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To cite this version:
R. Hasegawa. MAGNETIC PROPERTIES OF GLASSY (Fe-Ni)86B14 ALLOYS. Journal de Physique Colloques, 1980, 41 (C8), pp.C8-701-C8-704. <10.1051/jphyscol:19808176>. <jpa-00220278>

HAL Id: jpa-00220278
https://hal.archives-ouvertes.fr/jpa-00220278
Submitted on 1 Jan 1980

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MAGNETIC PROPERTIES OF GLASSY (Fe–Ni)$_{86}$B$_{14}$ ALLOYS

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Abstract. - Thermomagnetization, crystallization behavior, mass density and magnetostriction data obtained for glassy (Fe–Ni)$_{86}$B$_{14}$ alloys suggest that the local atomic structures resemble those of the corresponding crystalline Fe–Ni alloys.

INTRODUCTION

Previous studies of magnetic properties of glassy (Fe–Ni)$_{80}$B$_{20}$ alloys indicate a shift of the magnetic moment versus Fe–Ni composition (Slater–Pauling-like) curve toward lower Ni content region compared with the crystalline case, implying electron charge transfer from boron to the transition metal atoms. Supporting evidence for this has been provided by Mössbauer and NMR studies of various transition metal-metalloid base glassy alloys, although its detailed nature is not clear at this moment. Efforts to clarify the effects of the metalloids on the physical properties of metallic glasses by studying simple binary alloys such as Fe–B and Co–B have opened up some new aspects. For example, recent studies on the Fe–B system show some unexpected magnetic behaviors including a decrease of the Curie temperature and an increase of the magnetic moment on Fe as the boron content is decreased. It has been speculated that these Table I - Crystallization and Curie Temperatures of Fe$_{86-x}$Ni$_x$B$_{14}$ Alloys

<table>
<thead>
<tr>
<th>$x$</th>
<th>$T_{cl}$ (K)</th>
<th>$T_{c2}$ (K)</th>
<th>$\theta_1$ (K)</th>
<th>$\theta_2$ (K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>680</td>
<td>770</td>
<td>556±0.5</td>
<td>1040±5</td>
</tr>
<tr>
<td>8</td>
<td>638</td>
<td>745</td>
<td>660±5</td>
<td>1013±5</td>
</tr>
<tr>
<td>12</td>
<td>643</td>
<td>741.5</td>
<td>695±10</td>
<td>1010±5</td>
</tr>
<tr>
<td>16</td>
<td>640.5</td>
<td>735.5</td>
<td>704±10</td>
<td>*</td>
</tr>
<tr>
<td>19</td>
<td>644</td>
<td>743</td>
<td>725±10</td>
<td>*</td>
</tr>
<tr>
<td>22</td>
<td>640</td>
<td>729</td>
<td>730±15</td>
<td>997±5</td>
</tr>
<tr>
<td>25</td>
<td>658</td>
<td>728</td>
<td>730±10</td>
<td>988±5</td>
</tr>
<tr>
<td>27</td>
<td>647.5</td>
<td>721</td>
<td>730±5</td>
<td>960±5</td>
</tr>
<tr>
<td>29</td>
<td>657</td>
<td>711</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>32</td>
<td>644</td>
<td>725</td>
<td>*</td>
<td>*</td>
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<td>36</td>
<td>659</td>
<td>721</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>43</td>
<td>*</td>
<td>728</td>
<td>*</td>
<td>*</td>
</tr>
</tbody>
</table>

*Not determined.

EXPERIMENTAL

The constituent elements of purity higher than 99.9% were melted in vacuum by induction heating. The resultant alloys were rapidly quenched from the liquida. X-ray diffraction and differential scanning calorimetry (DSC) were used to determine the composition range in which the alloys were made noncrystalline. Magnetization behavior, in fields up to $8 \times 10^5$ A/m, of the alloys was studied at 4.2K and between 300 and 1040K by using a vibrating sample magnetometer. The sensitivity of the magnetometer is about $10^{-9}$ JT$^{-1}$ Kg$^{-1}$. The mass density and the magnetostriction at room temperature were measured by a conventional Archimedes' method and a bridge technique respectively.

RESULTS AND DISCUSSION

Of the alloys examined containing up to $x=86$ in Fe$_{86-x}$Ni$_x$B$_{14}$' those within the range 0.5 to 43 have been found to be fully noncrystalline. These alloys were found to have two well-defined crystallization temperatures, $T_{cl}$ and $T_{c2}$. The values of these quantities determined by DSC with a heating rate of 20K/min. are listed in Table I and are, as
expected, somewhat higher than those determined from thermomagnetization data taken at an average heating rate of 1K/min. The ferromagnetic Curie temperatures of the noncrystalline alloys, $\theta_a$, were found to be near or higher than $T_{c1}$, and when possible, were estimated by extrapolating the magnetization data taken below this temperature. The results are listed in Table I. X-ray diffraction taken on samples heated up to $(T_{c1}+T_{c2})/2$ shows that the samples consist of bcc Fe-Ni and glassy phases for $x \leq 25$ and of fcc Fe-Ni, bcc Fe-Ni and glassy phases for $25 < x < 43$. For example, the alloy Fe$_{78}$Ni$_8$B$_{14}$ transforms at $T_{c1} < T < T_{c2}$ into a composite of a glassy phase and a bcc Fe-Ni phase containing about 3.5 at.% Ni which was determined from the lattice constant ($a=0.2868 \text{ nm}$). Upon heating the samples beyond $T_{c2}$, the thermomagnetization data indicate two crystalline phases with ferromagnetic Curie temperatures, $\theta_{f1}^c$ and $\theta_{f2}^c$, which are given in Table I. Some representative examples of the thermomagnetization data are shown in Fig. 1. Combination of the x-ray diffraction taken on the samples heated up above $T_{c2}$ and the data of $\theta_{f1}^c$ and $\theta_{f2}^c$ leads to the following results. The alloys with $x \leq 25$ decompose above $T_{c2}$ into tetragonal Fe$_2$B containing small amounts of Ni, bcc Fe-Ni and small amounts of fcc Fe-Ni. For example, the crystallized alloy with $x=8$ contains (Fe-Ni)$_2$B with the lattice parameters $a=0.5088 \text{ nm}$ and $c=0.4223 \text{ nm}$, bcc Fe-Ni with

