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ABSTRACT

The influence of holmium on the magnetic properties of amorphous iron-holmium-boron alloys was investigated. Both the Curie temperature and the mean magnetic moment of iron and holmium decrease with increasing holmium content. The temperature dependence of magnetization shows a maximum at low temperatures.

АННОТАЦИЯ

Исследовалось влияние гольмия на магнитные свойства аморфного сплава железо-гольмий-бор. Как точка Кюри, так и средний магнитный момент, расчитанный на атомы железа и гольмия, уменьшается по мере увеличения содержания гольмия. При низких температурах намагниченность максимальная.

KIVONAT

Holmium hatását vizsgáltuk az amorf vas-holmium-bór ötvözet mágneses tulajdonságaira. Mind a Curie hőmérséklet, mind a vas és holmium atomokra számolt átlag mágneses momentum csökken növekvő holmium tartalommal. Alacsony hőmérsékleteken a mágnesezettség maximumot mutat.

1. INTRODUCTION

Previous investigations [1,2] have shown that the addition of a small amount of a rare earth element to binary iron-boron metallic glasses alters many magnetic and other physical properties. The influences of rare earth elements may be explained by taking into account

- the size effect of the rare earth (RE) atoms; this may cause a disturbance of the direct exchange between iron atoms thereby decreasing (or possibly increasing) the Curie temperature of the Fe-RE-B amorphous alloy compared with the binary Fe-B [3];
- the high chemical affinity between RE and B atoms; this affinity may lower the mobility of boron and thus stabilize the amorphous state making the crystallization temperature higher;
- the magnetic moment of RE, since, if such a moment exists, it alters the net magnetization of the alloy;
- the exchange interactions between the magnetically active atoms. Both in crystalline and amorphous RE-TM (transition metal) alloys the smallest in strength is the interaction between localized 4f moments [3]. The strongest interaction is between the 3d moments. The interaction between the 4f and 3d moments in all known heavy rare earth-transition metal alloys gives an antiparallel coupling;
- the single-ion anisotropy of RE - if it exists. Indeed holmium has such an anisotropy therefore the competition between the single-ion anisotropy and the exchange interaction may result in a random noncollinear magnetic structure of sperimagnetic type [4].

The aim of this work is to investigate the influence of holmium on the magnetic properties of Fe-B amorphous alloys with respect to the giant magnetic moment ($\simeq$10 μ_B) of Ho^{3+}. The ques-

tion is how the holmium influences the exchange interaction in ternary Fe-Ho-B amorphous alloys.

2. EXPERIMENTAL

The $Fe_{84-x}Ho_xB_{16}$ ($0 \leq x \leq 10$) ternary alloys were prepared from Fe-Ho and Fe-B master alloys by electron beam melting. The amorphous ribbons were prepared in inert gas atmosphere by the melt spun technique. The amorphicity of the ribbons was investigated by X-ray diffraction; the chemical compositions were measured by atomic absorption spectrometry.

Magnetization curves were measured by a vibrating sample magnetometer up to 7 T at various constant temperatures between 4.2 and 300 K. At higher temperatures the magnetization as a function of temperature was determined by Förster probes in a magnetic field of 0,5 T at a heating rate of 1,7 K/min.

3. RESULTS AND DISCUSSION

In *Fig.1* we show the temperature dependence of mass magnetic polarization, σ of Fe-Ho-B in the whole temperature range of the amorphous ferromagnetic state. For better comparison we used a relative temperature scale. The amorphous Curie temperatures, T_c, are given in *Fig.2*. On alloying holmium, the Curie temperature decreases.

This indicates that the holmium added to Fe-B weakens the ferromagnetic exchange between iron atoms. This decrease may be caused by various effects: one of them is the size-effect of the holmium atom due to the distance - dependent exchange interaction. Furthermore, it is well known that in Fe-RE amorphous alloys the RE has a significant influence on the electron structure of iron atoms, viz. on their magnetic moment, μ_{Fe}. It may be supposed the μ_{Fe} in the given alloys is decreased due to electron transfer from Ho to the 3d band of iron [5], like that of boron to iron [6]. On the other hand the great magnetic moment of Ho can induce a higher μ_{Fe} [7]. However, on adding holmium to Fe-B new interactions must

