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Thin Film Tape Media with Multilayers by Sputtering

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***Abstract*- Magnetic tape with Co-Cr/Ni-Fe multilayer has been prepared by using facing targets sputtering system and 10 μm thick polyimide sheet as a substrate. Read/write characteristics of this tape have been investigated using conventional VTR equipped with highly sensitive single-pole head. It has been proven that even tape with total thickness of magnetic layers of 0.33 μm should be highly efficient in recording and reproducing performance.**

I. INTRODUCTION

The perpendicular magnetic recording system using disk and tape media with Co-Cr/Ni-Fe bilayered film and single-pole head is ideal for high density recording because the perpendicular component of the head field has a "sharp" distribution pattern in the direction of both the head running and the track width. This has been verified through high density recording and reproducing operations using the drive systems for both flexible and rigid disks. In those operations, the thickness more than 0.5 μm of Ni-Fe soft magnetic layer was required to adequately perform the high density recording/reproducing for the bilayered media[1]. However, the total thickness of the magnetic layers δ_M in the conventional media were too thick and the tapes were too inflexible to be used as tapes for VTRs. In order to resolve these problems, δ_M has to be reduced to the value below 0.4 μm. A 0.20 μm thick Ni-Fe layer and a 0.13 μm thick Co-Cr layer were deposited on a 10 μm thick polyimide long sheet using a roll coating machine of a facing targets sputtering(FTS) system. The recording and reproducing characteristics of the bilayered tape were investigated using a VTR equipped with a highly sensitive single-pole head incorporated with the transverse return path core(TRC) in its rotary head drum.

II. EXPERIMENTS

Figure 1 shows the arrangement of targets and substrate in the facing targets sputtering(FTS) system as the roll coating machine for preparing the magnetic tape with Co-Cr/Ni-Fe multilayered film[2]. The targets were set on the holders as cathodes in the deposition chamber and had five kinds of composition: $Ni_{80}Fe_{20}$, $Co_{67}Cr_{33}$, $Co_{79}Cr_{21}$, $Co_{79}Cr_{17.7}Ta_{3.3}$ and $Co_{76.9}Cr_{16.7}Ta_{6.4}$. The 10 μm thick and 100mm wide polyimide (Upilex 10SX) long sheet was used as the substrate. The specifications of this sheet were as follow; tensile strength, 623 kg/mm^2; hygroscopic expansion coefficient, 1.5x10^{-5} cm/cm/%RH; thermal expansion coefficient, 0~0.4x10^{-5} cm/cm/℃ in the range of 50-100℃; surface roughness, R_{max}=10.3nm, R_a=2.0nm on the sputter-deposited side and R_{max}=13.1nm, R_a=2.1nm on the back side. The tension on the substrate sheet during the run was controlled at 1.6kg/mm^2 by adjusting the difference of revolution speeds of the motors between supply and take-up reels. The roll coating machine can drive substrate sheet in either of forward or reverse sense. The sheet was outgassed on the can roll at the temperature of 130 ℃. Table 1 lists the deposition conditions and the saturation magnetization M_s of each layer in the multilayered films for the magnetic tape. The layer thickness δ was controlled through the adjustment of sheet supply speed. The crystallinity was examined by X-ray diffractmetry(XRD). The magnetic characteristics such as M_s and the coercivity $H_{c\perp}$ were determined on the M-H loops measured perpendicularly to the film plane by vibrating sample magnetometer(VSM). The initial permeability μ_i of the multilayered films was estimated on the basis of the gradient in the in-plane initial magnetization curve. The recording and reproducing characteristics of the magnetic tape with substrate sheet which was slit into the 1/2"-wide strip rolled onto cassettes were investigated by using a conventional VTR equipped with a single-pole type of head incorporated the transverse return path core(TRC) which is called the transverse return flux(TRF) head. In the VTR, the drum rotation speed was 1,800 rpm and the tape/head relative speed was 7.1 m/sec.

