A simple method toward high density SrM dot arrays

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Strontium ferrite thin films have been deposited on Corning glass with Au underlayer by using DC magnetron sputtering system. Au island structure can be formed on Corning glass by heating the substrate over 100 °C. In order to achieve higher Au dot density and consequently higher density of SrM, an attempt to decreasing Au thickness has been carried out. The maximum of coercivity and remanent squareness ratio in perpendicular direction are almost constant at 2.3 kOe and 0.45, respectively, at Au underlayer thickness from 4 nm to 8 nm. The magnetic interaction between SrM grains prepared on Au nano-dots is less than that for the continuous film.

Key words: Au nano-dots, strontium ferrite, self-assembly, patterned media

1. Introduction

The areal density of hard disk drives continues to increase, so there has been a trend to decrease the grain size. However, the trend will be limited by thermal instability or superparamagnetism of the grains in medium. Significant research efforts have been expending in improving media to reduce thermal instability and in designing alternative methods for data storage. Patterned media,^{1), 2)} in which data are stored in isolated single-domain islands, have been one of the widely discussed possibilities for extending data densities with its capability to obtain higher storage densities well in excess of 1 Tbit/in².

Pattern generation can be accomplished by several methods e.g. lithography,³⁾ Irradiation through a mask,⁴⁾ milling with focused ion beam⁵⁾ and imprint technology.⁶⁾ In our present work, self-assembly configuration prepared by sputtering method is used because it has the potential to fabricate very fine-scale structures over large areas in a rapid process and no chemical used in the process.

The requirements of magnetic material for patterned media are high coercivity, chemical stability and perpendicular anisotropy. Hexagonal Strontium ferrite having the chemical formula of SrO·6Fe₂O₃ (SrM) as well as hexagonal Barium ferrite (BaO·6Fe₂O₃, BaM) has fairly large magnetocrystalline anisotropy, excellent chemical stability and magnetic moment parallel to the *c*-axis. In addition, the minimum stable grain size for SrM, computed for a storage time constant 10 years using the media stability criterion $K_u V > 60 \cdot k_B T$, is about 8.8 nm that is achieved 1.6 Tbits/in² with inter-dot distance of 10 nm.

The Au film, which has FCC structure, is expected to be used as the underlayer for promotion of *c*-axis orientation of hexagonal ferrite layer. The misfit ratio between (111) plane of FCC Au and *c*-plane of HCP SrM is 2.1%. It has also been reported that the Au islands structure can be formed on SiO₂/Si substrate⁷⁾ and Corning glass at substrate temperature, T_u , higher than

Fig. 1 SEM micrograph of Au surface at (a) r.t. and (b) 100 °C.

100 °C while the continuous films can be prepared at room temperature, r.t., as shown in Fig. 1 and the Au dot size decreases with increasing T_u .⁸⁾

Fig. 2 Dependence of saturation magnetization, M_s , of SrM thin films on substrate temperature, T_s .

Fig. 3 Schematic of cross sectional view of partially crystallization of SrM.

Figure 2 shows the dependence of saturation magnetization, M_s , of SrM thin films on the substrate temperature, T_s . The SrM thin films are amorphous at T_s below 550 and 515 °C for SrM thin films without underlayer and with Au underlayer, respectively. The M_s increases from zero to 80 emu/cm³ as substrate temperature, T_s , was elevated from 500 to 525 °C. Therefore, it is possible to get the isolated SrM grains on Au nano-dots prepared at T_s of 525 °C. The proposed cross sectional structure in this study is schematically shown in Fig. 3.

2. Experiments

The SrM film was deposited on Au underlayer using a magnetron sputtering apparatus. The glass was used as substrate and thickness of SrM layer was 30 nm. After evacuating the chamber to a pressure below 2×10^{-6} Torr, argon (Ar) was introduced and sputtering pressure was set at 2.0 mTorr for Au underlayer film. In order to get Au island structure, the substrate

temperature for Au underlayer, T_u , was kept at 300 °C.⁸⁾ A sintered ferrite disk with stiochiometric composition of M-type, i.e. Sr:Fe = 1:12, was used as the target for SrM film. The mixture gas of Ar and O₂ with gas pressure of 1.8 and 0.2 mTorr, respectively, was used as sputtering gas. The substrate temperature for SrM layer, T_s , was kept constant at 525 °C. The Au thickness was varied from 3 – 8 nm. The crystal structures of the films were determined by x-ray diffractometer (XRD) with Cu K α radiation. The magnetic properties were measured by vibrating sample magnetometer (VSM) with maximum field strength of 24 kOe. The surface morphologies of the films were observed by field emission type of scanning electron microscope (FE-SEM). The magnetic domain structures were observed by magnetic force microscope (MFM).

3. Results and Discussion

The Au dot size decreases with decreasing the thickness of Au underlayer, δ_{Au} , and its size is about 12 nm at δ_{Au} of 3 nm as shown in Fig. 4. So, the dot density and consequently the areal density of Au dot will be

Fig. 4 Dependence of Au dot size on Au thickness.

