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THE RESISTIVITY OF THE AMORPHOUS Fe₁₋ₓBₓ FILMS

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This work presents a systematic investigation of electrical resistivity in thin films of Fe₁₋ₓBₓ in wide range of concentration x up to x=0.70. Samples were prepared by RF sputtering technique described in paper [1]. Amorphous state exists for 0.12 ≤ x ≤ 0.70 which was tested by electron diffraction microscopy [1]. The film composition was determined by microprobe and Auger analysis with accuracy of 5 atomic percent of B. The resistivity was measured by four-probe method for temperatures between 4.2 and 300 K.

1. Composition effect

Specific resistivity ρ of Fe₁₋ₓBₓ films increase with increasing concentration of B /see Fig. 1/ up to about five times of its initial value and the films become amorphous at x=0.12. The resistivity increases slightly for 0.12 ≤ x ≤ 0.40 /1.5 times/ and there is a rapid increase above x=0.40.

Temperature Coefficient of Resistivity (TCR) decreases suddenly at the transition into the amorphous state. The TCR is linear against x and changes its sign at about x=0.25. Similar dependence of ρ(x) and TCR x was observed for amorphous alloys of Ni₁₋ₓPₓ [3] and Pd-Ni₁₋ₓPₓ [4] in the range of concentration 0.15 ≤ x ≤ 0.30 /although the magnitudes of changes of ρ and TCR were much higher.

Fig.1. The room temperature resistivity of Fe₁₋ₓBₓ films as a function of B content. (o) our results, (x) data after J.A.Aboaf and E.Klokhom [2]. The dotted line indicates the transition from crystalline (o) to amorphous state (A).

Fig.2. TCR at room temperature of Fe₁₋ₓBₓ films as a function of B content.

2. The dependence of the resistivity on temperature

Fig.3 shows typical dependence of ρ(T) for samples with different concentration of B. The data were found to fit
the following equations

for $x < 0.25$

\[
\frac{\rho(T)}{\rho(300)} = a + b \ln T + c T^2 \quad T < T_0
\]

\[
\frac{\rho(T)}{\rho(300)} = a' + d T \quad T > T_0
\]

for $x > 0.25$

\[
\frac{\rho(T)}{\rho(300)} = a + b \ln T \quad T < T_b
\]

\[
\frac{\rho(T)}{\rho(300)} = a' + d T \quad T > T_b
\]

where $\rho(300)$, $a$, $a'$, $b$, $c$ and $d$ are listed in Table I.

Fig. 3. The normalized resistivity of crystalline /c/ and amorphous /A/ Fe$_{1-x}$B$_x$ films as a function of $T$.

Low temperature dependence of resistivity is shown in Figs 4a and 4b. For a crystalline sample with small concentration of B /Fe$_{0.94}$B$_{0.06}$/ one can see weak increase of $\rho$ with decreasing temperature. This tendency is even stronger for amorphous films where $\rho \sim \ln T$. A monotonic increase of $T_b$ and $b$ with concentration /see Table I and Fig. 4/ of B takes place.

Fig. 4. The normalized resistivity change of crystalline /c/ and amorphous /A/ Fe$_{1-x}$B$_x$ films vs log $T$; a/ for $x < 0.25$ and b/ for $x > 0.25$. $T_b$ indicates the temperature where a deviation from the $\rho \sim \ln T$ becomes noticeable.

The coefficient $c$ and temperature $T_b$ decrease with $x$ /Fig. 5 and Table I/. For $x > 0.25$ /Fig. 3/ the resistivity decreases linearly vs temperature for $T > T_b$. The deviation for $T > 200$ K can be explained as the result of stress.
between substrate and the film.

Table I. Results of resistivity measurements of Fe$_{1-x}$B$_x$ films

<table>
<thead>
<tr>
<th>x</th>
<th>$\rho (300)$ ($\mu \Omega \text{cm}$)</th>
<th>$a'$</th>
<th>$a$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>21.3</td>
<td>-</td>
<td>0.5</td>
</tr>
<tr>
<td>0.06</td>
<td>85.5</td>
<td>0.885</td>
<td>0.9205</td>
</tr>
<tr>
<td>0.12</td>
<td>113</td>
<td>0.961</td>
<td>0.9901</td>
</tr>
<tr>
<td>0.18</td>
<td>131.6</td>
<td>0.985</td>
<td>0.9924</td>
</tr>
<tr>
<td>0.32</td>
<td>141</td>
<td>1.011</td>
<td>1.0133</td>
</tr>
<tr>
<td>0.37</td>
<td>151.2</td>
<td>1.0115</td>
<td>1.0169</td>
</tr>
</tbody>
</table>

Table II. A comparison of resistivity measurements between Fe$_{1-x}$B$_x$ film and ribbons

<table>
<thead>
<tr>
<th>x</th>
<th>$\rho (4.2)$ $\rho (300)$</th>
<th>$T_{min}$ (K)</th>
<th>$\frac{\Delta\rho}{\rho (300) \Delta T}$ (10$^{-4}$)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.18</td>
<td>0.9916</td>
<td>31</td>
<td>-6.4</td>
<td>film</td>
</tr>
<tr>
<td>0.20</td>
<td>0.968</td>
<td>15</td>
<td>-4.5</td>
<td>ribbon[6]</td>
</tr>
<tr>
<td>0.17</td>
<td>0.972</td>
<td>16</td>
<td>-3.7</td>
<td>ribbon[6]</td>
</tr>
</tbody>
</table>

3. Conclusions

We draw following conclusions from electrical resistivity measurements of amorphous Fe$_{1-x}$B$_x$ films:

- there is a transition concentration range 0.12 ≤ x ≤ 0.25 where contribution $\rho \sim cT^2$ from spin wave scattering characteristic for a crystalline state, is diminishing [7],

- low temperature resistivity anomalies $\rho \sim b \ln T$ strongly depend on concentration of B. Both $T_b$ and $b$ increase with x [Table I]; it can be explained after Grest and Nagel [8] as result of superexchange interactions between next-nearest-neighbor magnetic atoms which are separated by Boron atoms,

- negative TCR and temperature dependence of $\rho$ for $T > T_b$ for films with $x > 0.25$ is likely to be due to temperature dependence of form factor $S(K)$ [9],

- differences in between our results and given by Cochrane et al [5] and Tóth [6], especially with respect to $T_{min}$ and $\rho (4.2)/\rho (300)$ [see Table II], seem to indicate that sputtered
films are more amorphous than ribbons.

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References

/1/ F. Stobiecki, T. Stobiecki, S. Schwarzl, and H. Hoffmann, "Preparation and structure...", this Conference.

/2/ J.A. Aboaf, and E. Klokholm, JCM Munich /1979/.