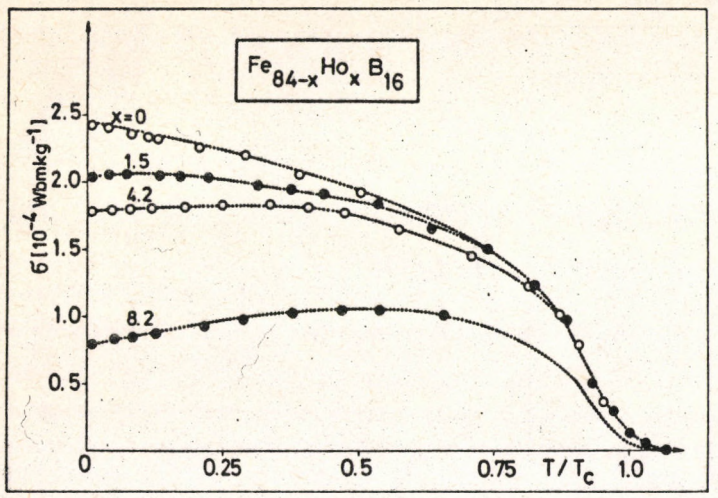

Figure 1
Temperature dependence of magnetic polarization

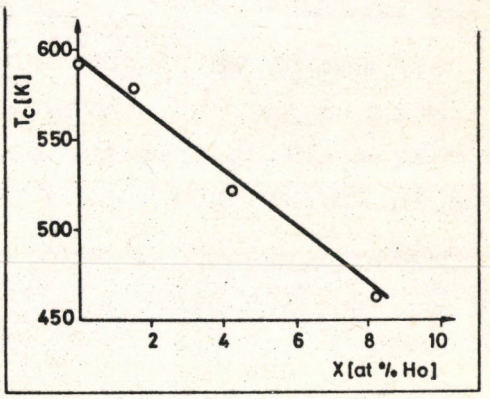

Figure 2
Amorphous Curie temperature as a function of holmium concentration

be taken into account too. As the Ho-Ho interaction is extremely weak, it may be neglected. In contrast the Ho-Fe interaction is much stronger and this, together with the random single-ion anisotropy of the holmium atom, may lead to misalignment between iron moments.

On the basis of the simple spin wave formalism, the magnetization at low temperature decreases with increasing temperature according to

$$\sigma(T) = \sigma(0)(1-BT^{3/2}+\ldots).$$

The $T^{3/2}$ dependence for many amorphous alloys was verified [8,9], but from the series of amorphous $Fe_{84-x}Ho_xB_{16}$ alloys only the binary $Fe_{84}B_{16}$ follows this dependence (see *Fig. 3*). The $\sigma(T^{3/2})$ curve in holmium containing alloys has a maximum. This maximum is more remarkable in the alloys containing more Ho and on increasing

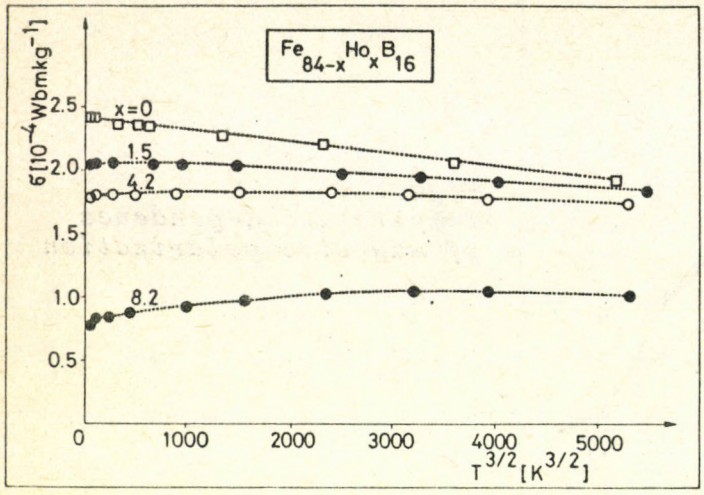

Figure 3
Magnetization as a function of $T^{3/2}$

the Ho content it is shifted towards higher temperature. Because of these maxima we cannot determine the absolute saturation magnetization using the conventional extrapolation of σ(T) to 0 K but only σ(4.2,0) from the measured $\sigma(T,H^{-1}\rightarrow 0)$ at T=4.2 K. As shown in *Fig. 4* this σ as a function of holmium content decreases linearly.

