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Journal of Magnetism and Magnetic Materials 310 (2007) 2381–2383
Journal of magnetism and magnetic materials
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Effects of annealing time on structural and magnetic properties of $L1_0$-FePt nanoparticles synthesized by the SiO_2-nanoreactor method

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Available online 16 November 2006

Abstract

We investigated effects of annealing time on structural and magnetic properties of the $L1_0$-FePt nanoparticles synthesized by the "SiO_2-nanoreacter" method. The magnetization and powder X-ray diffraction (XRD) studies revealed that the annealing at 900 °C for 9 h could convert all of the FCC-nanoparticles to the well-crystallized $L1_0$ structure with a large coercivity while keeping their particle size. Such monodisperse and highly crystalline $L1_0$-FePt nanoparticles are a promising material for the realization of ultra-high density recording.
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PACS: 61.46.+w; 75.50.Vv; 75.30.Gw

Keywords: Nano-particle; Nano-crystalline material; Nano-scale ferromagnet; Fe–Pt alloy cluster

1. Introduction

FePt nanoparticles synthesized by chemical solution-based methods attract much attention as one of the most promising candidates for the future recording media with ultra-high densities beyond 1 Tbit/in^2 [1,2]. However, the chemical methods can produce only disordered face-centered cubic (FCC) or partially ordered $L1_0$-FePt nanoparticles [3,4], and thus a post-thermal annealing is necessary to transform them into the desired, well-ordered $L1_0$ structure. This post-annealing results in coalescence and coarsening of the nanoparticles, leading to difficulties in fabricating desirable arrays on a substrate.

Recently, we have succeeded in solving these problems by developing a new synthetic strategy named "SiO_2-nanoreactor" method [5,6,7]. Previous studies revealed that annealing at 900 °C for 1 h could convert almost all of the FCC-FePt nanoparticles to the well-crystallized $L1_0$ structure with a high coercivity although only minor part of the sample remained unconverted [8].

Here, we report effects of annealing time on structural and magnetic properties of the nanoparticles synthesized by the SiO_2-nanoreactor method by means of SQUID magnetometry and powder X-ray diffractometry (XRD).

2. Experimental

$L1_0$-FePt nanoparticles were prepared according to the reported method [5,6]. The SiO_2-coated FCC-FePt nanoparticles (6.5 nm in diameter) were annealed at 900 °C for various periods of time in flowing H_2(5%)/Ar(95%) gas to convert them to the $L1_0$ structure. Elemental composition of the FePt nanoparticles was determined to be $Fe_{48}Pt_{52}$ by using an atomic absorption spectrometer (Shimadzu, AA-6300). The XRD profile collected by using Cu K_α radiation ($\lambda = 0.154$ nm) (Rigaku, RINT2500). Magnetic properties were characterized by using a SQUID magnetometer (quantum design, MPMS XL).

3. Results and discussion

Fig. 1 shows the room temperature hysteresis loops for the SiO_2-coated nanoparticles annealed at 900 °C for various periods of time. Here, M_s represents the overall sample magnetization at 50 kOe. Coercivity of the FePt nanoparticles annealed for 1 h reaches as large as 13 kOe,

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doi:10.1016/j.jmmm.2006.10.739

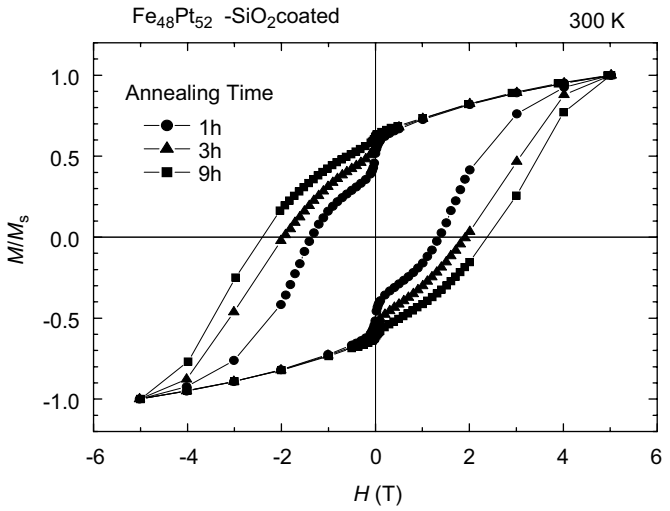


Fig. 1. Room temperature hysteresis loops of the SiO_2-coated FePt nanoparticles annealed at 900 °C for various periods of time.

confirming Fe and Pt atoms forms well-ordered $L1_0$ structure. However, the hysteresis loop shows a kink at low magnetic field. This indicates the sample includes magnetically soft phase, i.e. the FCC-phase, in addition to the $L1_0$-phase. The amount of the FCC-phase was estimated to be 15% of all the nanoparticles from the decrease of magnetization at the kink. It is notable that the decrease of magnetization at the kink became smaller (7.5% for 3h, almost 0% for 9h) and the coercivity became larger as the annealing time increased. These features indicate that the FCC-nanoparticles remained after annealing for 1 h could be converted to the $L1_0$-phase upon further annealing (Table 1).

