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Perpendicular Magnetic Recording Using Magneto-Optical Media

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TbFeCo perpendicular magnetic recording media were developed by employing an NiP underlayer to control the magnetic properties of the TbFeCo magnetic layer. With the NiP underlayer, the magnetization reversal changed from wall motion to the rotation mode. The dynamic write-read characteristics of a single-layer medium were examined using a conventional merged-type GMR head with a write core width of 1 μm that was designed for longitudinal magnetic recording. A clear magnetic pattern of 450 kFCI, high media SNR, and acceptable overwrite properties were obtained. It was shown that the thermal stability of the TbFeCo medium is sufficient for practical applications. A double-layer medium with a soft-magnetic backlayer exhibited practical overwritability for a narrow track pitch of 0.4 μm.

1. Introduction

Co-Cr based alloy films have been investigated as materials for perpendicular recording media. The films have a structure composed of segregated grains, and the main media noise sources are in-bit reversed magnetic domains.1) To decrease the noise, both the reversed domain formation and the reversed domain size must be reduced. Honda et al.2) showed that the squareness ratio ($Mr/Ms = S$) in the perpendicular M-H loop must be increased to suppress reversed domain formation and that the magnetic exchange coupling between adjacent grains must be reduced to reduce the reversed domain size. A smaller exchange coupling leads to a lower M-H loop slope. A large S is also required to prevent thermal fluctuation of perpendicular recording media at low linear densities due to the higher demagnetization fields.3) However, a large S and smaller loop slope are in a tradeoff relationship and very high coercivity is required to satisfy both of these requirements for the appropriate Ms value, which makes them difficult to achieve.

On the other hand, rare earth-transition metal (RE-TM) alloy films that are widely used as magneto-optical (MO) recording materials have an amorphous and continuous structure. Recently, new recording technologies combining thermo-magnetic or thermally assisted magnetic writing on MO media with magnetic flux reading using a GMR sensor have been proposed to achieve high-density recording.4),5)

From this background and as a novel approach, it seems feasible to apply RE-TM alloy films for perpendicular magnetic recording media, because reversed domain formation can be suppressed due to the high squareness ratio of these media. These films are expected to produce only low levels of media noise due to their amorphous continuous structure. In addition, they have features preferable for magnetic recording such as large perpendicular magnetic anisotropy (Ku), easily controllable magnetic properties, and fabrication at room temperature. **Figure 1** shows how the Ku and Ms of TbFe film depend on the composition as calculated using the molecular field model.

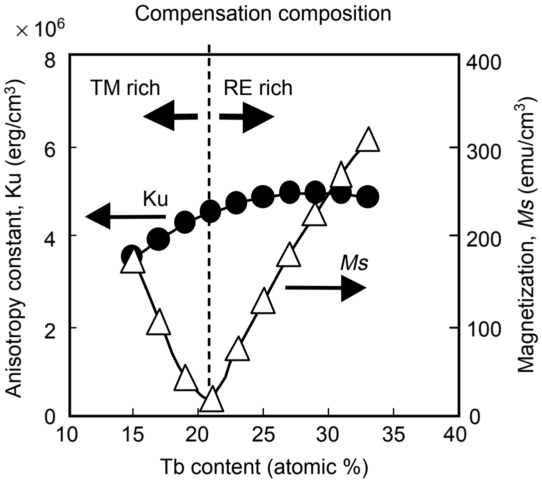


Figure 1
Composition dependence of anisotropy constant, Ku, and saturation magnetization, *Ms*, of TbFe as calculated using the molecular field model.

Because of the characteristics of ferrimagnetic material, there is a composition with $Ms = 0$, which is called the compensation composition. This variation in the Ku and *Ms* means that *Ms* can be tuned over a wide range by adjusting the composition. The value of Ku is from 3.5 to 5×10^6 erg/cm^3 (erg = 10^{-7}J), which is larger than that of Co-Cr alloy film (about 2×10^6 erg/cm^3 at maximum).

Indeed, investigations have already been made using RE-TM alloy films for perpendicular magnetic recording. Jenniot et al.[6] and Berstein et al.[7] demonstrated perpendicular recording with TbGdFe, TbFe, and GdFe thin films. Ohtani et al. examined the relationship between film fabrication conditions and read-write properties.[8] However, desirable recording characteristics have not been obtained in previous investigations, and as a result, it was thought that amorphous RE-TM media with a strong exchange interaction in the film were unsuitable for magnetic recording, because of the distortion of magnetic transition induced by domain wall motion. However, we believe that other issues in recording performance might have caused these results. For example, a sensitive GMR reading head was not yet available and the sputtering technique was not sophisticated at that time.

