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Magnetic and transport studies on nanocrystalline $Fe_{73.5}Si_{13.5}B_8CuNb_2VAl$ ribbon

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ABSTRACT

The magnetic and the transport properties of the $Fe_{73.5}Si_{13.5}B_8CuNb_2VAl$ nanocrystalline ribbon have been presented. The coercive field was found to increase from 0.24 to 1 Oe on lowering the temperature from 300 to 5 K. The irreversibility in the FC–ZFC was observed and the magnetization was found to follow $T^{3/2}$ law. Magnetoresistance measurements were done along the length of the ribbon and the MR of -0.07% was observed at 300 K. Cluster glass behavior was predicted by the power law.

1. Introduction

Considerable interest in the development of the magnetic sensors and heads employing the Fe- based nanocrystalline FeSiNbCuB ribbons has been generated because of the excellent magnetic softness in them [1]. It has also been shown that when the size of the particles/grains is in the nanometer range, the properties are drastically different from those of the materials on a macroscale. As has been observed by the Yoshizawa [2], this kind of materials can be obtained by the primary crystallization of amorphous precursors and thus the resultant microstructure contains a considerable amount of the residual amorphous phase.

A comprehensive description of the microstructural evolution during the growth of Fe–Si–B–Nb–Cu nanocrystalline has been given by Hono [3]. In these nanocrystalline materials the magnetic interactions between the two constituent magnetic phases mainly determine the macroscopic magnetic behavior and its temperature dependence. Recently, magnetoimpedance (MI) effect has been studied by our group in the $Fe_{73.5}Si_{13.5}B_8CuNb_2VAl$ nanocrystalline ribbon and has obtained the large MI of the order of $10^4\%$ [4]. This motivates us to know more details about the ribbon. Thus in the present work, the magnetic and the transport properties of the $Fe_{73.5}Si_{13.5}B_8CuNb_2VAl$ nanocrystalline ribbon are presented.

2. Experimental details

The $Fe_{73.5}Si_{13.5}B_8CuNb_2VAl$ alloys were prepared in arc furnace in the presence of argon atmosphere. Amorphous ribbons of 1–2 mm width and 30–40 μm thickness were prepared by the melt spinning technique. The as-cast ribbons are amorphous in nature and thus, to obtain the nanocrystalline state, the ribbons were annealed in vacuum at 500 °C (near to crystallization temperature) for 1 h. and their nanocrystalline nature was confirmed through XRD and TEM. The crystallization temperature was determined by differential scanning calorimetry and has been given in [4]. The magnetic domains were observed using the dimension 3100 (Nanoscope-IV) scanning probe microscope. The magnetoresistance (MR) and ac susceptibility measurements were performed using physical property measurement system (PPMS-Quantum Design). The measurements of the dc magnetization as a function of temperature and applied field have been performed by the commercial superconducting quantum interference device (SQUID) magnetometer.

3. Results and discussion

Fig. 1(a) shows the XRD patterns of the ribbon annealed at 500 °C for 1 h in vacuum. The α-FeSi particles of size 12 nm are observed in the bright field TEM (dark spots) pictures (Fig. 1(b)). The presence of the α-FeSi particles embedded in an amorphous phase is also verified by their corresponding Selected-area Electron Diffraction Pattern (SEDP) (Fig. 1(b)). Fig. 2 shows the

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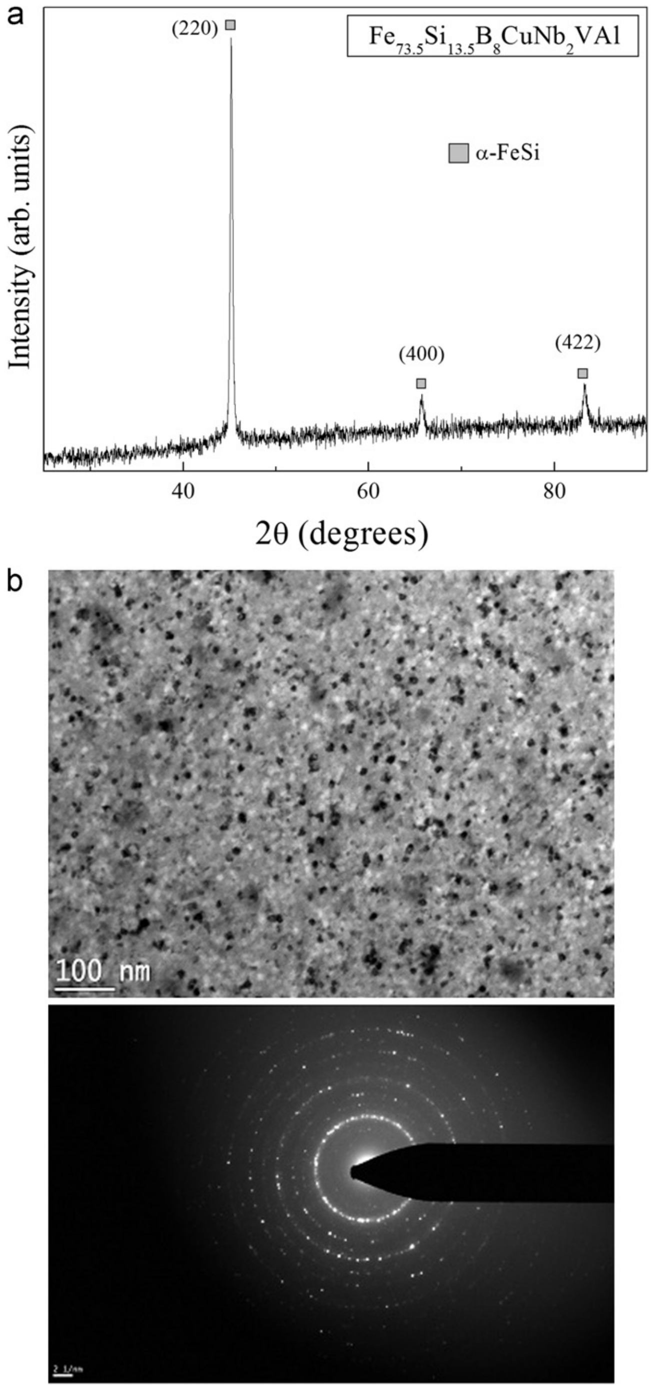

