Magnetization Fluctuations and Characteristic Lengths for Sputtered CoP/Cr Thin Film Media

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Magnetization fluctuations of uniformly magnetized media have been measured in sputtered CoP thin films as a function of Cr underlayer thickness. Increasing underlayer thickness from 20 nm to 400 nm yields decreasing magnetization fluctuation noise from 210 nm to about 25 nm, similar to the known decrease of transition noise. For every disk but one, the noise power dependence on magnetization is well fit by the square of the magnetization vs. current loop derivative, \((dM/dl)^2\). Thus, the noise mechanism appears to follow a modulation process independent of noise level. Analysis of measured magnetization noise spectra yields approximate correlation lengths which decrease with increasing Cr underlayer thickness.

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1. Introduction

Metallic magnetic thin films provide superior recording performance for high density magnetic recording. Medium noise can dominate system noise and the substantial research into identifying sources has been reviewed by Yogii[1]. It has been argued that the predominant mechanism yielding thin film transition noise is the existence of intergranular exchange coupling in these polycrystalline films[2]. Films are commonly produced by first sputtering a Cr underlayer on which is sputtered a Co alloy. Transition noise is known to decrease substantially with increasing Cr underlayer[3]. It is presumed that intergranular magnetic coupling is reduced as the underlayer thickness increases. It has been shown [4] that transition noise is directly related to the fluctuations of uniformly (dc) magnetized media so that a study of uniformly magnetized media can provide insights into physical noise mechanisms. In [5] noise power was measured versus magnetization state for a magnetic medium thickness series with fixed Cr underlayer thickness. The noise power varied as the square of the derivative of the magnetization curve indicating a medium inhomogeneity driven process[6]. Here the dependence of uniformly magnetized medium noise on loop shape is investigated as a function of medium microstructure [1] by varying the Cr underlayer thickness.

2. Experimental Procedure

The media [3] used consists of sputtered disks of 30-nm-thick Co-8at%P magnetic layer each, deposited over Cr underlayers in the thickness range of 20 to 400 nm. The measurement conditions were head-media separation \( d = 0.242 \, \mu m \), media speed \( v = 15 \, m/s \), and a single ferrite head with 17+17 turns, track width \( W = 55 \, \mu m \), gap length \( g = 1.03 \, \mu m \), and efficiency \( \varepsilon = 90\% \). As in [5] a sequence of dc currents were applied to the head in order to take the medium along
the major loop from one state of saturation magnetization remanence to that of the opposite polarity. At each state of uniform magnetization, noise power spectra were measured. The spectra were acquired in the frequency interval \(0.4 < f < 10\text{ MHz}\), corresponding to a wave number \(k = \frac{2\pi f}{v}\) interval \(0.16 < k < 4.2\text{ \mu m}^{-1}\). These spectra were corrected for gap and spacing factors, one power of track width, as well as absolute calibration factors such as \(M_r\delta\), channel gain and head efficiency to give a spectrum of the magnetization fluctuations. The magnetization level which resulted from each application of (non-saturating) dc current was determined for each disk from a recording measurement as described in [5]. The media magnetic properties are listed in Table 1.

3. Results

In Fig. 1 magnetization fluctuation spectra \(M_n(k)\) (eq. 6 of Ref. [5]) are plotted for three underlayer thicknesses. The media in Fig. 1 have been reversed dc demagnetized to the remanent coercive state which yields the maximum noise level. Noise spectra measured over the entire series, and exemplified in Fig. 1, decrease in level with increasing Cr underlayer thickness. The spectral shapes do not exhibit a simple form with a clear long wavelength asymptote. Over the wavelength range measured these spectra continuously decrease perhaps reflecting a broad distribution of noise domain sizes. These systems could exhibit self-organized behavior which contains no scale length and possess spectra which vary as a fixed power of the frequency over a wide range[7].

Correlation lengths (C.L.) can only be defined approximately for systems exhibiting complex spectral shapes. The procedure adopted here affords an unambiguous relative statement about the C.L. of various media or of various magnetization states of the same medium. A conventionally defined C.L. can be obtained by Fourier transforming measured noise spectra to obtain the autocorrelation function[8]. We define the C.L. to be the \(1/e\) point of the autocorrelation function. It is difficult to determine the low frequency
asymptote of noise power spectra to be used for the Fourier transform. The differentiating action of the playback process reduces medium noise measurements to system noise levels at long wavelengths. Thus the correlation lengths determined only give a relative trend of noise domain lengths in these media.

The autocorrelation functions found are of an approximate functional form \( P_n \exp(-|x|/\Lambda) \), were \( P_n \) is the total noise defined below and \( \Lambda \) is a C.L. defined by this convention. Over the entire series \( \Lambda \) varies from 3.6 \( \mu \)m to 1.6 \( \mu \)m, decreasing with increasing Cr underlayer thickness. Even if the physical concept of our C.L. is somewhat ambiguous due to the limited knowledge of the magnetization fluctuation spectra, it appears that reducing the intergranular exchange coupling reduces the size of the interaction domains.