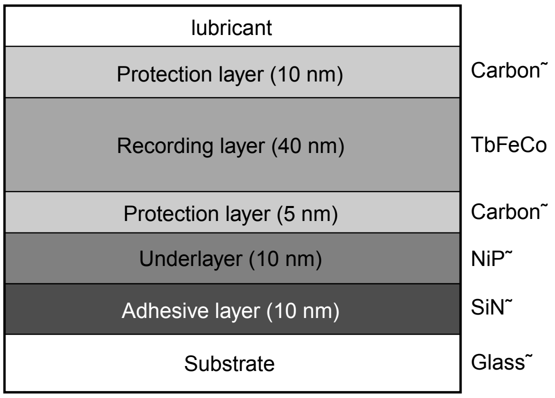


Figure 2
Structure of the TbFeCo single-layer perpendicular recording media.

In this paper, we explain that a high recording density can be achieved on a perpendicular magnetic recording medium with a TbFeCo film by controlling the magnetization reversal mode and improving the sputtering process. The dynamic write-read characteristics of a single-layer medium were examined using a conventional merged-type GMR head designed for longitudinal recording media. Also, we evaluated a double-layer medium with a soft magnetic backlayer using a head with a narrow core width.

2. Preparation of single-layer media

2.1 Structure and basic properties

Single-layer perpendicular media with the structure shown in **Figure 2** were fabricated by conventional DC magnetron sputtering at room temperature on 2.5-inch glass substrates. A thin SiN layer was formed on the glass substrates as an adhesive layer, on which an NiP underlayer with a thickness of 10 nm was sputtered. Then, TbFeCo with a thickness of 40 nm was sandwiched between protection layers of amorphous carbon. A lubricant was spin-coated on the top carbon layer for dynamic write-read measurements. **Figure 3** shows the Kerr rotation hysteresis loop of these single-layer perpendicular media. The media have a squareness ratio of 1 and a coercivity squareness

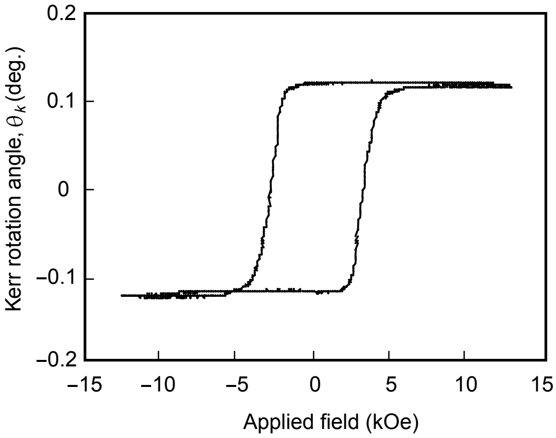


Figure 3
Kerr rotation hysteresis loop of single-layer perpendicular media.

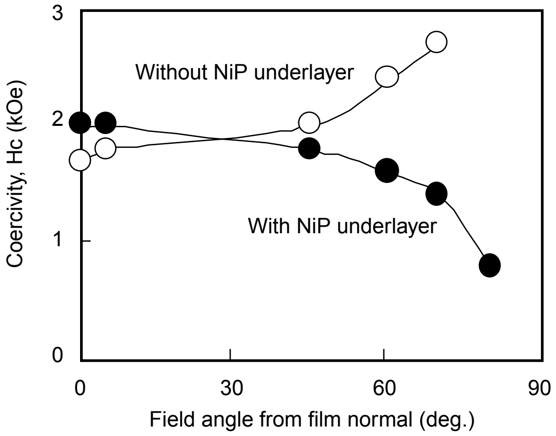


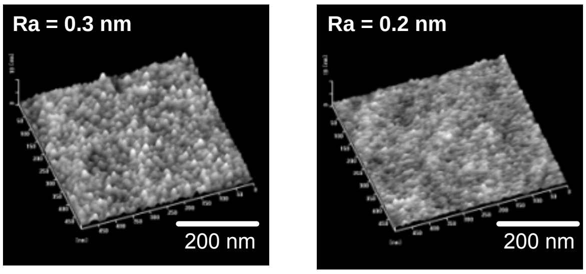
Figure 4
Angular variation of Hc for the samples with and without an NiP underlayer.

