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# ELECTRICAL RESISTANCE OF AMORPHOUS Fe-Ho-B ALLOYS AT LOW TEMPERATURES[1]

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The temperature dependence of electrical resistivity has been studied on amorphous Fe-Ho-B alloys in the temperature range from 4.2 K to 78 K. All investigated alloys show a minimum in the temperature dependence of electrical resistivity. The behaviour of electrical resistivity in dependence on the holmium content for $0 \leq x \leq 8.2$ is discussed.

## ЭЛЕКТРИЧЕСКОЕ СОПРОТИВЛЕНИЕ АМОРФНЫХ СПЛАВОВ Fe-Ho-B ПРИ НИЗКИХ ТЕМПЕРАТУРАХ

В работе приведены результаты измерений температурной зависимости электрического сопротивления аморфных сплавов Fe-Ho-B в области температур 4,2 – 78 K. Для всех исследуемых сплавов наблюдался в температурной зависимости минимум электрического сопротивления. Обсуждается поведение электрического сопротивления в зависимости от содержания Но в пределах $0 \leq x \leq 8.2$.

## I. INTRODUCTION

A number of experimental works indicates that the amorphous ferromagnetic alloys show a minimum in the temperature dependence of the electrical resistance [1]. To explain the physical origin of this minimum various physical models have been proposed [2]. The electrical resistance of Fe-B amorphous alloys may vary to a great extent owing to the substitution of iron by some other metal element [3]. It seems also that the resulting effect depends also on how the magnetic coupling between the iron atoms and the atoms of an additional element is realized [4]. Therefore we have investigated experimentally the electrical resistance of the amorphous Fe—B alloys with partial substitution of iron by holmium.

## II. EXPERIMENTAL RESULTS AND DISCUSSION

The experiments were made on amorphous samples in the form of thin ribbons, whose chemical composition was $Fe_{85}B_{15}$, $Fe_{84.9}Ho_{0.1}B_{15}$ (this sample contained a small amount of crystalline $\alpha$Fe), $Fe_{82.5}Ho_{1.5}B_{16}$, $Fe_{79.8}Ho_{4.2}B_{16}$, $Fe_{75.8}Ho_{8.2}B_{16}$. The samples were prepared by rapid quenching from the melt in an inert atmosphere. The electrical resistance of samples was measured by a four-probe DC method. The temperature was measured by the calibrated semiconductor thermometer N24 L09.

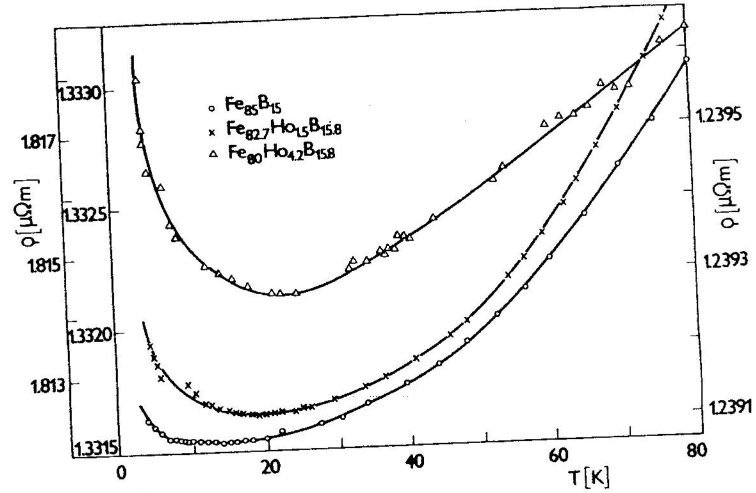

Fig. 1. Temperature dependence of the electrical resistivity for Fe-Ho-B amorphous alloys

Fig. 1 gives some typical temperature dependences of the electrical resistance ($\varrho$). All alloys investigated show minima in electrical resistance ($\varrho_m$), whose depth ($\varrho_{4.2}$—$\varrho_m$) as well as the temperature at which it appears ($T_m$) depends on the holmium content. Below $T_m$ a linear $(\varrho - \varrho_m)/\varrho_m$ vs log $T$ dependence was observed; the slope ($\beta$) of this dependence and the value of the measured electrical resistance are given in Table 1. Logarithmic dependence fits well the observed behaviour for temperature from $T_m$ to $T_1$, where $T_1$ lies approximately in the middle between $T_m$ and 4.2 K. The temperature dependence above $T_m$ may be fitted by formula $\varrho = A + BT^2$; the values of $B$ are given in Table 1. The quadratic dependence is well fitted for the given alloys in the temperature range from $T_m$ to approximately 75 K.

