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MAGNETIC VISCOSITY AND DEMAGNETIZATION BEHAVIOUR IN ISOTROPIC NANOCRYSTALLINE $Pr_{12}Fe_{82}B_6$ RIBBONS*

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We present the experimental results of the magnetic viscosity, demagnetization curve and recoil loop for isotropic nanocrystalline $Pr_{12}Fe_{82}B_6$ ribbons prepared by melt-spinning. The thermal fluctuation field, activation volume and irreversible demagnetization are discussed. The coercivity mechanism is mainly determined by the inhomogeneous nucleation rather than a simple nucleation of reverse domain.

Keywords: magnetic viscosity, nanocrystalline, permanent magnet
PACC: 7550V, 7560L, 7560E, 7560G

I. INTRODUCTION

An interfacial exchange coupling is found to play an important role in materials with a nanograin (or nanolayer) structure, as giant magnetoresistance[1] and excellent magnetic softness[2] have been discovered in addition to nanocomposite permanent magnets.[3] A giant energy product of $1MJ/m^3$ predicted for nanocomposite permanent magnets[4] attracts great interest in permanent magnetism. Nanocomposite magnets consisting of a mixture of magnetically hard and soft phases have been extensively studied.[5−14]

Unfortunately, the experimental optimum maximum energy product $(BH)_{max}$ is far less than the ideal one.[4] For example, the optimum $(BH)_{max}$ is about $180kJ/m^3$ for melt-spun $Pr_8Fe_{87}B_5$ ribbons.[8] More physical investigations have to be made for high-quality properties of nanocomposite permanent magnets.

The magnetic viscosity of magnetic materials is of great practical application as well as theoretical significance.[15−20] The magnetic viscosity can be expressed as

$$M(t) = M_0 - S\ln(t + t_0), \tag{1}$$

where S is the magnetic viscosity coefficient and M_0 is a constant. Physically S can be given as

$$S = n(E)k_BT, \tag{2}$$

where $n(E)$ is the distribution of thermal energy barrier E. The thermal fluctuation field H_f can be expressed as

$$H_f = k_B/\mu_0 v M_s = S/\chi_{irr}, \tag{3}$$

where v is the activation volume of the relaxation process and χ_{irr} is the irreversible susceptibility. Since magnetic viscosity parameters are associated directly with the microscopic structure and the processes responsible for magnetization reversal, the y may provide information on the magnetization mechanisms of materials and reveal ways by which improvement in magnetic properties may be realized.

In this paper, the mechanism of demagnetization for isotropic nanocrystalline $Pr_{12}Fe_{82}B_6$ ribbons is investigated by analysing the magnetic viscosity and demagnetization process.

II. EXPERIMENTAL DETAILS

The isotropic nanocrystalline $Pr_{12}Fe_{82}B_6$ ribbons were prepared by direct melt-spinning as described in Ref.[8]. The magnetic measurements were carried out using a superconducting quantum interference device (SQUID) magnetometer with a maximum field of μ_0H=6.0T applied along the longitudinal direction of

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the ribbons. In such a case, the demagnetization factor could be neglected. The magnetic viscosity, total susceptibility $\chi_{\rm total}$, reversible susceptibility $\chi_{\rm rev}$ and recoil curves were measured by the methods described in Refs.[20] and [21] at room temperature (RT).

Ⅲ. RESULTS AND DISCUSSION

Figure 1 shows the demagnetization curve and the typical recoil curves of the ribbons. The coercivity ($\mu_0 H_{\rm c}$=1.14T) and the remanence ($\mu_0 M_{\rm r}$=0.90T) are a little less than those reported in Ref.[8]. Because the reduced remanence $M_{\rm r}/M_{\rm s}$=0.90/1.58=0.57 is larger than that predicted for isotropic noninteraction magnets, the existence of the strong intergrain exchange coupling is obvious. Before the applied field ($\mu_0 H$) becomes as large as 0.9 T, the demagnetization curve is nearly reversible. The recoil loops are nearly closed and their susceptibilities are very small.