S^* of over 0.7 without compensation for the demagnetizing field. The Hc of the samples is 2.9 kOe [Oe = (1000/4π) A/m], and the product of film thickness and saturation magnetization, *tMs*, is about 1.0 memu/cm^2.

2.2 Effect of NiP underlayer

The NiP underlayer plays an important role in controlling the magnetic properties of the media.[9] In order to investigate the magnetization reversal mode, the angular dependence of the Hc of TbFeCo films with and without an NiP underlayer were measured. As shown in **Figure 4**, the Hc of a film with an NiP underlayer decreases as the magnetic field angle is varied from normal (0°) to parallel (90°) with respect to the film's plane, but the Hc of a film without an NiP underlayer increases with an increasing magnetic field angle. This suggest that the magnetization of a TbFeCo film without an NiP underlayer is reversed by the domain wall movement mode, but the magnetization of a TbFeCo film with an NiP underlayer is reversed mainly by the rotation mode.[10)]

Figure 5 shows media surfaces observed with an atomic force microscope. These observations show that the surface roughness is 0.3 nm with the NiP underlayer and 0.2 nm without it. **Figure 6** shows the effect of the NiP underlayer on the shape of the perpendicular hysteresis loop. Without an NiP underlayer, the slope of the loop is very steep. With the NiP underlayer, the slope of the loop decreases and the coercive force increases as the NiP thickness is increased, while the squareness ratio remains at 1. We believe that the difference in the surface morphology of the bottom carbon layer brought about by the NiP layer introduces wall motion pinning sites into the TbFeCo film, which changes the magnetization reversal mode.



(a) With NiP underlayer (b) Without NiP underlayer

Figure 5
Surface morphology of samples with and without an NiP underlayer.

3. Evaluation results of single-layer media

The dynamic properties of the single-layer medium were measured with a spin stand tester equipped with a merged-type GMR head (write core width = 1.0 μm, write gap length = 0.3 μm, read

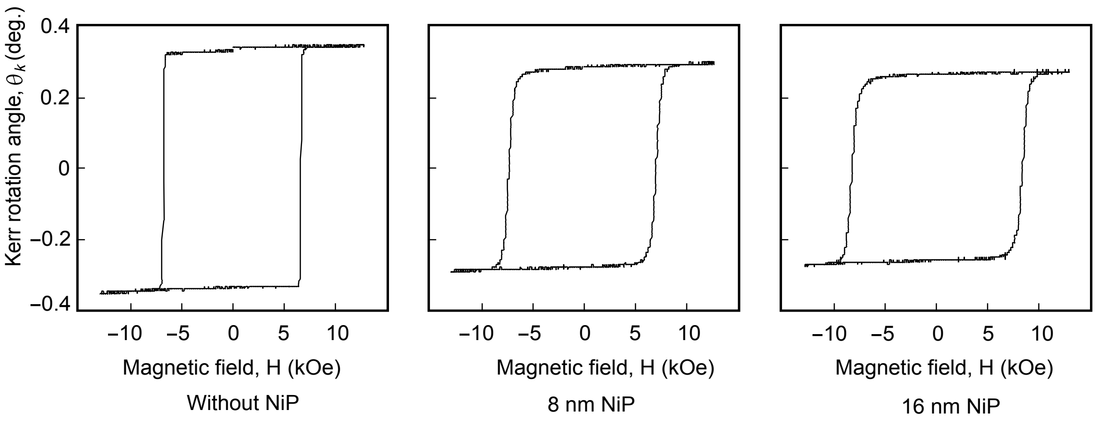


Figure 6
Effect of NiP underlayer on the shape of the hysteresis loop.

