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Direct evidence of chemical ordering in the FePt nanostructured alloy by HR-TEM

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ABSTRACT

The iron–platinum (FePt) alloy exhibits structural and magnetic phase transformation even at a low temperature of 300 °C with an insignificant grain growth. These transformation studies were understood nano-scopically using high resolution-transmission electron microscopy (HR-TEM). The FePt grains show strain induced structural transformation and adopts polycrystalline behaviour. The chemical ordering of FePt grains is explained using Fast Fourier Transform (FFT) analysis of the TEM image. HR-TEM image shows the hexagonal arrangement of Pt atoms in the [0 0 1] direction in the FePt unit cell which gives the direct evidence of chemical ordering in FePt nanostructured alloy. The filtration and reconstruction method has been employed with the help of inverse Fast Fourier Transformation tool, confirming the formation of $L1_0$ FePt phase. The chemical ordering is also confirmed by structural and magnetic measurements revealing an order parameter of 0.875 and coercivity 3 kOe respectively at a low annealing temperature of 300 °C. The chemical ordering at low annealing temperature makes it suitable for media storage applications.

1. Introduction

The bit areal density is one of the major factors affecting the media recording now days which can be achieved by reduction of size of the recording bits of the recording media [1]. The reduction in size

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of recording bit is limited by the thermal fluctuation of the magnetic spins even at room temperature which give rise to super paramagnetism. To overcome this super paramagnetic effect, a material should have high magneto crystalline anisotropy [2–4]. The $L1_0$ structures, like iron–platinum (Fe–Pt) alloy possess a large uniaxial magneto crystalline anisotropy ($K_u \approx 7 \times 10^6$ J/m^3) providing thermal stability to nano-sized particles even at room temperature [5–7]. Moreover, FePt system undergoes a structural and magnetic phase transition from disordered, face centered cubic (FCC, A1, $Fm\bar{3}m$) phase to ordered, face centered tetragonal (FCT, $L1_0$, P4/mmm) phase upon annealing at high temperatures [8,9]. The structural transformation arises due to the distortion in the lattice structure originating from the atomic rearrangement in the FePt unit cell [10].

The distortion in the unit cell can be estimated using the X-ray diffraction (XRD) technique. However, a clear picture of the atomic site is obtained by profile fitting the XRD data using the XRD pattern simulation software [11]. Selected area electron diffraction (SAED) mode in transmission electron microscopy (TEM) is also an alternative way of explaining a structural transformation in a desired system by indexing the obtained ring pattern [12]. Moreover, the atomic arrangement in the unit cell obtained in the high resolution TEM image (corresponding to the SAED) can also be understood using the Fast Fourier Transformation (FFT) image processing technique [13] by mapping the repeated and periodic discrete quanta of the data in the spatial domain with the reciprocal space [14,15]. Goswami et al. investigated the microstructure, interfaces and intermixing of multilayered FePt films with the help of TEM [16].

In this paper, a structural and magnetic phase transformation of FePt films has been investigated consequent to annealing at high temperature. A detailed investigation on bright and dark field TEM image has been performed by analysing the FFT of an image in the spatial domain. A correlation between the structural and magnetic phase transformation has also been made using HR-TEM, XRD and vibrating sample magnetometer (VSM).

2. Experimental

FePt films were prepared on polished Si ⟨100⟩ substrates by DC magnetron sputtering system (HINDHIVAC, model 12″ MSPT). High purity argon gas was introduced into the chamber to maintain the pressure at 0.03 mbar during the sputtering process. The DC power and deposition time was maintained at 30 W and 6 min respectively during the deposition of FePt thin films. The sputtering parameters mentioned above were chosen after several iterations. A microprocessor controlled furnace was used to perform the annealing. The films were subjected to annealing at temperature 300 °C for 1 h under Ar + 5% H_2 atmosphere with a 40 °C per min. ramp, followed by rapid cooling to room temperature.

The structural studies of as-deposited and annealed films of FePt were examined using XRD (D-8, Bruker) with Cu Kα radiation of $\lambda = 1.5405$ Å, operated at 40 kV, 40 mA with 2θ ranging from 20° to 52°. The magnetic studies at room temperature were performed using VSM (EV-9, Micro sense) in a magnetic field up to ±22 kOe. The microstructural analysis of the films was performed on films deposited on carbon coated grids using TEM (Tecnai, G^2 20), operated at 300 kV.

3. Results and discussion

In order to study the structural transformation, XRD measurements were performed on the as prepared FePt film and the film annealed at 300 °C for 1 h (shown in Fig. 1). As prepared FePt film shows the disordered FCC phase as indicated by the appearance of peak centered at 40.77° along with the hump centered at 47.17° Corresponding to (111) and (200) planes respectively. Evolution of (001) and (110) super lattice peaks on annealing, indicate the structural transformation from chemically disordered FCC phase to a chemically ordered FCT phase. The tetragonality induced in the system, due to the atomic displacement is studied by observing the splitting of the hump corresponding to (200) (FCC, Fig. 1(a)) into (200) and (002) peaks (FCT) as shown in Fig. 1(b). To estimate the lattice distortion, lattice parameters were calculated from (001) and (110) peaks (Fig. 1(b)) and are