# MAGNETIC PROPERTIES OF AMORPHOUS TRANSITION METAL ALLOYS

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The chemical short-range order of metallic glasses will be discussed and it will be shown that the structural disorder has minor effects on the shape of the magnetization curve, on the magnetic moments and Curie temperatures.

Metallic glasses show interesting magnetic properties such as the characteristic "flattening" of the magnetization curve, magnetic anisotropy in a presumably isotropic system, etc. A typical metallic glass obtained by rapid quenching from the melt consists of transition metals with about 15–25 at% of one or more kinds of metalloids. Their structure, the nature of the short-range atomic arrangements and its relation to the physical properties is a problematic issue.

The most direct information on the atomic structure of metallic glasses has been obtained from conventional X-ray and neutron scattering measurements in terms of the interference function. Although the interference functions contain information on both the short-range and long-range order in these amorphous alloys, this information can only be extracted by complex procedures which involves theoretical models. However, even if all the individual partial structure factors are determined separately, only the average of the atomic configurations can be obtained – no detailed information on the probability distributions of different possible atomic configurations is available.

## *Hyperfine field vs. magnetic moment*

Most of the magnetic properties and in particular those measured with microscopic techniques depend on the local atomic neighbourhood of the magnetic atoms. In a series of amorphous and crystalline transition metal–metalloid systems with one magnetic constituent like Fe or Co it was found [1–4] that the average hyperfine field is proportional to the average magnetic moments of the magnetic component. The hyperfine fields and magnetic moments at chemically inequivalent sites of the same crystal structure show the same proportionality as is observed in $Fe_3P$ [2]. Thus it seems reasonable to assume that this proportionality remains valid for the hyperfine field distributions $p(H)$ measured in metallic glasses.

It should be emphasized that the hyperfine field is determined mostly by the magnitude of the magnetic moment. The hyperfine field distribution is not related to the effective field distribution as is assumed e.g., in refs. [5] and [6], magnetic moments in a small (but nonzero) effective field may have a large hyperfine field.

It is well known from comparisons of various intermetallic compounds that the magnetic moment is determined mainly by the number of nearest metalloid neighbours, that is the magnetic moment (or hyperfine field) distribution reflects the distribution of the neighbouring metalloid atoms.

The value of the magnetic moments is determined by p–d hybridization and the simple charge transfer model is inappropriate to describe the observed trends [7, 8].

## *Chemical short-range order (CSRO)*

It has been shown [9] that in the crystallization of $Fe_{1-x}B_x$ $(0.15 \leqslant x \leqslant 0.25)$ glasses the $Fe_{75}B_{25}$ composition plays a dominant role. During the crystallization of these glasses two partly overlapping processes were observed, namely: 1, a precipitation of $\alpha$-Fe until the composition of the remaining glass reaches the $Fe_{75}B_{25}$ composition, and 2, the glass with this composition transforms into the metastable $Fe_3B$ intermetallic compound. It seems to be a general rule that during the crystallization of metallic glasses a metastable phase appears before the stable crystalline products are formed. It is obvious to approximate the CSRO of these amorphous alloys with the CSRO of these crystalline metastable compounds. The iron $p(H)$ distribution in the amorphous $Fe_{75}B_{25}$ measured by the Mössbauer method could be satisfactorily described [10] with the assumption that its local environments are similar to those in the $Fe_3B$ com-

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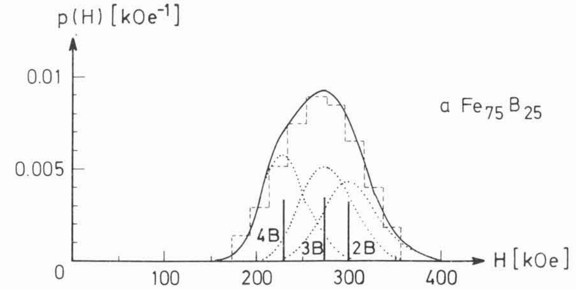

Fig. 1. Measured (broken line) and calculated (full line) iron hyperfine distributions. The dotted lines show the broadened distributions around the crystalline hyperfine fields of $Fe_3B$ represented by the bars corresponding to 2B, 3B and 4B nearest neighbours. The only parameter used in the fit [10] was the relative broadening of the crystalline hyperfine fields, $\Delta H/H = 0.103$.

pound, which is isostructural to the tetragonal $Fe_3P$ (fig. 1). The importance of the hyperfine fields of intermetallic compounds in our understanding of the $p(H)$ of amorphous FeBP alloys was emphasized by Durand and Yung [4].

Fig. 2 shows the concentration dependence of the average hyperfine field for the amorphous and crystalline $(Fe_{1-x}Ni_x)_{75}B_{25}$ alloys prepared by rapid quenching. These amorphous alloys crystallize into a single phase: on the Fe side into the tetragonal $Fe_3B$ structure, on the Ni side into the orthorhombic $Ni_3B$ structure (isostructural to cementite, $Fe_3C$). The tetragonal $(Fe_{1-x}Ni_x)_3B$ with $x = 0.20$ and 0.25 starts to decompose into the stable $(Fe_{1-x}Ni_x)_2B$ and bcc $Fe_{1-x}Ni_x$ at the onset of crystallization ($\approx$ 750 K).

It is remarkable that $\bar{H}_{Fe}$ decreases about 15% between $x = 0$ and 0.75 but the amorphous and crystalline values agree with each other within a few per cent.

