Influence on the Recording Performance due to exchange coupling field of Soft Underlayer in Perpendicular Recording Media

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CoPt-TiO₂ granular-type media with extremely thin Ru intermediate layer were prepared on a highly oriented high- B_s FeCo soft underlayer (SUL) pinned by an IrMn antiferromagnetic layer. Although the increase of the IrMn antiferromagnetic layer thickness deteriorates the crystal orientation of the media, the magnetic properties of the recording layer were little changed. On the other hand, the H_{ch} (H_c in the hard axis direction) of the SUL were greatly decreased and the H_{ex} (exchange coupling field) of the SUL was largely increased. The H_{ex} of about 10 Oe is effective for the magnetic domain control of the SUL. The recording performance was measured by using a SPT head. The S/N increased as the IrMn layer thickness was increased. This improvement of the recording performance seems to be responsible for the magnetic domain control by the IrMn antiferromagnetic layer. Moreover, enough effect was obtained by H_{ex} of about 10 Oe under environment of conventional spin stand measurement system.

Key words: perpendicular magnetic recording, CoPt-TiO₂ granular-type media, IrMn antiferromagnetic layer, FeCo soft underlayer.

1. Introduction

Perpendicular magnetic recording systems were proposed about 30 years ago as a method suitable for high-density magnetic recording¹⁾. At present they are adopted in almost all commercial hard disk drives.

Reduction of the film thickness of an intermediate layer between a recording layer and a soft underlayer (SUL) is needed for higher recording densities. Some approaches to reduce the intermediate layer thickness were reported²⁾⁻³⁾. However, obtained intermediate layer thicknesses were not very thin. So I proposed CoPt-TiO₂ media with a highly oriented FeCo SUL with a high- B_s of 2.45 T and a thin Ru intermediate layer⁴⁾. Due to a new designed medium⁵⁾⁻⁶⁾, the minimum Ru intermediate layer thickness for obtaining the squareness ratio (SQ) more than 0.99 was reduced down to 1.6 nm⁷⁾. The oscillatory interlayer magnetic interaction between the recording layer and the SUL was also observed as a function of Ru intermediate layer thickness for the media with such an extremely thin Ru intermediate layer.

In the above-mentioned media, the SUL is pinned by an IrMn antiferromagnetic layer. As it is desirable that the IrMn antiferromagnetic layer is thin to increase the crystal orientation of the FeCo layer and to decrease Ru intermediate layer thickness, the IrMn thickness of 4 nm was chosen. However, the pinned effect obtained by such a thin IrMn antiferromagnetic layer is decreased. The exchange coupling field (H_{ex}) measured from the magnetization curve in the easy axis direction was about 10 Oe. I wonder if the oscillatory behavior of the SUL may be caused due to the weak pinned effect and affect the medium noise. So, in this study, the IrMn antiferromagnetic layer thickness was changed, and the relationship between the pinned effect

(H_{ex} and magnetic domain) and the recording performance was investigated.

2. Experiment

Samples were prepared by using a dc and rf magnetron sputtering system in an Ar gas atmosphere. The composition of the alloy targets was (Co₈₀Pt₂₀)-(TiO₂) (CoPt : TiO₂ = 80 : 20 vol%, CoPt-TiO₂), Ru, Fe₇₀Co₃₀ (FeCo), Ir₂₀Mn₈₀ (IrMn), Pt, Ta, and C. The substrates were ϕ 2.5-inch glass disks. A magnetic field of about 100 Oe in the radial direction of the disk was applied to induce an in-plane magnetic anisotropy during deposition. The distance between target and substrate was about 77 mm. The base pressure was around $1\text{--}2 \times 10^{-5}$ Pa. The substrate temperature was 20 °C.

The film structure was investigated by X-ray diffraction (XRD) using the θ - 2θ scan method with Cu-K α radiation. Magnetic properties were measured by means of a vibrating sample magnetometer (VSM) calibrated by using standard samples (pure Ni and Fe) and a polar Kerr effect magnetometer. The magnetic domain of the film surface was observed by an optical surface analyzer (OSA).

Recording performance was evaluated by using a single-pole-type (SPT) head. A commercial SPT head (write track width; T_{ww} = 1000 nm, read track width; T_{wr} = 100 nm, shield gap length; G_s = 54 nm) is used. A read-write speed was 10 m/sec.

3. Results and Discussion

Figure 1 shows a schematic illustration of a prepared medium. The designed film structure was C (6 nm)/CoPt-TiO₂ (15 nm)/Ru (1.9 nm)/FeCo (50 nm)/IrMn

Fig. 1 Schematic illustration of a medium.

(x nm)/Pt (20 nm)/Ta (4 nm)/glass substrate. C, CoPt-TiO₂, and Ru are a protective, a recording, and an intermediate layer, respectively. The B_s of an FeCo SUL was 2.45 T. IrMn was used as an fcc underlayer to obtain soft magnetic properties in the FeCo film^{(8)–(9)}, and an antiferromagnetic layer to pin the FeCo film⁽¹⁰⁾. A Pt underlayer is effective in increasing the crystal orientation of the IrMn, which is necessary in order to enhance the exchange coupling energy between the FeCo and the IrMn films. Ta underlayer was greatly effective to enhance the crystal orientation of the whole film. The H_c of the recording layer and the H_{ch} (H_c in the hard axis direction) of the SUL oscillated as a function of Ru intermediate layer thickness⁽⁷⁾. The oscillation period was 0.5–0.8 nm. A medium with Ru intermediate layers of larger H_c (peak position) showed smaller H_{ch} of the SUL than that of valley position. Strong magnetic interlayer interaction deteriorates the magnetic properties of the recording layer and the SUL, and the recording performance. Ru layer of 1.9 nm was chosen as a medium with weak interlayer interaction.