III. DESIGN PROCEDURE

A. Relationship between Magnetic Characteristics of Backlayer and Readback Signal and Noise

The total thickness of magnetic layers δ_M in the Co-Cr/Ni-Fe bilayered film is preferably smaller than 0.4 μm so that it should retain sufficient mechanical flexibility. At first, it is necessary for reduction of δ_M to reduce the

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Table 1 Deposition conditions and saturation magnetization Ms of each layer in multilayered films.

Layer name		Underlayer	backlayer	Interlayer	Recording layer
Target composition	(at%)	$Co_{67}Cr_{33}$	$Ni_{80}Fe_{20}$	$Co_{67}Cr_{33}$	$Co_{79}Cr_{21}$
Argon gas pressure P_{Ar}	(mTorr)	1.0	1.0	1.0	1.0
Input power P_I	(kW)	0.5	1.0	1.0	1.0
Substrate temperature Ts	(℃)	130	130	130	130
Layer thickness δ	(nm)	0～30	100	0～50	100
Saturation magnetization Ms	(emu/cc)	51	776	51	514

Ni-Fe layer thickness $\delta_{Ni\text{-}Fe}$, because this accounts for the great percentage of δ_M in the conventional flexible disks. It has been reported that there are close relationships between the magnetic characteristics of Ni-Fe backlayer and the readback sensitivity and noise level, since this layer provides a path for recording and readback magnetic flux[3]. The recording and reproducing characteristics have been investigated for the flexible disk with Co-Cr/Ni-Fe bilayered film in which the uniaxial magnetic anisotropy of the Ni-Fe layer was in-plane. In this investigation, a single-pole type of head and the flexible disk with the bilayered film were used, driving the disk at a relative speed of 5.4m/sec. Figure 2 shows the relationship between (a)the readback signal and (b)the noise envelope. This figure indicates also that two signal peaks and bottoms occur in the readback signal envelope at 6 MHz during one revolution of disk. While there are two peaks in AC erase noise at about 0.5 MHz. Such cyclic manifestations of signal and noise seem to be synchronized with disk revolutions and may result from the magnetic characteristics of the recording layer. Then, the full one revolution of disk was divided into eight equal angles and the M-H loop in the head running direction was measured at each disk angle position using a VSM. As shown in Fig.2, the initial permeability μ_i at disk angle positions 1 and 5 was found to be below 200 which coincides with the easy magnetization axis parallel to the head scanning direction, while the initial permeability at disk angle positions 3 and 7 was found to be above 500 which coincides with the hard magnetization axis parallel to the head scanning direction. This may explain why the readback signal at 6 MHz dropped at the positions 1 and 5, so that the decrease of μ_i and output may be attributed to the coincidence in the direction between the easy magnetization axis and the head scanning at these positions. Likewise, the above-mentioned sharp increase in AC erase noise at these positions may be attributed to the Barkhausen noise because

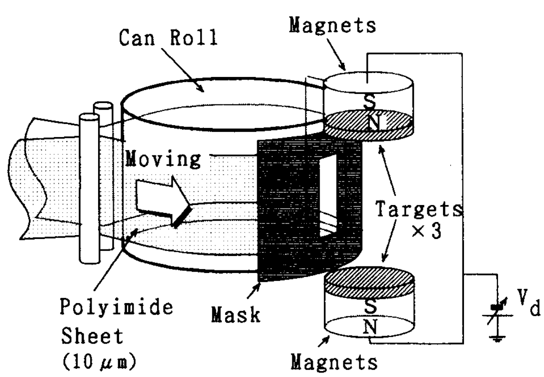


Fig.1 A schematic diagram of the FTS system.