Fig. 1. (a) XRD pattern of nanocrystalline $Fe_{73.5}Si_{13.5}B_8CuNb_2VAl$ ribbon, (b) TEM and SEDP picture of nanocrystalline $Fe_{73.5}Si_{13.5}B_8CuNb_2VAl$ ribbon.

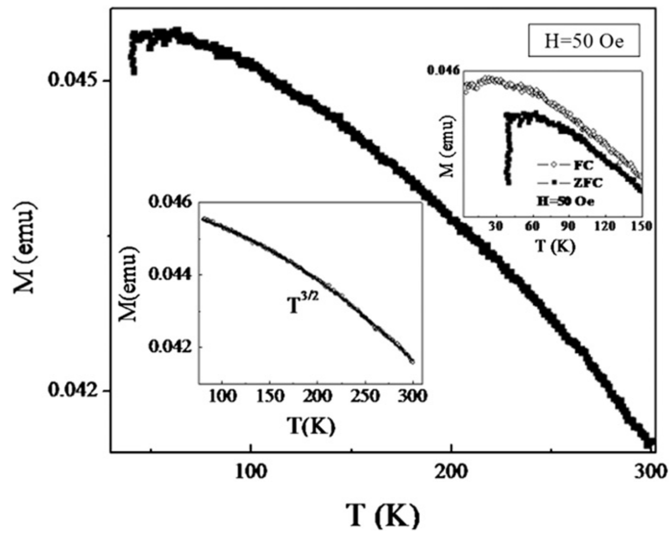

Fig. 2. Variation of *M* with *T* at 50 Oe in ZFC state (inset: Variation of M with *T* at 50 Oe in ZFC and FC state and $T^{3/2}$ fitted plot).

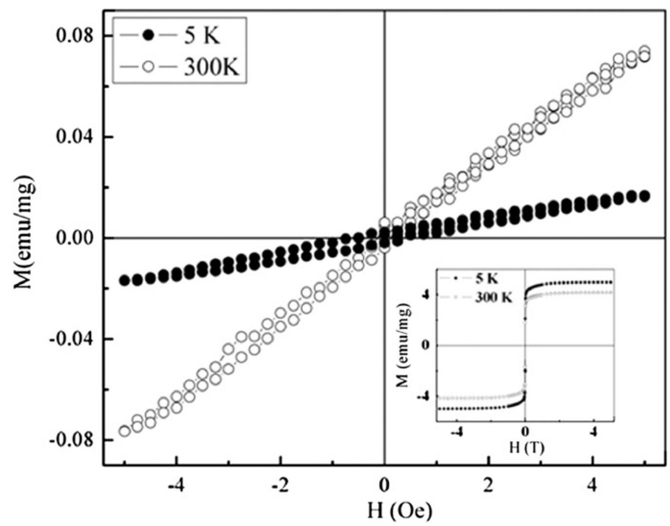

Fig. 3. Variation of *M* with *H* at 5 and 300 K.

low-field (50 Oe) magnetization (M) data recorded in zero-field-cooling (ZFC) and field-cooling (FC) state, in the temperature range of 5 K–300 K. The Curie temperature (T_C) is observed to be above 300 K, as what has been reported earlier [1]. Below 300 K, irreversibility in the field-cooled (FC) and zero-field-cooled (ZFC) measurements is observed (*inset* of Fig. 2). The irreversibility in M–T curves has been earlier observed in conventional ferromagnets also, at low fields and well below their *Tc*, which is due to the progressive stiffening of domain walls as the temperature is lowered through *Tc* to low temperatures (pinning effect). In addition to pinning effect, the presence of the competing anisotropies which may arise due to the presence of the two phases viz. amorphous and nano-phase, also results in a large bifurcation between FC and ZFC data. The magnetization in the temperature range from 80 to 300 K, is fitted to the equation as shown in the *inset* of Fig. 2 and it is found to follow the $T^{3/2}$ law. This indicates the presence of the spin wave excitations in the system and has been reported earlier in Fe-rich nanocrystalline alloys [5].

The magnetization curves at 5 and 300 K over the field range of 5 *T* to –5 *T*, are shown in the Fig. 3. A typical ferromagnetic behavior is observed at 5 K and 300 K (*inset* of Fig. 3). Till now, most of the studies done on the sample, are limited upto the field of the order of the few Oe [4], thus to study the magnetic properties of the sample at low fields, the hysteresis loop is measured from -5 to 5 Oe and is shown in the Fig. 3. The magnetization at 5 K is observed to be smaller than at 300 K. This can be due to the freezing of the spins at low temperature. The ribbons have been reported to be highly soft magnetic in nature [4]. On applying low fields, the magnetization of almost the whole sample orients towards the applied field while the magnetization of small regions with pinned or frozen spins still remains in the initial directions which in turn reduces the magnetization at 5 K. On increasing the temperature, due to the