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Fabrication of nonepitaxially grown double-layered FePt:C/FeCoNi thin films for perpendicular recording

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A noneptaxially grown double-layered thin-film medium of nanocompsite FePt:C with a FeCoNi soft underlayer for high-density perpendicular magnetic recording was fabricated and investigated. Square-shaped perpendicular loops with a remanance ratio nearly equal to one and a coercivity as large as 8.5 kOe were obtained for this ordered FePt:C double-layered medium. The formation of the ordered $L1_0$ phase is confirmed by electron diffraction experiments. Transmission electron microscope observations reveal that FePt grains with a uniform size less than 5 nm are embedded in the C matrix and appear to be well isolated. Our results show that nonepitaxially grown (001) textured double-layered nanocomposite $L1_0$ FePt-based films with perpendicular anisotropy are a promising candidate to realize extremely high-density perpendicular recording. © *2003 American Institute of Physics.* [DOI: 10.1063/1.1621071]

$L1_0$ nanocomposite FePt-based thin films attract attention for extremely high-density perpendicular recording media due to their high magnetic anisotropy. From the technological viewpoint, the easy magnetization axis, which corresponds to the *c* axis of the ordered FePt grains, should be aligned perpendicular to the film plane for perpendicular recording, and magnetic properties, microstructure, and grain size should be controlled as well. Obtaining the (001) textured $L1_0$ nanocomposite FePt-based films will align the easy magnetization axis of FePt grains perpendicular to the film plane. Recently, attempts to obtain the (001) textured $L1_0$ nanocomposite FePt-based films have been made by either epitaxial growth on a MgO (100) substrate[1–3] or nonepitaxial-growth on a silicon wafer and glass substrate.[4–6] The fabrication conditions, annealing processes, and magnetic properties of these (001) textured films also have been investigated systematically.[5–9] For practical applications, nonepitaxially grown $L1_0$ nanocomposite FePt-based thin films are advantageous because of the ease of growth. In this letter, we report the design and fabrication of nonepitaxially grown (001) textured $L1_0$ nanocomposite FePt:C thin films with a soft-magnetic underlayer (SUL). Also, we will discuss magnetic properties, grain size, magnetic interactions, and read/write performance results of this double-layered medium.

The double-layered media were sputtered onto Si(100) wafers with thermally grown oxide at room temperature. A brief ion etch was used to preclean the substrate. The base pressure of the chamber was 3×10^{-7} Torr and the working pressure was 2 mTorr. Microstructural properties of this medium were characterized by x-ray diffraction (XRD). The morphology of magnetic nanoparticles were checked and verified by plan-view and cross-sectional transmission electron microscope (TEM). Magnetic properties were determined with a superconducting quantum interference device (SQUID) magnetometer and polar–Kerr effect. Magnetic correlation lengths were observed by a magnetic force microscope (MFM). Read/write performance was tested utilizing a contact tester.

A $L1_0$ nanocomposite FePt:C perpendicular thin film with a SUL was designed and prepared using a nonepitaxial growth method. Figure 1(a) shows a schematic view of the cross section indicating the substrate and each layer in the film. The FeCoNi SUL was first deposited on thermally oxidized Si substrates. The saturation magnetization flux density (B_s) for this layer is approximately 20 kG. The FePt:C layer was then deposited on the SUL at room temperature by a multilayer deposition technique and subsequent annealing. The as-deposited film structure is $[C(0.3\ nm)/Fe(0.9\ nm)/Pt(1.0\ nm)]_5/C(5\ nm)$. The annealing process was rapid thermal annealing. In order to reduce the diffusion between the SUL and FePt:C layer during the

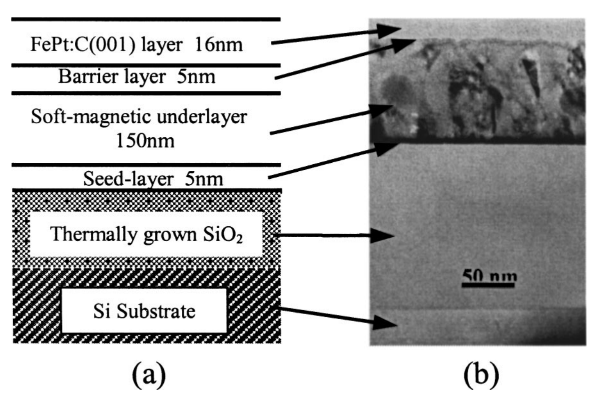

FIG. 1. FePt:C double-layered perpendicular composite medium construction. (a) Schematic sketch of the layers in the medium and (b) TEM cross-sectional images of this medium.

