

CORRELATION BETWEEN ANISOTROPY DIRECTION AND PULSE SHAPE FOR METAL EVAPORATED TAPE

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ABSTRACT. Measured replay pulses, recorded on Metal Evaporated tape, show a strong asymmetry and dependence on the direction of tape movement. It is found that pulse height and pulse width are unequal for both directions of tape movement. This is attributed to the non longitudinal easy-axis direction which causes differences in head-tape geometry for both directions resulting in a different transition width. A simulation model is proposed. The differences in pulse asymmetry and pulse width between both directions of tape movement are very well reproduced by this model. From X-ray diffraction measurements and the results of the simulations it is concluded that not the columns but the crystallites act as magnetic entities for this kind of tape.

INTRODUCTION

Metal Evaporated (ME) tape is being investigated as a new medium for high density magnetic tape recording. Production of this tape, according to the Continuously Varying Incidence (CVI) method, yields a magnetic layer with an easy axis parallel to the incidence plane and tilted about 15-30 degrees out of the plane of the film. It is known that the recording properties of ME tape depend on the direction of tape movement relative to the recording head^{1,2,3}. Figure 1 shows the geometry of tape and recording head and the definition of A and B direction of tape movement.

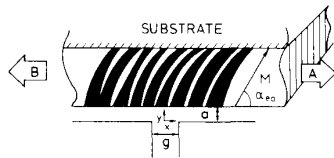


Figure 1: Schematic head geometry and definition of A and B direction of tape movement. α is the angle between easy axis direction and film plane.

Several authors investigated the frequency response of A and B direction and found that the A-direction yields a higher output at short wavelength. N. Ouchi et al.³ were able to clarify this phenomenon by investigation of the component of the headfield parallel to the easy axis direction. It was shown that this component is varying during a write cycle in a different way for A and B direction resulting in a different magnetization. In this paper we report the investigations of readback-pulses for which both shape and amplitude depend on the direction of tape movement. Also a simulation model, which reproduces the asymmetric pulses and the differences for A and B direction very well, is presented.

EXPERIMENTAL

Structural properties. TEM micrographs of a cross section of the tape, parallel to the coating direction, show a columnar structure with an average angle of 37 degrees relative to the plane of the film. The thickness of the magnetic film (d) is 140 nm. Auger Electron Spectroscopy (AES) revealed an average composition of $Co_{77}Ni_{10}O_{13}$ at.%. X-ray powder diffraction of the dissolved magnetic layer showed the presence of *Co hcp* and *NiO fcc* crystallites. The average grain size of the crystallites, as calculated from the halfwidth of the diffraction peaks, is about 30-50 Å which implies that the columns are not single crystals but consist of many crystallites. Other authors reported same results⁴.

Magnetic properties. By means of a Vibrating Sample Magnetometer (VSM) hysteresis loops were measured for several angles between applied field and the filmplane by rotating the sample relative to the measuring direction. Figure 2 shows remanence and coercivity ver-

sus angle. The easy axis direction (α_{ea}), estimated from the curve of the remanence, is 17 degrees relative to the filmplane. When compared to the average direction of the columns it is concluded that shape anisotropy of the columns is not the only source of the induced anisotropy in the film⁴. The saturation magnetization and maximum remanence were 5.3×10^2 and 4.3×10^2 kA/m respectively. The coercivity versus angle seems to follow a $1/\cos$ dependence in the vicinity of the easy axis. As reported in^{2,7} this behaviour is associated with domain nucleation and domain wall displacement. H_c is 74 kA/m for $\alpha = \alpha_{ea}$ which is comparable to H_c values reported by other authors^{2,4}.

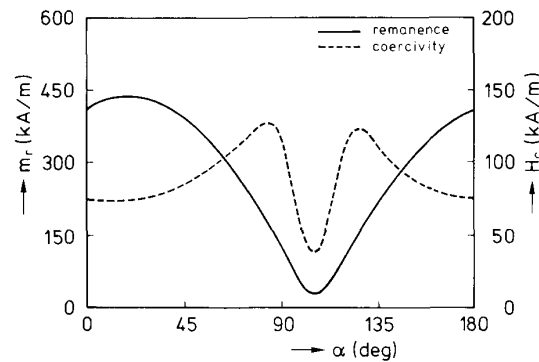


Figure 2: Remanence and coercivity versus the angle between applied field and filmplane.

