickel-zinc ferrite.

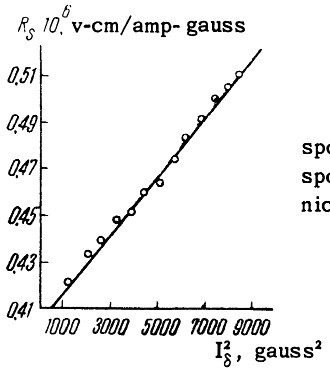

FIG. 5. Dependence of the spontaneous Hall constant on the spontaneous magnetization for nickel-zinc ferrite.

on the square of the spontaneous magnetization, I_s^2. At the Curie temperature both the spontaneous magnetization I_s and the spontaneous Hall emf are zero while the constant R_s is different from zero. The intercept of the line $R_s(I_s^2)$ and the ordinate axis possibly corresponds to the Hall constant due to the presence of paramagnetism above the Curie point.[6] The linear dependence of R_s on the square of the spontaneous magnetization is in agreement with existing theoretical concepts concerning the Hall effect in ferromagnetic materials.[7,8]

For magnetic fields H exceeding technical saturation, we propose to describe the Hall effect by the relation

$$E = R_0 H + R_s I_s + R_i I_i, \qquad (1)$$

where R_0 is the so-called ordinary or "classical" Hall constant, the value of which enables us to estimate the number and the sign of the carriers, R_i is the ferromagnetic Hall constant corresponding to the paramagnetic process, I_i is the magnetization of the paraprocess. Here the product $R_s I_s$ plays the role of a constant because it is independent of the magnetic field. Formula (1) is particularly suitable in the neighborhood of the Curie point, where the processes of technical magnetization are concluded in very weak fields and where the whole ferromagnetic behavior of a ferrite is almost fully determined by the paraprocess.

Volkov[9] was the first to point out the necessity of introducing two separate Hall constants, corresponding to the technical magnetization and to the paraprocess. By differentiating (1) with respect to H we obtain

$$\partial E / \partial H = R_0 + R_i \partial I_i / \partial H, \qquad (2)$$

where $\partial E/\partial H = \chi_E$ is the "susceptibility" of the Hall emf, and $\partial I_i/\partial H = \chi_i$ is the susceptibility of the paraprocess. Figure 6 shows the dependence of χ_E on χ_i for the nickel-zinc ferrite at 12°C. The intercept with the ordinate axis yields $R_0 = -0.9 \times 10^{-8}$ v-cm/amp-oe and the slope of the line determines the constant $R_i = +1 \times 10^{-6}$ v-cm/amp-gauss.

The conduction in the ferrite under study (at

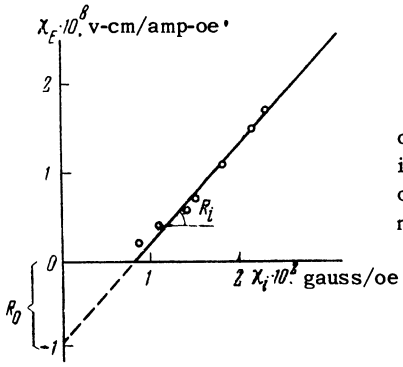

FIG. 6. Dependence of Hall emf susceptibility on the susceptibility of the paraprocess for nickel-zinc ferrite.