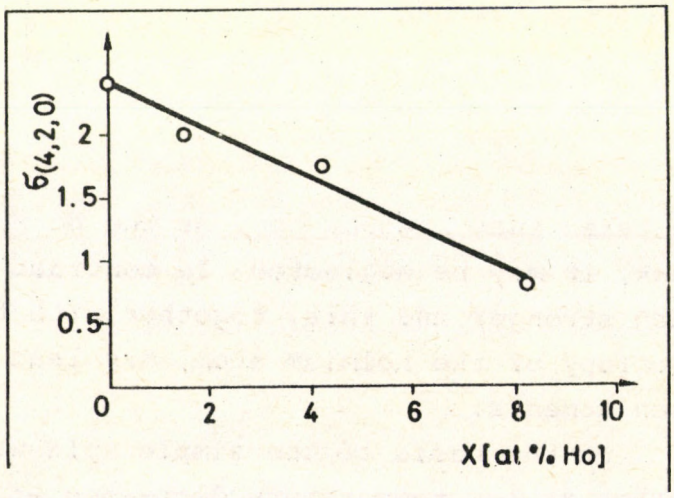

Figure 4
σ(4.2,0) as a function of Ho content

In order to investigate further the temperature dependence of magnetization we studied the role of the magnetic field in this dependence. In *Fig. 5* the σ(T,H) values measured in H=5.23 T and in H=0.025 T are given for comparison. There are great differences between these values in the case of $Fe_{82.5}Ho_{1.5}B_{16}$ and it seems that the decreasing of σ towards lower temperatures is hin-

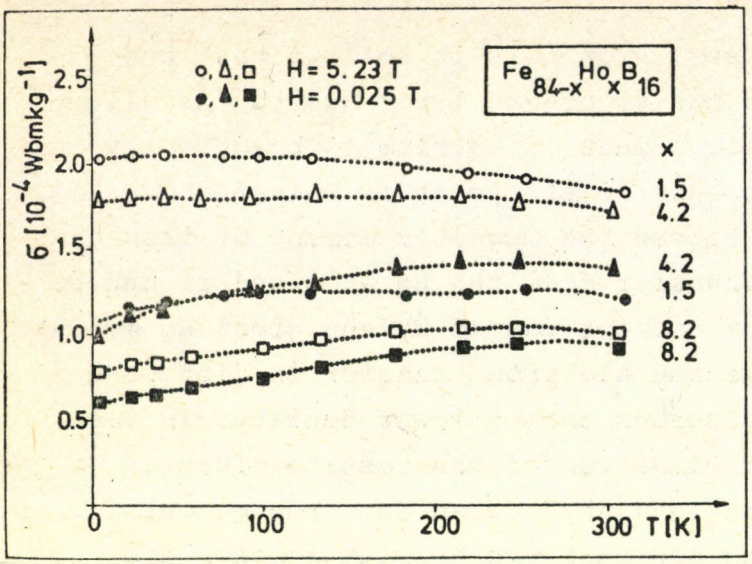

Figure 5
σ(T,H) measured in H=5.23 T and in H=0.025 T as a function of temperature

dered by the higher magnetic field. In the alloys containing more holmium these differences are lowered and the hindrance is also less effective.

The given results suggest that the magnetic moments of holmium atoms are oriented antiparallel to the iron moments. This is in agreement with the results on many amorphous RE-Fe alloys [10]. From the measured σ(4.2,0) values we determined the mean magnetic moment $\bar{\mu}_{Fe+Ho}$ which is given as a function of holmium content in *Fig. 6*. We give also the calculated μ^{calc}_{Fe+Ho} for collinear antipar-