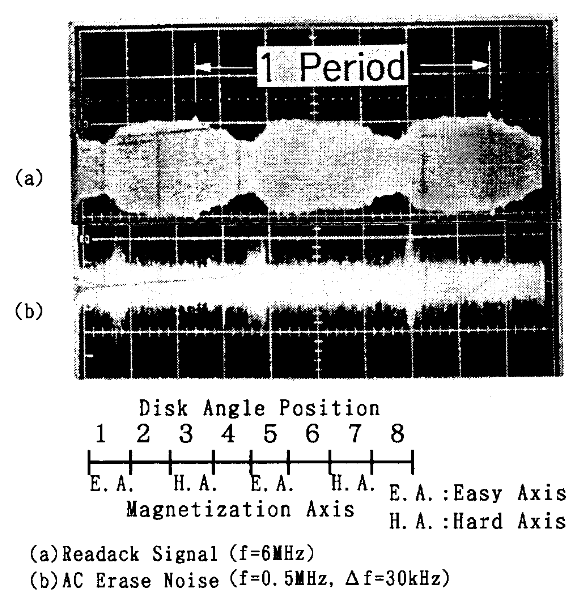


Fig.2 Relationship between (a)readback signal and (b)noise envelope and magnetization axis of Ni-Fe layer

of the direction of the easy magnetization axis of the Ni-Fe layer coincided with that of magnetic field in head. The Barkhausen noise is different from the Co-Cr layer noise, but will emerge as temporal fluctuation in magnetization during readback. Therefore, in order to attain large output and low noise, it is necessary to design the Co-Cr/Ni-Fe bilayered film so that the tape running direction should coincide with that of the hard magnetization axis of the Ni-Fe layer. μ_i of the Ni-Fe layer would drop with the decrease of $\delta_{Ni\text{-}Fe}$ if it were deposited together with a Co-Cr layer for bilayer construction.

Figure 3 shows the changes in μ_i of the Ni-Fe layer with the saturation magnetization M_s of Co-Cr layer in the bilayered film. As seen clearly in this figure, μ_i would eventually reduce to approximately one quarter of the intrinsic value as M_s increases to 600 (emu/cc). In order to prevent this decrease of μ_i, it is effective to insert the $Co_{67}Cr_{33}$ thin layer as M_s of 51 (emu/cc) between the $Co_{79}Cr_{21}$ and $Ni_{80}Fe_{20}$ layers. Figure 4 shows how μ_i would vary in relation to the changes in the thickness of a $Co_{67}Cr_{33}$ interlayer δ_I. As implied herein, μ_i of the Ni-Fe layer would be nearly the same as that of the single layer Ni-Fe film for δ_I above 30nm. Taking all these factors into account, a prototype of the magnetic tape with the bilayered film has been designed so that (1) δ_I may be 30nm and (2) the uniaxial magnetic anisotropy of Ni-Fe layer may be in-plane and, in addition, the direction of hard magnetization axis may coincide with the direction of the tape running.

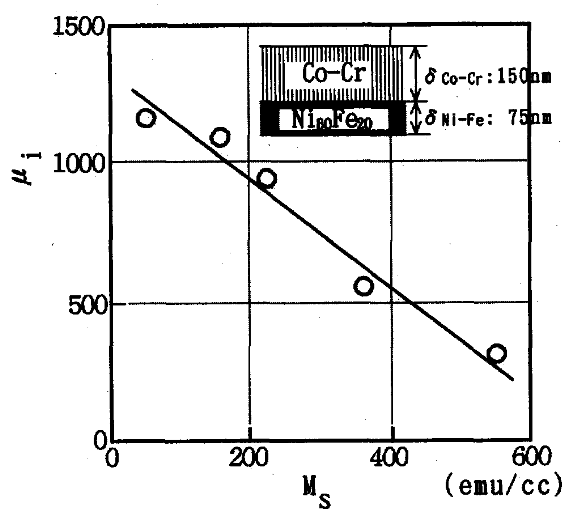


Fig.3 Relationship between saturation magnetization M_s of Co-Cr layer and initial permeability μ_i of Ni-Fe layer.

