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THE RESISTIVITY OF THE AMORPHOUS \( \text{Fe}_{1-x}\text{B}_x \) FILMS

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This work presents a systematic investigation of electrical resistivity in thin films of \( \text{Fe}_{1-x}\text{B}_x \) 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 \( 0.12 \leq x \leq 0.70 \) 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 \( \varrho \) of \( \text{Fe}_{1-x}\text{B}_x \) 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 \( 0.12 \leq x \leq 0.40 \) /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 \( \varrho(x) \) and TCR \( x \) was observed for amorphous alloys of Ni\(_{1-x}\)P\(_x\) [3] and Pd-Ni\(_{1-x}\)P\(_x\) [4] in the range of concentration \( 0.15 \leq x \leq 0.30 \) /although the magnitudes of changes of \( \varrho \) and TCR were much higher/.

Fig.1. The room temperature resistivity of \( \text{Fe}_{1-x}\text{B}_x \) films as a function of B content. (o) our results, (x) data after J.A. Aboaf and E. Klokholm [2]. The dotted line indicates the transition from crystalline \( (c) \) to amorphous state \( (A) \).

2. The dependence of the resistivity on temperature

Fig.2 shows typical dependence of \( \varrho(T) \) for samples with different concentration of B. The data were found to fit
the following equations

for \( x < 0.25 \)

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

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

for \( x > 0.25 \)

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

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

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 \( \rho \propto -\ln T \). 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 \( \rho \propto -\ln T \) 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.

Fig. 5. The normalized resistivity of the crystalline /c/ and amorphous /A/ Fe$_{1-x}$B$_x$ films as a function of $T^2$. $T_0$ indicates the temperature where deviation from the $\rho \sim T^2$ behaviour becomes noticeable.

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

<table>
<thead>
<tr>
<th>$x$</th>
<th>$\rho$(300) $\mu \Omega$ cm</th>
<th>$a'$</th>
<th>$a$</th>
</tr>
</thead>
<tbody>
<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>
<thead>
<tr>
<th>$x$</th>
<th>$\rho$(4,2) $\mu \Omega$ cm</th>
<th>$\rho$(300) $\mu \Omega$ cm</th>
<th>$T_{\min}$ K</th>
<th>$\Delta \frac{\rho}{\rho(300)}$ $10^{-4}$</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 $\leq$ $x$ $\leq$ 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 Töth [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. Klokholem, JCM Munich /1979/.