Fig. 2 shows a series of XRD patterns from $2\theta = 38^\circ$ to 44° of the SiO_2-coated FePt nanoparticles annealed 900 °C at for various periods of time. Though there are both the $L1_0$- and the FCC-phases (1 1 1) main reflection peaks in this range, it is difficult to directly estimate relative amount of them because of the broadening of peak width arising from the small size of the nanoparticles. Therefore, we divided the observed signal into two peaks of the $L1_0$- and the FCC-phases by assuming that they have Lorentzian form. A good fit to the signal could be obtained by assuming the constant size of the $L1_0$- and FCC-nanoparticles being 7.1 and 4.5 nm, respectively. We can estimate the relative amount of the $L1_0$- and FCC-nanoparticles from these parameters, which are shown in Table 1. The XRD studies also revealed the decrease of the amount of the FCC-nanoparticles with increasing annealing time. It is worth noting that the results from the XRD agree well with the estimation from the magnetization measurements.

Table 1
Relative amount of the $L1_0$- and FCC-nanoparticles estimated by XRD patterns of the SiO_2-coated FePt nanoparticles annealed for various periods of time

Annealing time (h)	$L1_0$ (%)	FCC (%)
1	83	17
3	93.4	6.6
9	100	0

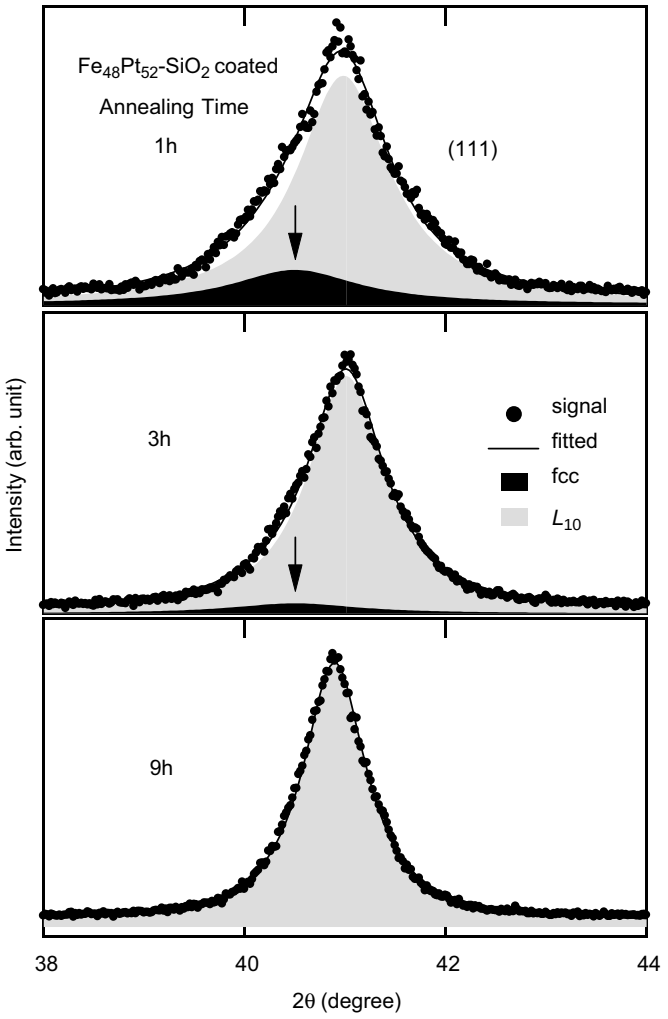


Fig. 2. XRD patterns of the SiO_2-coated FePt nanoparticles annealed at 900 °C for various periods of time.

4. Conclusions

We investigated effects of annealing time on structural and magnetic properties of the nanoparticles synthesized by the SiO_2-nanoreactor method. The magnetization and XRD studies revealed that the annealing at 900 °C for 9 h could convert all of the FCC-nanoparticles to the well-crystallized $L1_0$ structure with a large coercivity while keeping their particle size. We expect that such monodisperse and highly crystalline $L1_0$-FePt nanoparticles are a promising material for the realization of ultra-high density recording.

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