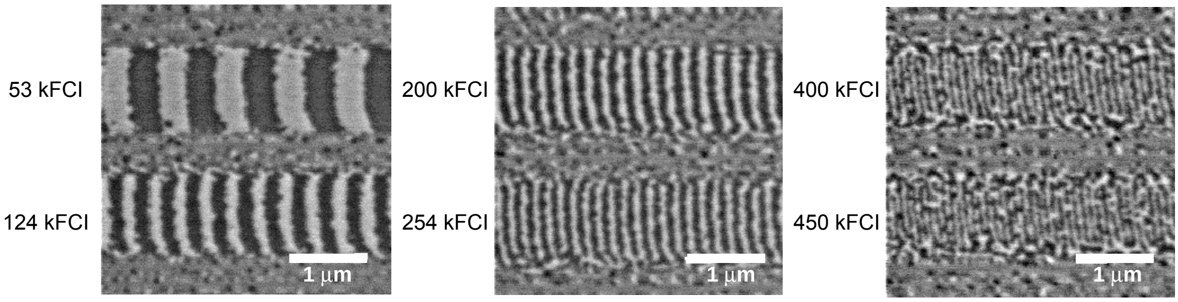
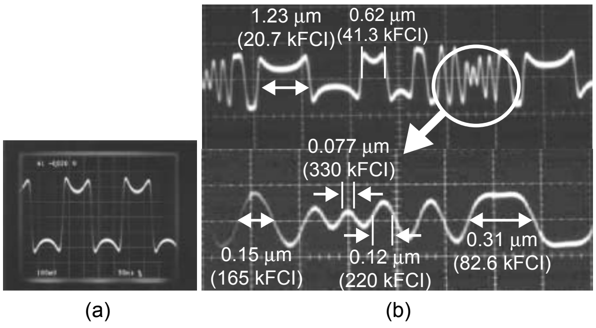


Figure 7
Magnetic force microscope images of magnetic patterns recorded by a ring-type write head with a core width of 1.0 μm and a gap length of 0.3 μm.

core width = 0.8 μm, read gap length = 0.12 μm) designed for longitudinal recording media. The linear velocity at writing and reading was 12 m/s.

3.1 Magnetic transitions

Figure 7 shows magnetic force microscope images of the written magnetic patterns on a TbFeCo medium. Reversed domains, which are often observed on Co-Cr-based alloy perpendicular recording media, do not occur inside the written domains, even for long marks (53 kFCI). The distortion of magnetic transitions is very small, and clear magnetic patterns can be observed even at 450 kFCI, although the track edges show evidence of "percolation." This indicates that high linear density recording is possible, even on films having large exchange couplings.



(a) (b)

Figure 8
Reproduced waveforms of (a) an isolated pattern and (b) a random pattern.

3.2 Dynamic properties

Figure 8 (a) shows the waveform of an isolated pattern which has a shape typical of single-layer perpendicular media. The dipulse ratio is 1, which means that recording is free of

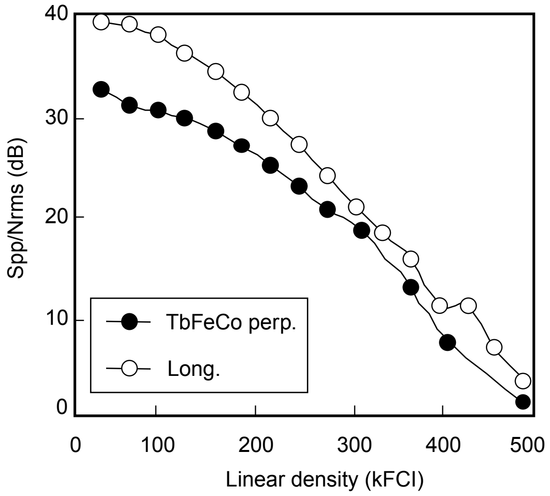


Figure 9
Linear density dependence of media signal-to-noise ratio.

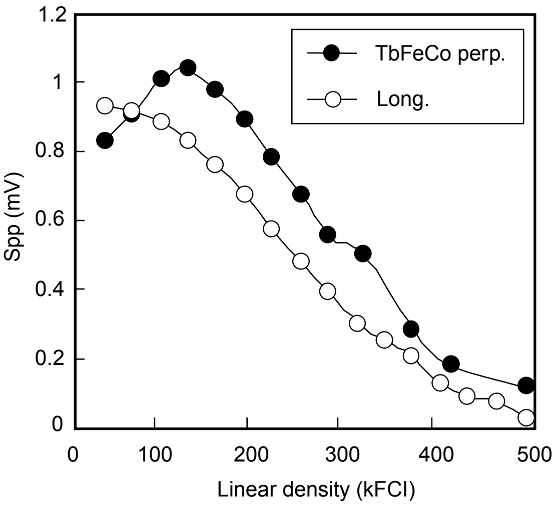


Figure 10
Linear density dependence of signal amplitude.

demagnetization at the trailing edge of the write head because the media has a high coercivity squareness. **Figure 8 (b)** shows the waveform of a random pattern. The waveform of 330 kFCI is clearly resolved. We observed a signal amplitude even at 650 kFCI.