Recording measurements. For recording measurements a drumhead configuration was used.⁵ Both reading and writing were performed with a ferrite head (number of turns $N = 16$, gaplength $g = 0.26 \mu m$, trackwidth $w = 100 \mu m$). The relative tape to head velocity (v) was 0.84 m/s. Medium and electronics noise were decreased by averaging 32 pulses for each direction. From experiments with reversed write and replay directions it was confirmed that the head behaved symmetrically. Measurement of the phase characteristic of the read amplifier showed some phase distortion at low frequencies for which the pulses were corrected. Figure 3 shows the measured pulses for A and B direction. Both directions show asymmetric pulses with a steep trailing edge for the A direction and a steep leading edge for the B direction. The pulse height (V_{op}) is 74 and 58 mV (per turn per m of trackwidth per m/s of velocity) for A and B direction respectively.

ANALYSIS

Fourier transformation in the k ($= 2\pi/\lambda$) domain provides a helpful tool for analyzing the measured pulses. Figure 4 shows the amplitude spectrum of a measured and a calculated pulse after Fourier transformation. From the slope of the amplitude spectrum the pulse width at half pulse height after phase equalization (PW_{50}) can be calculated. PW_{50} calculated according to this method contains the losses due to head to tape distance (a), tape thickness (d), gap loss and transition width (c). The intercept of the extrapolated spectrum with the y-axis is proportional to remanence, writedepth (δ) and read efficiency of the head (η). The product of remanence and writedepth ($\delta \cdot M_r$) is calculated taking $\eta = 0.8$. The results of the analysis are summarized in table 1.

From table 1 it can be seen that V_{op} is smaller for the B direction. $\delta \cdot M_r$ is nearly equal for both directions (especially when the accu-

Direction	V_{op}	PW_{50}	$\delta \cdot M_r$
A	74 mV	0.46 μm	27 mA
B	58 mV	0.53 μm	24 mA

Table 1: Data of the measured pulses.

racy of the method is taken into account). This view is confirmed by other measurements. This implies that the write depth is equal for both directions. Therefore it is concluded that the higher V_{op} for the A direction is caused by a smaller transition width which is also reflected by the values of PW_{50} .

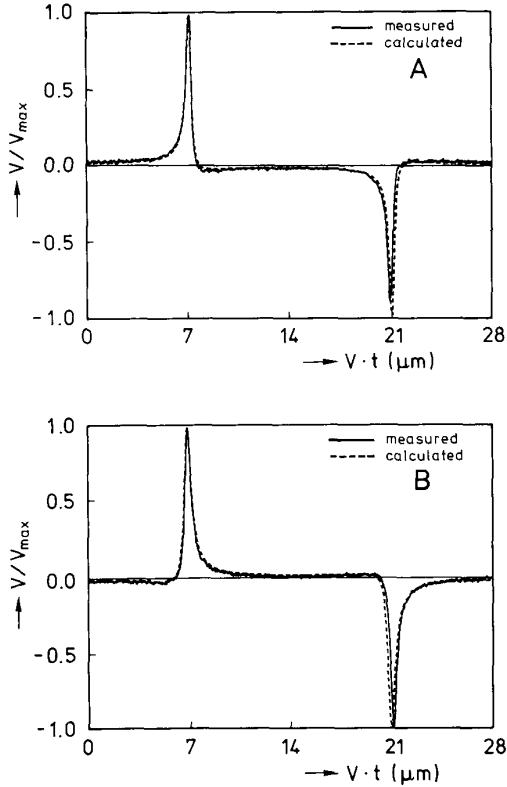


Figure 3: Measured and calculated pulses for tape movement in the A (upper figure) and B (lower figure) direction.

SIMULATIONS

Model. The following assumptions have been made to simulate readback pulses:

1. The magnetization is directed parallel to the easy axis (α_{ea}) over the entire trackwidth and thickness of the tape.
2. The magnetization has no z-component.
3. The shape and position of a transition are independent of z over the trackwidth.
4. A transition has an arctangent shape. The position in x direction and the width of the transition are a function of the depth in the layer:

$$\vec{M}(x,y) = \frac{2 M_r}{\pi} \arctan\left(\frac{x - \Delta x(y)}{c(y)}\right) \cdot \vec{e}_{ea} \quad (1)$$

in which $c(y)$ is the transition width, $\Delta x(y)$ is the position of the

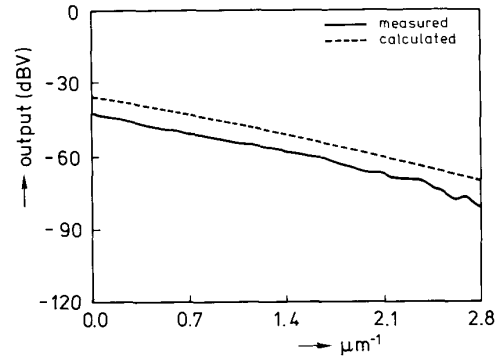


Figure 4: Amplitude spectrum of a measured pulse (solid line) and a simulated pulse (dashed line) after Fourier transformation (A direction).

transition and \vec{e}_{ea} is a unity vector in the direction of the easy axis.

