MAGNETIC PROPERTIES OF FLASH EVAPORATED AMORPHOUS (Nd, Fe) FILMS

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Abstract. – Magnetic and ^{57}Fe Mössbauer measurements are reported for amorphous (Nd, Fe). The ordering temperatures, but not the spontaneous magnetisation, are strongly influenced by the preparation conditions. A broad hyperfine field distribution, slightly increasing with increasing Nd content, is observed at 77 K. The mean hyperfine fields remain constant.

Nd_xFe_{1-x}, $0.05 \leq x \leq 0.80$, films of about 2000 Å thickness were prepared by flash evaporation with substrate temperatures at 78 K. From *in situ* resistivity measurements a pronounced maximum at $x \approx 0.33$ is obtained for the stability of the amorphous state (Fig. 1). For $0.21 \leq x < 0.5$ no crystalline contribution could be detected by X-ray diffraction and electron microscopy at room temperature. Atomic absorption spectrometry was used to determine the composition. Magnetic measurements were performed in fields up to 6.5 T from 2 to 300 K and ^{57}Fe Mössbauer spectra were recorded between 77 and 300 K.

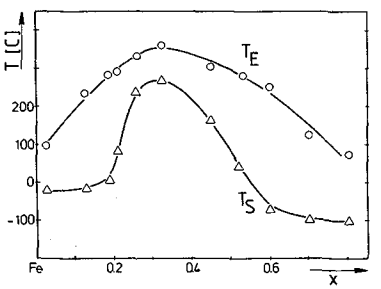

Fig. 1. – Stability of amorphous Nd_xFe_{1-x}. T_S starting, T_E finishing of the crystallisation process.

At room temperature the spectra of the pure amorphous samples exhibit only electrostatic hyperfine interactions. For x increasing from 0.27 to 0.40 the mean centershift (rel. to ^{57}FeRh) decreases from −0.14 to −0.20 mm/s.

At 77 K a broad hyperfine field distribution is observed. The spectra were fitted by a superposition of eight independent subspectra. The width of the distribution increases slightly with increasing x. For the investigated concentration range the mean hyperfine field (H_{hf}=18.4, 19.1 and 18.9 T for x = 0.27, 0.33 and 0.40) is nearly the same as observed for crystalline $NdFe_2$ [1], but lower than that reported for a co-evaporated amorphous sample with $x = 0.37$ at 4.2 K (H_{hf}=24.6 T [2]). The high field susceptibility determined from the magnetic isotherms recorded at 4.2 K (Fig. 2) increases from 0.70 to 1.47×10^{-4} emu/g for $x = 0.21$ to $x = 0.40$, respectively. The obtained values of the magnetisation are in agreement with those reported by Taylor *et al.* [2], however at much higher applied fields. This points to a higher anisotropy for the flash evaporated than for the co-evaporated samples.

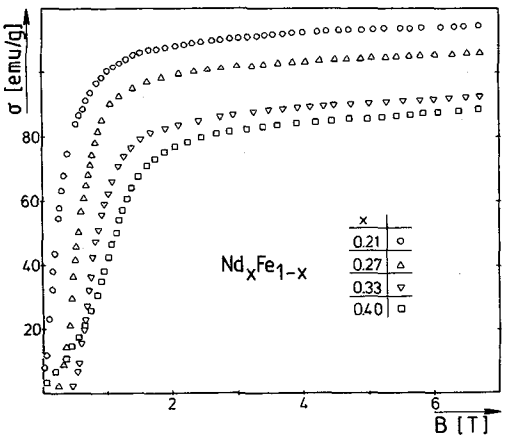

Fig. 2. – Field dependence of the magnetisation of amorphous Nd_xFe_{1-x} at 4.2 K.