Figure 9 shows the media signal-to-noise ratio, SNR, of TbFeCo and longitudinal mediums with a capability of 15 Gbit/in^2. **Figure 10** shows

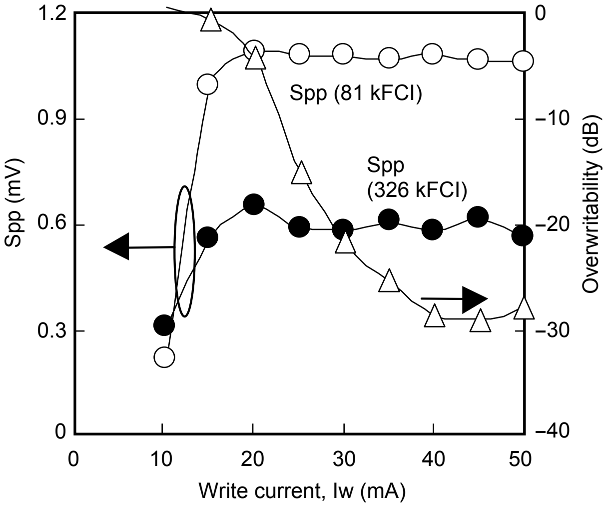


Figure 11
Write current dependence of signal amplitude and overwritability.

their peak-to-peak signal amplitudes (Spp). The media SNR is defined as SNR = 20 log10 (Spp/Nrms), where Nrms denotes the media noise that is derived by subtracting the system and head noise from the total noise. Even though the media SNR of the TbFeCo medium is smaller than that of the longitudinal medium, the total SNR, including the system and head noise, does not differ between the TbFeCo medium and the longitudinal medium, because we used TbFeCo media with a large signal amplitude.

Figure 11 shows the dependence of signal amplitude and overwrite properties on the write current, Iw. The signal amplitude was measured for 81 kFCI and 326 kFCI. Without recording demagnetization, the amplitude became saturated as Iw was increased. The overwrite properties were examined by measuring the residual signal level of 81 kFCI after overwriting with a 490 kFCI pattern. The overwritability value is –30 dB, which is acceptable for practical use.

3.3 Thermal stability

The static thermal stability of the TbFeCo medium was measured. A sample of the medium was saturated, and the temporal change in residual magnetization, *Mr*, without a magnetic field was measured using a SQUID. **Figure 12** shows the change of *Mr*/*Ms* against time at 25°C and 65°C. *Mr*/*Ms* shows no decay at 25°C, even after 10^4 seconds have elapsed. But at the high temperature of 65°C, *Mr*/*Ms* decreased at the rate of 1.3 %/decade because of the reduction of Hc. This rate is not so big, and moreover this could be improved by using high-Curie-point media or RE-rich media.

The change in recorded signal output voltage was also measured against time using a spin stand tester for 42 kFCI, 200 kFCI, and 400 kFCI at 25°C. It is known that, compared to longitudinal recording, perpendicular recording is subject to thermal agitation at lower linear densities, because perpendicular media have higher demagnetization fields. As shown in **Figure 13**, signals at all linear densities exhibit no significant decay.

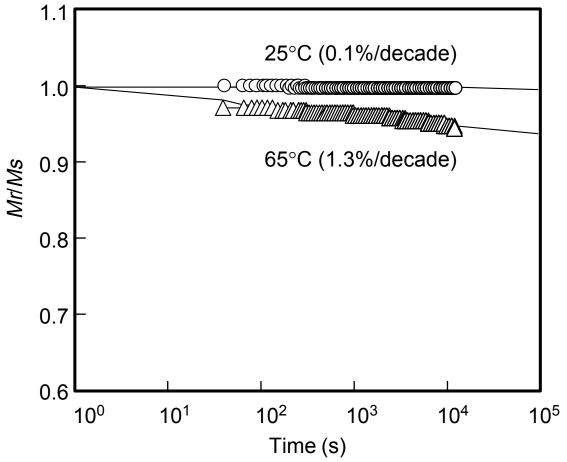


Figure 12
Time dependence of *Mr*/*Ms* for the TbFeCo perpendicular recording media.