5. $\Delta x(y)$ is calculated for a given y by evaluating the projection of the headfield on the easy axis direction ($H_{ea}(x,y)$) as a function of x and by determining the position for which:

$$|H_{ea}(x,y)| = |\vec{H}(x,y) \cdot \vec{e}_{ea}| = H_c \quad (2)$$

$\vec{H}(x,y)$ in (2) is the headfield for which the Karlquist expressions are used.

6. $c(y)$ is taken as the distance between the contours of $H_{ea}(x,y) = H_c$ and $H_{ea}(x,y) = 2H_c$ for given y (see figure 5).

Note that assumptions 5 and 6 imply that a transition is not necessarily parallel to the columnar structure, i.e. the columns are not the magnetic entities in the film.

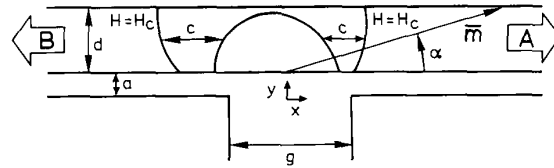


Figure 5: Calculated contours for $H_{ea}(x,y) = H_c$ and $H_{ea}(x,y) = 2H_c$. Note that a transition is written at the right hand side of tape movement in the A direction whereas it is written at the left hand side for the B direction. The simulation was performed for a magneto motive force (ηIN) of 96 mA turns and a head to tape distance of 50 nm.

Calculation of readback pulses is performed according to the following steps:

1. The magnetic film is divided in m layers with a thickness $\Delta y = d/m$.
2. For each layer $\Delta x(y)$ and $c(y)$ are calculated.
3. The output of each layer is calculated in the frequency domain i.e. the coefficients of the Fourier series are determined.
4. After summation of the contributions of all layers the pulse output is obtained by inverse Fourier transformation.

For steps 3 and 4 calculation is performed according to the following definitions:

$$e(t) = \sum_{n=-\infty}^{n=+\infty} c_n e^{jn\omega_0 t} \quad (3a)$$

$$c_n = \frac{1}{T_0} \int_0^{T_0} e(t) e^{-jn\omega_0 t} dt \quad (3b)$$

where T_0 is the period of the signal and $\omega_0 = 2\pi/T_0$. Using the

reciprocity theorem and the assumptions made before (3b) can be rewritten into:

$$c_n = \mu_0 w v \eta N \int_a^{a+d} \bar{H}(nk_0 y) \cdot jnk_0 \dot{M}(-nk_0 y) dy \quad (4)$$

in which N is the number of turns, w is the trackwidth, v is the velocity and $k_0 = 2\pi/\lambda T_0$. Taking the Karlquist headfield equations and the Fourier series of (1) it follows for the i th layer that:

$$c_{ni} = K_n (\cos \alpha_{ei} - j \operatorname{sign}(n) \sin \alpha_{ei}) e^{-|nk_0|(y_i + c(y_i))} e^{jn k_0 \Delta x(y_i)} \quad (5a)$$

$$K_n = \mu_0 w v \Delta y N \eta \frac{2M_r}{\pi k_0} \frac{\sin(nk_0 g/2)}{nk_0 g/2} \frac{1 - e^{-|nk_0| \Delta y}}{|nk_0| \Delta y} \quad n \neq 0 \quad (5b)$$

where $y_i = a + id/m$ ($i = 0, 1, 2, \dots, m-1$) and g is the gaplength. c_n follows from the summation of the c_{ni} of all m layers. Substitution of c_n into (3a) and rearranging c_n for positive and negative n yields:

$$c(t) = \sum_1^{\infty} a_n \cos(n\omega_0 t) + b_n \sin(n\omega_0 t) \quad (6)$$

$$a_n = 2K_n \sum_{i=0}^m \cos(\alpha_{ei} - nk_0 \Delta x(y_i)) e^{-nk_0(y_i + c(y_i))}$$

$$b_n = 2K_n \sum_{i=0}^m \sin(\alpha_{ei} - nk_0 \Delta x(y_i)) e^{-nk_0(y_i + c(y_i))}$$

