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FERROMAGNETISM, REENTRANT AND SPIN GLASS LIKE BEHAVIOURS IN AMORPHOUS Fe\textsubscript{1-x}T\textsubscript{80-x}B\textsubscript{20} (T = Re, W) ALLOYS

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Abstract. – Substitution of Re, W for Fe in amorphous ferromagnet Fe\textsubscript{80}B\textsubscript{20} results in reduction of \(T_c\), Fe moment and leads to reentrant and spin glass like behaviours. In Re rich reentrant alloys field cooling effects persist close to respective \(T_c\). Fe\textsubscript{50}Re\textsubscript{80-x}B\textsubscript{20} behaves differently from isoelectronic Mo substitution in Fe\textsubscript{75}P\textsubscript{16}B\textsubscript{6}Al\textsubscript{3}.

1. Introduction

The dilution of magnetic atoms in a ferromagnetic alloy by nonmagnetic atoms leads to the ultimate destruction of ferromagnetic order. The most interesting feature here is that prior to the establishment of a true paramagnetic state, the system may go through a mixed state where an infinite ferromagnetic network and finite clusters coexist. This may lead to reentrant behaviour or if the clusters dominate very much a spin glass like phase may result without the intervening ferromagnetism. In this context we have studied amorphous alloys of Fe\textsubscript{80}B\textsubscript{20} with 5d substitutions (Re, W), over wide range of concentrations, to probe the magnetic behaviour across the critical region for the disappearance of ferromagnetism. Earlier studies with these substituents are restricted to concentrations of less than 10 atomic percent of the dilutant and are in a region far from the critical concentration for the disappearance of ferromagnetic order \([1, 2]\). Also W belongs to the same group as Cr and Mo in the periodic table. The magnetic behaviour of (Cr\textsubscript{1-x}Fe\textsubscript{x})\textsubscript{80}B\textsubscript{20} \([3]\) and (Mo\textsubscript{1-x}Fe\textsubscript{x})\textsubscript{75}P\textsubscript{16}B\textsubscript{6}Al\textsubscript{3} \([4]\) are not similar. It is of added interest here to study the effect of W substitution.

2. Experimental

Amorphous alloys of Fe\textsubscript{1-x}Re\textsubscript{x}\textsubscript{80-x}B\textsubscript{20} \((x = 75, 70, 65, 60, 55, 50 \text{ and } 45)\) and Fe\textsubscript{1-x}W\textsubscript{x}\textsubscript{80-x}B\textsubscript{20} \((x = 75, 70, 67, 63, 60 \text{ and } 55)\) of nominal composition were made by melt spinning in an inert atmosphere and were characterised by X ray diffraction. The alloys were studied using the techniques of low field ac susceptibility, dc magnetization and \(^{57}\)Fe Mossbauer effect.

3. Results and discussion

3.1 Fe-Re-B ALLOYS. – Alloys with Fe concentration of 75, 70, 65, 60, 55 and 50 atomic percent show a sharp rise in their ac susceptibility \((\text{ac} \chi)\) at the Curie temperature, \(T_c\). This is illustrated in figure 1 for some of the alloys. For Fe\textsubscript{80}Re\textsubscript{30}B\textsubscript{20}, the susceptibility shows a fall around 40 K (below its \(T_c\)) as in a reentrant magnet. This is also reflected in the low field (15 Oe) dc magnetization of this alloy where field cooling effects were observed below its \(T_c\). In Re rich alloys (Fe\textsubscript{80}Re\textsubscript{30}B\textsubscript{20} and Fe\textsubscript{65}Re\textsubscript{35}B\textsubscript{15}) the field cooling effects persist close to their respective \(T_c\). This appears to imply that very high inhomogeneity is present in these systems with the infinite cluster responsible for long range order and clusters responsible for short range order coexisting in the temperature interval between \(T_c\) and the spin freezing temperature, \(T_F\). For Fe\textsubscript{45}Re\textsubscript{55}B\textsubscript{20} a cusp is observed at 14 K in low field dc magnetization as in a spin glass with field cooling effects observable below the cusp temperature. Ferromagnetic order is thus lost in this system between 50 and 45 atomic percent Fe concentration.

The Fe magnetic moment derived from magnetization data in 8 kOe field at 4.2 K (assuming a zero moment on Re) decreases linearly with decrease in Fe
Fig. 2. – Variation of Curie temperature ($T_c$) and average magnetic moment per Fe atom in Fe$_x$T$_{80-x}$B$_{20}$ ($T$ = Re, W) alloys with Fe concentration ($x$). The broken lines drawn through different sets of data points serve as a guide to the eye.

Concentration at the rate of 0.033μB/atomic percent in the range $x = 80$ to 50 (Fig. 2). The concentration dependence of the magnetic ordering temperature is also shown in figure 2. The fall in $T_c$ is nearly linear up to 60% Fe at the rate of 19 K per atomic percent. Above this concentration the fall is slower. For the ferromagnets Fe$_75$Re$_5$B$_{20}$, Fe$_70$Re$_{10}$B$_{20}$ and Fe$_65$Re$_{15}$B$_{20}$ magnetization in an applied field of 6 kOe could be fitted to a spin wave $T^{3/2}$ dependence over the temperature interval 4.2 K to 0.5 $T_c$ of the alloy, with corresponding values for the spinwave stiffness constant $B$ of 39, 56, 85 ($10^{-6}K^{-3/2}$) respectively.

3.2 Fe-W-B ALLOYS. – AC and low field dc magnetization measurements showed that the alloys Fe$_{75}$W$_5$B$_{20}$, Fe$_{70}$W$_{10}$B$_{20}$ and Fe$_{65}$W$_{15}$B$_{20}$ are ferromagnetic while the reentrant regime in Fe$_x$W$_{80-x}$B$_{20}$ system starts close to Fe$_{63}$W$_{17}$B$_{20}$. At $\chi$ of Fe$_{65}$W$_{25}$B$_{20}$ shows a cusp at 26 K similar to a spin glass. Thus ferromagnetic order in Fe$_x$W$_{80-x}$B$_{20}$ system disappears between $x = 55$ and 60. The observed behaviour with W is similar to isoelectronic Cr substitution in Fe$_{80}$B$_{20}$ [3] but is different from that reported for Mo substitution in Fe$_{76}$P$_{16}$B$_{6}$Al$_{3}$ where no evidence was found for a second low temperature transition to a spin glass state [4]. $T_c$ decreases rapidly with substitution of W for Fe in the range $x = 80$ to 65 (Fig. 2). The average Fe moment ($\bar{\mu}$) over this range found from magnetization measurements (assuming moment on W as 0) can be expressed as

$$\bar{\mu} = \mu_0 - K (80 - x)$$

where $\mu_0 = 2.16\mu_B$ and $K = 0.08\mu_B$/at. % $^{57}$Fe Mossbauer spectroscopy [5] shows that average Fe hyperfine field scales well with Fe moment (120 kOe/μB) in the range $x = 80$ to 60 implying that any moment on W (if present) is negligible.

4. Conclusions

Substitution of Re/W for Fe in ferromagnetic Fe$_{80}$B$_{20}$ leads to reentrant and spin glass like behaviour dependent on substituent concentration. Fe$_x$W$_{80-x}$B$_{20}$ behaves differently from isoelectronic Mo substitution in Fe$_{76}$P$_{16}$B$_{6}$Al$_{3}$.