Fig. 5 Saturation magnetization, M_s , of SrM thin films as a function of δ_{Au} .

Fig. 6 Dependence of coercivity, H_c , of SrM thin films on δ_{Au} .

Fig. 7 Squareness ratio, S , of SrM/Au thin films with various δ_{Au} .

increased. From these results in order to achieve higher Au dot density and consequently higher density of SrM, an attempt to decreasing Au thickness has been carried out.

Fig. 8 Δm^* deviations for SrM/Au thin films with different δ_{Au} .

Fig. 9 XRD diagrams for SrM thin films on Au underlayer prepared at various Au thickness, δ_{Au} .

Figure 5 shows the saturation magnetization, M_s , of SrM/Au thin films as a function of δ_{Au} . With decreasing Au thickness to 4 nm, the M_s is almost constant at about 80 emu/cm³. All of these values of M_s are lower

than that of the theoretical value of standard SrM film (360 emu/cm³). This might be due to non-magnetic phase existed in the space between the magnetic particles in SrM thin films. With further decreasing δ_{Au} , the M_s also decreases. It is contributed from decreasing degree of crystallization of SrM thin films.

Figure 6 shows the dependence of perpendicular and in-plane coercivity for the films on δ_{Au} . The perpendicular coercivities, $H_{c\perp}$, are higher than the in-plane coercivities, $H_{c\parallel}$. This means that the perpendicular anisotropy of SrM thin film. The $H_{c\perp}$ of SrM thin films on Au underlayer gradually increases and keeps almost constant at 2.3 kOe with increasing δ_{Au} above 4 nm. The $H_{c\parallel}$ is also gradually increases with increasing δ_{Au} to reach 1 kOe at δ_{Au} of 8 nm.

The value of remanent squareness ratio, S , of SrM thin film on Au underlayer as a function of δ_{Au} is shown in Fig. 7. The trend of S is also as same as that for H_c . The $S_{\parallel}$ gradually increases and keeps constant when δ_{Au} is above 4 nm.

The interactions between magnetic particles of the thin films have been evaluated with the Δm^* method.⁹⁾ Following this method, the presence and strength of interactions is described as this equation:

$$\Delta m^*(H) = m_i(H) - 0.5 \times [m_u(H) + m_l(H)] \quad (1)$$

where $m_i(H)$ is the initial magnetization curve, $m_u(H)$ is the upper branch and $m_l(H)$ is the lower branch of the hysteresis loop. The finite negative and positive values of Δm^* indicate the magnetostatic and exchange coupling, respectively.

In Fig. 8 the $\Delta m^*(H)$ deviations of the SrM/Au thin films with different δ_{Au} are reported. It indicates negative interactions in the films. The peak of Δm^* of SrM/Au thin films is smaller in all films compared to SrM/Pt that is the continuous film¹⁰⁾, which indicate a weaker interactions. From this results, it might be contributed from non-magnetic phase existed in the space between the magnetic particles in SrM thin films and hence the intergranular interactions is reduced.

Figure 9 shows the x-ray diffraction diagrams of the film prepared on Au underlayer with various thicknesses of underlayer, δ_{Au} . The preferred (111) orientation of FCC lattice of Au underlayer has been detected in the XRD diagrams. The intensity of the diffraction line from Au(111) decreases with decrease of δ_{Au} . No obvious SrM peaks for all films were found.

Figure 10 shows surface morphology of SrM deposited on Au(111) underlayer with various δ_{Au} . From these surface images, it was found that the SrM surface structure corresponds to that of underlayer surface. The grain size of SrM decreases with decreasing δ_{Au} .

Fig. 10 Surface images of SrM thin films on Au prepared at various δ_{Au} .

Fig. 11 (a) SrM surface and (b) SrM magnetic domain structure for Pt underlayer, (c) SrM surface and (d) SrM magnetic domain structure for 3 nm thick Au underlayer.

Figure 11 shows surface morphology and magnetic domain structure for SrM/Pt and SrM/Au thin films. The grain size of SrM deposited on 3 nm thick Au underlayer surface in Fig. 11(c) is less than that for Pt underlayer surface in Fig. 11(a). Observed magnetic domains shown in Fig. 11(b) are continuous with the length of over 400 nm. On the other hand, the magnetic domains shown in Fig. 11(d) are obviously divided into small sizes, and the sizes are around 50 nm at the minimum that is less than that for Pt underlayer in Fig. 11(b). The reasons why the observed magnetic domain size in Fig. 11(d) are larger than the Au nano-dots is supposed to do with the resolution limit of the MFM, and spread of the leakage field from the domains.

4. Conclusions

SrM thin films can be prepared on 3 – 8 nm thick Au nano-dots at T_u of 300 °C. With decreasing Au thickness, the dot density and consequently the areal density will be increased. Smaller magnetic domain size for SrM can be expected by reducing the Au nano-dots. The magnetic interaction between SrM grains prepared on Au nano-dots is reduced in compare with SrM/Pt thin film that is the continuous film.

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