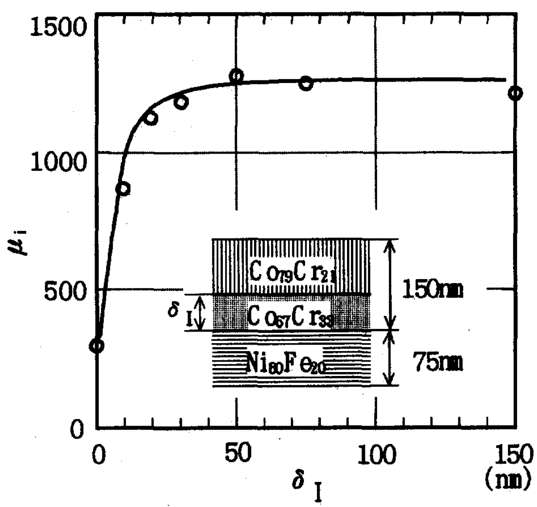
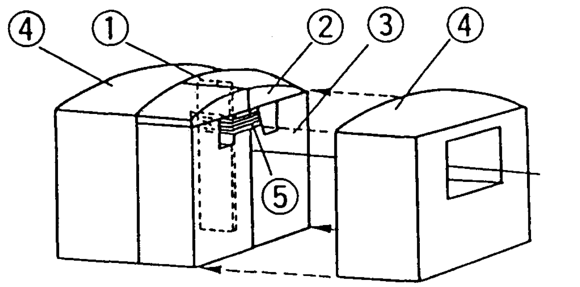


Fig.4 Dependence of initial permeability μ_i on $Co_{67}Cr_{33}$ interlayer thickness δ_I.

B. Relationship between Backlayer Thickness and Readback Sensitivity

In the conventional flexible disk media with Co-Cr/Ni-Fe bilayered films, $\delta_{Ni\text{-}Fe}$ is much larger than $\delta_{Co\text{-}Cr}$. To remodel the version from disk to tape, $\delta_M(=\delta_{Co\text{-}Cr}+\delta_{Ni\text{-}Fe})$ must be reduced. However, the reduction of $\delta_{Ni\text{-}Fe}$ below $0.5\mu m$ would increase the magnetic resistance of the Ni-Fe layer and decrease the readback sensitivity when the tape is running on the conventional single-pole head. One of the remedies for these shortcomings is to increase μ_i, as mentioned in the previous section, or to reduce the magnetic path length. The magnetic path can be shortened by modifying the construction of the single-pole head. Figure 5 shows the primary structure of the transverse return flux(TRF) head, one of the single-pole heads suitable for shortening the magnetic path [4]. In this head, the flux return path core is aligned in the direction of the track width of a W-shaped single-pole head in an effort to shorten the magnetic path in Ni-Fe layer. Using a three-dimensional finite element method, the reproduction of the TRF head has been simulated on the computer to see how much $\delta_{Ni\text{-}Fe}$ could be allowed to be reduced. The algorithmic parameters used in this simulation are listed in Table 2. Figure 6 shows the dependence of the normalized values of the calculation readback output V_R on the pole-to-core distance $d_{P\text{-}C}$, which is defined as the distance between the main pole in TRF head and the return path core in track width direction. Here, "Without TRC" in the figure denotes a W-shaped single-pole head. In this figure, reference output 0 dB is defined the results of simulation on the readback output generated in the disk with bilayered film at $\delta_{Ni\text{-}Fe}$ of 0.5μm using a W-shaped head. The simulation clarified that the value of V_R equivalent to the above-mentioned reference output 0 dB can be attained using TRF head with $d_{P\text{-}C}$ below 35μm for the tape medium with the bilayered film at $\delta_{Ni\text{-}Fe}$ of 0.1μm. Consequently, it was concluded from this simulation that $\delta_{Ni\text{-}Fe}$ could be 0.2μm.



① Main Pole
② Slider(Ceramics, Vickers Hardness=1600)
③ Side Core(Ferrite)
④ Transverse Return-path Core(TRC)(Ferrite)
⑤ Coil

Fig.5 Perspective view of transverse return flux(TRF) head.

Table 2 Values of parameters used in calculation.

