Characterization of Perpendicular Recording Media of CoPtCrO Granular Thin Films

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Abstract- Thermal stability of CoPtCrO granular thin films with perpendicular magnetic anisotropy is investigated. Magnetization decay with time $M(t)$ exhibits almost a linear dependence with $\ln(t)$, similar to that for longitudinal recording media. In comparison with amorphous rare earth-transition metal alloys media which shows a non-linear decay with $\ln(t)$, the differences in magnetization reversal process and energy barrier distribution are discussed. From magnetic viscosity measurements, activation volume is determined and shows a minimum of about $2 \times 10^{-18} \text{ cm}^3$ for CoPtCrO at fields near its coercivity, leading to a coupled region of 10 nm average diameter. Also recording performance is investigated using a conventional merged GMR head and magnetic force microscope. The linear recording density dependence of signal amplitude reveals that the 50% rolloff density D_{50} is about 300 kfc.

Key words: magnetic recording, granular media, amorphous RE-TM alloys, recording performance, thermal stability, activation volume, magnetic force microscope (MFM).

1. Introduction

In the last few years, the recording density of longitudinal media has been increasing by more than 100% each year. Recently, the achievement of 52 and 56 Gbits/in² in recording densities were reported [1,2]. Such achievements are through significant effort on innovation and elaboration of new magnetic structures with better thermal stability. As an areal density increases, a grain size of media must be reduced, therefore the thermal instability becomes a serious problem.

In this work, thermal stability of CoPtCrO granular thin films with perpendicular magnetic anisotropy has been investigated. The time dependent magnetization $M(t)$ was measured at different constant reversing fields. A comparison is made between granular media and TbFeCo amorphous films which is an other potential candidate for perpendicular magnetic recording. The difference in $M(t)$ behavior in these two media was explained in terms of magnetization reversal process and also of

energy barrier distribution, which was determined from DCD remanence curve. The activation volume related to the coupled length for magnetization is investigated based on $M(t)$ evolution at successive reversed fields. Also recording characteristics of CoPtCrO granular thin films was investigated by spin-stand setup for different linear densities.

2. Experimental

Granular and amorphous thin films were deposited by sputtering on glass substrates. In the case of CoPtCrO, a non-magnetic layers of 12 nm Ti thickness and 50 nm Ru thickness are used as underlayers to optimize the magnetic properties for recording performance. TbFeCo amorphous films are protected against corrosion with a 10 nm thick Si₃N₄. The time dependence of magnetization was investigated by an alternating gradient field magnetometer. Saturation magnetization and magnetic anisotropy were measured by VSM and a torque magnetometer with the applied field up to 15 kOe. The intergranular coupling was determined from isothermal remanence magnetization curves M_{IRM} and M_{DCD} . The first starts from demagnetized state, then the external magnetic field was applied progressively and remanence magnetization was measured. The second one was measured for different reversed fields starting from the saturated state. The recording characteristics of CoCrPtO granular thin films are investigated by conventional merged GMR head and magnetic force microscope (MFM).

3. Results and discussion

3.1. Time dependence of magnetization

The time decay of magnetization is shown in figure 1a for a 24 nm-thick CoPtCrO granular film. The $M(t)$ exhibits nearly a linear behavior in $\ln(t)$ and can be described by a well known magnetic viscosity equation:

$$M(t) = M_0 + S \cdot \ln(t), \quad (1)$$

where S is a viscosity constant and can be obtained by differentiating Eq. 1:

$$S = dM(t)/d(\ln(t)), \quad (2)$$

On the other hand, $M(t)$ curves for a 20 nm-thick amorphous TbFeCo film are no longer linear in $\ln(t)$. This $M(t)$ behavior is related to the mechanism responsible for switching process. This form of $M(t)$ decay is strongly controlled by the energy barrier distribution [5,6]. The first phenomenological difference between the two media appears from the shape of their respective hysteresis loops. The physical origin of this difference between CoPtCrO granular and MO films is related to their respective energy barrier distribution which is determined from DCD demagnetizing curve. The TbFeCo thin film has a narrow energy barrier distribution which leads to a high squareness (Fig. 2b) [7,8], whereas the CoPtCrO thin film has a broader distribution of the energy barrier and as a consequence it exhibits less squareness (Fig. 1b).

3.2. Activation volume

Thermal activation can be expressed by fluctuation field which is defined as:

$$H_f = S/\chi_{irr}, \quad (3)$$

where χ_{irr} is irreversible susceptibility. Measurements of H_f can be used to evaluate the activation volume V_a , using the following relation:

Fig. 1: Time dependence of magnetization for a 24 nm-thick CoPtCrO granular media (a). Insert is the hysteresis loop measured in perpendicular direction (b).

Fig. 2: Time dependence of magnetization for a 20 nm TbFeCo thick amorphous media (a). Insert is the hysteresis loop measured in perpendicular direction (b).

$$V_a = kT/M_s H_f, \quad (4)$$

where k is Boltzmann constant, T is the absolute temperature and M_s is the saturation magnetization.