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Table 1

| Sample | $\varrho_{293}$ [μΩm] | $\varrho_m$ [μΩm] | $\frac{\varrho_{4.2}-\varrho_m}{\varrho_{4.2}}$ | $T_m$ [K] | $\beta \times 10^4$ | $B$ [μΩm/K²] | $T_m^{calc(1)}$ [K] | $T_m^{calc(2)}$ [K] |
|---|---|---|---|---|---|---|---|---|
| $Fe_{85}B_{15}$ | 1.87361 | 1.81194 | $198 \times 10^{-6}$ | $13 \pm 2$ | 1.5 | $1.1 \times 10^{-7}$ | 8.5 | 33.0 |
| $Fe_{84.9}Ho_{0.1}B^{*}_{15}$ | 1.94898 | 1.87473 | $207 \times 10^{-6}$ | $11 \pm 2$ | 2.0 | $1.9 \times 10^{-7}$ | 20.0 | 32.7 |
| $Fe_{82.7}Ho_{1.5}B_{15.8}$ | 1.35490 | 1.33164 | $219 \times 10^{-6}$ | $19 \pm 1$ | 2.1 | $2.2 \times 10^{-7}$ | 16.7 | 22.5 |
| $Fe_{80}Ho_{4.2}B_{15.8}$ | 1.26388 | 1.23928 | $242 \times 10^{-6}$ | $24 \pm 1$ | 1.7 | $0.6 \times 10^{-7}$ | 27.5 | 34.8 |
| $Fe_{75.8}Ho_{8.2}B_{16}$ | 1.14920 | 1.13568 | $506 \times 10^{-6}$ | $50 \pm 5$ | 7.0 | $0.6 \times 10^{-7}$ | 53.6 | 48.0 |

* amorphous + small αFe

The values of $T_m$ were compared with those obtained according to [5]:

$$\varrho = \varrho_m(1 + \alpha - \beta \log T) + BT^2 \tag{1}$$

resp. [6]

$$\varrho = \varrho_0 - C \ln (T^2 + \Delta^2) + DT^2 , \tag{2}$$

where $\alpha$, $\varrho_0$, $C$ and $D$ are temperature independent constants; $\Delta$ is the splitting in the energy between two states.

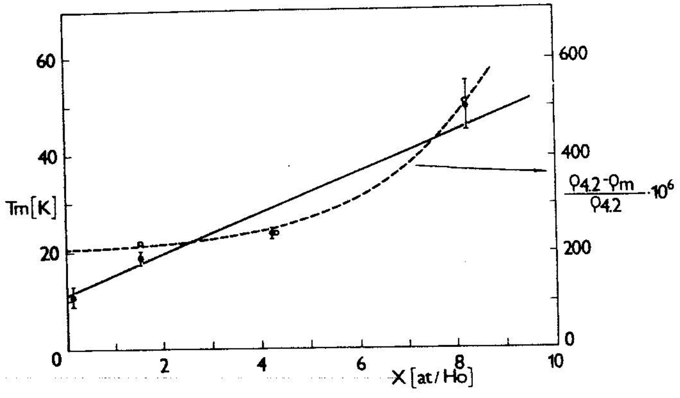

Fig. 2. Concentration dependence $x$ of $T_m$ and of $\frac{\varrho_{4.2}-\varrho_m}{\varrho_{4.2}}$

Formula (1) includes the Kondo conception of the physical origin of the minimum in the temperature dependence of electrical resistance (values $T_m^{calc\,(1)}$ in Tab. 1), whereas relation (2) supposes that the minimum has a structural origin and that the electron scattering on the structural inhomogeneities in the alloy is responsible for it (values $T_m^{calc\,(2)}$). The experimental values are better fitted by the calculated values $T_m^{calc\,(1)}$, which indicates that the minimum in the temperature dependence of the electrical resistance of amorphous Fe-Ho-B alloys could be mainly of magnetic origin. This is supported also by conclusions given in [4], where it was shown that also in concentrated ferromagnetic amorphous alloys the spins (local magnetic moments) may exist, located in the zero effective magnetic field leading to the possible existence of the Kondo effect. Here an effect of boron is expected analogous, to that in the superexchange. Therefore, the Kondo effect should be more pronounced in binary iron-boron alloys with a higher boron content. When iron is substituted by holmium, the relative content of boron — in relation to iron — is in fact increased in these alloys and as can be seen in Fig. 2, the value of $T_m$ and that of $(\varrho_{4.2} - \varrho_m)/\varrho_{4.2}$ increase with the holmium content. It also follows from [4], that the magnetic structure of the alloy has an important influence on the character of the electrical resistance minimum. In addition, the magnetic moments of holmium and iron atoms are coupled antiferromagnetically in these alloys (resp. they form a spheromagnetic structure) [7], therefore the probability of the superexchange also increases with the increasing holmium content. This again leads to a more pronounced Kondo effect. However, it should be noted that the magnetic origin of the minimum may be confirmed experimentally by the thermopower or the electrical resistance measurements in high magnetic fields.

The quadratic temperature dependence of the electrical resistance of the given alloys above $T_m$ may be caused by an electron-electron, an electron-magnon or an electron-phonom scattering. However, the electron-electron scattering may be observed only in pure metals, the electron-magnon scattering is proportional to $T^{3/2}$, so that the electron-phonon scattering will play the main role here.

In [8] the electronic structure of the amorphous Fe-Ho-B alloys was studied by X-ray photoelectron spectroscopy. It was found that the density of the $d$ states on the Fermi level $N_d(E_F)$ decreases in iron-boron alloys when iron is substituted by holmium. It is well known that the electrical resistance of the alloy is proportional to $N_d(E_F)$ and therefore a decrease of the electrical resistance of Fe-Ho-B alloys in comparison with that of the binary Fe-B may be expected. When iron is substituted by holmium, the iron content in the alloy decreases and therefore the $s$-$d$ scattering decreases, whereas the $s$-$f$ scattering has no apparent effect.

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