Using 14.5 T/μ_B, as determined for yttrium iron compounds [3], leads to μ_{Fe}=1.3 μ_B compared with μ_{Fe}=1.7 μ_B extrapolated from the concentration dependence of the spontaneous magnetisation. The difference points either to a slight dependence of μ_{Fe} on x, or to a not neglectable valence contribution to the total H_{hf}. Following previous arguments [2, 4] and assuming μ_{Fe} to be constant, a comparison of the measured concentration dependence of the spontaneous magnetisation (Fig. 3) with those of hypothetical ones – ferromagnetic or antiferromagnetic alignment of Fe and

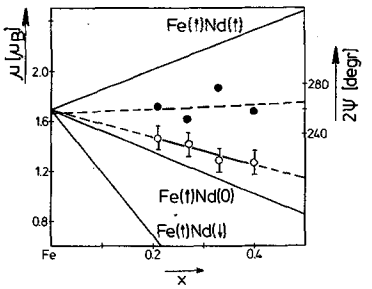

Fig. 3. – Concentration dependence of the spontaneous magnetisation (○) and of the distribution angle ψ (●) for amorphous Nd_xFe_{1-x}.

Nd or ferromagnetic alignment of Fe with random distribution of Nd – indicates that Nd is nearly random distributed with a small net moment parallel to the Fe moments. A possible scatter of the Fe moments cannot be excluded, but considering the hyperfine field distribution, it should be nearly independent of x. If the atomic moment of Nd (3.27 μ_B) is not altered by the Fe substitution, the distribution angle defined by $\bar{\mu}_{Nd}=1/2\ \mu_{Nd}\ (1+\cos\psi)$ [5] increases slightly with increasing x (Fig. 3).

The ordering temperature (T_C) obtained from magnetisation measurements at $\approx$ 2 mT are in agreement with the temperatures T_A determined by the vanishing of the magnetic hyperfine splitting (Fig. 4). Whereas T_C values determined from the high field part of $\sigma^2\,(H/\sigma)$ diagrams are approximately 70 K higher (Fig. 4). The values are much lower than those reported for amorphous samples prepared by other techniques. Small angle neutron scattering experiments (SANS) performed on sputtered, amorphous $NdFe_2$ points to a spin glass behaviour [6]. However the observed maximum in the correlation length at 285 K is higher than T_A. This must be mainly due to the different preparation conditions since no additional components were observed in the hyperfine splitting down to 77 K. Application of external fields leads to increasing clusters, which do not contribute to SANS [6], but may cause the increase of the magnetisation at temperatures above T_C and the observed strong field dependence of T_C.

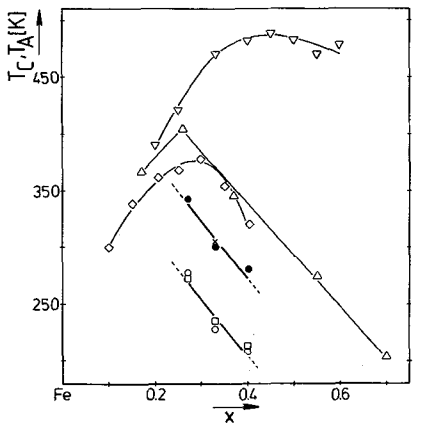

Fig. 4. – Concentration dependence of the ordering temperatures T_C determined at 2 mT (○), from $\sigma^2\,(H/\sigma)$ (●) and of T_A (▫), determined by the vanishing of the magnetic hyperfine splitting, for amorphous Nd_xFe_{1-x}. T_C for co-evaporated [2] (△), dc-sputtered [6] (×), [7] (◇) and melt spun [8] (▽) samples. The lines are only guides for the eyes.

To check the influence of the sample preparation conditions two samples with $x = 0.33$ and 0.40 were annealed at different temperatures for one hour in high vacuum. Annealing at temperatures below T_S (Fig. 1) is of minor influence on T_C. Using temperatures close to or higher than T_S causes a distinct increase of T_C (e.g. after annealing at 300 °C T_C is 325 K for $x = 0.33$). Since T_C is still much lower than recorded for crystalline samples (e.g. $T_C\,(NdFe_2)$ =578 K [1]) and no indications for the appearance of different T_C were obtained in the magnetisation curves, the main part of the samples should be still amorphous.

To sum up, the exchange interaction, but not the spontaneous magnetisation, is strongly influenced by the preparation conditions. A ferromagnetic aligned Fe sublattice with, in the investigated concentration range, constant moments and nearly randomly oriented Nd moments may explain the observed behaviour.

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