As proposed by Folks et al. [9], H_f can be determined by the expression:

$$H_f = H_2 - H_1 / (\ln(dM_2/dt) - \ln(dM_1/dt)), \quad (5)$$

where H_i is the external applied field during time dependent magnetization measurement $M_i(t)$, i refers to the i^{th} measurement at a fixed field H_i .

The activation volume V_a has been determined as a function of external magnetic field based on $M(t)$ evolution at successive reversed fields (Fig. 3). The V_a exhibits a minimum value of about $2 \times 10^{-18} \text{ cm}^3$ near coercivity which is of about $H_c \sim 4.5 \text{ kOe}$. This value of V_a leads to a coupled region of 10 nm average diameter. This value is close to an average grain volume obtained by TEM [3]. Nearly the same value of V_a for granular media is obtained for advanced longitudinal recording media with 56 Gbits/in² [1]. However, it is much smaller than for both conventional recording media of CoCrPtTa with 8 Gbits/in² and amorphous TbFeCo and its multilayers {TbFeCo/Pt}. The difference in $M(t)$ behavior shown in Fig. 1 and 2 is reflected in activation volume curves, which is broader for CoPtCrO granular film, similar to the case of longitudinal recording media such CoPtCrTa and CoPtCrB thin films. On the other hand, V_a curve is

Fig. 3: Activation volume as a function of external magnetic field for CoPtCrO granular media, amorphous TbFeCo media and its multilayer (TbFeCo/Pt), also for longitudinal recording media with 5 and 20 Gb/in² areal density and advanced CoPtCrB/Ru/CoPtCrB longitudinal recording media with 56 Gb/in² areal density.

narrow for TbFeCo amorphous film and the {TbFeCo/Pt} multilayer.

3.3. Recording performance

Fig. 4 shows the normalized readout signal, measured by both spin-stand technique and MFM as a function of linear density for CoPtCrO granular perpendicular recording media. The 50% decrease of signal occurs at about 300 kfc in this media. From MFM images it is shown that up to 300 kfc the percolation inside the bits become a serious issue (Fig. 5). The signal-to-noise ratio deduced from the spin-stand measurement reveals that the CoCrPtO media exhibits a SNR of 26 dB at 400 kfc with 0.6 μ m wide GMR head. This kfc value corresponds to an real density higher than 11 Gbits/in².

4. Conclusions

Magnetic viscosity measurements were carried out in granular CoPtCrO and amorphous TbFeCo thin films with perpendicular magnetic anisotropy. Magnetization decay for CoPtCrO granular media exhibits nearly the linear dependence in $\ln(t)$. On the other hand, rare earth-transition metal alloys MO media exhibits a non-linear decay in $\ln(t)$. The correlation between magnetization reversal process

Fig. 4: Normalized readout signal measured by spin-stand technique and by MFM from written bits as a function of linear density for CoPtCrO granular perpendicular recording media. The noise is also plotted in the same figure.

Fig. 5: Written bits in CoPtCrO granular media for different linear densities.

and $M(t)$ form was described. Activation volume was determined from the magnetization waiting time method at different constant fields. It shows a minimum of about 2×10^{-18} cm³ for CoPtCrO near its

coercivity which leads to a coupled region of 10 nm average diameter.

Also recording performance was investigated by conventional GMR head. This study reveals recording performance with a linear density D_{50} value of 280 kfc/i. The media exhibited a SNR value of 26 dB at 400 kfc/i which leads to an areal density of 11 Gbits/in².

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References

- 1) E.N. Abarra, M. Suzuki and I. Okamoto : presented at Intermag'2000, Toronto, paper AA-01.
- 2) H. Zaitzu, F. Tomiyama, K. Nakamoto, T. Kawabe and H. Suzuki, T. Kanbe, Y. Hosoe, H. Takano and Y. Shiroishi : presented at Magnetic Society of Japan Annual Meeting, Waseda University, Tokyo, paper 15pA-01 (2000).
- 3) S. Oikawa, A. Takeo, T. Hikosaka and Y. Tanaka : presented at Intermag'2000, Toronto, paper DP-05.
- 4) Digital Instruments, Santa Barbara, CA, 93117.
- 5) P. Gaunt : *J. Appl. Phys.*, 59, 4129 (1986).
- 6) T. Tomson, K. O'Grady, P.W. Haycock and E.W. Williams : *IEEE Trans. Magn.*, 28, 251 (1992).
- 7) M. El-Hilo, K. O'Grady, R.W. Chantrell and D.P.E. Dickson : *J. Magn. Magn. Mat.*, 123, 30 (1993).
- 8) R. Sbiaa, M. Mochida, Y. Itoh and T. Suzuki : presented at Intermag'2000, paper GP-02 (to be published in *IEEE Trans. Magn.*).
- 9) L. Folks and R. Street : *J. Appl. Phys.*, 76, 6391 (1994).