Head	Main Pole	thickness t_M	(μm)	0.2
		length l_M	(μm)	10
		initial permeability μ_i		1000
	Yoke	μ_i		1000
	Ferrite	μ_i		1000
Tape	Co-Cr layer thickness $\delta_{Co\text{-}Cr}$		(μm)	0.15
	μ_i			1
	Ni-Fe layer thickness $\delta_{Ni\text{-}Fe}$		(μm)	0.1~0.5
	μ_i			1000
Interface	Head-media spacing $S_{H\text{-}M}$		(μm)	0.02

IV. Results And Discussion

A. Relationship between Crystallinity and Magnetism of Co-Cr Layer

In order to obtain the adequate recording/readback characteristics at short wavelength and small domain size, it is necessary to minimize the dispersion in the perpendicular coercivity $H_{c\perp}$ of Co-Cr layer. Figure 7 shows how to determine the $H_{c\perp}$ dispersion $\Delta H_{c\perp}$ from the M-H hysteresis loop of Co-Cr layer[5]. Using the values of $H_{c\perp}$, $\Delta H_{c\perp}$ and the magnetic anisotropy field H_k determined thereby, the dispersion amount σ_{hk} was evaluated according to the relation equation as follow $\sigma_{hk} = \Delta H_{c\perp} \cdot H_k/(1.35 \cdot H_{c\perp})$. For the minimization of σ_{hk}, it is recommended to attain the perfect c-axis orientation of Co-Cr crystallites normal to the layer plane as possible.

Table 3 lists the sputtering conditions and the saturation magnetization M_s of $Co_{67}Cr_{33}$ underlayer for assisting c-axis orientation for Co-Cr-(Ta) recording layer. Figure 8 shows the dependence of the ratio σ_{hk}/H_k on $I_{(002)}$. σ_{hk}/H_k became below 0.15 for $I_{(002)}$ above 5 kCPS. On the base of this result, the $Co_{79}Cr_{21}/Co_{67}Cr_{33}/Ni_{80}Fe_{20}$ triple-layered tape media have been prepared.

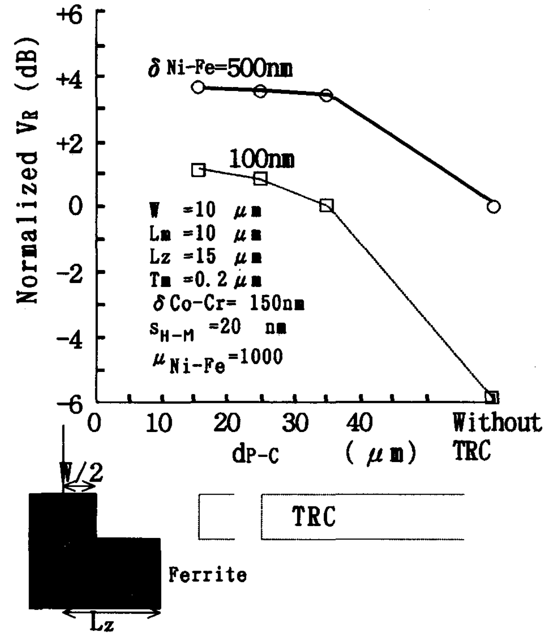


Fig.6 Dependencies calculated readback output V_R on distance $d_{P\text{-}C}$ between main pole and transverse return-path core for $\delta_{Ni\text{-}Fe}$ of 100 and 500nm.

B. Recording/Readback Characteristics of Bilayered Tape

Figure 9 shows the comparison in the cross-sectional structure between (a) the conventional bilayered flexible disk medium and (b) the $Co_{79}Cr_{21}/Co_{67}Cr_{33}/Ni_{80}Fe_{20}$ triple-layered tape prepared in this study. The magnetic layer thickness δ_M ($\delta_{CoCr}+\delta_{NiFe}$) in the tape medium was