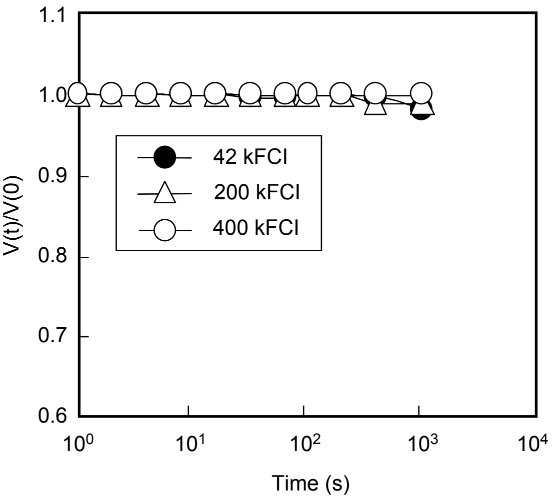


Figure 13
Time dependence of output signal voltage for different linear densities.

4. Double-layer media

4.1 Media and head

Perpendicular magnetic recording media often have a soft magnetic backlayer to increase the perpendicular writing field in the recording layer. We tried the double-layer media configuration to enhance the overwrite performance for narrow track widths.

The media structure is shown in **Figure 14**. We used a CoZrNb amorphous film with a thickness of 500 nm as a soft magnetic backlayer. The layer structure of TbFeCo, NiP, and C in the double-layer media was the same as the layer structure of the single-layer media described in Subsection 3.1. The Hc of the double-layer medium was 2.9 kOe.

Figure 15 shows the bottom-view of the head that we prepared to evaluate the double-layer medium. A merge-type GMR head having a very

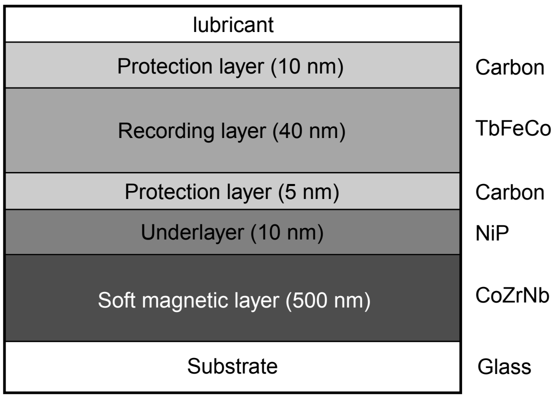


Figure 14
Structure of TbFeCo double-layer media with a soft magnetic backlayer.

narrow write track width of 0.4 µm was FIB trimmed from the air bearing surface. As shown in the figure, there are two FIB trimmed depressions. One of them is made to obtain a wide gap length, and the other is made to obtain a straight trailing edge. The resulting configuration resembles a single-pole head for perpendicular recording. On the other hand, a non-trimmed head with a write core width of 0.5 µm was used to evaluate the single-layer medium described in Section 3 for comparison.

4.2 Dynamic properties

Figure 16 shows the readout waveform of the double-layer medium; this is a typical waveform for perpendicular recording with a single-pole head. The overwrite properties of each medium were examined using a residual signal of 81 kFCI after overwriting at 490 kFCI as shown in **Figure 17**. The overwrite performance of the single-layer medium is poor for the narrow track width. However, the overwritability of the double-layer medium, even for a track width of 0.4 µm, is sufficient for practical applications. **Figure 18** shows the media SNR of each medium. Unfortunately, the media SNR of the double-layer medium is smaller than that of the single-layer medium. This is because the write noise of the double-layer medium is high. Reduction of the write noise is an important issue for research, and the media structure must be optimized for double-layer media.

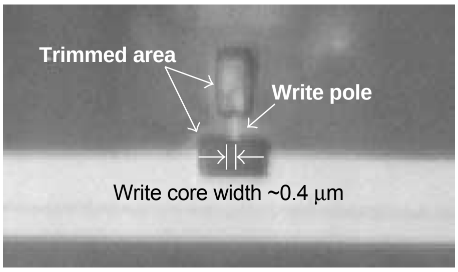


Figure 15
Bottom-view of FIB trimmed head for evaluation of the double-layer medium.

