

MAGNETIC PROPERTIES IN BULK AND GLASSY $\text{Nd}_{50}\text{Fe}_{40}\text{Si}_{10-x}\text{Al}_x$

H. CHIRIAC¹, N. LUPU^{1,2}, K.V. RAO²

¹*National Institute of Research and Development for Technical Physics,
47 Mangeron Blvd, R-6600 Iasi, Romania*

²*Department of Materials Science, Royal Institute of Technology,
S-10044 Stockholm, Sweden*

Abstract. Magnetic properties of $\text{Nd}_{50}\text{Fe}_{40}\text{Si}_{10-x}\text{Al}_x$ ($x = 0; 10$) melt-spun ribbons with thicknesses between 30 and 150 μm and bulk rods up to 2 mm in diameter prepared by suction casting were investigated in the temperature range 5 - 600 K. The dependence of the coercive field on the thickness of the sample and the method of preparation is ascribed to the existence in the amorphous matrix of very small ferromagnetic clusters that can not be detected by X-ray diffraction. The coexistence of two types of magnetic order: spin glass short-range order and ferromagnetic long-range order is proved by the specific behaviour of zero-field cooled and field cooled magnetization curves.

1. Introduction

Binary RE-Fe amorphous alloys have been studied extensively not only for their physical interest but also for technological importance for permanent magnets, magnetostrictive materials and magneto-optical recording materials. These materials form a variety of magnetic structures ranging from ferromagnetic to sperrimagnetic or sperrimagnetic one due to the competition between the development of RE large single ion anisotropy and exchange interaction [1]. It was found that RE-Fe melt-spun ribbons exhibit very large coercive force, which increases dramatically as a function of the quenching rate [2]. Recently, it has been reported that Nd-Fe-Al and Nd-Fe-Si ternary amorphous alloys are formed in a wide range of compositions and exhibit also good hard magnetic properties at room temperature [3,4]. This paper focuses on structure and magnetic properties of $\text{Nd}_{50}\text{Fe}_{40}\text{Al}_{10}$ and $\text{Nd}_{50}\text{Fe}_{40}\text{Si}_{10}$ amorphous melt-spun ribbons and cast rods in the temperature range 5 - 600 K. Comparative studies as a function of the composition and the shape of the amorphous samples are presented.

2. Experimental

Ribbons with thicknesses between 25 and 145 μm were obtained by melt-spinning method in Ar atmosphere, by changing the surface velocity of the substrate and

maintaining constant the orifice size and the ejection pressure. Rods with diameters between 0.5 and 2 mm were prepared by suction casting method. Data about the amorphicity of the samples were obtained by X-ray diffraction (XRD), while information about the glass-forming ability were obtained from differential scanning calorimetry measurements (DSC). Hysteresis loops below room temperature and at magnetic fields up to 800 kA/m were performed using a MPMS₂ SQUID magnetometer. Zero-field-cooled (M_{ZFC}) and field-cooled (M_{FC}) magnetization measurements were carried out using a vibrating sample magnetometer (VSM).

3. Results and discussion

XRD patterns indicate fully amorphous structures for $Nd_{50}Fe_{40}Al_{10}$ melt-spun ribbons in the entire range of thicknesses and for cast rods. $Nd_{50}Fe_{40}Si_{10}$ cast rods and melt-spun ribbons thicker than 120 μm are fully crystalline, while the ribbons thinner than 80 μm are completely amorphous. These measurements are in agreement with those obtained from DSC curves that indicate an enlargement of the glass-forming ability by replacement Si with Al, *i.e.* an increase of the reduced crystallisation temperature (T_x/T_m) from 0.76 to 0.87 (T_x and T_m represent crystallisation and melting temperatures).

The addition of Al and Si to Nd-Fe binary alloys influences in different way the magnetic characteristics of the amorphous samples, as it can be seen in Fig. 1. One observes that the coercive force increases with the increase of the amorphous ribbons' thickness, regardless of their composition. The dependence of the coercive force on the thickness, namely the quenching rate, can be explain by assuming the presence in the amorphous matrix of very small magnetic clusters, which approach of single domain and can not be evidenced by XRD.