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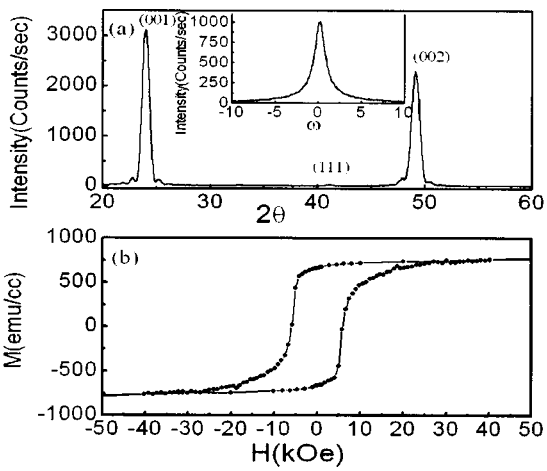

FIG. 2. XRD pattern (a) and hysteresis loop (b) of a 16 nm thick FePt:C composite film. Film annealed at 550 °C for 300 s. Inset (a) is the (001) rocking curve. Loop measured by SQUID at room temperature.

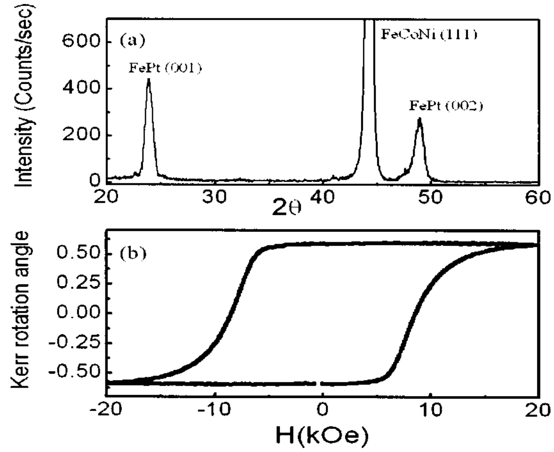

FIG. 4. XRD pattern (a) and hysteresis loop (b) of FePt:C double-layered media. Loop measured by polar–Kerr Effect at room temperature.

annealing process, a 5 nm Ta barrier layer was introduced between the SUL and FePt:C layer. A cross-sectional TEM image [Fig. 1(b)] verifies that this medium consists of a nanocompsite FePt:C layer with FePt nanoparticles embedded in a C matrix and 150 nm soft FeCoNi underlayer.

By adjusting both the initial as-deposited layer structure and annealing process, a face-centered-tetragonal (001) texture can be obtained for the nanocomposite FePt:C thin films. Figure 2(a) shows the XRD pattern and Fig. 2(b) shows the hysteresis loop of FePt:C films without the SUL, deposited directly on a Si substrate and annealed at 550 °C for 300 s. It is clear that only (00ℓ) peaks appear on the XRD pattern, which indicates a high degree of (001) texture of the film after annealing. The full width at half maximum, obtained from the rocking curve of the (001) peak (shown in the inset of Fig. 2), is less than 2° confirming a high degree of (001) texturing. Hysteresis loop measurement [Fig. 2(b)] shows a large perpendicular anisotropy of the film due to the high degree of preferential orientation of the *c* axis of FePt grains perpendicular to the film plane. $H_c = 6.2$ kOe and remanance ratio $S = 0.89$ are achieved when measured with the applied field perpendicular to the film plane. The details regarding the attainment of these preferential (001) oriented FePt-based composite films and their perpendicular magnetic properties have been reported and discussed in our previous papers.[5,7]