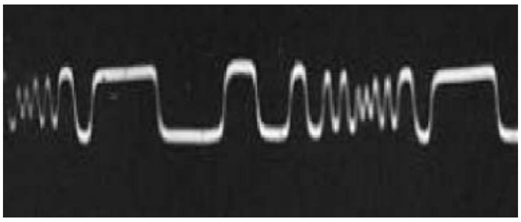


Figure 16
Readout waveform of the double-layer medium.

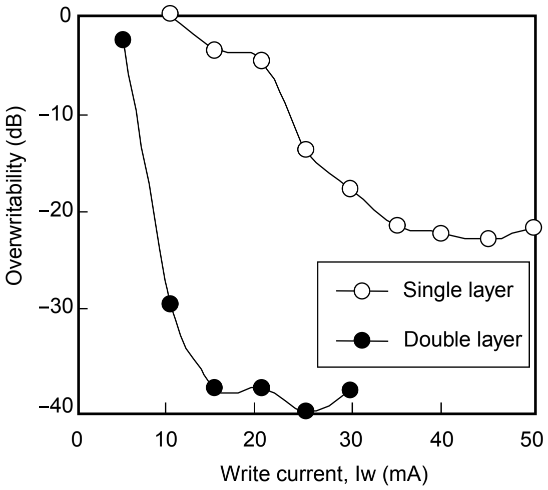


Figure 17
Write current dependence of overwritability of the double-layer and single-layer media with a narrow track pitch head.

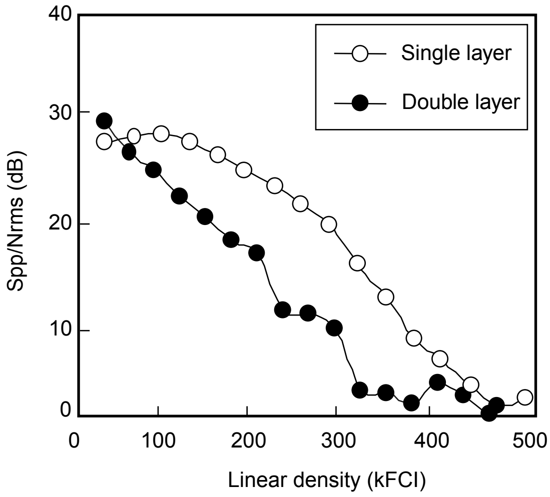


Figure 18
Media signal-to-noise ratio of the double-layer and single-layer media with a narrow track pitch head.

4.3 New soft magnetic backlayer

We developed a soft magnetic backlayer composed of FeC.[11] FeC films were fabricated on glass disks using DC magnetron sputtering by a conventional cosputtering method with Fe and C targets. The films were deposited at room temperature without application of magnetic fields. No heat processes were applied after deposition. The Fe and C contents in the films were varied by individually controlling the electrical power for the Fe and C targets. Nano-scale downsizing of both the film structures and the magnetic domains and the formation of radial magnetic anisotropy in an as-deposited state produce soft magnetic FeC films with a low media noise and a high saturation magnetization of around 19 kGauss (Gauss = 10^{-4}T). A coercive force in the easy magnetic axis of less than 1 Oe reduces media noise in the FeC film. Also, an anisotropy field of over 20 Oe suppresses spike noise in the FeC film. Moreover, the high electrical resistivity of about 120 μΩcm and the high permeability of around 900, which remains constant up to 1 GHz, suggest future applications of FeC films for high-density recording media.

5. Conclusion

We have developed TbFeCo perpendicular magnetic recording media by controlling the film's magnetic properties. We found that an NiP underlayer changes the magnetization reversal to the rotation mode, suppresses the distortion of magnetic transition, and elevates the recording resolution. A single-layer TbFeCo perpendicular medium exhibited clear magnetic transitions of 450 kFCI and high media SNR with a conventional merged-type GMR head. Also, the thermal stability is good enough for practical applications. A double-layer medium with a CoZrNb soft-magnetic backlayer has excellent overwritability for a narrow track pitch of 0.4 μm, but the media structure must be improved to achieve a higher media SNR.

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