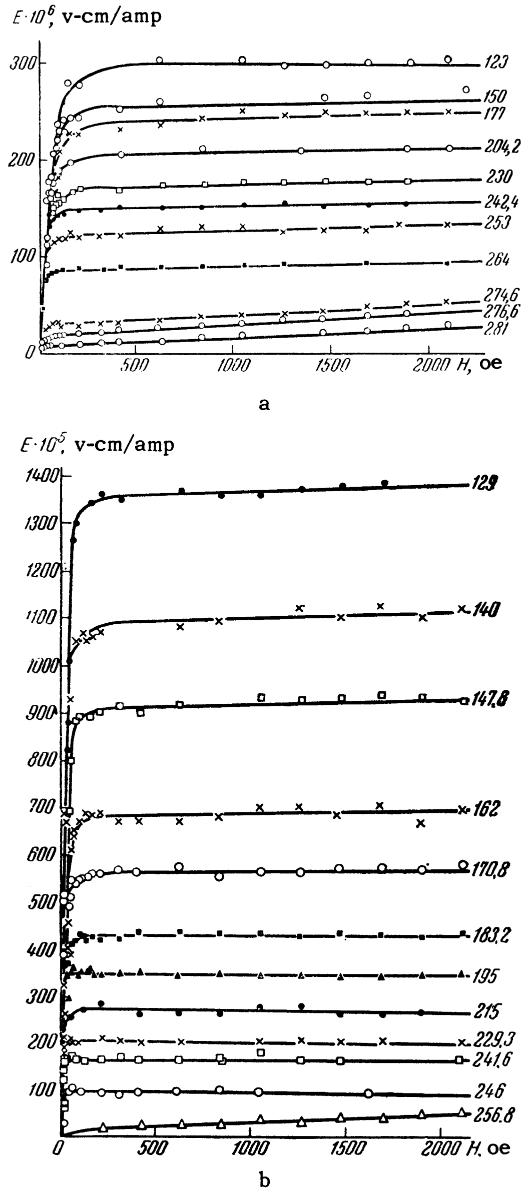

FIG. 7. Dependence of the Hall emf on the magnetic field at different temperatures. a – manganese polycrystalline ferrite, b – a single crystal of manganese ferrite. (The numbers adjacent to curves indicate °C).

12°C) is electronic, as evidenced by the negative sign of the constant R_0. The number of the carriers can be estimated from the relation $R_0 = -3\pi/8en$, where n is the electron concentration and e the electron charge. It was found that $n \cong 1 \times 10^{19} cm^{-3}$. The concentration n and the electric conductivity at 12°C being known, we found the carrier mobility to be 0.08 cm^2/v-sec. This agrees with the values obtained for nonferromagnetic oxide semiconductors.

To conclude this section we wish to point out, that the method previously used of determining R_0 as the slope of the curve E(B) (where B is the magnetic induction) cannot always be used in strong magnetic fields (cf. references 1, 2, 10, 11, and others) for the study of the Hall effect in ferromagnetic materials, because this method does not take into account the influence of the paraprocess. The presence of the paraprocess demands evaluation of the product $R_i \partial I_i / \partial H$ for a correct estimate of R_0.

3. POLY- AND SINGLE CRYSTALS OF MANGANESE FERRITE ($MnO \cdot Fe_2O_3$)

Figure 7 shows the isotherms of the Hall emf for polycrystalline and single-crystal specimens of manganese ferrite of nearly stoichiometric composition. The Hall emf in a single crystal is one order of magnitude greater than in the polycrystalline specimen, while the magnetizations are almost the same. The smaller value of the Hall emf in the polycrystalline specimen may be due to the effect of the potential barriers between the grains on the movement of the electrons that produce the Hall potential difference. In a single crystal such barriers should not exist. However this problem requires additional study.

Figure 8 shows the temperature dependences of R_S for manganese-ferrite polycrystalline and single-crystal specimens, determined in the foregoing manner (the method of thermodynamic coefficients). In the polycrystalline specimen R_S increases with temperature up to a certain maximum and then falls rapidly as the Curie point is approached.

In the single crystal the constant R_S decays exponentially with rising temperature, analogous to the curve of electrical resistance vs. temperature. Using the above method, we obtained the following results at 120°C

polycrystalline manganese ferrite	single-crystal manganese ferrite
$R_0 = -1 \times 10^{-7}$ v-cm/amp-oe	$R_0 = -50 \times 10^{-7}$ v-cm/amp-oe
$R_i = +2 \times 10^{-6}$ v-cm/amp-gauss	$R_i = +20 \times 10^{-6}$ v-cm/amp-gauss
$n = 1 \times 10^{18} cm^{-3}$	$n = 2 \times 10^{16} cm^{-3}$
$u = 0.08 cm^2$/v-sec	$u = 2.6 cm^2$/v-sec

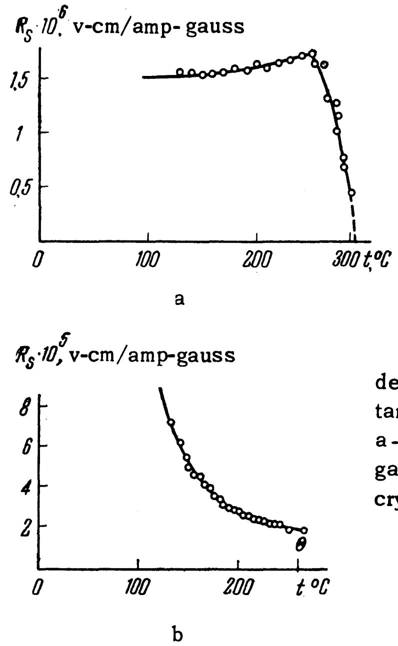

FIG. 8. Temperature dependence of the spontaneous Hall constant. a – polycrystalline manganese ferrite, b – single-crystal manganese ferrite.

The data obtained are in agreement with the electrical properties of nonferromagnetic oxide semiconductors.

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