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PARAMAGNETIC TO FERROMAGNETIC TRANSITION IN $\text{Fe}_x\text{Ni}_{80-x}\text{B}_{18}\text{Si}_2$ GLASSES

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Abstract. — Initial susceptibility and electrical resistivity of amorphous $\text{Fe}_x\text{Ni}_{80-x}\text{B}_{18}\text{Si}_2$ alloys indicate the onset of ferromagnetism at $x_c \approx 2.3$. Down to $x_c$, both the electrical and magnetic measurements show sharp transitions at $T_C$. The critical exponent $\delta = 4.5 \pm 0.5$ does not vary with $x$ for $x \geq x_c$.

Previous investigation of the electrical [1] and magnetic properties [2, 3] of amorphous $\text{Fe}_x\text{Ni}_{80-x}\text{B}_{18}\text{Si}_2$ alloys have shown that the alloys with $x \geq 3$ have well defined Curie temperatures, $T_C$, (in spite of the magnetic inhomogeneity [4]) whereas the alloys with $x \leq 2$ show a spin-glass behaviour. Because of this we performed a systematic investigation of the alloys with $2 \leq x < 3$. Careful preparation of the master alloys enable us to vary $x$ in steps of 0.1 over most of the range explored.

The characteristic temperatures $T_0$ ($T_C$ for ferromagnets, $T_g$ for spin-glasses) for the whole range of $\text{Fe}_x\text{Ni}_{80-x}\text{B}_{18}\text{Si}_2$ alloys are shown in figure 1. The inset shows the present results for the variation of $T_0$ (obtained from the initial susceptibility) with $x$ in the vicinity of critical concentration ($x_c$). We note the almost linear variation of $T_0$ for $x \geq 2.3$ (reminiscent of a dilute Heisenberg ferromagnet) and a positive curvature below that value.

Figure 2 shows the initial susceptibilities of three characteristic alloys ($x = 2, 2.3$ and $2.6$). All susceptibility measurements were performed in the same manner (standard a.c. technique, ZFC, $H_{ac} = 0.01$ Oe rms) and on the samples with practically the same geometry ($6 \times 1 \times 0.02$ mm$^3$). Therefore the demagnetizing factor was small and roughly the same for all samples. In the absence of static magnetic field the susceptibilities of all samples exhibit a sharp maximum at a temperature which increases with $x$. A static magnetic field ($H \leq 50$ Oe) was applied in order to find out the origin of this peak. For the alloys with $x \geq 2.3$ the maximum broadens and its size considerably decreases with increasing magnetic field. At higher fields the initial single peak evolves into two maxima (Fig. 2). On increasing $H$, the broader maximum at lower temperatures is shifted to lower temperatures, whereas the other one (sharper) is shifted to higher temperatures. The effect of $H$ on the initial susceptibility of the alloy with $x = 2$ is considerably smaller and no splitting of the maximum occurs.
It is natural to assume that more concentrated alloys behave as soft ferromagnets which is also supported by the electrical measurements (Fig. 3). For a dilute ferromagnet a peak at higher temperature is associated with the critical fluctuations close to \( T_C \) [5]. In that case the change in size of the peak \( (x_m) \) with field can be used [5] to deduce the critical exponent \( \delta \), \( x_m \sim H^{\frac{\delta}{2}} \). For the alloys with \( x \geq 2.3 \), plots of \( \log x_m \) vs. \( \log H \) were linear, showing no obvious \( x \) dependence. They yield an average \( \delta = 4.5 \pm 0.5 \), close to the prediction for the 3D Heisenberg ferromagnet.

The other maximum can be associated with the Hopkinson’s maximum the size and shape of which cannot be easily predicted since it depends on the actual domain structure and on the magnetic anisotropy. This maximum may also be related to the reentrant ferromagnet to spin-glass transition (F-SG), determining \( T_F \). Our results do not show any clear difference between the Hopkinson’s maxima at higher \( x \) \((x > 3)\) and those possibly related to \( T_F \) (close to \( x_c \)). Besides, for all our alloys the temperatures of these maxima (extrapolated to \( H = 0 \)) strongly increase with \( x \), whereas \( T_F \) values for other amorphous alloys [6] decrease with \( x \). Therefore from our measurements we cannot establish the F-SG line in the magnetic phase diagram of our system (Fig. 1 inset).

Electrical resistivity measurements, shown in figure 3, confirm our susceptibility results and yield practically the same \( T_C \)’s for the alloys with \( x \geq 2.3 \). For the alloy with \( x = 2 \) we do not observe an anomaly around \( T_0 \) (5.5 K) but the variation of \( d\rho/dT \) of this alloy is distinctly different from that for the paramagnetic \( x = 0 \) alloy (Fig. 3). Rather well defined anomalies in \( d\rho/dT \) for \( x \geq 2.3 \) are striking and seem to indicate either good magnetic homogeneity or a large inhomogeneity on an atomic scale (we note that in other amorphous systems sharp anomalies in \( d\rho/dT \) appear only for \( x \geq 2x_c \)).

Taken together our results set \( 2 < x_c < 2.3 \) for \( \text{Fe}_x\text{Ni}_{80-x}\text{B}_{18}\text{Si}_2 \) alloys. Both the magnetic and electrical measurements show a sharp F-PM transition even for the alloy with \( x = 2.3 \) \((\approx x_c)\) which is usually not observed in amorphous alloys and is possibly related to the very low \( x_c \). Limited accuracy prevented us from determining the critical exponents \( \gamma \) and \( \beta \) but judging by the values of \( \delta \) a large deviations of these exponents from the corresponding values for homogeneous ferromagnets is not likely.