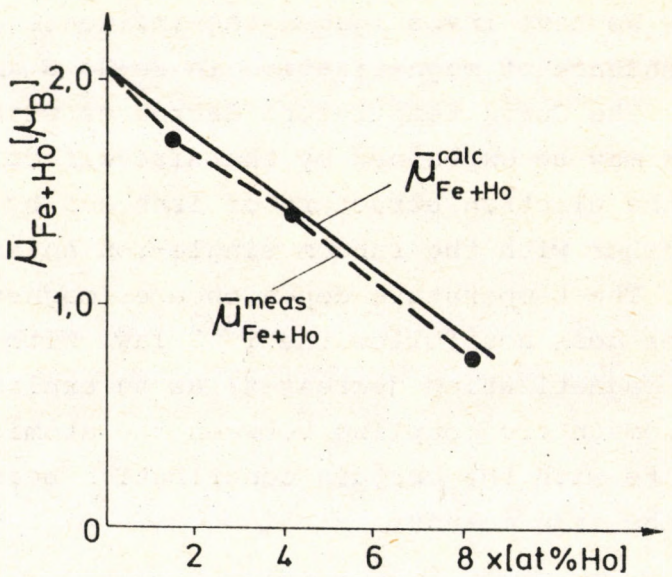

Figure 6
Mean magnetic moment versus holmium content

allel oriented Ho and Fe magnetic moments using $\mu_{Ho}=10.3\mu_B$ and $\mu_{Fe}=2.05\mu_B$ (determined in $Fe_{84}B_{16}$). All measured values are not

higher than the calculated ones. From this it follows that the mean magnetic moment of iron has to become lower due to the alloying of Ho because the magnetic moment of holmium is practically the same in all of its ferromagnetic alloys as in a free atom [11].

As has already been mentioned the magnetic moment of iron can be lowered due to electron transfer from the Ho atom and it can be raised by the induced magnetic moment caused by the great Ho moment. In the amorphous RE-Fe alloys the electron transfer is disturbed by chemical and structural disorder and by lower density. In view of this, we propose, as an explanation of the results given in *Fig. 6*, the existence of misalignment between the iron moments. Moreover, it can also be imagined that the holmium moments are randomly distributed and form together with the iron moments a non-collinear magnetic structure of sperimagnetic type. But the direction distribution of iron moments must overcome that of holmium. From magnetization measurements alone, it is not possible to determine the quantitative contribution of both moments to the magnetic structure.

4. CONCLUSION

We have investigaged the influence of Ho on the temperature dependence of magnetization in Fe-Ho-B amorphous alloys.

The Curie temperature decreases with increasing Ho content; this may be explained by the size-effect of Ho, by its influence on the electron structure of iron and by the Ho-Fe interaction together with the random single-ion anisotropy of holmium.

The temperature dependence of magnetization at low temperatures does not follow the $T^{3/2}$ law. With decreasing temperature the magnetization decreases; as an explanation we suggest antiferromagnetic coupling between the atomic magnetic moments of Ho and Fe with the certain contribution being due to the misalignment of the iron moment.

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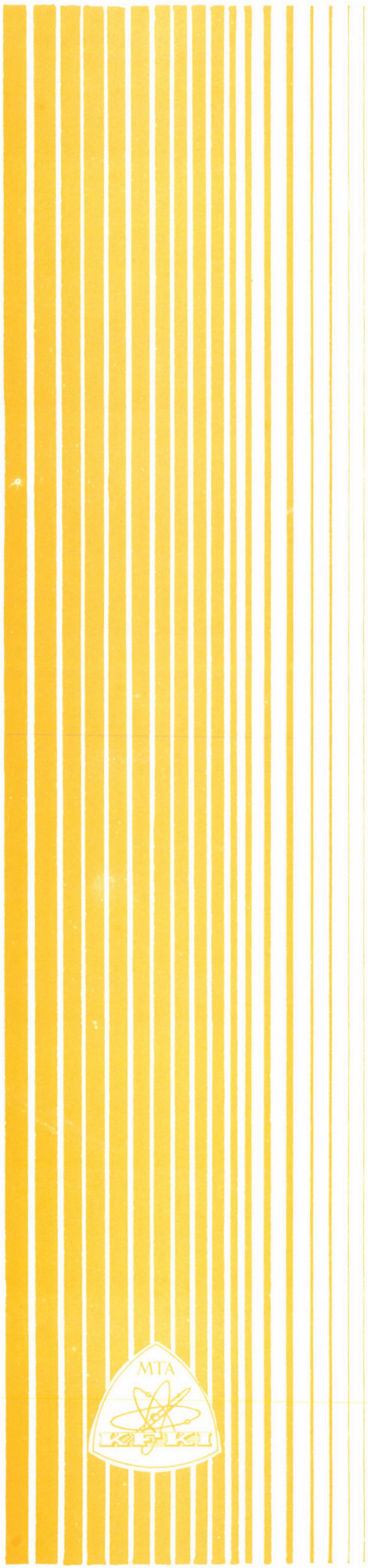

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