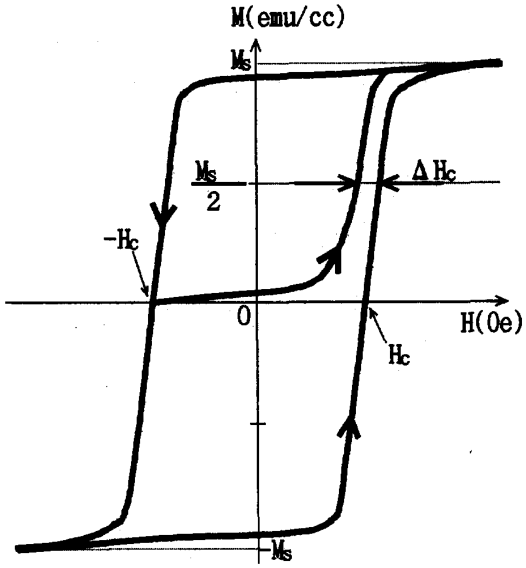


Fig.7 Definition of ΔH_c represented by distribution width of particle's critical field H_c.

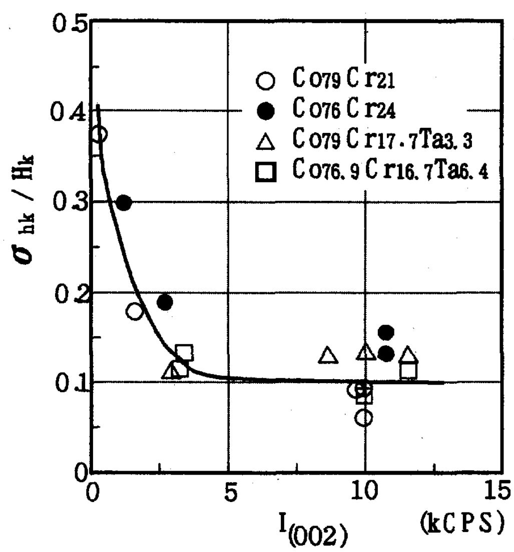


Fig.8 Dependencies of ratio σ_{hk}/H_k of standard deviation of H_k σ_{hk} to H_k on $I_{(002)}$ of Co-Cr-Ta recording layer.

Table 3 Deposition conditions of Co-Cr layer

Layer name		Underlayer	Recording layer
Target composition	(at.%)	$Co_{67}Cr_{33}$	$Co_{79}Cr_{21}$, $Co_{76}Cr_{24}$ $Co_{79}Cr_{17.7}Ta_{3.3}$ $Co_{76.9}Cr_{16.7}Ta_{6.4}$
Argon pressure P_{Ar}	(mTorr)	1.0	1.0
Input power P_I	(kW)	0.5	1.0
Substrate temperature T_s	(℃)	130	130
Layer thickness $\delta_{Co\text{-}Cr}$	(nm)	0~30	100
Bias voltage V_B	(V)	0	150
Saturation magnetization Ms	(emu/cc)	51	250~514

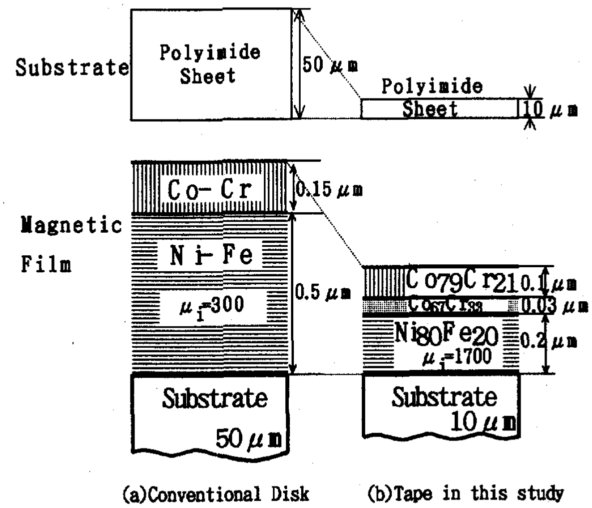


Fig.9 Structure of (a)disk and (b)tape media with Co-Cr/Ni-Fe bilayer.