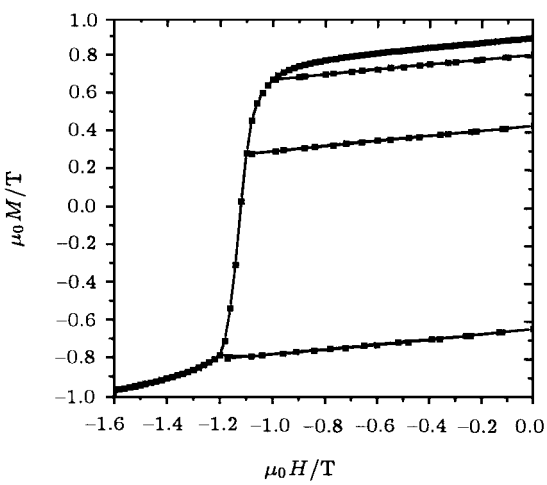


Fig.1. The demagnetization curve and the typical recoil curves of the ribbons.

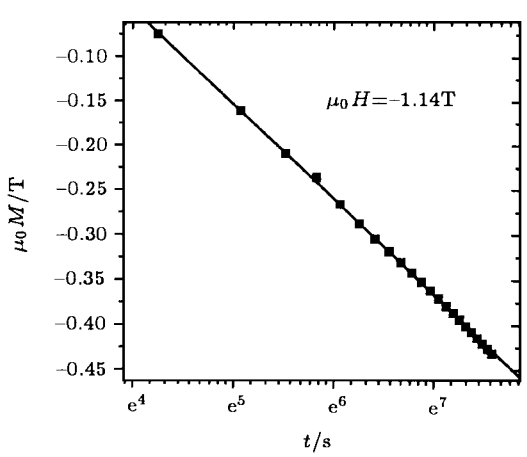


Fig.2. Time dependence of magnetization in the field of $\mu_0 H$=−1.14T.

Figure 2 shows the time dependence of magnetization in the field of $\mu_0 H$=−1.14T. The linear relationship can be well fitted using Eq.(1). The value of t_0 is found to be about 60s, which means the physical zero time is about 60s ahead of the measuring zero time when using SQUID.

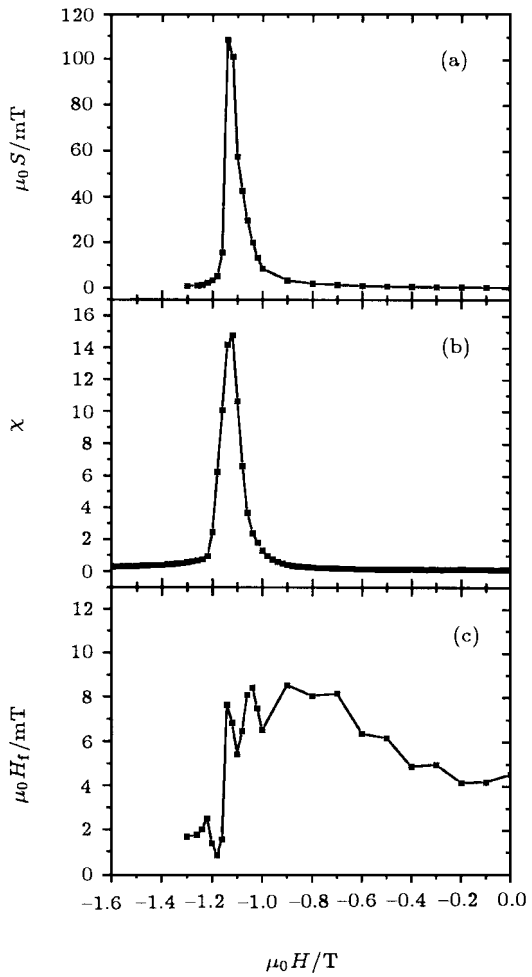


Fig.3. The field dependence of S (a), $\chi_{\rm total}$ (b) and $H_{\rm f}$ (c).