In order to study exchange coupling between magnetic grains, the correlation length of this sample was analyzed by MFM. Figure 3 shows the MFM image for an 11 nm thick FePt:C film in the thermally demagnetized states. The image was obtained using a high coercivity CoPt MFM tip magnetized along the *z* direction (perpendicular to the sample surface). A threshold at 50% of the largest frequency shift in the image was used to estimate correlation length. The correlation length of this sample is 65 ± 13 nm (as estimated from the mean values of the ten largest magnetically coupled regions). This relatively short magnetic correlation length indicates weak intergranular coupling between FePt magnetic grains.[10]

Figures 4(a) and 4(b) respectively show the XRD pattern and hysteresis loop of the FePt:C double-layered nanocomposite thin-film medium. The SUL FeCoNi (111) peak and the $L1_0$ FePt (001) and (002) peaks are shown only in the XRD pattern. This means that the preferred crystal orientation of $L1_0$ FePt:C nanocompsite film is obtained on this SUL by nonepitaxial growth. The polar–Kerr measurement shows a square loop that is only sensitive to the top layer; the Kerr effect data shown in this loop give the coercivity $H_c = 8.5$ kOe, nucleation field $H_n = 5.65$ kOe, remanance ratio $S = 1$, and loop slope (at H_c) $\alpha = 3.3$, respectively.

The nanostructure of the double-layered nanocomposite FePt:C thin-film medium was characterized by TEM. Electron diffraction shows that the crystallites are FePt with the $L1_0$ structure. Figure 5 shows the bright-field and cross-sectional TEM images. The bright-field image [Fig. 5(a)]

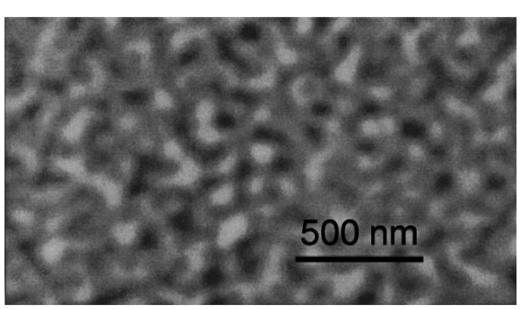

FIG. 3. MFM image of 16 nm thick FePt:C composite film. Film annealed at 550 °C for 300 s.

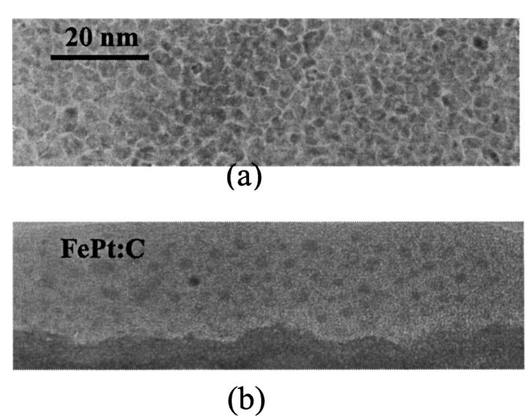

FIG. 5. TEM images. (a) Bright-field image and (b) cross-section image. Same sample as in Fig. 4.

shows that the FePt grain size is about 5 nm and relatively uniform. The cross-sectional study [Fig. 5(b)] verifies that FePt crystallites are imbedded in the C matrix and well isolated from each other. The investigations of high-resolution transmission electron microscopy and electron diffraction on atomic ordering reactions, ordering degrees, and orientation mechanism of the FePt crystallites embedded in the C matrix will be published separately.

Due to the high coercivity of this medium, initial recording experiments on several double-layered coupons were performed using a contact read-write tester. Our initial results show that the track definition of double-layered FePt:C media was clearly visible with the write current of the head up to the current limit ($\sim$80 mA). By comparison, in ''regular'' perpendicular media, the track definition can be made visible by using a write current of about 10 mA. Obviously, the saturation field of these media is higher than the field that the present perpendicular recording heads can deliver. Further efforts to control and understand the coercivity, loop slope, and read/write performance for this medium are underway.

A chemical ordered $L1_0$ double-layered FePt:C nanocomposite thin-film medium with (001) texture was achieved by nonepitaxial growth. The excellent nanostructure and magnetic properties of this medium are very promising for extremely high-density perpendicular recoding.

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