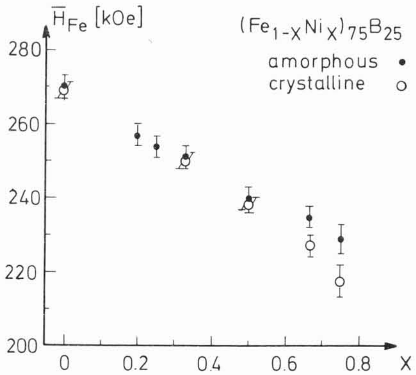

Fig. 2. Average iron hyperfine field extrapolated to 0 K in amorphous and crystalline $(Fe_{1-x}Ni_x)_{75}B_{25}$ alloys.

These results suggested a more general model according to which the complex structure of metallic glasses at arbitrary composition is determined by two dominant contributions, namely:

(i) structural disorder, and

(ii) chemical disorder.

In this terminology structural disorder means the local distortion of the corresponding intermetallic compound (in the above case: $TM_{75}M_{25}$) which can be characterized by a Gaussian broadening of the lattice parameter and also consequently of the hyperfine field around the crystalline values. Chemical disorder results from deviations from this special composition which cause distortion of the "ideal" amorphous structure (that of the $TM_{75}M_{25}$ glass) and can be described by analogy with the case of non-stoichiometric intermetallic compounds.

This structural model implies that the CSRO of amorphous alloys prepared by sputtering or evaporation can be different from those prepared by rapid quenching from the melt. Also it follows that no meaningful extrapolation is possible for the properties of pure amorphous transition metals (Fe, Co or Ni) from the investigation of TM–M glasses.

### *Temperature dependence of magnetization*

The reduced magnetization $\sigma = M(T)/M(0)$ versus reduced temperature $\tau = T/T_c$ drops more rapidly in metallic glasses than in pure crystalline Fe, Co, and Ni (fig. 3). This "flattening" of $\sigma(\tau)$ is attributed to a spread in the exchange interactions resulting from the amorphous structure. The experimental data are often described with the mean-field model of Handrich [11] resulting in $\delta = (\langle \Delta J^2 \rangle)^{1/2}/\langle J \rangle = 0.3$ to 0.5 for the ratio of exchange fluctuations to the strength of the exchange interactions [5, 12–14].

However, the difference between the magnetization curves of the amorphous and crystalline $(Fe_{1-x}Ni_x)_{75}B_{25}$ alloys is substantially smaller, only a few per cent, and the magnetization in both states decreases much faster with temperature than in metallic iron. Typical curves are shown in fig. 4, similar results were obtained for $x = 0$ and 0.67. These results show that structural disorder has a minor effect on the shape of $\sigma(\tau)$ and that the high metalloid content is responsible for the rather fast

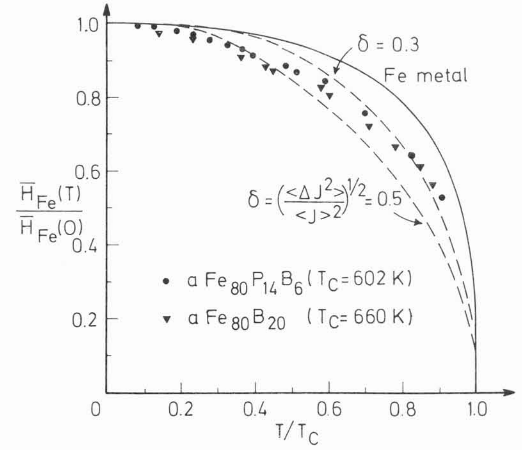

Fig. 3. Temperature dependence of the reduced average iron hyperfine field for amorphous $Fe_{80}B_{20}$ (▼) (data are from refs. [13] and [16]), $Fe_{80}P_{14}B_6$ (●) and crystalline $\alpha$-Fe (solid line). The broken curves are the results of Handrich's model for various ratios of exchange fluctuations to exchange.

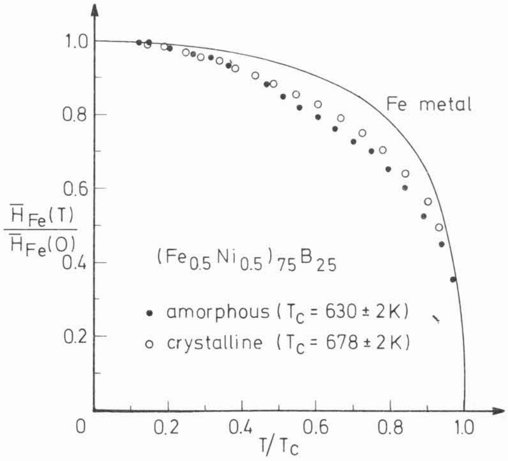

Fig. 4. Temperature dependence of the reduced average iron hyperfine field in amorphous (●) and crystalline (○) $(Fe_{0.5}Ni_{0.5})_{75}B_{25}$.

decrease of the magnetization in these materials. It is worth emphasizing that in metallic glasses the effects of the replacement of Fe by other transition metals or the B by other metalloids on the shape of $\sigma(\tau)$ are comparable with the effects of structural disorder.

The Curie temperatures of the amorphous $(Fe_{1-x}Ni_x)_{75}B_{25}$ alloys are lower than those of the crystalline ones. The difference is less than about 10%, and it can be attributed to the effect of structural disorder but some contribution originating from chemical disorder cannot be excluded.

It has been reported [15] that low temperature annealings resulting in structural relaxation can increase the $T_c$ of metallic glasses. According to our measurements, annealing, which increases the Curie temperature of a $Fe_{40}Ni_{40}P_{14}B_6$ by 10 K (120 min at 350°C) does not influence the shape of $\sigma(\tau)$. This observation agrees with the earlier result [16] that in metallic glasses all magnetic moments follow the same magnetization curve determined by long-range correlations. Models using only first neighbour interactions are inappropriate to describe the effects of structural and chemical disorder on $T_c$ and $\sigma(\tau)$.

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