Figures 3(a)–3(c) give the field dependence of S, $\chi_{\rm total}$ and $H_{\rm f}$, respectively. The maximum value of S is observed under the field near the coercivity, and its value ($\mu_0 S_{\rm max}$) is about 108mT. A very narrow distribution of energy barrier E at RT can be obtained according to Eq.(2). Compared with our previous reports for nanocrystalline $Sm_2Fe_{15}Si_2C$ ribbons,[22,23] both the high value of $S_{\rm max}$ and the narrow distribution of E may be caused by the homogeneity of grain sizes in nanocrystalline $Pr_{12}Fe_{82}B_6$ ribbons. The curve of $\chi_{\rm total}$ versus H (as shown in Fig.3(b)) exhibits the same shape as that shown in Fig.3(a). Due to the value of $\chi_{\rm rev}$ being very small, we can approximately use the value of $\chi_{\rm total}$ as that of $\chi_{\rm irrev}$.

According to Eq.(3), the value of $\mu_0 H_f$ and v near the coercivity are about 7mT and 4.7×10^{-25}m^3, respectively. The value of $\mu_0 H_f$ is the same as that in sintered NdFeB magnets,[17] but it is higher than that of nanocomposite NdFeB/Fe type ribbons, as reported in Ref.[24]. The thermal activation volume v is far less than the volume of grain (grain size is about 20nm). This is not the case for an isolated fine particle, and may be explained by a single jump between a pinning centre and the next one for a domain wall. Meanwhile, we notice a large value of S in the field near coercivity. Therefore, the mechanism of magnetization reversal is mainly controlled by the inhomogeneous nucleation and pinning of walls at grain boundaries rather than pure nucleation type or strong pinning model.[8,22]

After a previous saturation in the opposite direction in the field $\mu_0 H$=6T takes place, an analysis of the magnetization change along with the demagnetization curve is given in Figs.4 (a) and 4(b). The irreversible portion is described by the dc field demagnetization remanence $M_d(H)$, a remanence acquired after saturation in one direction and subsequent application of a dc field H in the opposite. The field dependence of $D(H) = [M_r - M_d(H)]/2M_r = -\Delta M_{irrev}(H)/2M_r$ is shown in Fig.4(a). Using the method given in Ref.[3], the nucleation field $\mu_0 H_n$ for irreversible magnetization reversal is about 1.07T from the experimental curve $D(H)$. Figure 4(b) shows the reversible portion $-\Delta M_{rev}(H)/M_r$ versus H. A sharp peak of the curve exists under a field $\mu_0 H$=1.08T. The maximum value of $-\Delta M_{rev}(H)/M_r$ is far less than those in nanocomposite ribbons.[3,24] It seems that the high reversible portion is mainly attributed to the existence of magnetic soft phase in nanocomposite magnets.

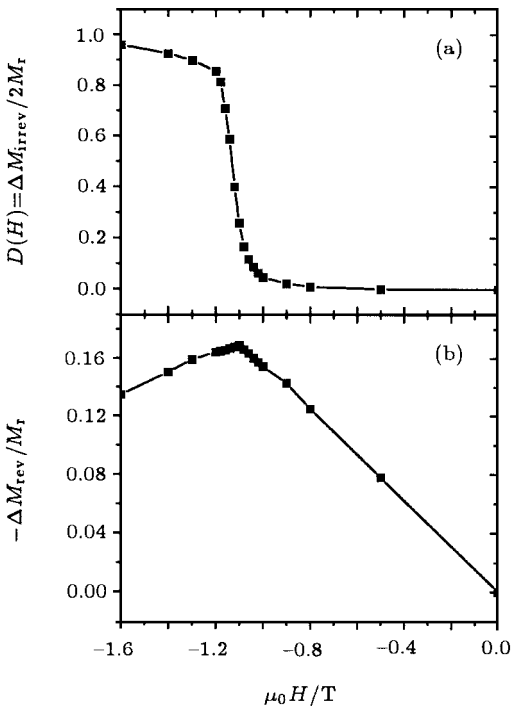


Fig.4. Irreversible portion $D(H)=[M_r - M_d(H)]/2M_r=-\Delta M_{irrev}(H)/2M_r$ (a) and reversible portion $-\Delta M_{rev}(H)/M_r$ (b) versus the field.

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