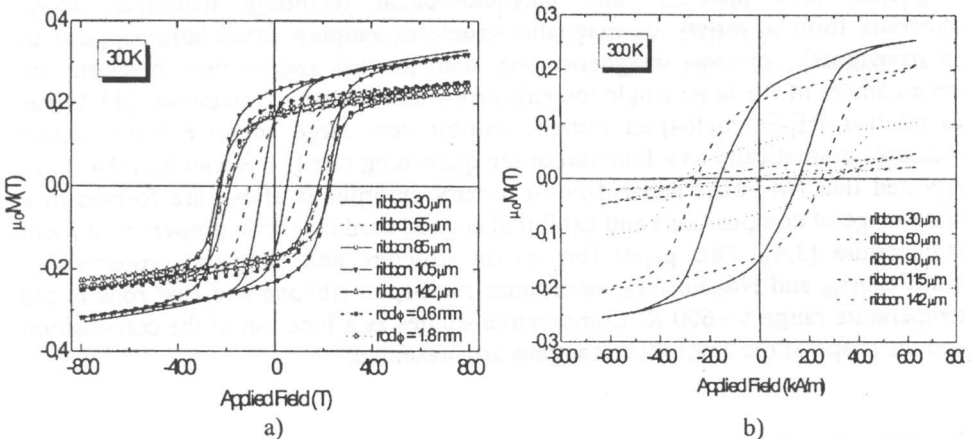


Fig. 1. Hysteresis loops for $Nd_{50}Fe_{40}Al_{10}$ (a) and $Nd_{50}Fe_{40}Si_{10}$ (b) melt-spun ribbons and cast rods, at room temperature

It is worth to note that the on-set of the crystallisation in $\text{Nd}_{50}\text{Fe}_{40}\text{Si}_{10}$ ribbons with thicknesses above $90\ \mu\text{m}$ results in the increase of the coercive force and a drastically decrease of the magnetisation, while the $\text{Nd}_{50}\text{Fe}_{40}\text{Si}_{10}$ fully crystalline ribbons have no B-H hysteresis loops. $\text{Nd}_{50}\text{Fe}_{40}\text{Al}_{10}$ amorphous cast rods exhibit large values for the coercive force, which are almost the same with those obtained for $\text{Nd}_{50}\text{Fe}_{40}\text{Al}_{10}$ thick amorphous ribbons. The coercive force measured for $\text{Nd}_{50}\text{Fe}_{40}\text{Si}_{10}$ thin amorphous ribbons is about three times larger than that obtained for $\text{Nd}_{50}\text{Fe}_{40}\text{Al}_{10}$ ones, this difference being determined by the difference in the atomic radii of Al and Si and by the small thicknesses of the ribbons. The decrease of the quenching rate and consequently the increase of the ribbon thickness have as a result the appearance of structural relaxation and the obtaining of one more relaxed amorphous structure in which magnetic clusters are homogeneously dispersed.

Figure 2 presents comparatively the magnetisation and coercive force as a function of temperature for $\text{Nd}_{50}\text{Fe}_{40}\text{Al}_{10}$ and $\text{Nd}_{50}\text{Fe}_{40}\text{Si}_{10}$ amorphous ribbons $30\ \mu\text{m}$ thickness. In the temperature range $5\text{--}300\ \text{K}$ several magnetic transitions take place. At very low temperatures the large anisotropy of Nd^{3+} ions plays the predominant role in freezing the spins of the magnetic atoms randomly and a sperrmagnetic structure is obtained. By increasing the temperature the exchange energy compensate the anisotropy of Nd ions and as a consequence the sample become ferromagnetic. It is important to note that at room temperature the magnetisation measured for both Al and Si containing amorphous ribbons has the same value. The maximum values of about $580\ \text{kA/m}$ and $480\ \text{kA/m}$ attained for coercive force at around $200\ \text{K}$ for amorphous ribbons containing Si and Al, respectively, prove that near this temperature the thermal activation effects and the anisotropy energy are small enough and the exchange energy plays the predominant role in the mechanism of coercivity.