0.33 μm, almost half of that in the disk. Table 4 lists the specifications of Co-Cr/Ni-Fe bilayered tape and the parameters of the TRF head used for a series of recording/readback tests. The pole-to-core distance in the TRF head was 28 μm. The tests were performed using a 1/2" industrial VTR driven at the relative speed of 7.1 m/sec.[6] Figure 10 shows the dependencies of the reproduced output $V_{Rep.}$ on the linear bit density $D_{L.B.}$ and the magneto-motive force $F_{M.M.}$. The normalized value of the calculated $V_{Rep.}$ of a prototype of Co-Cr/Ni-Fe bilayered tape was 100[$nV_{O\text{-}P}/(\mu m \cdot T \cdot m/s)$] at lower $D_{L.B.}$. This value was at the same level as that of the flexible disk tested using the same head. Furthermore there is no sharp increase in AC erase noise because of the Barkhausen noise.

V. Conclusion

Tape media with 0.33 μm thick $Co_{79}Cr_{21}/Ni_{80}Fe_{20}$ bilayered films have been prepared by using the facing targets sputtering(FTS) system and the 10 μm thick

Table 4 Parameters of TRF head and Co-Cr/Ni-Fe bilayered tape media.

Head			
Main pole thickness t_M (μm)	0.2		
Track width w_T (μm)	8.9		
Turn number N_t	30		

Media	recording layer	Interlayer	Ni-Fe layer
Layer thickness $\delta_{Co\text{-}Cr}$, $\delta_{Ni\text{-}Fe}$ (μm)	0.13	0.03	0.2
Magnetization Ms (emu/cc)	430	51	780
Coercivity Hc (Oe)	1400		0.6
Initial permeability μ_i			1700

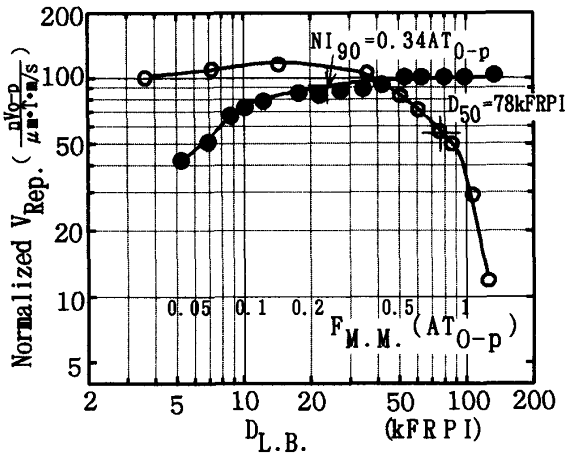


Fig.10 Dependencies of reproducing output V_{Rep} on linear bit density $D_{L.B}$ and magneto-motive-force $F_{M.M}$.

polyimide sheet as a substrate. The obtained results are as follow ;

1) The easy magnetization axis in the Ni-Fe backlayer must be normal to the head scanning direction to suppress the noise and increase of the readback sensitivity.

2) The decrease of the Ni-Fe layer thickness $\delta_{Ni\text{-}Fe}$ to improve the mechanical flexibility of the tape media causes the significant drop in μ_i of Ni-Fe layer. This drop can be prevented by inserting a 30nm thick $Co_{67}Cr_{33}$ interlayer between the Co-Cr and Ni-Fe layers.

3) The normalized dispersion value σ_{hk}/H_k of H_k and the perpendicular coercivity $H_{c\perp}$ of the Co-Cr recording layer were 0.15 and 1400 Oe, respectively.

4) The recording/readback characteristics of a prototype of 1/2" wide tape media were tested using the VTR system equipped with the TRF head. The normalized value of the reproducing output $V_{Rep.}$ of the tape media were 100 $nV_{O\text{-}P}$ /(μm·T·m/s).

Consequently, it has been confirmed that the very flexible tape media having a Ni-Fe layer as thin as 0.2μm took sufficient value of $V_{Rep.}$ using a novel type of TRF head developed in this study.

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