Figure 2(a) shows the IrMn antiferromagnetic layer thickness dependence of the full width at half maximum value of the rocking curve ($\Delta\theta_{50}$) of the FeCo SUL and the CoPt-TiO₂ recording layer for the media with Ru thickness of 1.9 nm. The $\Delta\theta_{50}$ of the recording layer and the SUL was increased as IrMn layer thickness was increased from 2 nm to 4 nm. The increase of the IrMn layer thickness deteriorates the crystal orientation of the media. The media with IrMn layer of 4 nm and 6 nm is almost same value of the $\Delta\theta_{50}$.

Figures 2(b) and 2(c) show the IrMn antiferromagnetic layer thickness dependence of SQ and H_c of the recording layer. The SQ more than 0.99 was obtained for all the media. The values of the H_c of the recording layer were 4.4–4.8 kOe. The magnetic properties of the recording layer were little changed due to the increase of the IrMn layer thickness.

Figures 2(d) and 2(e) show the IrMn antiferromagnetic layer thickness dependence of H_{ch} and H_{ex} of the SUL. As the IrMn thickness was

Fig. 2 IrMn antiferromagnetic layer thickness dependence of (a) $\Delta\theta_{50}$ (full width at half maximum value of the rocking curve) of the recording layer and the soft underlayer, (b) SQ (squareness ratio), (c) H_c of the recording layer, (d) H_{ch} (H_c in the hard axis direction), and (e) H_{ex} (exchange coupling field) of the soft underlayer.

Fig. 3 OSA images of the FeCo films with IrMn antiferromagnetic layer of (a) 0 nm, (b) 2 nm, (c) 4 nm, and (d) 6 nm.

increased, the H_{ch} of the SUL were greatly decreased due to the effect of an fcc underlayer⁷⁾. On the other hand, the H_{ex} of the SUL was largely increased as the IrMn thickness was increased. The critical IrMn thickness for obtaining the H_{ex} exists between 2 nm and 4 nm.

Figures 3(a), 3(b), 3(c), and 3(d) show the OSA images of the surface in the FeCo films on IrMn thickness of 0 nm, 2 nm, 4 nm, and 6 nm, respectively. As mentioned before, a magnetic field of about 100 Oe was applied in the radial direction of the disk to induce an in-plane magnetic anisotropy during deposition. The most part with an uniform domain is magnetized in the radial direction. Several clear magnetic domain walls were observed irregularly in the FeCo on the IrMn layer of 0 nm and 2 nm. On the other hand, the FeCo on the IrMn layer of 4 nm and 6 nm show single-like domain structure except the edge of the disk, which seems to be affected by the induced magnet. This indicates that even H_{ex} of about 10 Oe is effective for the magnetic domain control of the SUL.

Recording performance was evaluated by using a SPT head for the media with different IrMn antiferromagnetic layer. Figures 4(a), 4(b), and 4(c) show the IrMn antiferromagnetic layer thickness dependence of a reproduced output, a medium noise, and an S/N for different recording densities, respectively. As IrMn layer thickness was increased from 0 nm to 4 nm, the reproduced output was increased and the medium noise was decreased. As a result, the S/N increased as the IrMn layer thickness was increased. The media with IrMn layer of 4 nm and 6 nm have almost same values of the reproduced output, the medium noise, and the S/N. Taking into account the deterioration of the crystal orientation and the similar magnetic properties of the recording layer due to the increase of the IrMn layer thickness, this improvement of the recording performance seems to be responsible for the decrease of the H_{ch} , and the increase of the H_{ex} , and the magnetic domain control by the IrMn antiferromagnetic layer of the SUL. The immediate cause of the increase in the reproduced output is not clear. Moreover, enough effect was obtained by H_{ex} of about 10 Oe under environment of conventional spin stand measurement system. Larger H_{ex} does not affect

the recording performance. The origin of large noise in this system seems to be caused by crystalline SUL, extremely thin intermediate layer, and peculiar in-plane structure of the recording layer.

4. Conclusions

CoPt-TiO₂ granular-type media with extremely thin Ru intermediate layer were prepared on a highly oriented high- B_s FeCo SUL pinned by an IrMn antiferromagnetic layer. The IrMn antiferromagnetic

Fig. 4 IrMn antiferromagnetic layer thickness dependence of (a) reproduced output, (b) medium noise, and (c) S/N for the media.

layer thickness was changed to investigate the effect of H_{ex} and the recording performance.

Although the increase of the IrMn layer thickness deteriorates the crystal orientation of the media, the magnetic properties of the recording layer were little changed. The H_{ch} of the SUL were greatly decreased and the H_{ex} of the SUL was largely increased as the IrMn antiferromagnetic layer thickness was increased. From OSA observation, even H_{ex} of about 10 Oe is effective for the magnetic domain control of the SUL.

The recording performance was measured by using a SPT head. The S/N increased as the IrMn layer thickness was increased. This improvement of the recording performance seems to be responsible for the magnetic domain control by the IrMn antiferromagnetic layer. Moreover, enough effect was obtained by H_{ex} of about 10 Oe under environment of conventional spin stand measurement system. Although the H_{ex} should be determined in conditions of real use, this result expands the degree of freedom in the design of a SUL.

The highly controlled structure is useful as a model medium for investigating such sensitive effect as thin intermediate layer and SUL, the magnetic interlayer interaction, the shape and arrangement of the recording

layer, and the noise.

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