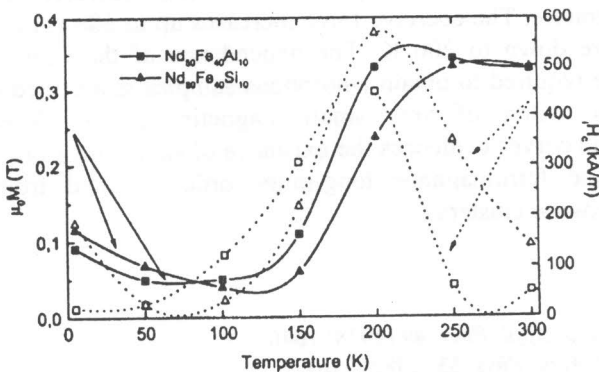


Fig. 2. The magnetisation (solid lines and solid symbols) and coercive force (dashed lines and open symbols) dependence on temperature for $\text{Nd}_{50}\text{Fe}_{40}\text{Al}_{10}$ and $\text{Nd}_{50}\text{Fe}_{40}\text{Si}_{10}$ thin amorphous ribbons $30\ \mu\text{m}$ thickness

The coexistence of two types of magnetic order, short-range spin-glass-like and long-range ferromagnetic order even in amorphous rods, is evidenced by zero-field and field cooled thermomagnetic measurements in Fig. 3. The presence of the maximum on the M_{ZFC} curves and the bifurcation between M_{ZFC} and M_{FC} curves prove the existence of two magnetic phases. The displacement of the M_{ZFC} maximum towards high temperatures with the increase of the thickness of the amorphous ribbons is determined by the fact that as thicker the ribbons the glassy disorder is higher and the thermal energy required to destroy it is higher.

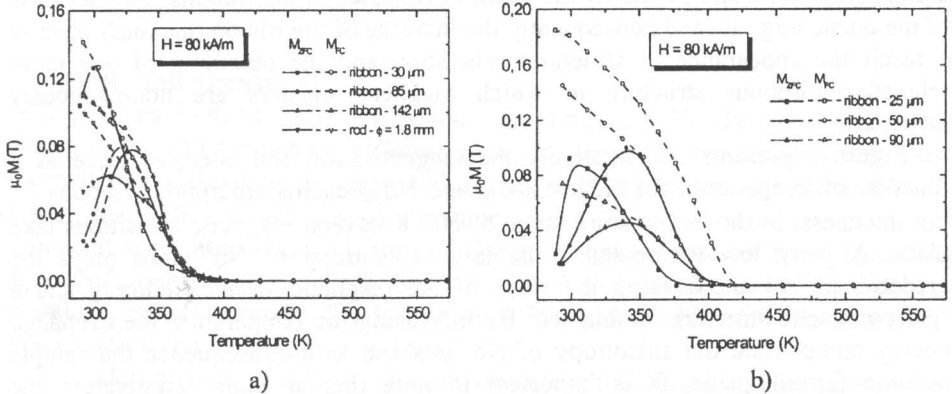


Fig. 3. M_{ZFC} and M_{FC} curves plotted against temperature for $Nd_{50}Fe_{40}Al_{10}$ (a) and $Nd_{50}Fe_{40}Si_{10}$ (b) amorphous samples

4. Conclusions

It was found that $Nd_{50}Fe_{40}Al_{10}$ melt-spun amorphous ribbons and cast amorphous rods as well as $Nd_{50}Fe_{40}Si_{10}$ melt-spun ribbons exhibit coercivities up to 300 kA/m at room temperature. The coercive force increases up to 580 kA/m with decreasing the temperature down to 200 K. The dependence of the coercive force on the quenching rate required to obtain amorphous samples is ascribed to the formation in amorphous matrix of very small magnetic clusters. The shape of the thermomagnetic curves evidences the existence of short-range order existent inside the clusters and ferromagnetic long-range order resulted from the exchange interactions between clusters.

References

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