![Fig. 1. Thermomagnetization taken with a field of 720 kA/m for glassy Fe$_{78}$Ni$_8$B$_{14}$ and Fe$_{59}$Ni$_{27}$B$_{14}$ alloys. The arrows indicate Curie temperatures of glassy ($\theta^a_f$) and crystalline ($\theta^c_f$) phases.](image-url)
The alloys with 25<x<_43 decompose mainly into fcc Fe-Ni with the Ni content between 40 and 46 at.%. Consulting with the known Curie temperatures of crystalline (Fe-Ni)\textsubscript{2}B and Fe-Ni\textsubscript{2}, we may conclude that the values of \(\theta_{\text{c1}}\) for all \(x\) of Table I are those of (Fe-Ni)\textsubscript{2}B and the values of \(\theta_{\text{c2}}\) for \(x>8\) correspond to those of fcc Fe-Ni alloys.

The important point to be made here is that the first crystalline phase nucleating at \(T_{\text{cl}}\) is bcc Fe-Ni for \(x\leq25\) and fcc Fe-Ni for 25<x<_43. If the first crystalline phase nucleating upon crystallization of glassy alloys reflects the local short range order in the noncrystalline state as speculated previously, the present results imply the local atomic arrangements are bcc-like for the glassy alloys with \(x\leq25\), and fcc-like for 25<x<_43.

The mass density, \(D\), as a function of the Ni content is shown in Fig. 2, in which the data are compared with those of glassy (Fe-Ni)\textsubscript{80B20} alloys. It appears that \(D\) for the present alloys increases with Ni content faster than that for the system with 20 at.\% B up to about \(\text{Ni}/(\text{Fe-Ni}) = 0.3\) or \(x=25\). Beyond this concentration, \(D\) seems to be parallel to that for (Fe-Ni)\textsubscript{80B20}. The fast initial rise of \(D\) may be evidence for a loosely packed atomic structure changing eventually into a more densely packed one. The extrapolation of the data of \(D\) for \(x=25\) to \(x=0\) line gives \(D=7.55\) g/cm\(^3\) which is identical to the extrapolated value of \(D\) for Fe\textsubscript{86}B\textsubscript{14} based on the density data obtained for the Fe-B alloys containing more than 20 at.\% boron. The actual value of \(D\) for this alloy is 7.44 g/cm\(^3\), being less dense by about 0.11 g/cm\(^3\) than that predicted on the basis of the data taken for atomically dense-random-packed (DRP) alloys such as Fe\textsubscript{80}B\textsubscript{20}.

The linear saturation magnetostriction at room temperature, \(\lambda_{\text{B}}\), versus Ni content for the present glassy alloys is compared in Fig. 4 with those for glassy (Fe-Ni)\textsubscript{86B14} and (Fe-Ni)\textsubscript{80B20} alloys and crystalline alloys. The linear saturation magnetostriction at room temperature, \(\lambda_{\text{B}}\), versus Ni content for the present glassy alloys is compared in Fig. 4 with those for glassy (Fe-Ni)\textsubscript{86B14} and (Fe-Ni)\textsubscript{80B20} alloys and crystalline alloys.
Fig. 4. Room temperature saturation magnetostriction as a function of Ni content for glassy and crystalline alloys.

For the latter alloys, the quantity \( \lambda_s \) varies as \( \sigma_s^2 \), where \( \sigma_s \) is the room temperature saturation magnetization. We find that this simple relationship does not hold for the glassy alloys containing 14 at.\% B. Although not precisely, \( \lambda_s \) versus Ni content for the present alloys exhibits some features of the magnetostriction behavior of crystalline Fe-Ni alloys, implying gradual change of the local short range order from 12-fold coordinated DCP to bcc-like LRP structures as the Ni content is reduced.

CONCLUSION

Based on the thermomagnetization, crystallization behavior, mass density and magnetostriction data obtained for glassy (Fe-Ni)\(_{86}\)B\(_{14}\) alloys, one may conclude that the local atomic arrangements of transition metal base noncrystalline alloys with low boron content resemble those of corresponding crystalline metallic systems without metalloids. Thus bcc-like short range order could be realized in such glassy alloys.

ACKNOWLEDGMENTS

The author is grateful to Elisabeth Musso who has helped him collect the data contained in this article. The glassy samples were made by Robert Costa and James Briggs, Jr.

REFERENCES