Results. Simulations have been performed using the values of M_r , H_c , α_{ei} , d as determined with VSM and TEM and g , N , v and write current as in the recording experiments as described above. The head to tape distance, the number of layers (m) and η have been taken 50 nm, 50 and 0.8 respectively. k_0 was approximately equal as during the recording measurements. Figures 3, 4 and 6 show the results of the simulation (dashed) compared to the measured pulses. From figures 3 and 4 it can be seen that the asymmetry and the PW_{50} of the pulses are very well reproduced by the model. Nevertheless V_{op} and $\delta \cdot M_r$ of the simulated pulses are larger which can be seen from figure 4 and table 2.

Direction	V_{op}	PW_{50}	$\delta \cdot M_r$
A	170 mV	0.42 μm	61 mA
B	144 mV	0.51 μm	61 mA

Table 2: Data of simulated pulses.

Figure 6 shows the calculated phase characteristic of both a measured and a simulated pulse (A direction) as obtained after Fourier transformation. The phase of the simulated pulse increases with decreasing wavelength like the phase of the measured pulse. This is caused by the write contours (as shown in figure 5) which can be seen from (6).

CONCLUSIONS AND DISCUSSION

Structural, magnetic and recording measurements on ME tape are reported. Small crystallites are observed by X-ray diffraction. The easy axis of the investigated tape was found 17 degrees tilted out of the filmplane. Measured readback pulses of ME tape show a dependence of shape and output on the direction of tape movement which are attributed to the non-longitudinal easy axis direction. It is found that the A direction yields higher maximum output and smaller PW_{50} , caused by a smaller transition width. Simulations of readback pulses, including a write model, confirm this view. Figure 5 clearly illustrates that the gradient of $H_{ed}(x, y)$ is larger for the A direction resulting in sharper transitions. However, V_{op} and $\delta \cdot M_r$ of the simulated pulses were found to be higher than for the measured pulses. $\delta \cdot M_r$ of the measured pulses was lower than the value expected from magnetostatic measurements (61 mA).

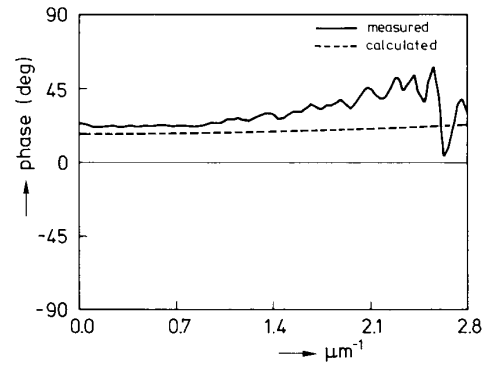


Figure 6: Phase characteristic of measured (solid line) and simulated (dashed line) pulses for the A direction of tape movement after Fourier transformation.

In order to clarify this discrepancy measurements with a metal in gap (MIG) type head⁸, with a high saturation magnetization, were carried out too. The results of these measurements were: $V_{op} = 119$ and 97 mV for A and B direction respectively. (nearly equivalent results were reported in⁶). The corresponding values of $\delta \cdot M_r$ were 47 and 46 mA for A and B direction respectively. This is in reasonable agreement with the 61 mA of the magnetostatic measurements if the uncertainty of η is considered. From these experiments it is concluded that it is not possible to saturate the magnetic layer completely by means of a ferrite head due to the high coercivity of the medium. Use of a MIG head enables deeper writing. The discrepancy in $\delta \cdot M_r$ and V_{op} between the pulses as measured with a ferrite head and the simulated pulses is thought to arise from incomplete saturation of the magnetic layer which is not incorporated in the model.

In the calculation of the width and position of the transition no influence of demagnetizing fields were taken into account (except for the arctangent shape itself). Because the model predicts the transition width very well it is concluded that demagnetization does not play a significant role, i.e. the transition width is mainly determined by the coercivity of the film and the gradient of the headfield. Indeed, the transition width does not exceed the minimum transition width determined by the demagnetizing field, estimated from the measured $\delta \cdot M_r$ and H_c ⁹.

From the results of the simulation it is revealed that not the columns but the crystallites act as magnetic entities. Simulation of hysteresis loops, as reported in⁷, electron diffraction studies as reported in⁴ and the x-ray studies reported here seem to confirm this view.

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