The spectra in Fig. 1 can be integrated to yield total noise power \( P_n \) at the remanent coercive state. \( P_n \) is plotted vs. Cr underlayer thickness in Fig. 2. The units are nm corresponding to a track-width direction effective correlation length times an intrinsic process variance[5]. The noise decreases from about 200 nm by an order of magnitude in the range of Cr thicknesses from 40 - 100 nm corresponding to the reported decrease in high density transition noise[3].

The medium magnetization \( M(I) \) obtained from long-wavelength, non-saturating, square-wave recording [5] is plotted in Fig. 3 vs. reverse dc current. These curves approximately reflect the major \( M-H \) loop. The current where the magnetization vanishes corresponds to a medium field approximately equal to the remanent coercivity \( H_{Cr} \), which increases with increasing underlayer thickness. The curve shape becomes less steep with increasing underlayer thickness reflecting a decrease in intergranular exchange.

For each disk, thin film medium noise varies with the level of magnetization attaining a sharp maximum as the magnitude of magnetization decreases. The total (integrated over frequency) noise power \( P_n(I) \) is plotted vs. excitation current in Fig. 4 for the disk with
a 20 nm Cr underlayer. The noise power dependence on magnetization is compared in Fig. 4 with functional forms expected for specific noise mechanisms. In Fig. 4 $dM/dI$ and $(dM/dI)^2$ are plotted versus current. In addition, the $1-[M(I)/M_r]^2$ variation expected of totally independent grains is shown. All curves are vertically scaled to yield the same maximum value. It is clear that the noise power varies closely with the square of the loop derivative as found in [5]. All media were similarly evaluated and it was found that for all underlayer thicknesses except 150 nm the noise power varied as $(dM/dI)^2$. This is seen clearly in Fig. 5 where, for Cr underlayer thicknesses of 20, 80, and 300 nm, the noise power is plotted with the squared derivative of the in-situ $M-I$ loop.

4. Discussion

It is remarkable that the noise power varies as $(dM/dI)^2$ virtually over the whole underlayer series. A squared variation is indicative of a modulation process [6]. For a Cr underlayer thickness of 150 nm the variation appears to fall between linear and quadratic. In this instance perhaps intrinsic processes as discussed in [7] are relatively strong. Modulation processes can arise from variations in underlayer smoothness or inhomogeneities in the film microstructure leading to variations in intergranular exchange coupling between large regions of grains. In a modulation process the strength of the modulation source can vary with film growth conditions and therefore, as in this case, Cr underlayer thickness. The scale factor relating total noise to $(dM/dI)^2$ is listed in Table 1. There is not one invariant constant relating the loop derivative to the noise power. One should notice that the factor varies within a 7% band in the 40 - 100 nm Cr range, suggesting perhaps a common noise mechanism for these films. The data shows that in none of the films does the noise follow a $1-[M(I)/M_r]^2$ statistical variation due to independent grains.

C.L. are difficult to determine unambiguously due to uncertainties at extremely long wavelengths. We used a well-defined numerical
procedure applied to the fully deconvolved magnetization fluctuation spectra in order to derive a C.L. without need for assumptions about the spectral shape $M_n(k)$. For any given disk, the C.L. thus obtained showed a maximum at the remanent coercive state, in strict correlation to the uniform magnetization noise power $P_n(l)$ variation.

5. Conclusion

Noise arising from uniformly magnetized thin film media has been studied for a series of media with varying Cr underlayer thickness. Magnetization fluctuations are shown to vary quadratically with magnetization loop derivative over the entire series indicating the predominance of a modulation process. The driving mechanism of this process cannot be identified from these measurements, but it is shown that the modulation source strength varies over the series. Fluctuation C.L. are estimated which decrease with increasing Cr underlayer thickness. It is shown that the noise power decreases with increasing underlayer thickness in good correspondence with measurements of high density transition noise.

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References


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Figure Captions

Fig. 1. Uniform magnetization fluctuation spectra for various Cr underlayer thicknesses.

Fig. 2. Total noise power at the remanent coercive state vs. Cr underlayer thickness.

Fig. 3. Medium magnetization vs. current for various Cr underlayer thicknesses.

Fig. 4. Total noise power and normalized $dM/dI$, $(dM/dI)^2$ and $1-(M(I)/M_r)^2$ vs. current for the 20-nm-thick Cr underlayer film.

Fig. 5. Total noise power and $(dM/dI)^2$ for various Cr underlayer thicknesses. For each curve, the only fit parameter is a scale factor.
Fig. 1
Fig. 2
Fig. 5